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Assessing the Key Determinants of ICT Inclusion in Pakistan from Demand and Supply Perspective

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Abstract

As Pakistan moves toward a digital economy, ensuring equal access to technology has become more crucial now for inclusive development. However, country faces a persistent digital divide that limits the inclusive economic growth. Therefore, this study examined the key determinants of ICT inclusion (adoption, literacy and transformation) in Pakistan, considering both demand and supply side factors. Study used the data of Pakistan Social and Living Standards Measurement (PSLM) 2019-20 and applied the Probit-IV technique to get the causal relationship between education and ICT inclusion. The findings reveal a significant digital divide, with ICT inclusion being higher among individuals with educational attainment, income levels, and access to ICT facilities at home. However, formal education's impact on ICT literacy and transformation is limited when accounting for unobserved heterogeneity, suggesting that innate ability and self-learning plays a more crucial role in ICT adoption. Additionally, younger individuals exhibit higher ICT adoption, while regional ICT infrastructure has a minimal direct impact on individual's ICT skills. The study highlights the need for policy interventions, including ICT-integrated curriculum, broadband expansion, and digital literacy programs, particularly in underserved regions.

Key words: ICT inclusion, Digital divide, ICT literacy

JEL classification: L83, O33, D83

1. Introduction

ICT emerged as a transformative force in the twenty first century behind regional and global progress by fostering innovation, connectivity, and efficiency across the various sectors. The ICT has transformed communication, by enabling real-time global interaction and collaboration, while providing access to paramount knowledge and information resources. Economically, ICT drives growth by supporting digital entrepreneurship and optimizing business operations. In education, it facilitates e-learning, while in healthcare, it enhances services through telemedicine and digital diagnostics.

The growing importance of digital technologies and the emergence of the digital economy in the advancement and prosperity of a society has broadly been acknowledged. From the industrial revolution to the digital age, technology has consistently propelled social change (Nawaz, 2023). The United Nations' Sustainable Development Goals highlight the role of ICT in realizing universal identification, promoting efficient governance, enhancing financial inclusion, and generating more jobs.

However, despite its vast potential, Pakistan is far behind in ICT progress, as it ranked 45th out of 52 countries in the internet development index (Chinese Academy of Cyberspace Studies, 2023). Pakistan faces significant challenges, including low internet penetration in

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rural areas, limited digital literacy, a sizeable gender gap, and weak institutional trust. Addressing these issues will be crucial for Pakistan to fully realize its potential as an advancing digital economy in the region (Digital Planet, 2025). Hence, ICT inclusion, literacy and transformation is indispensable for bridging the widening gap of socioeconomic disparities, creating more job opportunities for youth, and enhancing inclusive growth and development. With its transformative potential, ICT remains a key pillar in building a more connected, knowledgeable and progressive society.

Despite a rapid expansion in ICT across the globe, Pakistan still faces disparities in ICT inclusion across regions, gender and income groups. Studies conducted in Pakistan report that socioeconomic, demographic and geographical factors influence this ICT inclusion (Lythreatis et al., 2022; Shair et al., 2023). However, these studies have overlooked the multidimensional nature of ICT inclusion focusing merely on access and neglecting the demand and supply side factors.

Moreover, past studies that examined the factors influencing ICT inclusion indicate a positive relationship between education level and technology adoption; however, these findings are likely to be distorted by the endogeneity of education and may not accurately represent the actual causal relationship between education and ICT inclusion. Specifically, unobserved factors that relate to both education and ICT use may give rise to positive relationships between the two variables. For example, individuals with higher innate ability and stronger motivation may be more likely to be early adopters of new technologies and also more likely to acquire enhanced schooling. On the other hand, it is possible that the ability of individuals may vary even with the same level of educational achievement. Therefore, ignoring the impact of ability while analyzing the ICT inclusion model may cause biasness known in literature as omitted variable bias. To the best of our knowledge, only Riddell and Song (2017) has examined the causal relationship between education and ICT adoption using an IV approach for Canadian economy.

