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Effect of the adoption of Information and Communication Technologies on gender gaps in access to education in Sub-Saharan Africa

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Abstract

This study empirically investigates the effect of Information and Communication Technologies (ICT) adoption on the gender gap in access to education in Sub-Saharan African (SSA) countries over the period 2006-2021. Three indicators of ICT adoption are considered: Internet usage, mobile phone subscriptions, and fixed broadband subscriptions. Gender disparities in education are measured using the gender disparity in education index. Employing Instrumental Variable Quantile Regressions (IVQR), the main findings are as follows: (i) ICT adoption reduces the gender gap in access to education in SSA; (ii) the effect of ICT adoption on gender inequality in educational access is more pronounced in countries with medium to high levels of inequality (from the 50th to the 95th quantile); (iii) specifically, ICT adoption reduces gender disparities in access to primary, secondary, and higher education, with the effect being particularly significant in narrowing the gender gap in higher education; and (iv) when accounting for cultural and religious factors, the interaction between ICT adoption and Muslim religion is found to be more conducive to reducing gender inequality in access to education than Catholicism, while ethnic diversity may hinder progress toward gender equality in educational access in SSA. Therefore, policies aimed at accelerating ICT adoption are essential for reducing gender disparities in access to education across SSA.

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1. Introduction

The issue of access to education is growing, including gender inequalities¹. This is especially true in sub-Saharan Africa (SSA), where access to and retention of education or learning is a real challenge (Poggi & Waltmann, 2019). The Sustainable Development Goal (SDG) of “ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all” underscores the urgency of addressing gender disparities in education. Similarly, gender equality and the empowerment of women have long been recognized as core development priorities (Adeleye et al., 2024). Gender equality is not only a fundamental human right but also a prerequisite for a peaceful, prosperous, and sustainable world (Shah & Krishnan, 2024). Gender-based inequalities, including those in education, often reinforce and exacerbate broader societal disparities (van Deursen et al., 2021; Campos & Scherer, 2024).

Despite global commitments, the Millennium Development Goal (MDG) of universal primary education was not achieved, largely due to enduring issues of poverty² and inequality (Asongu & Nwachukwu 2018; Fosu, 2015; Ncube et al., 2014; Tchamyu et al., 2019). Despite numerous efforts and global campaigns to eliminate gender disparities in education, the issue remains deeply rooted in many developing countries (Acheampong et al., 2024). The 2030 Agenda for Sustainable Development (SDG) reaffirms the urgency of addressing these disparities, yet progress remains uneven, with girls disproportionately affected by dropout rates and limited access (UNESCO, 2022). According to data from the UNESCO Institute for Statistics (2020), for the school year ending in 2018, approximately 260 million children worldwide were out of school and gender inequality was a major contributing factor (Bulathwela et al., 2024). In this context, the UN’s 2030 Agenda for SDG centered on the principle of “leaving no one behind” calls for more inclusive strategies to address educational inequalities (UN, 2015). This highlights the potential of information and communication technologies (ICTs) to reduce barriers to education by overcoming physical and informational constraints (Acemoglu et al., 2014). ICTs are widely recognized as one of the most effective instruments for achieving the SDGs (Vitalis et al., 2025). Their effective application has been highlighted as a means of contributing directly to SDG targets particularly Goal 10, which aims to “reduce inequalities” (United Nations, 2020).

This study investigates the effect of ICT adoption on gender disparities in access to education in SSA. Three primary motivations guide this research: (i) the failure to meet the MDGs related to education and the setbacks caused by the COVID-19 pandemic in achieving the SDGs; (ii) the increasing recognition in contemporary literature of ICTs as tools for inclusive development; and (iii) persistent gaps in the literature regarding gender inequality in education in SSA.

First, 2023 marked the halfway point toward achieving the 2030 SDG targets. Alarming, 30% of targets have stalled or regressed, and an additional 50% show insufficient progress (UNDP, 2024). The COVID-19 pandemic significantly worsened global inequalities and reversed gains in poverty reduction, making it one of the largest developmental setbacks in recent decades (UNDP, 2024; World Bank, 2020). Data from the World Economic Forum’s (WEF) Global Gender Gap Report 2023 reveal that SSA is the least advanced region in terms of gender parity in access to education, with only 86% of the gap closed. This figure is significantly lower than the global average (95.2%) and that of other regions such as Europe (99.6%), North America (99.5%), and Latin America and the Caribbean (99.2%). Despite some progress, these numbers

¹ In this study gender inequalities, gender gap and gender disparity are used interchangeably.

² According to Fosu(2015), growing inequality directly increases poverty.

highlight that SSA ranks last among the eight major world regions in reducing gender disparities in education, making it a critical priority for development policies: at the current pace, it would take 102 years to fully bridge the gender gap in the region (WEF, 2023). The region still ranks last globally in gender equality in education, with only a few countries Botswana, Lesotho, and Namibia achieving full gender parity in compulsory education. In contrast, 16 SSA countries report gender parity levels below 90%, with the Democratic Republic of Congo and Chad ranking among the lowest (WEF, 2023).

Second, SSA has experienced a significant increase in ICT penetration, which has captured the attention of scholars examining its potential impact on development outcomes (Tchamyou, 2017; Minkoua Nzié et al., 2017; Abor et al., 2018). According to the International Telecommunication Union (2021), internet penetration in SSA rose from less than 1% in 2005 to 33.8% in 2021, while mobile subscriptions climbed from 63.5 to 87.0 per 100 inhabitants between 2015 and 2021. Unlike other regions with saturated ICT markets, SSA still holds considerable potential for further digital expansion (Penard et al., 2012; Tchamyou, 2017). the adoption of ICTs may help reduce gender disparities by promoting equitable access to information, resources, and training (Roozbahani, 2025).

Theoretically, the neoclassical perspective on economic growth emphasizes the importance of technological progress in driving prosperity and reducing inequalities (Abramowitz, 1986; Bernard & Jones, 1996). Recent studies (e.g., Asongu & Odhiambo, 2019; Uduji & Okolo-Obasi, 2018; Asongu et al., 2019) argue that ICT adoption can bypass traditional barriers and facilitate inclusive development, particularly by enhancing educational access for women and girls. ICTs are thus seen as tools for innovation and knowledge diffusion, capable of narrowing gender gaps in education. Stigler (1961) notes the centrality of information often costly or asymmetrically distributed in human development, and ICTs have the potential to reduce these asymmetries, particularly between men and women. From a broader perspective, economic theory from Marshall (1890) to Kuznets (1971) acknowledges the cyclical relationship between knowledge, innovation, and economic transformation (Howells, 2005).

Third, Empirical studies have attempted to explore the link between ICTs, education, and inequality in Africa. In a similar vein, Asongu et al. (2024) assess the relationships between information technology, inequality, and adult literacy in 57 developing countries over the period 2012-2016. The empirical evidence is based on interactive Tobit regressions. The results show that only access to the Internet in schools unconditionally promotes adult literacy. The corresponding inequality threshold, beyond which Internet access in schools no longer continues to promote adult literacy, is 0.739 on the Gini coefficient scale. Asongu et al. (2019), using data from 42 African countries (2004-2014) and the Generalized Method of Moments (GMM), identified income inequality thresholds measured by the Gini coefficient and Atkinson index beyond which ICT penetration no longer positively affects inclusive education. Similarly, Asongu et al. (2021) demonstrated that for ICTs to enhance gender-inclusive education in 57 developing countries (2012–2016), income and poverty levels must remain below specific critical values.

