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Mobile Technologies and Digital Inclusion: Empirical Evidence of Their Joint Impact On Human Development in African Countries

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Abstract:
This study examines the extent to which mobile technologies can foster human development when combined with digital inclusion factors such as access to electricity and higher education. It seeks to provide an integrated understanding of how these complementarities influence development outcomes in African countries.The analysis employs a hierarchical Bayesian mixed-effects model on panel data from 36 African countries covering the period 2000–2022, accounting for heterogeneity, temporal dynamics, and statistical uncertainty. The study applies Bayesian Model Averaging (BMA) to ensure the robustness and reliability of empirical results.
The results reveal three main insights. First, direct effects show that mobile phone technologies, rural electrification, female labor force participation, and rural population size have a significant positive impact on human development, while variables such as political stability and public health spending display varying effects depending on the development level. Second, the impact of mobile technologies is more pronounced in countries with a low HDI, following an inverted U-shaped relationship where initial gains diminish as countries advance in development. Third, the mediating role of digital inclusion is evident, as the benefits of mobile technology adoption are greatly amplified when combined with higher education enrollment or access to electricity in rural areas, sometimes doubling the observed impact.
The findings underline the importance of designing integrated public policies that harmonize technological innovation and digital inclusion strategies to promote sustainable and equitable human development, especially in rural and marginalized areas.
This study contributes to the literature by focusing on African countries where mobile technologies have rapidly expanded despite persistent structural challenges in education, health, and poverty reduction. It moves beyond prior research that primarily investigated direct ICT–development links, offering an integrated perspective on the interplay between ICTs, digital inclusion, and human development. The methodological use of advanced Bayesian econometrics further strengthens the credibility of the results.

Keywords: Mobile technologies, human development, Bayesian mixed-effects regression, African countries
JEL Classification: C35, O15, O33, I28

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1. Introduction

Over the past decade, the rapid advancement of information and communication technologies (ICTs) has profoundly transformed modes of communication within societies, as well as access to essential services. A growing consensus highlights their potential to foster more inclusive, sustainable, and resilient societies. These technologies have generated significant positive externalities across numerous sectors, including business, education, healthcare, employment, commerce, and finance (Asongu & De Moor, 2015). Among them, mobile technologies — particularly mobile phones and internet access — have emerged as essential tools, shaping both individuals' daily lives and broader socio-economic development dynamics.

However, while the effects of ICTs are more pronounced in developed countries, their actual impact on economic growth and human development remains limited in developing countries, especially in Africa. Empirical studies have highlighted the positive effects of ICTs on development (Andrianaivo& Kpodar, 2011; Chavula, 2013; Klasen, 2016; Asongu et al., 2017, 2018), as well as the factors driving their adoption and diffusion (Jakopin & Klein, 2011; Lechman & Kaur, 2016). These studies reveal deep North–South disparities, driven by persistent digital inequalities and structural constraints: limited financial resources, low digital literacy, restricted human capital, inadequate infrastructure, and high connectivity costs (Ngwenyama et al., 2006; Hashem, 2015; Niebel, 2018; Abu-Shanab & Al-Jamal, 2015; Mendoza-Lozano et al., 2021; Zhang, J. 2019).

Majeed & Ayub (2018) find that ICT positively influences GDP growth across more than 170 countries (1990–2019), while Internet use, mobile phone adoption, and internet servers show an inverted U-shaped link with growth. Their results highlight ICT and digitalization as key drivers of long-term economic growth. A number of recent research papers emphasize the importance of eliminating the digital divide in order to fully utilize the benefits of ICTs. These studies highlight equity, the development of basic infrastructure, and the implementation of inclusive public policies as key factors in ensuring universal digital access. Jetha et al. (2023) call for technology design based on inclusive principles, while Wilkin et al. (2017) emphasize the role of educational institutions in developing digital skills among youth. Vong et al. (2017) emphasize the importance of knowledge management practices in rural areas.

Together, these studies converge on the conclusion that the digital divide is a major barrier to human development, whereas digital inclusion serves as a strategic lever (Jetha et al., 2023).

Yet, empirical linkages between ICTs, digital inclusion, and sustainable development remain largely underexplored — with the exception of recent contributions such as Muftawu Dzang et al. (2024). This study thus aims to fill this gap by investigating the mediating role of digital inclusion in the relationship between mobile technologies and human development. It is guided by a central research question: To what extent can digital inclusion, as a mediating factor driven notably by mobile technologies, contribute to improving human development indicators in African countries?

Based on this foundation, this study adopts a socio-economic development perspective, consistent with the frameworks proposed by Muftawu-Dzang et al. (2024) and Roztocki. N et al., (2019). It examines Africa-specific contextual factors - particularly rural electrification and tertiary education enrollment - as key drivers in the relationship between mobile technologies and human development. To this end, it uses a dataset covering 37 African countries over the period 2000-2022 and applies a Bayesian model averaging (BMA) approach to address model uncertainty and produce robust empirical results (Byun & Lee, 2017; Gelman et al., 2014).

This study contributes to the existing literature by focusing on African countries, where mobile technologies have experienced rapid growth, while persistent structural challenges remain in the areas of education, health, and poverty reduction (World Bank, 2015). The study highlights the transformative role of mobile technologies in improving service delivery and expanding access to education, particularly in marginalized rural areas (Kliner et al., 2013).

By moving away from previous research that has primarily examined the direct relationship between ICTs and development, this study proposes an integrated perspective of the interactions between ICTs, digital inclusion, and human development. This study shows that access to higher education and rural electrification act as key factors that help amplify the impact of ICTs. Methodologically, the study utilizes an advanced econometric technique - Bayesian Model Averaging (BMA) - applied to a multi-country dataset to ensure the robustness and reliability of the empirical results.

The remainder of the paper is organized as follows: The literature review on mobile technologies and human development is presented in section 2; the methodology and data are summarized in section 3; the empirical analysis, validation and discussion of the results are presented in section 4; and the main policy implications conclude in section 5.

2. Literature Review

In developing countries and developed economies alike, ICTs have profoundly transformed patterns of social interaction, economic models and channels of access to basic services. In response, a growing body of research has examined the potential impact of ICTs on human development, defined by the United Nations Development Program (UNDP)[1] as the expansion of individuals' choices, freedoms and capabilities. While empirical findings generally confirm a positive relationship between ICT diffusion and improvements in the HDI, they also highlight that this impact is not uniform or guaranteed. Institutional, economic and societal contexts play a crucial role in shaping how ICTs affect health, education and income outcomes. Moreover, digital inclusion emerges as a key mediator in this relationship. It represents the actual ability of individuals to access, understand, and effectively utilize these technologies. In this section, we propose to review the literature in two parts. First, we look at studies that investigate the direct effects of ICTs on human development. Second, we analyze the mediating role of digital inclusion in this relationship, paying particular attention to the specific challenges faced by African countries.

2.1. Effects of ICTs on human development

Over the past two decades, Information and Communication Technologies (ICTs) have been recognized as key drivers of development, capable of profoundly transforming societies. Their role extends beyond the technological domain, embedding itself fully in the dynamics of human development, as defined by the United Nations as a process of expanding individuals' choices and capabilities. By facilitating access to information, education, healthcare, and public services, ICTs help improve quality of life and promote the empowerment of populations (Roztocki & Weistroffer, 2016; Asongu et al., 2016).

The relationship between ICTs and human development has been widely studied in recent literature. Numerous studies highlight a positive influence of ICTs—such as mobile telephony and Internet access—on education, health, and income indicators.