Furthermore, in case of Pakistan no study has demonstrated a causal relationship between education and technology adoption. Previous studies conducted in Pakistan have either defined ICT in terms of ICT adoption, ICT literacy or ICT transformation, but in our study, we have tried to conceptualize all the three pertinent aspects of ICT in Pakistan for the first time. Understanding these dimensions is essential when one navigates the complex terrain of ICT gap in Pakistan as only then one can formulate the targeted interventions and policies that can close the gap and guarantee that everyone can benefits from the digital age. Therefore, our study addresses this literature gap by measuring the ICT inclusion across three domains: ICT adoption, ICT literacy and ICT transformation, by providing a more nuanced perspective on the digital divide, using the data of PSLM 2019-20. To analyze the impact of demand-side factors—such as demographic and socio-economic characteristics—and supply-side factors, specifically ICT infrastructure in a given area, on technology inclusion we have also attempted to control for unobserved heterogeneity bias related to education.

More specifically present study is based on these research questions.

- What are the key demand- and supply-side determinants of ICT inclusion in Pakistan?
- How do these determinants differ across the three dimensions of ICT inclusion?

- To what extent is education's role causal rather than correlational across the three dimensions of ICT inclusion?

The rest of paper is organized as follows: the section 2 elaborates the measuring of ICT inclusion and its determinants, also focuses on econometric technique. While section 3 discusses the data and descriptive statistics. Section 4 highlights the empirical results and the last section is about the conclusion of the study.

2. Measuring ICT Inclusion and its Determinants

ICT inclusion is considered multidimensional rather a unidimensional phenomenon caused by a series of factors (Lythreatis et al., 2022), as a single indicator is not enough to reflect the digital gap at the individual or household level. ICT inclusion also involves highlighting the accessibility, utilization, and outcome gaps of the digital economy (Van Dijk, 2006).

There always exist some disparities among individuals in every aspect of life, and similarly digital divide is one of these. The disparity mainly refers to the insufficient access to ICT tools and equipment (Park, 2008). In the literature, ICT inclusion is classified into three different levels (Goedhart et al., 2019; Lythreatis et al., 2022). At the first level ICT inclusion, measured through ICT adoption, assesses the reach of internet and ICT tools. It mainly emphasizes the individual with or without internet or smart phone. At the second level ICT inclusion, measured through ICT literacy, refers to dissimilarities among individuals regarding ICT knowledge. And at the third level ICT inclusion, measured through ICT transformation, refers to the disparities in digital transformation or individuals' actual implementation of ICTs (Van Deursen and Van Dijk, 2014; Soomro et al., 2020; Van Dijk, 2006; Iqbal & Ahsan., 2024). ICT adoption, literacy and transformation have been measured through binary variables, details of which are provided in Appendix Table 4.

The diffusion and inclusion of information and communication technologies is a multifaceted phenomenon, deeply intertwined with a complex interplay of demand side factors like demographic, socioeconomic, ICT access and supply side factors like ICT infrastructure and urbanization. Understanding these determinants is crucial for tailoring policies and interventions aimed at bridging the ICT inclusion and fostering inclusive growth (Asrani, 2022). Demographic Variables such as age, gender, and education significantly shape an individual's propensity to adopt and effectively utilize ICT (Shair et al., 2023).