Qaisrani et al. (2014), focusing on lower-middle-income countries between 2000 and 2010, found that while ICTs have the potential to foster gender equality in education, the empirical link remains weak partly due to data limitations and ineffective ICT integration. These findings underscore the need for more detailed and context-specific research on how ICTs influence gender disparities in education, especially in SSA.

This study contributes to the existing literature in four main ways: (i) It expands the scope of analysis by focusing on ICT-enabled disparities in educational access between men and women, rather than solely on women's inclusion. A disparity index is introduced, capturing multiple educational dimensions literacy and enrollment at primary, secondary, and tertiary levels where previous work, such as Asongu et al. (2021a), was limited to primary and secondary education.

(ii) In addition to a composite index of gender inequality in access to education, the study develops separate indices for each educational level, allowing for a more detailed and nuanced analysis, which to our knowledge is unprecedented. (iii) Methodologically, the study applies instrumental variable quantile regressions to address endogeneity and to assess the effects of ICT adoption across the full distribution of human development, offering insights into how these effects vary by initial levels of gender inequality. (iv) The analysis incorporates a broader range of ICT indicators including internet use, mobile phone subscriptions, and fixed broadband using data from 2006 to 2021 for a more comprehensive and updated perspective. The overarching research question is: what is the effect of ICT adoption on the gender gap in access to education in Sub-Saharan Africa? The testable hypothesis is that ICT adoption reduces this gender gap.

In order to better structure our reasoning, the study is as follows: (2) data and methodological strategy, (3) presentation and discussion of results, and (4) concludes the research by presenting the implications and future directions of the research.

2. Data and Methodology

2.1. Data

The scope of this study covers 33 countries (see Table A1), utilizing an annual panel dataset spanning the period from 2006 to 2021. This time frame was selected based on data availability constraints at the time of the research. The data for our analysis are drawn from several reputable sources, including the International Telecommunication Union (ITU), World Development Indicators (WDI), World Inequality Database (WID), Worldwide Governance Indicators (WGI), and the World Economic Forum (WEF).

First, the dependent variable is the gender inequality index in access to education, calculated using data from the WEF's annual Global Gender Gap Reports. These reports provide yearly assessments of gender parity, particularly in education, since 2006. However, in this study, our focus is on disparities in educational access between men and women. The gender inequality index in access to education (*IG_Educ*) is constructed as follows:

$$IG\ Educ = 1 - \text{gender parity in access to education} \quad (1)$$

This index incorporates several components, including the female-to-male literacy rate, the net enrollment rate of females versus males in primary education, the net enrollment rate of females versus males in secondary education, and the gross enrollment rate of females versus males in tertiary education.

Second, as key independent variables, we consider three indicators of ICT adoption, all sourced from the ITU database: (1) mobile phone penetration, measured by mobile cellular subscriptions per 100 people; (2) internet penetration, measured by the percentage of the population with access to the internet; and (3) fixed broadband subscriptions, measured as fixed broadband subscriptions per 100 people. The selection of these three ICT adoption indicators is consistent with recent studies by Asongu and Odhiambo (2024), Mohammadou et al. (2024), Ongo Nkoa and Song (2022), and Efobi et al. (2018).

Third, with regard to our variables of interest, in line with recent literature on development in Africa (Ngoa & Song, 202; Asongu et al., 2021a; Asongu et al., 2019; Tchamyu, 2017), we incorporate non-monetary household well-being variables, public policy variables, and governance variables (see Table 1). Correlation matrix are provided in the appendix (see Table A4).

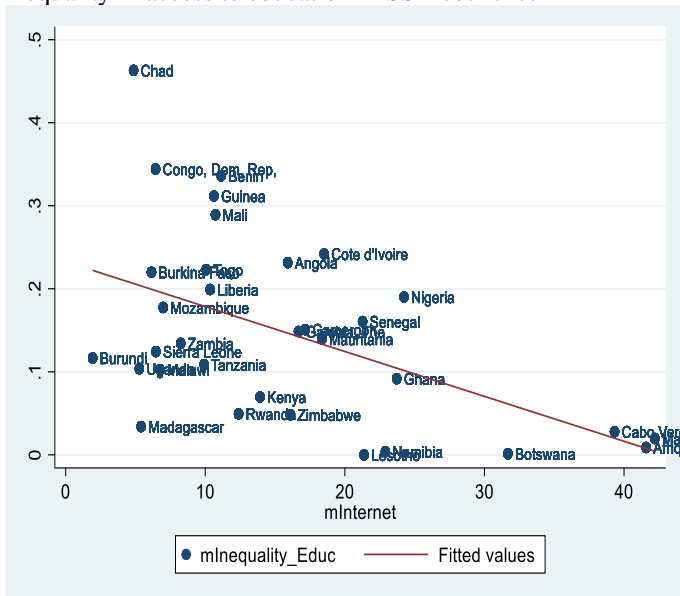
Table 1: Variable Presentations and descriptions

VARIABLES	DESCRIPTIONS	SOURCES
PHONEMOBILE	Mobile phone subscriptions (per 100 people)	ITU
INTERNET	Internet use (% population)	ITU
BROADBANDF	Fixed broadband subscriptions (per 100 people)	ITU
IdICT	ICT Adoption Index	Author calculation from ITU
ICTGOODEXPORTS	ICT goods exports (% of total goods exports)	WDI
IG_EDUC	Index of the gender gap in access to education	Calculation of the authors from WEF
IG_EDUCPRI	Index of the gender gap in access to primary education	Authors calculation from WDI
IG_EDUCSEC	Index of the gender gap in access to secondary education	Authors calculation from WDI
IG_EDUCTER	Index of the gender gap in access to tertiary education	Authors calculation from WDI
GDP	GDP per capita growth (% annual)	WDI
TRADEOP	The commercial opening obtained by carrying out the operation: Exports of goods and services (% of GDP) + Imports of goods and services (% of GDP)	WDI
REMIT	Remittances received (% of GDP)	WDI
CREDIT	Domestic credit provided to the private sector (% of GDP)	WDI
GINI	Income inequality between economic agents, it will be between 0 and 1	WID
CC	Corruption control, Takes values from – 2.5 to 2.5.High values indicate more good governance efforts.	WGI
CATHO	The percentage of the population belonging to the Catholic religion	La Porta et al. (1999)
MUSLIM	The percentage of the population belonging to the Muslim religion	La Porta et al. (1999)
ETHNIC	The ethnic fragmentation of a country	La Porta et al. (1999)

Source: authors

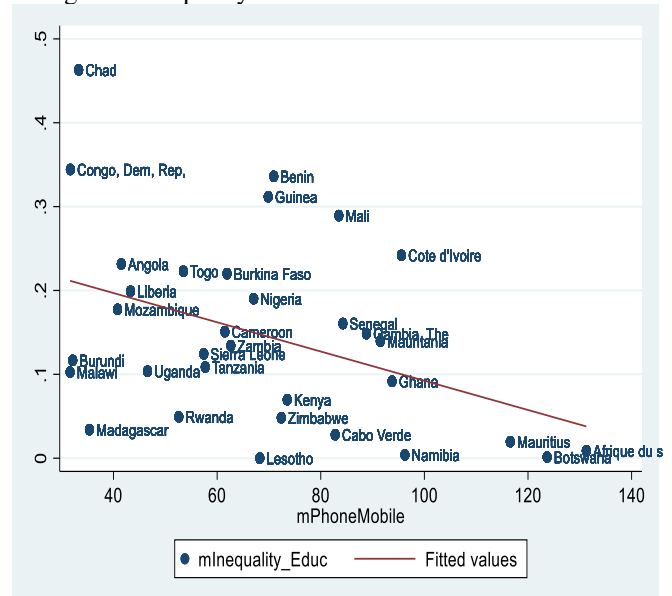
The hypotheses discussed are consistent with the stylized facts relating to the links between ICT adoption (Internet, mobile telephony, and fixed broadband subscription) and inequalities in access to education for men and women in SSA. The analysis of Figure 1 below reveals a negative relationship between mobile phone use and the index of inequality of access to gender education in SSA. Indeed, the index of unequal access to gender education in SSA tends to decrease in countries where the level of mobile phone subscription is high (Cape Verde, Lesotho, Mauritius, etc.); similarly, when mobile telephony (Figure 2) is adopted, however, we observe (Figure 3) the low appropriation and adoption of fixed subscription in the countries of our sample except for one country that stands out: Mauritius. Nevertheless, the trend remains negative between the adoption of the latter and the index of gender inequality in access to education in these economies.