For instance, Ježić et al. (2022) assessed the impact of ICTs on the Human Development Index (HDI) across countries with varying income levels. Their results reveal a positive effect of ICTs and higher education on HDI—an effect that is significant in all countries when using a fixed effects estimator, but limited to upper-middle-income countries when using the GMM estimator. From an economic policy perspective, the results underscore the importance of ICTs as a relevant instrument capable of positively influencing people's lives, both directly and indirectly

David and Grobler (2020), focusing on the African continent, also highlight the positive impact of ICT diffusion on HDI, emphasizing the strategic importance of investment in this sector to stimulate economic growth and social progress. However, other studies offer more nuanced conclusions. Pratama and Al-Shaikh (2012) show that despite a sharp increase in Internet users between 2000 and 2010, improvements in HDI remained limited, suggesting that access to ICTs alone is not sufficient to guarantee a positive effect.

Asongu and le Roux (2017) argue that the impact of ICTs is heavily conditioned by structural factors such as income level, political stability, and cultural norms. This heterogeneity is also demonstrated by Bankole et al. (2011), who observe differentiated effects depending on countries' levels of development. Moreover, studies such as those by Chinn (2010) or Kaur and Tao (2014) examine the determinants of ICT diffusion, identifying facilitating factors such as urbanization, electricity consumption, or the quality of regulatory frameworks, while other variables, such as income or education level, appear to be less decisive than expected.

2.2. The Mediating role of digital inclusion

Despite the significant potential of Information and Communication Technologies (ICTs), their actual contribution to human development is neither automatic nor guaranteed. It largely depends on the degree of

[1]UNDP, Human Development Index, http://hdr.undp.org/en/content/human-developmentindex-Hdi

digital inclusion within a society. Digital inclusion refers to the set of conditions that enable individuals to access ICTs, acquire the necessary skills to use them effectively, and derive tangible benefits from their use. It therefore serves as a key mediating factor in the relationship between technology and human well-being (Jia et al., 2024).

Digital inclusion aims to enable all individuals to fully participate in the digital economy and digital society. It is based on four main dimensions: ICT access, assistive technologies, digital literacy, and social inclusion of disadvantaged groups. However, the digital divide goes beyond just internet access; it also involves a lack of skills, confidence, motivation and poorly designed digital services. The most vulnerable populations - women, the elderly, minorities, people with disabilities, rural dwellers and those from low socio-economic backgrounds - are the most affected. A holistic approach must combine infrastructure, accessibility, education and support to close these gaps. The most widely accepted definition, however, is that proposed by the Building Digitally Inclusive Communities Framework, which defines digital inclusion as "the ability of individuals and communities to access and use ICTs. Digital inclusion includes not only access to the Internet, but also the availability of hardware, software, related content and services, and training in digital literacy skills necessary for effective use of ICTs" (IMLS et al., 2012).

It is therefore necessary not only to invest in infrastructure and technologies to expand access to the Internet, but also to provide appropriate training and support to acquire the digital skills required in an advanced society. Public policymakers and private companies, both locally and internationally, have recognized the importance of this issue and have launched several initiatives to promote digital inclusion by developing infrastructure and offering digital literacy training programs.

Many studies suggest that ICTs generate lasting positive impacts only when they are effectively integrated into the socio-economic environment (Hettiarachchi, 2019). Other research, such as that by Asongo and de Moor (2015) and Ojo et al. (2012), highlights the role of ICTs in reducing inequalities - particularly those related to gender and rural development - by improving access to education, financial services and economic information. From this perspective, digital inclusion determines individuals’ ability to appropriate technological tools and leverage them for both personal and collective advancement. However, persistent inequalities—in access, usage, and digital competencies—observed both between countries and within societies, tend to perpetuate or even worsen forms of economic, social, and geographic exclusion.

Consequently, many scholars emphasize the importance of addressing structural barriers that impede digital inclusion, especially in developing countries. These include inadequate infrastructure, limited electricity coverage, and low levels of higher education attainment. Accordingly, this literature review sheds light on the specific challenges faced by African countries and proposes a renewed reading of the mediating role of digital inclusion—particularly through rural electrification and access to higher education—in the relationship between mobile technologies and human development.

In summary, the literature highlights the significant potential of ICTs to enhance human development, particularly through improvements in education, health, and income. Numerous studies point to the positive effects of ICTs—especially mobile phones and Internet access—on the Human Development Index (HDI). However, these effects are far from uniform, as they depend heavily on the structural, economic, and institutional contexts in which ICTs are deployed.

One of the critical conditions for the effectiveness of ICTs lies in the level of digital inclusion. Digital inclusion plays a central mediating role by enabling individuals not only to access technology but also to use it effectively to improve their living conditions. Inequalities in access, usage, and digital literacy thus remain major obstacles to realizing the full benefits of ICTs, particularly in developing regions.

This dual lens—considering both the direct effects of ICTs and the structuring role of digital inclusion—underscores the need for an integrated approach. Such an approach should combine technological advancement, equitable access to basic infrastructure (such as electricity), and the enhancement of human capacities (notably through education). From this standpoint, the empirical analysis presented in this study seeks to assess the extent to which the interaction between mobile technologies, digital inclusion, and socio-economic contexts contributes to improving the HDI in African countries.

3. Data and methodology

This section presents the dataset used in the study and the methodological framework. It identifies key variables related to ICT, digital inclusion, and human development, along with their sources and descriptive statistics. It also outlines the application of the hierarchical Bayesian mixed-effects model.

3.1 Data

This study examines a panel of 36 African countries over the period 2000–2022 using data from the World Bank's African Development Indicators. The dependent variable is the human development index (HDI), which captures national achievements in health and longevity, a decent standard of living, and access to knowledge.

The principal explanatory variable in this study is mobile technology, understood as the set of technologies enabling communication and data exchange through portable devices connected to networks, particularly cellular infrastructures. Following Bahia et al. (2019), it is measured by penetration rates. Due to data constraints and the specific context of African countries, it is operationalized through two indicators: the mobile phone penetration rate and the internet penetration rate, both per 100 inhabitants.

A set of socio-economic and institutional control variables is included to address potential omitted variable bias, following Mlachila et al. (2014) and Seneviratne & Sun (2013). These variables comprise the female employment rate (female labor force participation as a percentage of women aged 15 and above), the gross enrollment ratio in higher education (tertiary enrollment as a percentage of the relevant age group), the share of the rural population with access to electricity (proxy for rural infrastructure and inclusion), domestic government health expenditures (as a percentage of GDP), the rural population share (percentage of the total population residing in rural areas), and political stability (a perception-based index measuring the likelihood of government destabilization or overthrow by unconstitutional or violent means, including domestic violence and terrorism, as in Kaufmann et al., 2010).

Countries are classified into high, medium, and low HDI groups (Appendix table A1), with Libya, Algeria, Tunisia, Egypt, South Africa and Botswana recording the highest scores.

Variable definitions, data sources, summary statistics, and the correlation matrix are presented in Appendix tables A2–A4. The descriptive statistics indicate comparable means and sufficient variation for meaningful estimation. The correlation matrix reveals no significant multicollinearity, except for a high correlation between school enrollment and rural electricity access. The average HDI is 0.52 (range: 0.26–0.75), with substantial heterogeneity in rural electricity access and higher education enrollment, particularly in high-HDI countries.

3.2 Methodology

In line with recent inclusive development literature (Asongu & Le Roux, 2017), the analytical model adopted in this study draws on prior research investigating the impact of ICTs on human development.

To assess whether the effect of mobile technologies on human development is influenced by higher education enrollment rates and rural electricity access, we include interaction terms between mobile technologies and each of these two variables in the model.

Our framework is inspired by the IPAT model, originally proposed by Paul Ehrlich and John Holdren (1971) and later adapted by Zheng and Wang (2022), which captures the impact of population (P), economic activity (A), and technology (T) on human systems. This is expressed in the following equation for human development:

I (Human Development) = P (Population) × A (Activity) × T (Technology)   (1)

Where I represents the development level of a country (proxied by the human development index, HDI), P is the total population, A is the level of economic development, and T refers to mobile technologies that improve living conditions.