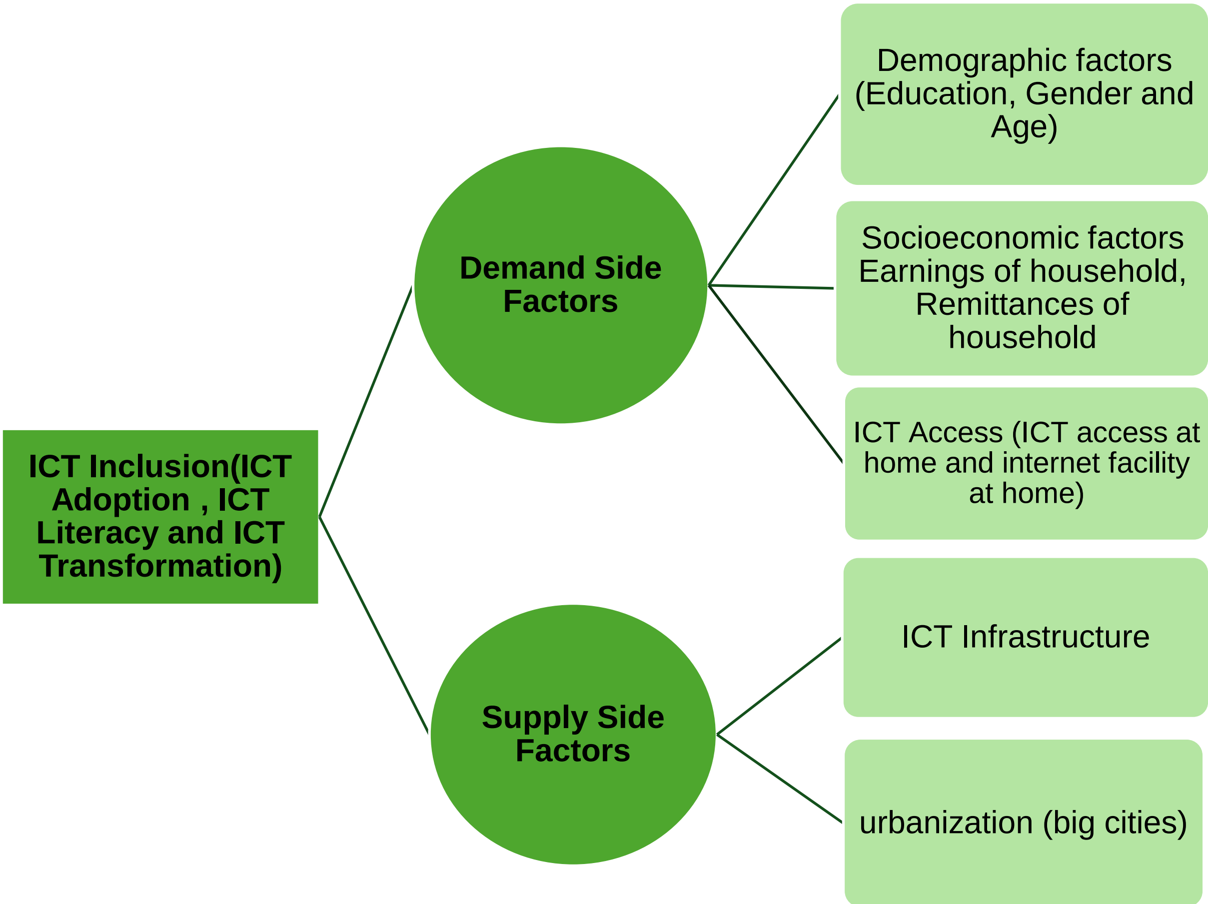
Further education also plays a pivotal role in shaping an individuals' ICT skills, knowledge, and awareness, thereby influencing their ability to effectively utilize these technologies. Individuals with higher levels of education are more likely to adopt ICTs and leverage their potential for various purposes, including communication, information seeking, and economic advancement (Asrani, 2022). Moreover, gender, another critical demographic variable, can also influence ICT inclusion patterns. In many contexts, a gender gap exists in access to and adoption of ICTs, potentially attributable to sociocultural norms, disparities in educational attainment, and unequal access to economic opportunities (Gupta & Jain, 2015).

Age, for instance, often exhibits an inverse relationship with ICT adoption, with younger individuals generally demonstrating greater familiarity and willingness to embrace new technologies compared to older generations (Moghaddam & Khatoon-Abadi, 2013). This disparity may stem from differences in digital literacy, comfort levels with technology, and perceived relevance of ICTs to their daily lives. Sun et al., (2025) investigates adoption of smart devices among older individuals; finds factors like age, health status, education, income, previous internet usage, and household composition important for adoption.

Similarly, socio economic factors like earnings and remittances also play a vital role in improving ICT adoption and ICT skills (Chakraborty and Bosman, 2005). The study of Ali et al. (2024) finds that migrants' remittances increased the mobile ownership by 27 % and internet facility by 12 %.

There are many studies which find that ICT access at home improves the digital adoption, literacy and its transformation (Joshkun et al., 2024). Improved access to technological resources at the household level facilitates greater familiarity with digital tools, fostering higher ICT competency and inclusion rates.