Figure 1: Correlation between the internet use and gender inequality in access to education in SSA countries



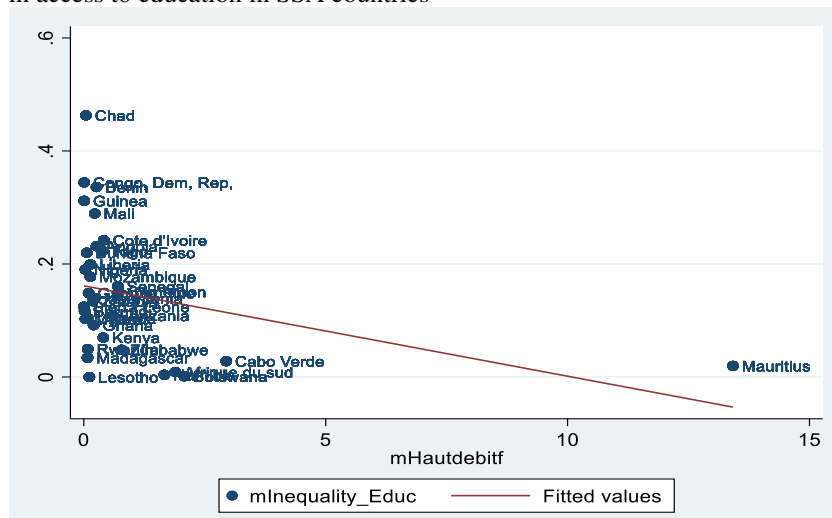
Notes: The axes represent the index of the gender gap in access to education while axes x indicate the Internet use
Source: authors

Figure 2: Correlation between mobile phone subscription and gender inequality in access to education in SSA countries



Notes: The axes represent the index of the gender gap in access to education while axes x indicate the mobile phone subscription
Source: authors

Figure 3: Correlation between fixed broadband subscription and gender inequality in access to education in SSA countries



Notes: The axes represent the index of the gender gap in access to education while axes x indicate the fixed broadband subscription.
Source: authors

Summary statistics for the main variables (including the mean, standard deviation, and minimum and maximum values) are presented in Table 2 below. Our results suggest that gender disparity in access to education remains prevalent on average in most countries (0.14 on average on a scale of 0 to 0.533). The minimum value (Min) of 0 represents the country or countries that have closed the gender gap in access to education in SSA; based on our data, these are Botswana, Lesotho, and Namibia. The maximum value (Max) of 0.533 represents the country in SSA with the greatest gender inequality in access to education; our data analysis reveals that this is Chad.

Some countries perform very well in terms of ICT adoption, mainly due to Internet usage rates, which average 22% and reach a maximum of 73% of the population, and mobile phone subscriptions per 100 people. On average, 68 out of 100 people have a mobile phone subscription in the countries in the sample. As for fixed broadband subscriptions, adoption is not fully guaranteed in SSA countries, as on average only one person in 100 has such a subscription. The highest subscription rate is in Mauritius, where approximately 25 out of 100 people have a fixed broadband subscription. The average GDP per capita growth rate is only 4.17% in the sample countries, with a minimum value of -20.48% (recorded in Sierra Leone in 2015 according to WDI data) and a maximum value of 21.45% (recorded by Zimbabwe in 2010 according to WDI data).

The Gini index in the countries in the sample averages 0.61, closer to its maximum value (0.77), reflecting the very high level of income inequality in SSA, considered one of the most unequal regions on the planet. According to the World Bank, one of the reasons that prevented SSA countries from achieving the MDGs is the high level of income inequality. Another relevant fact from the table indicates that control of corruption remains very weak in most countries (-0.55 on average on a scale of -1.58 to 1.03). This result allows us to argue that the countries in the sample are not homogeneous in terms of their level of development. It is therefore necessary to conduct a more robust analysis that includes various controls for heterogeneity.

Table 2: Descriptive statistical table

Variable	Obs	Mean	Std. Dev.	Min	Max
IG educ	444	.14	.117	0	.533
IG educpri	449	.042	.081	-.164	.371
IG educsec	327	.102	.198	-.388	.641
IG educter	319	.271	.319	-.494	.853
idTIC	498	4.020	1.461	-1.825	7.525
ICTgoodsexports	546	.681	2.126	.0	20.977
Phonemobile	524	68.343	37.604	2.612	168.924
Internet	527	15.734	16.631	.228	73.5
Broadbandf	501	.904	2.82	0	25.321
GDP	528	4.171	4.266	-20.491	21.452
Gini	528	.619	.058	.495	.773
Remit	512	3.799	5.544	0	37.939
tradeop	493	67.672	26.409	16.352	163.619
Credit	488	23.436	25.438	.003	142.422
CC	528	-.553	.632	-1.581	1.035

Notes : Std.dev: standard deviation, Min= Minimum, Max=Maximum.

Source: Authors

2.2. Methodology

In order to empirically analyze the effect of ICT adoption on gender inequality in access to education in SSA, the random-effects OLS method and the Discoll-Kraay method will be used in this work to perform preliminary regressions in accordance with the recent work of Njangang et al., (2024). The model is defined as follows:

$$IG_educ_{i,t} = \beta_1 \ln Internet_{i,t} + \beta_2 GDP_{i,t} + \beta_3 Gini_{i,t} + \beta_4 Remit_{i,t} + \beta_5 \ln Tradeop_{i,t} + \beta_6 \ln Credit_{i,t} + \beta_7 CC_{i,t} + \eta_i + \varepsilon_{i,t} \quad (2)$$

$$IG_educ_{i,t} = \beta_1 \ln Phonemobile_{i,t} + \beta_2 GDP_{i,t} + \beta_3 Gini_{i,t} + \beta_4 Remit_{i,t} + \beta_5 \ln Tradeop_{i,t} + \beta_6 \ln Credit_{i,t} + \beta_7 CC_{i,t} + \eta_i + \varepsilon_{i,t} \quad (3)$$

$$IG_educ_{i,t} = \beta_1 Broadbandf_{i,t} + \beta_2 GDP_{i,t} + \beta_3 Gini_{i,t} + \beta_4 Remit_{i,t} + \beta_5 \ln Tradeop_{i,t} + \beta_6 \ln Credit_{i,t} + \beta_7 CC_{i,t} + \eta_i + \varepsilon_{i,t} \quad (4)$$

With $i=1...33$ representing the number of individuals and $t= 1...16$, representing the study period. In the equations above, IG_educ represents the gender gap in access to education, and the indicators of ICT adoption are represented by: Ln Internet, Ln mobile phone and Broadbandf. NB: the Internet, Phonemobile, Tradeop and CI variables have been linearized in order to resolve a scaling problem between the variables. In addition, η_i et $\varepsilon_{i,t}$ represent fixed country effects and the error term respectively.