ICTs significantly affect all aspects of human societies and influence HDI through two main channels. First, ICTs stimulate economic growth and productivity gains in the real world. This relationship has been observed in both developed and developing countries. Bouhari (2023) shows that the impact of ICT development on economic growth in MENA and African countries (2000-2020) is non-linear. Using a PSTR model, the study finds that the effect depends on the level of ICT development, with threshold effects at 2.1 and 3.88 separating positive and negative effects. Second, ICTs have a direct impact on people's daily lives. Several studies (Asongu & Le Roux, 2017; David & Grobler, 2020) emphasize the direct impact of ICTs on the daily lives of individuals by reshaping access to information, communication, learning, and basic services. This digital dimension complements traditional economic indicators and reinforces the multidimensional nature of human well-being. Human development is defined as “the process of expanding the freedoms that people enjoy”. Within this framework, ICTs are one of the most accessible tools to enable individuals to live a life they have reason to value.

The empirical analysis is based on the following equation:

$$y_{it} = \alpha_0 + \alpha_1 X_{it} + \alpha_2 Z_{it} + u_i + v_i + \varepsilon_{it} \quad (2)$$

Where y_{it} is the human development index for country i at time t, X is the mobile technology variable, and Z represents the control variables presented above. u_i are the random intercepts; v_i is the random coefficient (slope) for the variable, and ε is the error term. The indices i and t refer to the country and the year, respectively.

This study employs a Bayesian mixed-effects modelling approach (Daunizeau, 2019). There are several reasons for this choice. First, mixed-effects models provide a comprehensive framework to understand how mobile technologies influence human development across countries and regions by incorporating both fixed effects (consistent across observations) and random effects (varying by group). Second, the Bayesian framework allows for flexible modelling of complex relationships, the integration of prior knowledge, and the management of parameter uncertainty. Bayesian methods estimate all possible model combinations with different predictors and yield posterior probabilities for the inclusion of explanatory variables. This helps identify the most relevant predictors and optimal model specification—something that traditional OLS models often struggle with due to loss of precision and reduced degrees of freedom. Bayesian modeling also tests the robustness of variables across multiple specifications.

Finally, a mixed-effects model is suitable for hierarchical or grouped data, where units (e.g., countries) may have different base levels or respond differently to predictors. In the case of mobile technologies and HDI, countries may exhibit different development baselines or heterogeneous responses to ICT investments. The fixed effects estimate the average impact of mobile technologies on HDI while controlling for covariates such as economic factors, education levels, and infrastructure (e.g., electricity access). The random effects capture the variation across countries or regions not explained by fixed effects—either through random intercepts (differences in baseline HDI) or random slopes (variation in the effect of mobile technologies on HDI).

We introduce two interactive terms into our model to examine whether the impact of mobile technologies on human development is influenced by social development factors:

Mobile technologies x Higher education enrollment and Mobile technologies x Access to rural electricity.

If these interaction effects turn out to be positive and statistically significant, this suggests that the impact of mobile technologies on human development is conditioned by complementary factors. More specifically, mobile technologies will have a greater impact when deployed in contexts characterized by a high level of education and adequate energy infrastructure, especially in rural areas.

The model parameters will be estimated using a Bayesian Markov Chain Monte Carlo (MCMC) algorithm, which is well suited for modelling hierarchical effects and capturing uncertainty in parameter estimates. While these models can be implemented in statistical environments such as R or Python, the analysis in this study will be conducted using Stata 17.

4. Empirical analysis, validation and discussion of the results

This section highlights the main results from the econometric estimates. It also presents the validation of the results, and interprets these results in light of the existing literature.

4.1 Empirical results

Three econometric estimates were conducted, each capturing a different dimension of the impact of mobile technologies. The first estimate assesses the direct impact of mobile technologies (table 1). The second estimate looks at the combined effect with school enrollment (table 2), while the third explores the interaction with access to electricity in rural areas (table 3)

According to the results in table 1, the analysis of the estimated effects across the three HDI categories reveals marked differences in the role of economic, technological, and social factors. In high-HDI countries, domestic health expenditure emerges as the most influential determinant, alongside a high share of the rural population, female employment, and access to electricity in rural areas—all with positive and statistically significant impacts.

Mobile technologies show a positive but non-significant effect, while political stability presents asignificant negative association, suggesting that politically dynamic or contested environments may coexist with high human development.

In medium-HDI contexts, the female employment rate exerts the strongest positive influence, followed by access to rural electricity, mobile technologies, and political stability, all of which are significant. In contrast, rural population exerts a negative and significant impact, reflecting persistent service disparities between urban and rural areas. Health expenditure, although positive, remains statistically insignificant.

For low-HDI countries, mobile technologies, female employment, rural population, and rural electricity access all contribute positively and significantly to the HDI, underlining the critical role of basic infrastructure and labor inclusion in early development stages. However, health expenditure shows a significant negative association, potentially indicating inefficiencies or misallocation of resources, while political stability has no statistically significant effect. Overall, these findings highlight the differentiated impact of similar factors depending on the level of human development, suggesting that tailored policy priorities are essential for maximizing HDI gains across contexts.

Following previous research, several interpretations can be drawn from these findings. The results indicate that mobile technologies have a positive and significant effect on human development, particularly in countries with a low Human Development Index (HDI). Female employment and access to rural electricity also exert a favorable impact, especially in medium-HDI countries. Conversely, political stability shows a negative effect in high-HDI countries, a result attributed to the case of Libya, which experiences persistent political instability despite having a high HDI.

In medium-HDI countries, a higher proportion of the rural population negatively affects the HDI due to insufficient access to basic services, leading residents to migrate to urban areas. This observation is consistent with Khan et al. (2018), who demonstrated the role of urbanization in accelerating human development in Pakistan. Urbanization also stimulates the labor market and drives industrialization, as emphasized by Shen et al. (2017) and Guan et al. (2018), who highlight its potential to foster economic growth and improve living standards.

The positive role of female employment observed in our results echoes the findings of Lechman and Kaur (2015), who examined the relationship between female labor force participation and economic growth in 162 countries from 1990 to 2012. Using a non-linear panel data analysis, they tested the hypothesis of a U-shaped relationship between the two variables. Their study, conducted on both the entire sample and separate income groups (low, lower-middle, upper-middle, and high income), confirmed the existence of this U-shaped relationship at the global level. However, they also revealed significant heterogeneity across countries and found no evidence supporting the hypothesis in low-income countries.

Table 1. Impact of economic, technological and socialfactors on the HDI
(**HDI = Human Development Index*****)***

High Human Development						
	Mean	Std. dev.	MCSE	Median	[95% cred. interval]	
Mobile technologies	.0029819	.001987	.000029	.0029607	-.0008744	.0068208
Female employment rate	.0475538	.0141873	.000277	.0475111	.0200112	.0757473
Domestic health expenditure	.0817741	.0133627	.000208	.0818215	.0557008	.108278
Rural population	.081468	.0148456	.000693	.0814247	.0518931	.1107435
Access to electricity in rural areas (% of rural population)	.0303535	.0049811	.000325	.0303556	.0204724	.0402028
Political stability	-.0358061	.0072943	.000141	-.035840	-.0502849	-.0215539
Medium Human Development						
	Mean	Std. dev.	MCSE	Median	[95% cred. interval]	
Mobile technologies	.0112468	.0014485	.000044	.0112516	.0083931	.0141148
Female employment rate	.145665	.0072287	.000072	.1457126	.1316355	.1599703
Domestic health expenditure	.0081206	.0061401	.000065	.0081349	-.0038473	.0201546
Rural population	-.0404832	.0081583	.000138	-.040458	-.0565419	-.0246091
Access to electricity in rural areas (% of rural population)	.0428977	.0037471	.00018	.0428678	.0357842	.0504155
Political stability	.0300239	.0061281	.000062	.0300168	.0180494	.042172
Low Human Development						
	Mean	Std. dev.	MCSE	Median	[95% cred. interval]	
Mobile technologies	.0116208	.0005879	8.4e-06	.0116183	.0105019	.0127814
Female employment rate	.037675	.0075128	.000086	.0377233	.0228597	.0525231
Domestic health expenditure	-.02327	.0035525	.000039	-.023262	-.0302025	-.0163415
Rural population	.060096	.0076356	.000096	.0600436	.0450835	.0750838
Access to electricity in rural areas (% of rural population)	.0249321	.0015926	.000039	.0249422	.0218122	.0280322
Political stability	.0037198	.0023397	.000023	.0037292	-.0008954	.0083336