From supply side perspective the regional ICT access density plays an important role regarding network availability, which positively impacts ICT inclusion or learning effects (Goolsbee & Klenow, 2002; Asrani, 2022). Similarly, the other supply side exogenous variables are size of the market and urbanization (Andonova, 2006; Vicente &López, 2011). Both of them can influence the cost of supplying ICT instruments. Size of the market provides economies of scale which can reduce average cost of supply. Urban areas having better infrastructure facilities and higher concentration of population, utilize greater diffusion of ICT facilities. Similarly, Internet and mobile networks along with quality of their services also influence the ICT inclusion (Barman et al., 2018)



Source: Asrani (2022); Guha & Mukerji (2021) and authors. Whereas construction of variables is given in appendix, table 1.

2.1 Econometric Methodology

The investigation into the determinants of technology inclusion (ICT adoption, ICT literacy and ICT transformation), has led us to frame these as binary variables. Therefore, Probit model emerges as a particularly apt technique for this purpose, given its capacity to model the probability of a binary outcome— whether an individual, household, or firm utilizes ICTs— based on a set of predictor variables, the probit Model is defined as below.

$$Log\left[\frac{P_i}{1-P_i}\right] = \beta_j X_i + U_i \qquad (1)$$

Here P_i is the probability of the occurrence of the event such as ICT inclusion while P_i / (1-P_i) shows the odd ratio of event being not occurred. Whereas X_i is a vector of explanatory variables influencing ICT inclusion indicators and β_j are the estimated coefficients of the predictor variables. Whereas U_i is the error term capturing unobserved factors. As we defined ICT inclusion by ICT adoption, ICT literacy and ICT transformation, we estimated three models separately to analyze the determinants for ICT inclusion. This approach allows for a more precise understanding of the factors influencing each component of ICT inclusion.

2.2 Correction of Heterogeneity Bias

The above model given in equation (1) assumes that education attainment is an exogenous variable; therefore, estimating equation (1) by Probit model provides consistent or unbiased results. However, if this assumption does not hold i.e., education attainment (E_i^a) is not exogenous, then endogeneity exists due to omitted variable bias or reverse causation. For example, individuals with higher innate ability and stronger motivation may be more likely to be early adopters of new technologies and likely to acquire more schooling. Hence education would be correlated with error term.

$$\text{Cov}\ (E_i^a; \varepsilon\, i\,) \neq 0, \text{ for some } i = 1, ..., k.$$

Therefore, positive correlations between education and technology use and inclusion based on simple Probit model estimates may overestimate the effects of education on inclusion of technology and fail to reveal the true causal link between the two.

Therefore, to handle the potential bias related to observable educational variables included in the empirical specification, we applied the instruments variable (IV) technique. To apply IV technique, each instrumental variable, denoted by z, must be uncorrelated with the error term (exogeneity), that is Cov (z, ε) = 0 but should have high sample correlation with the endogenous explanatory, (relevance), that is Cov (z, E_i^a,) ≠ 0.

Our first instrument is the average level of education attained (as defined by ISCED) in the enumeration block where the individual lives. The reason for using this instrument is to have the combined effect of several commonly used exogenous factors, such as social environment, distance from school, number of educational institutes in the area and general trend towards education.