Most empirical studies in economics tend to focus on average effects through mean-based estimation techniques (D'Haultfoeuille & Givord, 2013). While such approaches provide valuable insights, they offer only a partial view of the impact of policies or structural changes. Evaluating the effectiveness of public interventions, particularly in education, often requires examining the distributional consequences beyond mean outcomes. For instance, a policy that substantially reduces the share of students experiencing severe educational difficulties may be preferable from a social welfare perspective, even if it has little impact on the average performance level.

To capture this heterogeneity in policy effects, the Instrumental Variable Quantile Regression (IVQR) method offers a richer analytical framework. Unlike traditional linear models, which are restricted to the conditional mean, IVQR allows for a detailed exploration of how explanatory variables affect different points of the conditional distribution of the outcome variable. This is particularly relevant in contexts characterized by significant disparities, such as gender gaps in access to education.

A key methodological challenge in this type of analysis is endogeneity, often resulting from simultaneity, measurement errors, or omitted variable bias. When an explanatory variable is correlated with the error term, the fundamental assumption of orthogonality is violated, leading to biased and inconsistent estimates. This issue is especially relevant in the present study, as ICT adoption may be both a cause and a consequence of gender disparities in education. To mitigate such concerns, the study adopts an instrumental variable estimation strategy, in line with the empirical strategies proposed by Asongu & Nwachukwu (2018) and Dethier et al. (2008). By doing so, it ensures the credibility of the causal inferences drawn.

The IVQR framework used in this study draws on the foundational work of Koenker & Bassett (1978), the structural refinements introduced by Chernozhukov & Hansen (2008), and the more recent contributions of Machado & Santos Silva (2019). This methodological choice aligns with a growing strand of literature that emphasizes the importance of examining the conditional distribution of development outcomes (Avom & Mallah, 2022; Asongu et al., 2021b; Asongu & Odhiambo, 2019).

Importantly, IVQR allows us to assess whether the effect of ICT adoption on educational gender inequality differs depending on the initial level of inequality. This feature is particularly useful for identifying whether the benefits of ICTs are concentrated among countries with relatively low inequality, or whether they are also effective in contexts where disparities are more pronounced. Thus, beyond estimating average effects, this approach enables a more nuanced and policy-relevant analysis of how technological change interacts with structural inequalities across Sub-Saharan Africa.

The quantile estimator of gender gap in access to education is obtained by solving the following optimization problem (4), presented as such for simplicity and ease of presentation.

$$\min_{\beta \in R^K} \left[\sum_{i,t: y_{it} \geq x'_{it}\beta} \theta |y_{it} - x'_{it}\beta| + \sum_{i,t: y_{it} < x'_{it}\beta} (1-\theta) |y_{it} - x'_{it}\beta| \right] \quad (4)$$

Where Y_i represents the inequality index of access to education for men and women in country i , β reflects the vector of the parameters to be estimated and x'_i a vector $K-1$ of the independent variables and $\theta \in (0,1)$ The conditional quantile of the gender inequality index in education or Y_i given x_i is:

$$Y(\theta/x_i) = x'_{it}\beta_\theta \quad (5)$$

Here, unique slope parameters are modeled for each specific quantile. This formulation is analogous to $E\left(\frac{y}{x}\right) = x_i\beta$. As part of this study, IG_Educ_{it} restate the indices of gender inequalities in education in countries in the 10th, 25th, 50th, 75th, and 95th quantiles, according to the recent studies of Hamadou et al. (2026), Avom & Mallah (2022) and Asongu & Odhiambo (2019).

3. Empirical results

3.1. Preliminary results

Table 3 reports the preliminary results on the impact of ICT adoption on gender inequality in access to education in SSA. Two estimation approaches are employed: the random effects model (columns 1, 2, and 3) and the Driscoll-Kraay estimator, which is robust to autocorrelated errors (columns 4, 5, and 6). Additionally, a complementary analysis using the Generalized Least Squares (GLS) estimator, which is robust to heteroskedasticity, is presented in Appendix A4.

The results from the random effects regressions (columns 1-3) suggest that, on average, both internet usage (column 1) and mobile cellular subscriptions (column 2) have a statistically significant negative effect on gender inequality in access to education in SSA. Specifically, a 1% increase in internet usage and mobile cellular subscriptions is associated with a reduction in gender disparities in educational access by approximately 0.0197 and 0.0228 percentage points, respectively. In contrast, fixed broadband subscriptions (column 3) exhibit an insignificant effect on gender inequality in education.

These findings are further supported by the Driscoll-Kraay estimations (columns 4-6), which confirm the negative and statistically significant impact of ICT adoption on gender inequality in education, even after accounting for autocorrelated errors and country-specific effects. Once again, fixed broadband subscription does not yield a significant effect on the outcome variable. Moreover, robustness checks using the GLS estimator (Appendix A5) reinforce the consistency of these results. The negative relationship between ICT adoption and gender inequality in education remains statistically significant, while the impact of fixed broadband continues to be insignificant.

While these preliminary results offer valuable insights into the average effect of ICT adoption on gender inequality in educational access, they do not account for potential heterogeneity based on initial levels of inequality across countries, nor do they address endogeneity concerns, as emphasized by Asongu et al. (2021a).

Table 3: Preliminary results of the effect of ICT adoption on inequalities in access to education between men and women in SSA

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS (Random effect)			Discoll-Kraay		
VARIABLES	IG_Educ	IG_Educ	IG_Educ	IG_Educ	IG_Educ	IG_Educ
ln_Internet	-0.0197*** (0.0019)			-0.0124*** (0.0035)		
ln_Phonemobile		-0.0228*** (0.0063)			-0.0247*** (0.0065)	
Broadbandf			-0.0002 (0.0017)			-0.0005 (0.0007)
GDP	0.0008** (0.0004)	0.0007 (0.0007)	0.0010 (0.0008)	0.0008 (0.0005)	0.0008 (0.0006)	0.0011* (0.0006)
Gini	-0.2187*** (0.0801)	0.2966** (0.1436)	0.3191** (0.1441)	0.4435*** (0.1091)	0.4857*** (0.0960)	0.5018*** (0.1384)
Remit	-0.0023*** (0.0006)	0.0002 (0.0013)	-0.0005 (0.0013)	0.0008 (0.0008)	0.0010 (0.0010)	0.0004 (0.0009)
ln_tradop	-0.0276*** (0.0084)	-0.0468*** (0.0161)	-0.0409** (0.0164)	-0.0593*** (0.0119)	-0.0548*** (0.0147)	-0.0501*** (0.0137)
ln_credit	-0.0219*** (0.0063)	-0.0267** (0.0124)	-0.0554*** (0.0098)	-0.0254 (0.0190)	-0.0184 (0.0212)	-0.0518*** (0.0133)
CC	-0.0515*** (0.0084)	-0.0720*** (0.0145)	-0.0693*** (0.0146)	-0.0713*** (0.0135)	-0.0694*** (0.0136)	-0.0702*** (0.0164)
Constant	0.4904*** (0.0619)	0.2874** (0.1165)	0.2424** (0.1164)	0.0878 (0.1443)	0.0817 (0.1501)	0.0931 (0.1473)
Observations	375	438	438	438	438	438
R-squared				0.8611	0.8624	0.8573
Fixed countries effects	No	No	No	Yes	Yes	Yes
Chi2	279.8***	106.1***	90.55***			
Fisher				3596***	3885***	2224***

Notes: ***p < 1%, **p < 5%, *p < 10%. Heteroscedasticity robust standard errors reported in parentheses.

Source: authors.

3.2. Baseline results

Tables 4, 5, and 6 present the empirical results of our analysis, highlighting the heterogeneity of the effect of ICT adoption on gender inequality in access to education across different levels of initial inequality (low, medium, and high) within the conditional distribution of the outcome variable.