Mean: average estimated effect on the HDI. Std. dev.: standard deviation (dispersion of the estimates). MCSE: Monte Carlo standard error (precision of the estimate). Median: median of the estimated effects. [95% cred. interval]: Bayesian credibility interval (95% probability that the true value lies within this range).

A more comprehensive analysis includes interactions between mobile technologies and the education variable.

The analysis of table 2 reveals that the mediating effect of the school enrollment rate in the relationship between mobile technologies and the Human Development Index (HDI) varies across countries with different development levels.

In high-HDI countries, this effect is positive but moderate (0.009), while it is more pronounced in medium-HDI countries (0.0167) and remains significant in low-HDI countries (0.0113). Domestic health expenditure exerts a strongly positive impact in high-HDI countries (0.098), has a limited effect in medium-HDI countries (0.0024), and a negative effect in low-HDI countries (-0.026), which may be explained by resource allocation inefficiencies or low effectiveness in the latter group. The share of the rural population is positively associated with HDI in all categories, with a particularly strong effect in high-HDI (0.124) and medium-HDI countries (0.112). Access to electricity in rural areas also contributes positively to HDI, with a slightly greater effect in medium-HDI countries (0.025). Finally, political stability plays a marginal role in high-HDI countries (0.0017) but shows a substantially greater effect in medium-HDI countries (0.033), confirming that governance is a critical driver at this stage of development.

Uddin et al. (2017) find, using dynamic system-GMM and quantile regression on data for 120 developing countries (1996–2014), that political stability fosters economic growth, whereas instability hampers it, particularly in low- and middle-income OIC countries and oil-dependent economies, mainly through its adverse effects on investment and human capital accumulation

Regarding the importance of education, several studies have confirmed its decisive role in fully harnessing the benefits of ICT. Abu Alfoul et al. (2024) show, based on a panel ARDL model applied to 17 MENA countries over the period 2000–2020, that the impact of ICT on economic growth is negative, but that education levels positively moderate this relationship. However, this positive effect is hindered by brain drain, leading the authors to recommend the implementation of policies aimed at retaining talent and effectively combining ICT and education to foster economic development.

Table 2. Impact of economic, technological and socialfactors on the HDI

Mediating role of the enrollment rate in explaining the effect of mobile technologies on the HDI

High Human Development						
	Mean	**Std. dev.**	**MCSE**	**Median**	**[95% cred. interval]**	
Mobile technologies * School enrollment rate	**.0090181**	**.0019841**	**.000122**	**.009021**	**.0051762**	**.0129651**
Domestic health expenditure	**.0976797**	**.0114143**	**.000587**	**.0975148**	**.0757228**	**.1201659**
Rural population	**.1238797**	**.0075555**	**.000341**	**.123821**	**.1093719**	**.1389982**
Access to electricity in rural areas (% of rural population)	**.0213464**	**.004899**	**.0002**	**.0213996**	**.0113546**	**.0306218**
Political stability	**.0017293**	**.0016439**	**.000168**	**.0012138**	**.0000447**	**.0061769**
Medium Human Development						
	Mean	**Std. dev.**	**MCSE**	**Median**	**[95% cred. interval]**	
Mobile technologies * School enrollment rate	**.01672**	**.0018618**	**.000102**	**.0167148**	**.0131372**	**.0204518**
Domestic health expenditure	**.0024353**	**.0022223**	**.00013**	**.0018884**	**.0000734**	**.0078844**
Rural population	**.1124304**	**.003548**	**.000279**	**.1123237**	**.1056676**	**.1198223**
Access to electricity in rural areas (% of rural population)	**.0252445**	**.0052471**	**.000306**	**.025678**	**.0140456**	**.0344648**
Political stability	**.0334625**	**.0083736**	**.000383**	**.0333603**	**.017038**	**.0505653**
Low Human Development						
	Mean	**Std. dev.**	**MCSE**	**Median**	**[95% cred. interval]**	
Mobile technologies * School enrollment rate	**.0113103**	**.0005062**	**.000016**	**.0113108**	**.0102812**	**.012292**
Domestic health expenditure	**-.0262058**	**.0032895**	**.000209**	**-.0262475**	**-.0326432**	**-.0197434**

Rural population	**.0956332**	**.0009575**	**.000061**	**.0956834**	**.0936856**	**.0974381**
Access to electricity in rural areas (% of rural population)	**.0193228**	**.0015561**	**.000098**	**.0193447**	**.0163674**	**.0223533**
Political stability	**.0066561**	**.002239**	**.000122**	**.0066949**	**.0021763**	**.0110057**

The results of the third estimation, presented in table 3, focus on the mediating role of electricity access in the impact of mobile technologies on enhancing human development.

The analysis highlights the significant mediating role of electricity access in the relationship between mobile technologies and the Human Development Index (HDI) across all three country groups. The combined effect of mobile technologies and electricity access is positive and statistically significant in all cases, with the highest magnitude observed in medium-HDI countries (0.0210), compared to 0.0144 in low-HDI countries and 0.0092 in high-HDI countries. These results suggest that electricity access amplifies the impact of mobile technologies on human development, particularly in contexts where development levels remain intermediate.

Moreover, female employment emerges as a key factor, especially in medium-HDI countries, where its effect (0.1230) is substantially higher than in the other groups. Domestic health expenditure exerts a strong positive impact in high-HDI countries but appears negative and significant in low-HDI countries, which may reflect inefficiencies or misallocation of resources. Rural population has a positive and significant effect in high- and low-HDI countries but is slightly negative and not significant in medium-HDI countries, indicating disparities in rural integration into development processes.

Political stability plays a contrasting role: it contributes positively to human development in medium-HDI countries, shows a negative effect in high-HDI countries, and is not significant in low-HDI countries. Overall, these results underline the importance of integrated policies combining improved electricity access, greater adoption of mobile technologies, women's economic inclusion, and tailored governance measures to foster human development, while taking into account the specificities of each development level.

This finding is supported by Laura E. Armey and Laura Hosman (2016), who showed that increasing electricity distribution within a country — and thereby making electricity available to a larger proportion of the population — promotes internet usage. The data includes a panel of 40 low-income countries, based on the World Bank classification over a ten-year period. The authors conclude that policies aimed at improving population access to electricity in these countries would increase internet usage rates and support economic growth based on both industry and knowledge.

T.J. MacGinley et al. (2025) conduct a systematic review of 92 studies to assess the relationship between electricity access and human development across 15 dimensions, such as health, education, economy, and equality. Their findings show that while 64.1% of reported outcomes are positive, non-positive results—often linked to supply quality, affordability, and mismatches between services and community needs—highlight the need for policy approaches that go beyond connection counts to achieve the SDGs by 2030.