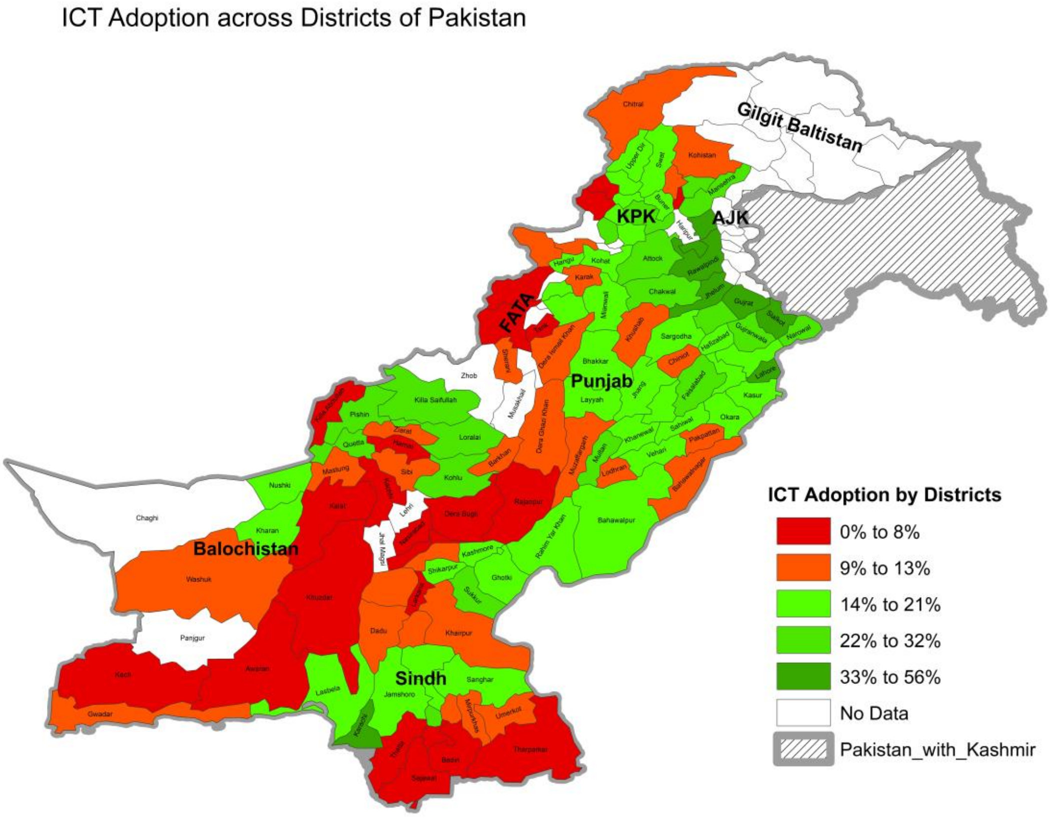
Second instrument by making use of macroeconomic variable, specifically, the condition of labor market in the year when individual is at age of 14 years, as this is the age when an individual decides either to continue his/her education or to enter the labor market. A high unemployment rate at this time is likely to make individual to stay in the schooling system if they can afford as the labor market may not be offering suitable job opportunities. These exogenous variables have an influence on the education attainment but may not affect the dependent variable i.e. ICT adoption.

To address the issue of endogeneity, we applied the Instrumental Variables (IV) Probit model, as our dependent variables are binary in nature as also used by Liu et al (2023). By applying the IV Probit model, we effectively address potential endogeneity concerns while maintaining the appropriate structure for binary dependent variables in our analysis of ICT inclusion determinants.

3. Data and Descriptive Statistics

PSLM 2019-20, very first time has introduced the ICT module and tried to provide very comprehensive information like adoption, literacy and transformation of ICT at individual level. By focusing on individual-level data, we can capture variations in ICT adoption, literacy, and transformation across different demographic groups, leading to more precise and policy-relevant insights.

Below map illustrates ICT adoption across different districts in Pakistan, highlighting disparities in ICT adoption. The ICT adoption ranges from lowest 0-8% to highest 33-56%, providing insight into regional variations regarding ICT disparity. Higher ICT inclusion in urban areas of Punjab and Sindh like Lahore, Rawalpindi, Faisalabad, and Karachi, Hyderabad, is due to better infrastructure and better law and order situation in these cities. However, a few districts of Khyber Pakhtunkhwa (KPK) show a moderate ICT adoption.