Table 3 examines the effect of internet usage using IVQR. The results indicate that in SSA countries with relatively low levels of gender inequality in education (i.e., at the 10th and 25th percentiles), internet usage has no statistically significant effect on the outcome. This suggests that, in these countries, the reduction in educational disparities between men and women is likely driven by factors other than ICT adoption. However, beyond a certain threshold of inequality specifically from the 50th to the 95th percentiles the impact of internet usage becomes both significant and consistently negative. At these higher levels of inequality, internet adoption contributes meaningfully to reducing gender disparities in education. More precisely, a 1% increase in internet usage is associated with a decrease in gender inequality by 0.0105, 0.0216, and 0.0306 percentage points at the 50th, 75th, and 95th percentiles, respectively (see columns 3, 4, and 5 of Table 4).

Table 5 presents the results for mobile cellular subscriptions. Similar to the findings on internet usage, the effect of mobile subscriptions is negative but statistically insignificant in countries with low gender inequality (10th and 25th percentiles). However, from the 50th percentile onward representing countries with medium to high levels of inequality the effect becomes significant at the 1% level. Specifically, a 1% increase in mobile subscription rates corresponds to reductions in gender inequality of 0.0228, 0.0431, and 0.0553 percentage points at the 50th, 75th, and 95th percentiles, respectively (see columns 3, 4, and 5).

In contrast, Table 6 reveals that fixed broadband subscriptions, despite their relatively low adoption rates across SSA, have a consistently negative and statistically significant effect on gender inequality throughout the entire conditional distribution from the 10th to the 95th percentile at the 5% and 1% significance levels. This result challenges the earlier average effect analysis in Table 2, where fixed broadband appeared to have an insignificant effect. Thus, the quantile approach uncovers meaningful impacts that average models fail to detect, particularly in contexts of varied inequality levels.

Taken together, the results in Tables 4, 5, and 6 indicate that the negative effect of ICT adoption on gender inequality in education becomes more pronounced as the level of inequality increases across SSA countries. That is, the greater the initial gender disparity in educational access, the more impactful ICT adoption appears to be in reducing it. The results also suggest that the effects of internet usage and mobile subscriptions are closely aligned although this is nuanced by the fact that mobile phones often serve as a primary access point to the internet in many SSA countries.

In summary, the hypothesis that ICT adoption mitigates gender inequality in access to education in SSA cannot be rejected, especially when taking into account the heterogeneity of effects across different inequality contexts.

Table 4: Effect of Internet adoption on inequalities in access to education between men and women in SSA

Dep.var: Index of gender gap in access to education					
Indp.var: Use of the Internet					
	(1)	(2)	(3)	(4)	(5)
	<u>Lower quantile</u>		<u>Middle quantile</u>	<u>Upper quantile</u>	
	Q (0.1)	Q (0.25)	Q (0.5)	Q (0.75)	Q (0.95)
VARIABLES	IG_educ	IG_educ	IG_educ	IG_educ	IG_educ
ln_Internet	-0.0009 (0.0039)	-0.0040 (0.0038)	-0.0105** (0.0047)	-0.0216*** (0.0075)	-0.0306*** (0.0104)
GDP	0.0004 (0.0006)	0.0004 (0.0006)	0.0001 (0.0007)	-0.0002 (0.0010)	-0.0005 (0.0014)
Gini	-0.2582*** (0.0930)	-0.3382*** (0.0837)	-0.5083*** (0.0908)	-0.7982*** (0.1460)	-1.0323*** (0.2081)
Remit	-0.0028*** (0.0009)	-0.0033*** (0.0008)	-0.0043*** (0.0008)	-0.0061*** (0.0015)	-0.0075*** (0.0021)
ln_tradeop	-0.0072 (0.0160)	-0.0012 (0.0144)	0.0114 (0.0150)	0.0329 (0.0249)	0.0502 (0.0358)
ln_credit	-0.0281*** (0.0071)	-0.0284*** (0.0068)	-0.0292*** (0.0090)	-0.0304* (0.0167)	-0.0314 (0.0237)
CC	-0.0166* (0.0089)	-0.0244*** (0.0083)	-0.0409*** (0.0103)	-0.0691*** (0.0178)	-0.0918*** (0.0253)
Constant	0.3258*** (0.0890)	0.3810*** (0.0774)	0.4984*** (0.0764)	0.6985*** (0.1274)	0.8600*** (0.1871)
Observations	375	375	375	375	375

Notes: Values in brackets correspond to standard deviations corrected for heteroscedasticity. * P < 0.10; ** P < 0.05; *** P < 0.01 indicate the significance thresholds for the different coefficients. These are 10%, 5% and 1% respectively.

Source: authors

Table 5: Effect of mobile phone subscription on inequalities in access to education between men and women in SSA

Dep.var : Index of gender gap in access to education					
Indp.var : Mobile phone subscription					
VARIABLES	(1)	(2)	(3)	(4)	(5)
	Lower quantile		Middle quantile	Upper quantile	
	Q (0.1)	Q (0.25)	Q (0.5)	Q (0.75)	Q (0.95)
	IG_educ	IG_educ	IG_educ	IG_educ	IG_educ
ln_Phonemobile	-0.0064 (0.0079)	-0.0122 (0.0075)	-0.0228*** (0.0082)	-0.0431*** (0.0125)	-0.0553*** (0.0162)
GDP	0.0004 (0.0006)	0.0003 (0.0006)	0.0003 (0.0005)	0.0002 (0.0004)	0.0001 (0.0005)
Gini	-0.2118*** (0.0807)	-0.3087*** (0.0734)	-0.4890*** (0.0738)	-0.8318*** (0.0895)	-1.0385*** (0.1206)
Remit	-0.0026*** (0.0008)	-0.0033*** (0.0007)	-0.0045*** (0.0006)	-0.0070*** (0.0008)	-0.0084*** (0.0011)
ln_tradeop	-0.0049 (0.0140)	0.0002 (0.0122)	0.0097 (0.0139)	0.0277 (0.0267)	0.0385 (0.0363)
ln_credit	-0.0274*** (0.0063)	-0.0280*** (0.0058)	-0.0290*** (0.0055)	-0.0309*** (0.0074)	-0.0320*** (0.0094)
CC	-0.0130 (0.0083)	-0.0224*** (0.0075)	-0.0400*** (0.0075)	-0.0733*** (0.0092)	-0.0934*** (0.0124)
Constant	0.3094*** (0.0780)	0.3981*** (0.0675)	0.5631*** (0.0766)	0.8769*** (0.1375)	1.0660*** (0.1908)
Observations	375	375	375	375	375

Notes: Values in brackets correspond to standard deviations corrected for heteroscedasticity. * P < 0.10; ** P < 0.05; *** P < 0.01 indicate the significance thresholds for the different coefficients. These are 10%, 5% and 1% respectively.