Table 3. Impact of economic, technological, and social factors on the HDI
Mediating role of access to electricity in explaining the effect of mobile technologies on the HDI

	Mean	Std. dev.	MCSE	Median	[95% cred. interval]	
High Human Development						
	Mean	**Std. dev.**	**MCSE**	**Median**	**[95% cred. interval]**	
Mobile technologies * access to electricity	.0091907	.0022099	.000219	.0091962	.004627	.0135519
Female employment rate	.0194123	.0144143	.000826	.0196798	-.0096814	.0486075
Domestic health expenditure	.0580226	.0137229	.000708	.0580018	.0314823	.0846164
Rural population	.1359669	.0115629	.000913	.1359139	.1133456	.1587034
Political stability	-.0201147	.0072807	.00044	-.020230	-.0340455	-.0058057
Medium Human Development						
	Mean	**Std. dev.**	**MCSE**	**Median**	**[95% cred. interval]**	
Mobile technologies * access to electricity	.0209802	.0010287	.000056	.0209845	.018949	.0230235
Female employment rate	.1229813	.0075885	.000256	.123133	.1082611	.1381263
Domestic health expenditure	.0079572	.0063427	.000462	.0079685	-.0046017	.0204231
Rural population	-.0081488	.0079727	.000283	-.008065	-.023738	.0071171
Political stability	.0309735	.0066288	.000277	.0307735	.0180682	.0438624
Low Human Development						
	Mean	**Std. dev.**	**MCSE**	**Median**	**[95% cred. interval]**	
Mobile technologies * access to electricity	.0143941	.0005295	.000022	.0143727	.0133509	.0154467
Female employment rate	.0212987	.008225	.00048	.0214456	.005831	.0374163
Domestic health expenditure	-.0264486	.0038762	.000163	-.026426	-.0342751	-.0184046
Rural population	.07681	.0081643	.000468	.0766201	.0604484	.0920025
Political stability	.0027054	.0026839	.000136	.0025748	-.0022259	.0079571

4.2 Checks for model robustness

When applying MCMC algorithms, the convergence of the chain must be verified. We used tests such as the Effective Sample Size (ESS) and the CUSUM diagram, although trace plots and autocorrelation plots can also be used.

The Effective Sample Size (ESS) is closely related to the convergence characteristics of a Markov Chain Monte Carlo (MCMC) sample. A remarkably small ESS relative to the total sample size (T) indicates non-convergence. ESS estimates are considered better as they approach the MCMC sample size. Moreover, the lower the correlation times and the higher the efficiencies, the better the situation.

The correlation time is defined as T/ESS, and the efficiency is defined as the reciprocal of the correlation time, i.e., ESS/T. Since ESS ranges from 0 to T, efficiency ranges from 0 to 1. However, it is important to note that high ESS values do not necessarily guarantee MCMC convergence. Indeed, pseudo-convergence — resulting from incomplete exploration of the distribution by the MCMC method — can also lead to high ESS values (Block et al. 2011; Thach 2020a; Thach et al. 2021).

As a general rule, an efficiency above 10% is considered good for the MH algorithm. Tables 5A, 6A, and 7A in the appendix show that efficiency exceeds 10% for all variables and across the three groups of countries, except for the rural population and rural electricity access in high-HDI countries, and rural electricity access in medium-HDI countries. For the other variables, ESS and efficiency are higher, which means that only a few more iterations are needed to estimate a variable with the same precision as another.

Tables A8, A9, and A10 in the appendix examine the correlation between HDI and mobile technologies. These two variables are correlated at 0.6051. When using access to electricity as a moderating factor, the correlation rises to 0.735. It reaches 0.746 when using the enrollment rate as a moderating variable. Such values, close to 1, indicate that mobile technologies are strongly correlated with HDI.

For the CUSUM test, we focused on the relationship between HDI and the mobile technologies variable, along with its interactions with access to electricity and higher education enrollment rate. When interpreting the CUSUM graph, the "slope" is the informative part. An upward-sloping segment indicates a period during which values tend to be above the average. Likewise, a downward-sloping segment indicates a period during which values tend to be below the average. Vertical lines at the inflection points of the curve indicate when the effect on HDI shifts from one phase to another.

For high-HDI countries, at the beginning, the effect of mobile technologies was below average, and then it became above average. The robustness test results (CUSUM) are shown in figures 1 to 4 in the appendix. Overall, the model is effective, and the study results are insightful.

In summary, initial efficiency indicators such as the acceptance rate and average efficiency are sufficiently high to ensure that the MCMC chains have reached convergence. Similarly, the CUSUM test shows that irregular lines for the parameters do not indicate any sign of non-convergence.

4.3 Discussion

Our findings are in line with previous research while offering new insights. The first result highlights that the impact of mobile technologies on human development varies across groups of countries categorized by the Human Development Index (HDI). In countries with a low or medium HDI, the impact is more pronounced, supporting the findings of Warren, M. (2007), Donner, J. (2008), and Rangaswamy, N., & Nair, S. (2010) who emphasize the benefits of mobile phones in resource-limited settings.

This result can be explained by the reduction of information asymmetry and the improvement of access to services and markets, as demonstrated by Asongu et al. (2016), Asongu & Nwachukwu (2018b), and Tchamyou (2018a, 2018b). In contrast, the effect observed in countries with a high HDI—namely Algeria, Tunisia, Egypt, and South Africa—is more moderate. A plausible explanation lies in the compensatory effect of environmental degradation, which may offset the gains derived from technological development. Similarly, Pratama & Elsheikh (2012) point out that an increase in Internet penetration does not automatically lead to improvements in the HDI. Asongu & Le Roux (2017) also emphasize that these differences stem from the specific dynamics of ICT and the macroeconomic characteristics unique to each country. Furthermore, Asongu & Nwachukwu (2017) show that inclusive human development persistently depends on the use of mobile phones within the framework of knowledge diffusion. Moreover, countries with low levels of inclusive human development are gradually catching up with their more advanced counterparts. Policy implications are discussed, with particular emphasis on how to leverage common knowledge economy initiatives to promote inclusive development.

The second finding relates to the combined effect of mobile technologies with higher education enrollment and access to electricity in rural areas, significantly enhancing their impact on development. Nipo et al. (2023) analyze, using a panel of 46 Asia–Pacific countries over the period 2010–2019, the effect of ICT, access to electricity, and governance on human development, employing a Driscoll–Kraay standard error regression. The results indicate that Internet use, access to electricity, and governance have a significant positive impact, while the effect of mobile subscriptions is observed only in countries with high human development, highlighting the importance of integrated policies combining technology, infrastructure, and governance to strengthen human development.

The interaction between technological factors and social inclusion variables seems to multiply the overall impact on human development. As Shen et al. (2017), Guan et al. (2018), and Khan et al. (2019) note, access to electricity enables the provision of basic services in education, healthcare, and economic activity - especially in underserved rural areas. These improvements also contribute to women's empowerment and improve overall living conditions.

Overall, these findings underscore the importance of coordinated investments in digital infrastructure, ICT skills development, rural electrification, and the promotion of higher education. Such a multidimensional approach maximizes the social return of mobile technologies and enhances their role as an engine for inclusive growth. This study confirms existing literature while providing a renewed perspective on the interplay between technological innovation and social inclusion in shaping human development trajectories across the African continent.

5. Conclusion

This study highlights the important role of mobile technologies in promoting human development in 37 African countries, using a hierarchical mixed-effects mixed-effects regression model with Monte Carlo and Gibbs sampling techniques, especially when combined with social inclusion factors such as higher education enrollment and access to electricity in rural areas. The results reveal that the developmental impact of mobile technologies is most pronounced in low- and middle-HDI countries where they help bridge information gaps and expand access to basic services. However, this impact diminishes in high HDI contexts, where structural and environmental factors may offset potential benefits.