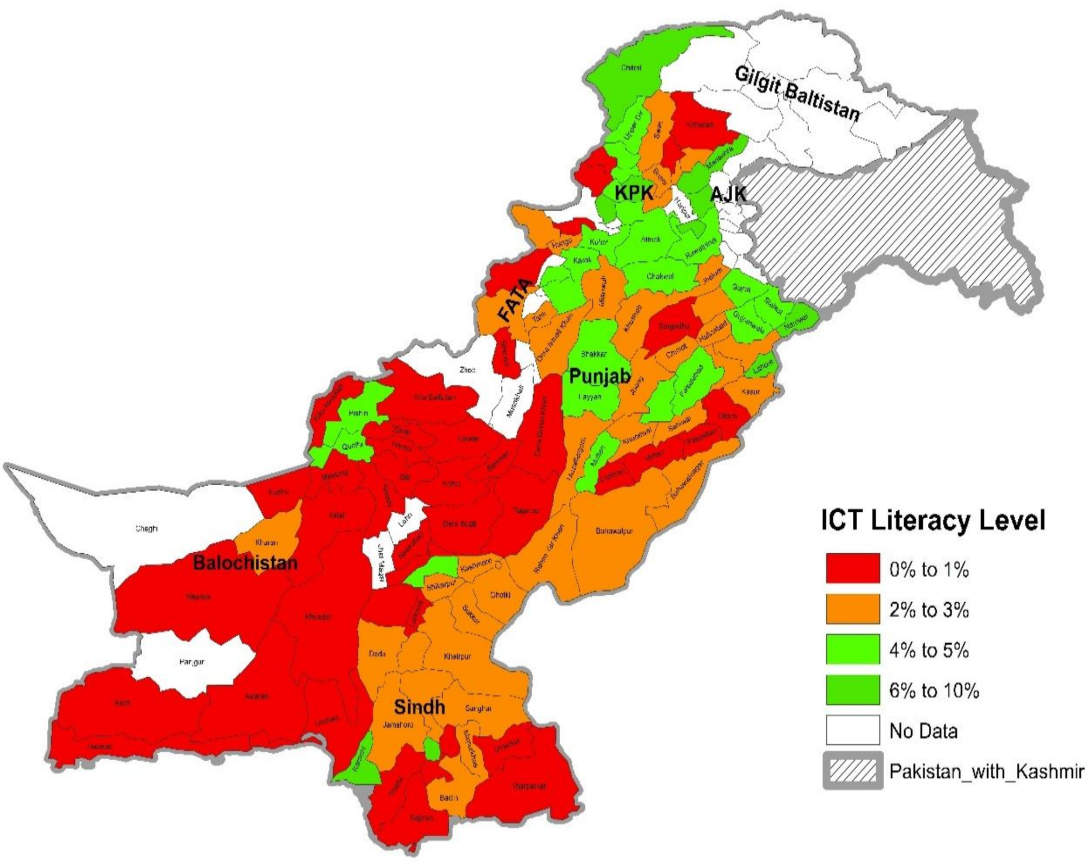


The lower ICT adoption observed in Baluchistan and FATA, is perhaps due to poor internet access, lack of education, economic constraints, and security issues.

The below map shows the ICT literacy rate across different districts in Pakistan. Whereas the majority of Baluchistan, Sindh, and parts of Punjab and KPK have very low ICT literacy levels (0% to 3%), indicating limited access to digital education and technology, many areas in FATA show extremely poor ICT literacy, likely due to underdeveloped infrastructure and lower educational opportunities.

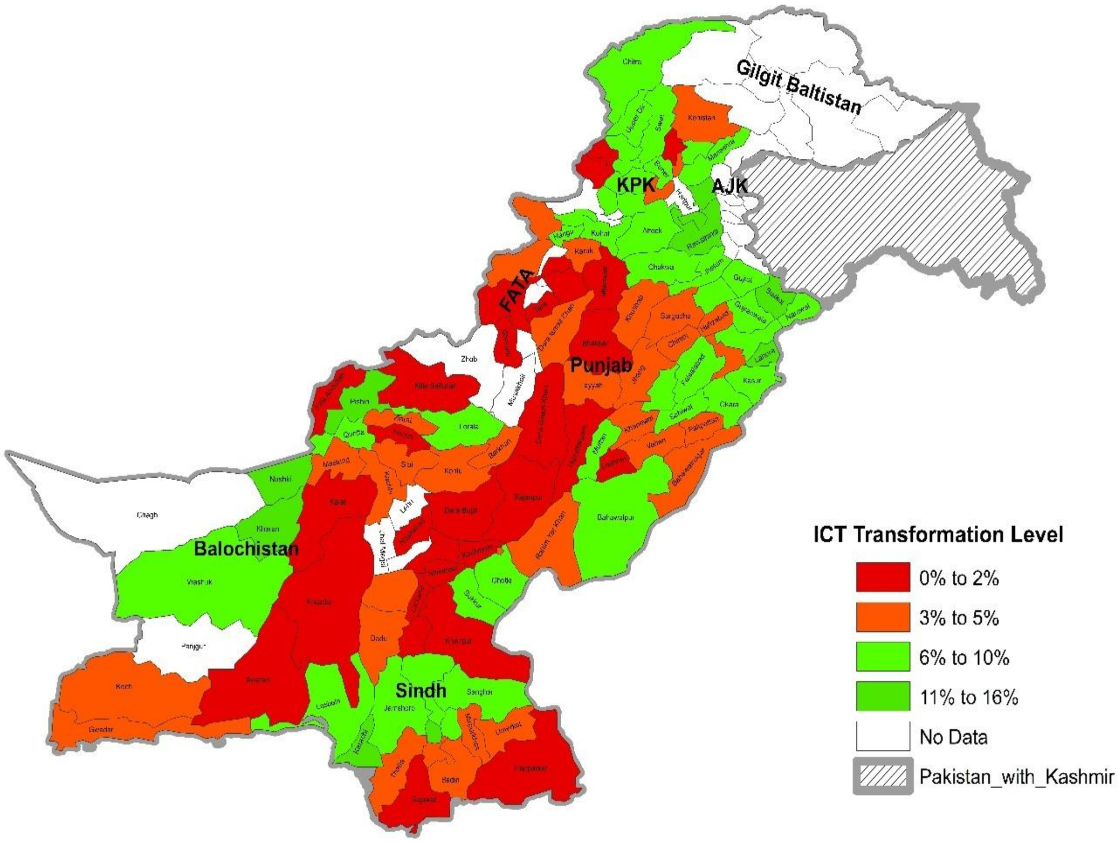
Some districts in Punjab, Sindh and KPK show the moderate level of ICT literacy (4% to 10%), reflecting better digital adoption, education facilities, and government initiatives. Hence, ICT literacy in Pakistan remains alarmingly low, especially in rural and underdeveloped regions.