Source: authors

Table 6: Effect of fixed broadband adoption on inequalities in access to education between men and women in SSA

Dep.var : Index of gender gap in access to education					
Indp.var : Fixed broadband subscription					
VARIABLES	(1)	(2)	(3)	(4)	(5)
	Lower quantile		Middle quantile	Upper quantile	
	Q (0.1)	Q (0.25)	Q (0.5)	Q (0.75)	Q (0.95)
	IG_educ	IG_educ	IG_educ	IG_educ	IG_educ
Broadbandf	-0.0027** (0.0014)	-0.0031*** (0.0012)	-0.0039*** (0.0011)	-0.0053*** (0.0016)	-0.0066*** (0.0024)
GDP	0.0001 (0.0007)	0.0001 (0.0006)	0.0001 (0.0006)	0.0002 (0.0007)	0.0002 (0.0010)
Gini	-0.3357*** (0.1034)	-0.4130*** (0.0903)	-0.5659*** (0.0862)	-0.8175*** (0.1292)	-1.0612*** (0.1992)
Remit	-0.0028*** (0.0008)	-0.0034*** (0.0008)	-0.0047*** (0.0008)	-0.0068*** (0.0014)	-0.0088*** (0.0021)
ln_tradeop	-0.0055 (0.0142)	0.0017 (0.0119)	0.0159 (0.0164)	0.0393 (0.0342)	0.0620 (0.0536)
ln_credit	-0.0135** (0.0054)	-0.0183*** (0.0046)	-0.0277*** (0.0065)	-0.0433*** (0.0133)	-0.0583*** (0.0208)
CC	-0.0157** (0.0076)	-0.0228*** (0.0069)	-0.0369*** (0.0097)	-0.0601*** (0.0183)	-0.0826*** (0.0279)

Constant	0.3238*** (0.0909)	0.3806*** (0.0718)	0.4929*** (0.0640)	0.6777*** (0.1271)	0.8567*** (0.2121)
Observations	371	371	371	371	371

Notes: Values in brackets correspond to standard deviations corrected for heteroscedasticity. * P < 0.10; ** P < 0.05; *** P < 0.01 indicate the significance thresholds for the different coefficients. These are 10%, 5% and 1% respectively.

Source: authors

3.3.Sensitivity analysis through the construction of the ICT adoption index

In this subsection, we will make an analysis of the sensitivity of our results by constructing the ICT adoption index using the Principal Component Analysis (PCA) method to test the validity of our results. PCA is a statistical technique that reduces the number of variables in an analysis by describing a series of uncorrelated linear combinations of variables that contain most of the variance. The objective of the PCA is to find linear combinations of unit lengths of variables with the greatest variance. The first component has the maximum overall variance. In other words, the first component contains more information than the others. To analyze our PCA, we used the three ICTs variables to discover the variation and contribution of the factors. According to the results presented in Table A2, the second principal component is chosen as the proxy for ICT because it has an Eigen value greater than one and contains around 92% of the information combined in the three ICTs variables. The choice of the first principal component is based on the Kaiser 1 criterion (Kaiser, 1974) in the light of recent literature (see Tchamyou, 2017). Thus, PCA is only a linear transformation of data.

Table 7: Effect of the ICT adoption index on inequalities in access to education between men and women in SSA

VARIABLES	Dep.var: Index of gender gap in access to education				
	Indp.var: ICT adoption index				
	(1)	(2)	(3)	(4)	(5)
	Lower quantile		Middle quantile	Upper quantile	
Q (0.1)	Q (0.25)	Q (0.5)	Q (0.75)	Q (0.95)	
IG_educ	IG_educ	IG_educ	IG_educ	IG_educ	
idICT	-0.0031* (0.0019)	-0.0047*** (0.0017)	-0.0079*** (0.0026)	-0.0142** (0.0057)	-0.0198** (0.0088)
GDP	0.0002 (0.0005)	0.0002 (0.0005)	0.0002 (0.0005)	0.0003 (0.0007)	0.0003 (0.0010)
Gini	-0.2862*** (0.0925)	-0.3627*** (0.0821)	-0.5097*** (0.0809)	-0.8082*** (0.1211)	-1.0717*** (0.1849)
Remit	-0.0026*** (0.0008)	-0.0032*** (0.0007)	-0.0042*** (0.0007)	-0.0063*** (0.0011)	-0.0081*** (0.0016)
ln_tradeop	-0.0059 (0.0143)	-0.0019 (0.0129)	0.0059 (0.0147)	0.0216 (0.0281)	0.0354 (0.0429)
ln_credit	-0.0224*** (0.0064)	-0.0230*** (0.0060)	-0.0240*** (0.0077)	-0.0262* (0.0153)	-0.0281 (0.0230)
CC	-0.0140* (0.0085)	-0.0215*** (0.0079)	-0.0358*** (0.0096)	-0.0648*** (0.0171)	-0.0905*** (0.0256)
Constant	0.3220*** (0.0839)	0.3759*** (0.0719)	0.4794*** (0.0680)	0.6896*** (0.1172)	0.8752*** (0.1857)
Observations	371	371	371	371	371

Notes: Values in brackets correspond to standard deviations corrected for heteroscedasticity. * P < 0.10; ** P < 0.05; *** P < 0.01 indicate the significance thresholds for the different coefficients. These are 10%, 5% and 1% respectively.

Source: authors

Overall, the estimation results presented in Table 7 are consistent and reinforce the core findings discussed previously. Specifically, the composite indicator of ICT adoption continues to exhibit a statistically significant and negative effect on gender inequality in access to education across all conditional distributions of inequality levels in Sub-Saharan Africa (SSA). This finding confirms the robustness of the relationship between ICT usage and reduced gender disparities in educational access.

3.4.Sensitivity analysis using an alternative ICT measure

So far, our indicator of ICT adoption has been measured by internet usage, mobile phone subscriptions and fixed broadband subscriptions. However, to ensure that our results are not influenced by the way ICT adoption is measured, we consider exports of ICT goods as a percentage of total exports of goods. This variable is commonly used in the literature (Asongu & Odhiambo, 2019; Soluk et al. 2021) to measure technology usage.

The results presented in Table 8, using an alternative measure of ICT adoption, support those presented above. In particular, we find that exports of ICT goods contribute significantly to reducing gender inequalities in access to education at the 10% threshold, especially in the 25th quantile (see column 2) and the 50th quantile (see column 3).

Table 8: Effect of ICT goods exports on gender inequalities in access to education in SSA

Dep.var: Index of gender gap in access to education					
Indp.var: ICT goods exports					
VARIABLES	(1)	(2)	(3)	(4)	(5)
	Lower quantile		Middle quantile	Upper quantile	
	Q (0.1)	Q (0.25)	Q (0.5)	Q (0.75)	Q (0.95)
	IG_educ	IG_educ	IG_educ	IG_educ	IG_educ
ICTgoodsexports	-0.0058 (0.0038)	-0.0055* (0.0032)	-0.0049* (0.0025)	-0.0040 (0.0033)	-0.0031 (0.0056)
GDP	0.0009 (0.0007)	0.0009 (0.0006)	0.0009 (0.0006)	0.0010 (0.0006)	0.0011 (0.0008)
Gini	-0.2971*** (0.1063)	-0.3725*** (0.0982)	-0.5052*** (0.1002)	-0.7353*** (0.1435)	-0.9728*** (0.2160)
Remit	-0.0017* (0.0009)	-0.0024*** (0.0008)	-0.0035*** (0.0010)	-0.0054*** (0.0020)	-0.0074** (0.0033)
ln_tradeop	-0.0238 (0.0151)	-0.0147 (0.0129)	0.0014 (0.0152)	0.0293 (0.0293)	0.0582 (0.0473)
ln_credit	-0.0122** (0.0052)	-0.0179*** (0.0047)	-0.0279*** (0.0052)	-0.0453*** (0.0088)	-0.0633*** (0.0139)
CC	-0.0095 (0.0078)	-0.0187** (0.0073)	-0.0349*** (0.0092)	-0.0630*** (0.0166)	-0.0919*** (0.0261)
Constant	0.3610*** (0.0848)	0.4121*** (0.0688)	0.5022*** (0.0698)	0.6582*** (0.1350)	0.8193*** (0.2247)
Observations	345	345	345	345	345

Notes: Values in brackets correspond to standard deviations corrected for heteroscedasticity. * P < 0.10; ** P < 0.05; *** P < 0.01 indicate the significance thresholds for the different coefficients. These are 10%, 5% and 1% respectively.