Importantly, the analysis shows that combining mobile technologies with inclusive infrastructure - such as electricity and education - can significantly enhance their impact, doubling their contribution to human development outcomes. These insights underscore the need for integrated public policies that simultaneously promote digital access, education advancement, and rural electrification.

By confirming and extending previous research, this study contributes to the literature on ICT and development by providing a nuanced understanding of how technological innovation, when combined with inclusive measures, can serve as a catalyst for sustainable and equitable development in Africa. Future research could further explore the mediating roles of institutional quality, environmental factors and gender equality in amplifying or modifying these effects.

Notes

Data Availability Statement

The datasets generated and/or analyzed during the current study are publicly available from the following sources:

Human Development Index (HDI): United Nations Development Programme (UNDP) – Human Development Data Center, available at: http://hdr.undp.org/en/data.

Mobile and Internet usage data: International Telecommunication Union (ITU) – World Telecommunication/ICT Indicators Database, available at: https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx.

Socioeconomic variables (e.g., rural electrification, higher education enrollment, political stability, female labor force participation, health expenditures): World Bank – World Development Indicators, available at: https://databank.worldbank.org/source/world-development-indicators.

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Appendixes

Table A1: Country rankings according to the Human Development Index in 2020

Human Development Index (HDI)					
High Human Development		**Medium Human Development**		**Low Human Development**	
Countries	**Value**	**Countries**	**Value**	**Countries**	**Value**
Libya	**0,746**	**Morocco**	**0,698**	**Nigeria**	**0,548**
Algeria	**0,745**	**Gabon**	**0,693**	**Rwanda**	**0,548**
Tunisia	**0,732**	**Eswatini**	**0,61**	**Togo**	**0,547**
Egypt	**0,728**	**Namibia**	**0,61**	**Côte d'Ivoire**	**0,534**
South Africa	**0,717**	**Ghana**	**0,602**	**Tanzania**	**0,532**
Botswana	**0,708**	**Kenya**	**0,601**	**Senegal**	**0,517**
		Congo	**0,593**	**Sudan**	**0,516**
		Angola	**0,591**	**Benin**	**0,504**
		Cameroon	**0,587**	**Liberia**	**0,487**
		Zambia	**0,569**	**Congo (Democratic Republic of the)**	**0,481**
		Uganda	**0,55**	**Guinea**	**0,471**
		Zimbabwe	**0,55**	**Mozambique**	**0,461**
				Sierra Leone	**0,458**
				Burkina Faso	**0,438**
				Burundi	**0,42**

				Mali	**0,41**
				Niger	**0,394**
				Central African Republic	**0,387**

Source : https://hdr.undp.org/data-center

Table A2: Variable descriptions

Human Development Index (HDI)	Measures the average outcomes in the three core dimensions of development: life expectancy, education, and a decent standard of living. Source: Human Development Report
Internet	Internet users per 100 inhabitants
Mobiles	Mobile cellular subscriptions per 100 inhabitants
Rural population	The rural population refers to people living in rural areas as a percentage of the total population.
Female employment rate	Female labor force participation rate (% of female population aged 15 and above)
Access to electricity in rural areas	Percentage of the rural population with access to electricity
Political stability	Political stability/absence of violence (estimate): measured as the perception of the likelihood that the government will be destabilized or overthrown by unconstitutional or violent means, including domestic violence and terrorism.
Higher education enrollment	Gross enrollment ratio in higher education (% of the total age group population)
Domestic health expenditures	Domestic general government health expenditure (% of GDP)

Table A3: Descriptive statistics

The full sample					
Variable	**Obs**	**Mean**	**Std, dev,**	**Min**	**Max**
IDH	**851**	**0,52**	**0,12**	**0,26**	**0,75**
Mobile	**851**	**57,91**	**45,69**	**0,02**	**206,70**
Internet	**851**	**15,38**	**19,32**	**0,01**	**92,14**
Female employment rate	**851**	**3,94**	**0,40**	**2,51**	**4,47**
Domestic Health Expenditures	**851**	**7,37**	**3,66**	**0,73**	**29,35**
Rural population	**851**	**3,97**	**0,39**	**2,23**	**4,52**
Access to Electricity in Rural Areas	**851**	**29,42**	**32,58**	**0,51**	**128,39**
Political stability	**851**	**-0,67**	**0,86**	**-2,70**	**1,20**
Higher education enrollment	**851**	**12,82**	**14,36**	**0,53**	**93,14**
Low human development					
Variable	**Obs**	**Mean**	**Std, dev,**	**Min**	**Max**

IDH	414	0,44	0,06	0,26	0,55
Mobile	414	43,56	37,69	0,02	174,03
Internet	414	9,15	12,28	0,01	68,93
Female employment rate	414	4,07	0,27	3,34	4,47
Domestic health expenditures	414	1,20	0,63	0,062	3,47
Rural population	414	4,17	0,17	3,84	4,52
Access to Electricity in Rural Areas	414	14,19	18,94	0,508	128,39
Political stability	414	-0,97	0,87	-2,70	0,82
Higher education enrollment	414	6,60	4,49	0,64	18,04
Medium human development					
Variable	Obs	Mean	Std, dev,	Min	Max
HDI	276	0,55	0,07	0,38	0,71
Mobile	276	60,62	43,26	0,16	149,11
Internet	276	16,82	20,19	0,03	92,14
Female employment rate	276	4,01	0,32	2,98	4,36
Domestic health expenditures	276	1,84	1,13	0,14	5,27
Rural population	276	3,90	0,47	2,23	4,45
Access to electricity in rural areas	276	26,91	24,64	0,63	100
Political stability	276	-0,40	0,62	-2,04	1,20
Higher education enrollment	276	9,49	7,55	0,53	46,17
High human development					
Variable	Obs	Mean	Std, dev,	Min	Max
HDI	161	0,70	0,04	0,58	0,75
Mobile	161	90,14	51,13	0,28	206,70
Internet	161	28,94	24,56	0,19	85,29
Female employment rate	161	3,48	0,50	2,51	4,10
Domestic health expenditures	161	72,88	34,03	0,77	100,66
Rural population	161	3,59	0,30	2,93	4,05
Access to electricity in rural areas	161	3,92	1,28	-0,26	4,61
Political stability	161	-0,37	0,91	-2,57	1,10
Higher education enrollment	161	34,49	18,80	6,76	93.14

Table A4: Correlation coefficients between variables – full sample

	(1)	(2)	3)	(4)	(5)	(6)	(7)
Mobile*Internet (1)	1						
Female employment rate (2)	-0,3305	1					
Domestic health expenditures (3)	0,3896	-0,3303	1				

Rural population (4)	-0,4678	0,4135	-0,2724	1			
Access to electricity in rural areas (5)	0,4715	-0,5387	0,2691	-0,3544	1		
Political stability (6)	0,141	0,0284	0,319	-0,2162	0,2233	1	
Higher education enrollment (7)	0,445	-0,5443	0,473	-0,5907	0,4214	0,0439	1

Table A5: Convergence Test based on effective sample size

		Mobile technologies	Female employment rate	Domestic health expenditures	Rural population	Access to electricity in rural areas	Political stability
High-HDI Countries	ESS	4366.73	2279.49	4123.22	471.95	256.34	2703.17
	Corr. time	2.29	4.39	2.43	21.19	39.01	3.70
	Efficiency	0.4367	0.2279	0.4123	0.0472	0.0256	0.2703
Medium-HDI Countries	ESS	923.52	10000.0	9661.09	2882.72	403.41	10000.0
	Corr. time	10.83	1.00	1.04	3.47	24.79	1.00
	Efficiency	0.0924	1.0000	0.9661	0.2883	0.0403	1.0000
Low-HDI Countries	ESS	4927.00	7678.50	8444.10	6280.51	1690.76	10000.0
	Corr. time	2.03	1.30	1.18	1.59	5.91	1.00
	Efficiency	0.4927	0.7679	0.8444	0.6281	0.1691	1.0000

Table A6: Convergence Test Based on Effective Sample Size – Mediating role of electricity access in explaining the effect of mobile technologies on HDI

		Mobile technologies* Access to electricity	Female employment rate	Domestic health expenditures	Rural population	Political stability
High-HDI Countries	ESS	368.36	500.12	463.09	770.59	708.86
	Corr. time	27.15	20.00	21.59	12.98	14.11
	Efficiency	0.0368	0.0500	0.0463	0.0771	0.0709
Medium-HDI Countries	ESS	376.63	217.06	298.55	214.55	327.83
	Corr. time	26.55	46.07	33.49	46.61	30.50
	Efficiency	0.0377	0.0217	0.0299	0.0215	0.0328
Low-HDI Countries	ESS	407.45	182.85	142.19	187.65	463.77
	Corr. time	24.54	54.69	70.33	53.29	21.56
	Efficiency	0.0407	0.0183	0.0142	0.0188	0.0464

Table A7: Convergence Test Based on effective sample size – Mediating role of higher education enrollment in explaining the effect of mobile technologies on HDI

		Mobile technologies * Higher	Domestic health expenditures	Rural population	Access to electricity in rural areas	Political stability

		education enrolment				
High-HDI Countries	ESS	266.55	378.23	491.65	600.80	95.91
	Corr. time	37.52	26.44	20.34	16.64	104.27
	Efficiency	0.0267	0.0378	0.0492	0.0601	0.0096
Medium-HDI Countries	ESS	335.18	294.24	161.87	293.53	477.70
	Corr. time	29.84	33.99	61.78	34.07	20.93
	Efficiency	0.0335	0.0294	0.0162	0.0294	0.0478
Low-HDI Countries	ESS	972.96	247.29	244.91	252.40	337.60
	Corr. time	10.28	40.44	40.83	39.62	29.62
	Efficiency	0.0973	0.0247	0.0245	0.0252	0.0338

Table A8: Correlation coefficients between the human development index and mobile technologies – full ample

	HDI	Mobile technologies =Mobile*Internet
HDI	1	
Mobile technologies= Mobile*Internet	0,6051	1

Table A9: Correlation coefficients between the human development index and mobile technologies combined with higher education enrollment – full sample

	HDI	Mobile*Internet* Higher education enrollment
HDI	1	
Mobile*Internet* Higher education enrollment	0,7464	1

Table A10: Correlation coefficients between the human development index and mobile technologies combined with electricity access – full ample

	HDI	Mobile*Internet* Access to electricity in rural areas
HDI	1	
Mobile*Internet* Access to electricity in rural areas	0,7352	1

Figure 1: CUSUM test for HDI and Mobile technologies – High-HDI Countries

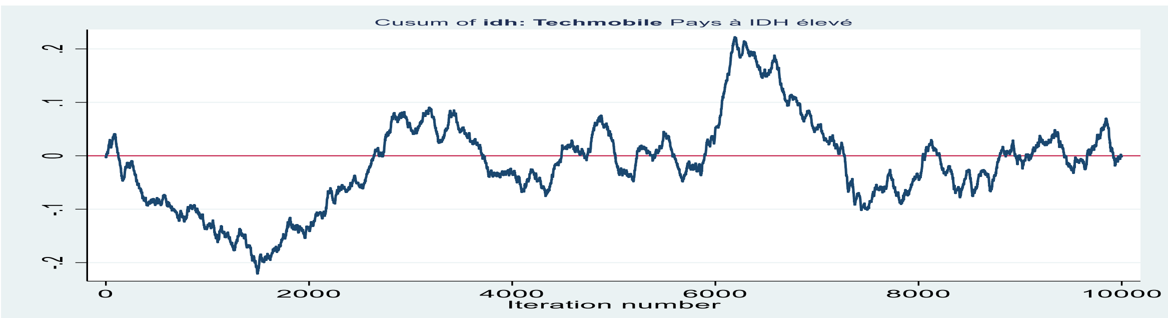


Figure 2: CUSUM Test for HDI and Mobile technologies – Medium-HDI Countries

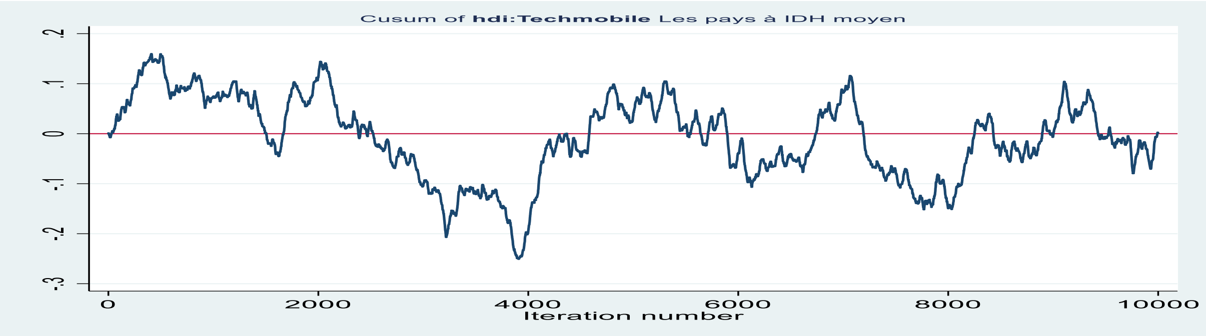


Figure 3: CUSUM Test for HDI and Mobile technologies – Low-HDI Countries

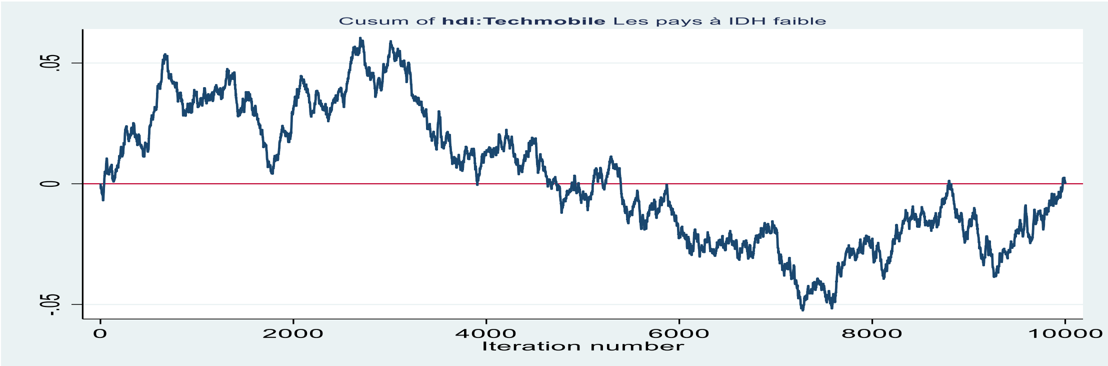


Figure 4: CUSUM Test for HDI and Mobile Technologies with electricity access as a Moderator – High-HDI Countries