Source: authors

3.5.Sensitivity analysis by decomposing the gender education inequality index

In our previous analyses, gender inequality in access to education in SSA was measured using a composite index that accounts for enrollment at the primary, secondary, and tertiary levels. However, to gain a more nuanced understanding, we calculated specific gender inequality indices for each level of education primary, secondary, and tertiary based on data from the

World Bank's World Development Indicators (WDI). These indices were constructed using a methodology inspired by the World Economic Forum (WEF).

Specifically, gender inequality in access to primary education (denoted as *IG_Educpri*) is calculated as follows:

$$IG\ Educpri = 1 - \left(\frac{\text{Female primary school enrollment rate}}{\text{Male primary school enrollment rate}} \right) \quad (6)$$

The same formula is applied to compute gender inequality in access to secondary education (*IG_Educsec*) and tertiary education (*IG_Eduter*). This disaggregated approach allows us to better capture the differential impact of ICT adoption on gender inequality at each educational level. Ultimately, this enables us to formulate more targeted and effective policy recommendations.

Table 9: Effect of ICT adoption on gender inequalities in access to primary education in SSA

Dep.var : Index of gender gap in access to primary education					
Indp.var : ICT adoption index					
VARIABLES	(1)	(2)	(3)	(4)	(5)
	Lower quantile		Middle quantile	Upper quantile	
	Q (0.1)	Q (0.25)	Q (0.5)	Q (0.75)	Q (0.95)
	IG_educpri	IG_educpri	IG_educpri	IG_educpri	IG_educpri
idICT	0.0002 (0.0026)	-0.0039* (0.0021)	-0.0086*** (0.0018)	-0.0164*** (0.0014)	-0.0266*** (0.0020)
Constant	-0.0431*** (0.0070)	-0.0097** (0.0044)	0.0280*** (0.0051)	0.0903*** (0.0069)	0.1728*** (0.0145)
Observations	428	428	428	428	428

Notes: values in parentheses correspond to standard deviations corrected for heteroscedasticity. * P < 0.10; ** P < 0.05; *** P < 0.01 indicate the significance thresholds of the different coefficients. These are 10%, 5% and 1% respectively.

Source: authors

Table 10: Effect of ICT adoption on gender inequalities in access to secondary education in SSA

Dep.var : Index of gender gap in access to secondary education					
Indp.var : ICT adoption index					
VARIABLES	(1)	(2)	(3)	(4)	(5)
	Lower quantile		Middle quantile	Upper quantile	
	Q (0.1)	Q (0.25)	Q (0.5)	Q (0.75)	Q (0.95)
	IG_educsec	IG_educsec	IG_educsec	IG_educsec	IG_educsec
idICT	-0.0305** (0.0149)	-0.0373*** (0.0109)	-0.0428*** (0.0078)	-0.0489*** (0.0052)	-0.0599*** (0.0061)
Constant	-0.1221*** (0.0296)	-0.0076 (0.0156)	0.0863*** (0.0104)	0.1893*** (0.0205)	0.3744*** (0.0363)
Observations	311	311	311	311	311

Notes: values in parentheses correspond to standard deviations corrected for heteroscedasticity. * P < 0.10; ** P < 0.05; *** P < 0.01 indicate the significance thresholds of the different coefficients. These are 10%, 5% and 1% respectively.

Source: authors

Table 11: Effect of ICT adoption on gender inequalities in tertiary education in SSA

Dep.var: Index of gender gap in access to tertiary education					
Indp.var: ICT adoption index					
	(1)	(2)	(3)	(4)	(5)
	<u>Lower quantile</u>		<u>Middle quantile</u>	<u>Upper quantile</u>	
	Q (0.1)	Q (0.25)	Q (0.5)	Q (0.75)	Q (0.95)
VARIABLES	IG_educter	IG_educter	IG_educter	IG_educter	IG_educter
idTIC	-0.1582*** (0.0189)	-0.1424*** (0.0136)	-0.1280*** (0.0109)	-0.1143*** (0.0118)	-0.1035*** (0.0145)
Constant	-0.1024** (0.0414)	0.1034*** (0.0275)	0.2915*** (0.0209)	0.4691*** (0.0219)	0.6103*** (0.0216)
Observations	309	309	309	309	309

Notes: values in parentheses correspond to standard deviations corrected for heteroscedasticity. * P < 0.10; ** P < 0.05; *** P < 0.01 indicate the significance thresholds of the different coefficients. These are 10%, 5% and 1% respectively.

Source: authors

The results presented in Tables 9, 10, and 11 indicate that ICT adoption has a negative and statistically significant effect (at the 1%, 5%, and 10% levels) on gender disparities in access to primary, secondary, and tertiary education. In other words, our findings suggest that increased ICT adoption is associated with a reduction in gender inequality in educational access across all levels particularly at the primary, secondary, and higher education tiers.

Notably, the effect appears to be most pronounced at the tertiary level. According to human capital theory, improved access to ICT can enhance educational opportunities for women, thereby strengthening their skills and employability. Furthermore, the technology acceptance model suggests that women may derive greater benefits from ICT at the higher education level, as they are more likely to adopt these technologies to acquire specialized knowledge and pursue advanced career opportunities.

3.6. ICT Adoption and Gender Inequality in Access to Education: The Role of Religious and Cultural Variables

In addition to the previous findings, it is essential to explore the transmission channels through which ICT adoption affects gender inequality in access to education in SSA. While earlier analyses have shown that ICT adoption contributes to reducing gender disparities in educational access, a more comprehensive understanding requires consideration of the religious and cultural contexts within SSA countries.

In this study, we incorporate religious and cultural variables to account for these contextual influences. Specifically, we include the percentage of the population adhering to the two most prevalent religions in the region Islam and Catholicism. Additionally, we consider a measure of ethnic diversity, as proposed by La Porta et al. (1999), to capture cultural heterogeneity. These factors may significantly shape the impact of ICT adoption on our outcome variables and thus merit careful examination.

Table 12: Effect of religious and cultural variables on the relationship between ICT adoption and gender inequality in access to education in SSA

VARIABLES	(1)	(2)	(3)
	OLS (random effect)		
	IG_educ	IG_educ	IG_educ
idTIC	-0.0140*** (0.0026)	-0.0052** (0.0020)	-0.0034 (0.0059)
Catho	-0.0007 (0.0007)		
c.idTIC#c.Catho	0.0002** (0.0001)		
Muslim		0.0010* (0.0006)	
c.idTIC#c.Muslim		-0.0002*** (0.0001)	
Ethnic			0.1107* (0.0600)
c.idTIC#c.Ethnic			-0.0085 (0.0085)
GDP	0.0011*** (0.0004)	0.0011*** (0.0004)	0.0011*** (0.0004)
Gini	-0.2165** (0.0884)	-0.2070** (0.0894)	-0.1778* (0.0955)
Remit	-0.0021*** (0.0007)	-0.0018** (0.0007)	-0.0021*** (0.0007)
ln_tradeop	-0.0240** (0.0096)	-0.0237** (0.0095)	-0.0269*** (0.0096)
ln_credit	-0.0404*** (0.0069)	-0.0365*** (0.0069)	-0.0404*** (0.0070)
CC	-0.0441*** (0.0092)	-0.0381*** (0.0092)	-0.0407*** (0.0094)
Constant	0.5047*** (0.0700)	0.4426*** (0.0717)	0.4045*** (0.0788)
Observations	371	371	371
Chi2	154.8***	164.2***	154.3***

Notes: values in parentheses correspond to standard deviations corrected for heteroscedasticity. * P < 0.10; ** P < 0.05; *** P < 0.01 indicate the significance thresholds of the different coefficients. These are 10%, 5% and 1% respectively.