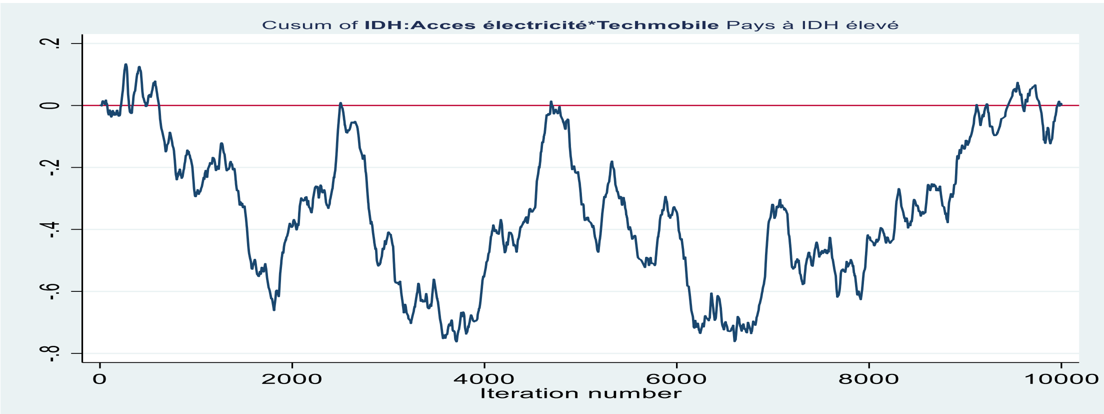


Figure 5: CUSUM Test for HDI and Mobile technologies with electricityaccess as a Moderator – Medium-HDI Countries

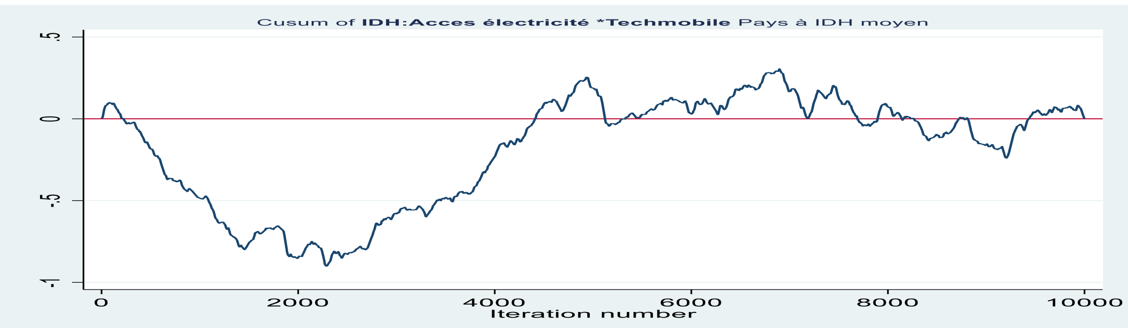


Figure 6: CUSUM Test for HDI and Mobile technologies with electricityaccess as a Moderator – Low-HDI Countries

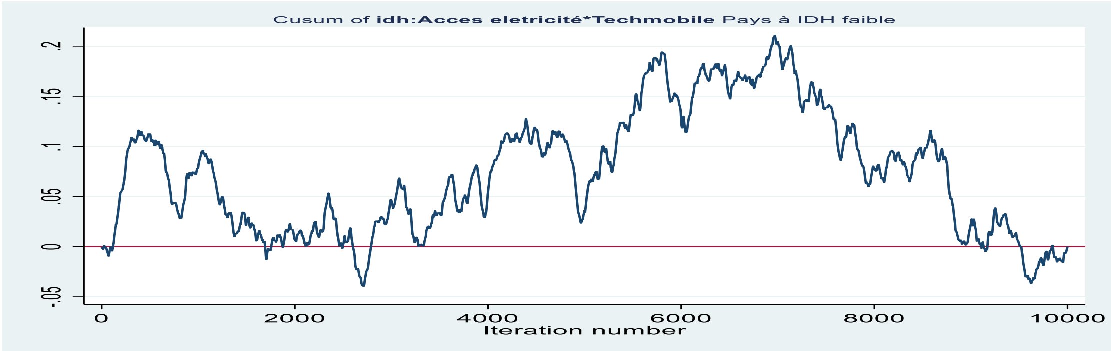


Figure 7: CUSUM Test for HDI and Mobile technologies with higher education enrollment as a Moderator – High-HDI Countries

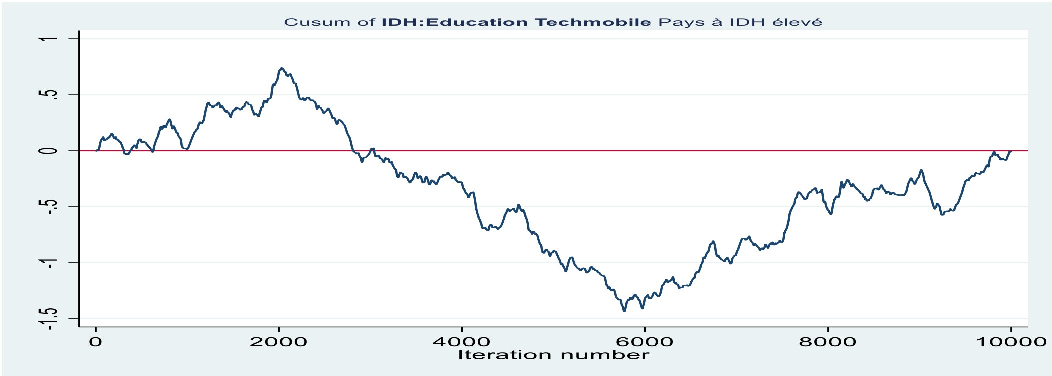


Figure 8: CUSUM Test for HDI and Mobile technologies: Higher education enrollment as a Moderator – Medium-HDI Countries

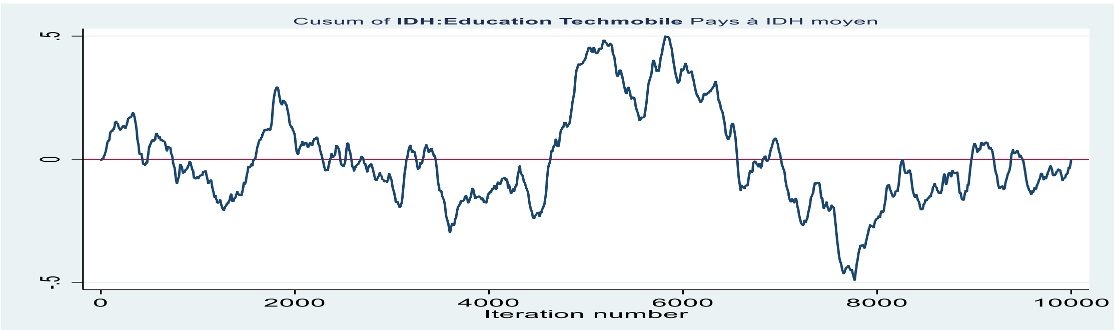
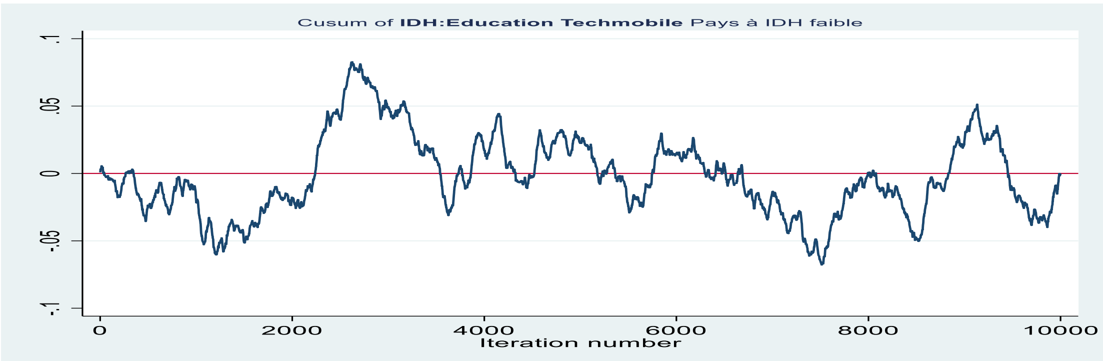


Figure 9: CUSUM Test – Mobile technologies and HDI with Education as a Moderator (Low-HDI Countries)



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