Source: authors

The results in Table 12 are consistent with those of the baseline model and align with the literature highlighting the negative effect of ICT adoption on gender inequality in access to education in SSA.

First, Catholicism shows a negative and significant effect on gender inequality in education (Column 1). However, its interaction with ICT adoption is positive and significant at the 5% level, suggesting that ICT, despite enabling remote learning, may be perceived in Catholic communities as a threat to traditional gender roles, limiting its equalizing effect.

Second, Column 2 shows that Islam is positively and significantly associated with gender inequality, reflecting social norms that often prioritize boys' education. Yet, the interaction with ICT adoption is negative and highly significant (1%), indicating that ICT may be accepted in Muslim communities when aligned with religious values, serving as a culturally appropriate tool to expand educational access for women. D'Aiglepierre & Bauer (2018) also note that Quranic schools in SSA are often more gender-inclusive than formal systems, which may support this result.

Third, Column 3 reveals that when ethnic diversity is accounted for, the previously significant negative effect of ICT adoption on gender inequality becomes insignificant. This suggests that high ethnic fragmentation may hinder progress toward gender parity in education due to varying cultural norms across groups.

Overall, the findings are robust to several checks: (i) the construction of the ICT adoption index; (ii) the use of an alternative ICT measure; (iii) disaggregating gender inequality by education level; and (iv) accounting for religion and culture in SSA. Thus, the main hypothesis that ICT adoption reduces gender inequality in access to education in SSA cannot be rejected.

4. Conclusions and future directions of research

This study empirically examined the effect of Information and Communication Technologies (ICT) adoption on gender inequality in access to education across Sub-Saharan African (SSA) countries between 2006 and 2021. ICT adoption was proxied by internet usage, mobile phone subscriptions, and fixed broadband subscriptions, while gender disparities in education were captured through a composite index based on the World Economic Forum's gender parity indicators. To account for distributional heterogeneity and potential endogeneity, the analysis employed the Instrumental Variable Quantile Regression (IVQR) method.

Initial estimates using Ordinary Least Squares (OLS) and Driscoll-Kraay regressions revealed, on average, a significant negative relationship between ICT use specifically internet access and mobile phone subscriptions and gender inequality in education. However, the effect of fixed broadband subscriptions was not statistically significant, possibly reflecting the limited reach of broadband infrastructure in the region. The IVQR estimates provided a more nuanced picture. While confirming the general inverse relationship between ICT adoption and gender inequality, the results showed substantial variation across the inequality distribution. In countries with lower levels of educational gender disparity (10th and 25th quantiles), ICT indicators had no significant impact suggesting that other structural or institutional factors may be more influential. Conversely, in countries facing moderate to high levels of gender inequality (50th to 95th quantiles), ICT adoption had a consistently negative and statistically significant effect, indicating its greater relevance in contexts where disparities are more pronounced.

These findings underscore the importance of expanding ICT access as a lever for reducing gender disparities in education. Targeted public policies particularly universal access initiatives and subsidized ICT programs could accelerate adoption and foster more inclusive educational systems. Such efforts are critical to meeting the Sustainable Development Goals (SDGs), especially in light of persistent shortfalls in achieving the Millennium Development Goals (MDGs) across much of SSA.

Lastly, this study was constrained by data availability, focusing on only three ICT proxies. Future research should adopt a microeconomic approach to examine the role of ICT adoption within schools and households, incorporating additional variables such as laptop use, digital teaching tools, and mobile broadband connectivity to provide a more comprehensive understanding of ICT's role in promoting educational equity.

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APPENDIX

Table A1: Sample country

<i>Angola, Benin, Botswana, Burkina Faso, Burundi, Capt vert, Cameroon, Chad, Côte d'ivoire, DR Congo, Gambia, Ghana, Guinea, Kenya, Mauritius, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Namibia, Uganda, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Tanzania, Togo, Zambia, Zimbabwe</i>

Source: authors

Table A2: Approach to constructing the gender inequality index

❖ Principal components				
<i>Component</i>	<i>Eigenvalue</i>	<i>Difference</i>	<i>Proportion</i>	<i>Cumulative</i>
<i>Comp1</i>	2.14593	1.51844	0.7153	0.7153
<i>Comp2</i>	.627491	.400912	0.2092	0.9245
<i>Comp3</i>	.226579	.	0.0755	1.0000
❖ Principal components (the eigenvectors)				
<i>Variable</i>	<i>Comp1</i>	<i>Comp2</i>	<i>Comp3</i>	<i>Unexplained</i>
<i>Internet</i>	0.6258	-0.2334	-0.7443	0
<i>Phonemobile</i>	0.5973	-0.4703	0.6496	0
<i>Hautdebitf</i>	0.5017	0.8511	0.1549	0

Source: authors

Table A3: Correlation matrix between sample variables

Variables	(1)	(5)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) IG_educ	1.000										
(5) idTIC	-0.372*	1.000									
(7) Phonemobile	-0.345*	0.875*	1.000								
(8) Internet	-0.347*	0.917*	0.767*	1.000							
(9) Broadbandf	-0.277*	0.735*	0.414*	0.523*	1.000						
(10) GDP	0.112*	-0.244*	-0.164*	-0.258*	-0.163*	1.000					
(11) Gini	-0.405*	0.069	0.104*	0.105*	0.001	-0.048	1.000				
(12) Remit	-0.205*	0.035	0.051	0.110*	-0.059	-0.059	-0.186*	1.000			
(13) tradeop	-0.224*	0.205*	0.152*	0.136*	0.232*	-0.019	0.174*	0.305*	1.000		
(14) Credit	-0.432*	0.637*	0.539*	0.560*	0.554*	-0.174*	0.369*	-0.103*	0.193*	1.000	
(15) CC	-0.534*	0.448*	0.429*	0.414*	0.344*	-0.014	0.387*	0.148*	0.353*	0.50*	1.000

Source: authors

Table A4: Results of the effect of ICT adoption on gender inequality in access to education in SSA by GLS

	(1)	(2)	(3)
	GLS		
VARIABLES	IG_Educ	IG_Educ	IG_Educ
ln_Internet	-0.0124*** (0.0036)		
ln_Phonemobile		-0.0247*** (0.0061)	
Broadbandf			-0.0005 (0.0016)
GDP	0.0008 (0.0007)	0.0008 (0.0007)	0.0011 (0.0007)
Gini	0.4435*** (0.1563)	0.4857*** (0.1547)	0.5018*** (0.1575)
Remit	0.0008 (0.0013)	0.0010 (0.0013)	0.0004 (0.0013)
ln_tradeop	-0.0593*** (0.0162)	-0.0548*** (0.0160)	-0.0501*** (0.0164)
ln_credit	-0.0254** (0.0125)	-0.0184 (0.0129)	-0.0518*** (0.0100)
CC	-0.0713*** (0.0159)	-0.0694*** (0.0158)	-0.0702*** (0.0162)
Constant	0.0878 (0.1467)	0.0817 (0.1461)	0.0931 (0.1491)
Observations	438	438	438
Fixed countries effects	Yes	Yes	Yes
Chi2	2715***	2744***	2631***

Notes: values in parentheses correspond to standard deviations corrected for heteroscedasticity. * P < 0.10; ** P < 0.05; *** P < 0.01 indicate the significance thresholds of the different coefficients. These are 10%, 5% and 1% respectively.

Source: authors