ICT Literacy Level across Districts of Pakistan



The below map illustrates the ICT transformation levels across districts in Pakistan. Higher ICT transformation is concentrated in parts of Punjab, while lower ICT transformation is prevalent in rural and underdeveloped regions of Baluchistan. This can be attributed to low level of ICT Knowledge and lack of infrastructure like poor electricity availability, fiber optics and broadband network.

ICT Transformation Level across Districts of Pakistan



4. Empirical Results

Table 1 highlights the determinants of ICT adoption at individual level, whereas column 1 explains the marginal effects of Probit model. To check whether our explanatory variable i.e. education is endogenous or not, we apply the Wald test for exogeneity, where the null hypothesis exhibits that endogenous repressor is exogenous (i.e., no endogeneity exists). Our results show that the value of Wald test χ^2 statistic is not statistically significant (p-value of Wald test is 0.5246) indicating that our explanatory variable is exogenous in this model.

This may suggest that innate ability or unobserved characteristics do not systematically influence both education levels and ICT adoption, and the Probit model well explains the relationship between the explanatory variables and ICT adoption. Education has significant impact on ICT adoption as the marginal effect of education shows that there is a 3.6% probability that individual who is well educated has more chance of using ICT compared to low educated individual. Prior studies have explored that education influences the likelihood of ICT inclusion (Hargittai, 2007). Moreover, the marginal effect of gender significantly shows that the probability of ICT adoption among males is 5.3% higher compared to female. This may be the result of harmful stereotypes that portray technology as "for boys" and limit women's roles in the society thus discouraging girls and women from using technology (Sáinz, & López-Sáez 2010).

Table 1: Determinants of ICT Adoption in Pakistan

VARIABLES	(1) Probit Model
Grade ISCED	0.0368***
	(0.000279)
Male	0.0534***
	(0.00187)
Age 15-24	0.139***
	(0.00235)
Age 25-34	0.142***
	(0.00231)
Age 45-44	0.121***
	(0.00240)
Age 45-54	0.0494***
	(0.00250)
Log of Per Capita Earnings	0.0118***
	(0.000718)
Log of Per Capita Remittances	0.00108***
	(0.000212)
ICT Access at Home	0.184***
	(0.00161)
Internet Access at Home	0.129***
	(0.00130)
ICT Infrastructure at Stratum Level	0.0331***
	(0.00876)
Big Cities	0.0102***
	(0.00115)
Observations	211,683

Note: Standard errors are given in parentheses. The parameters significant at 10%, 5% and 1% levels of significance are indicated by *, ** and *** respectively.

Moreover, past studies also show that adoption of computers, smartphones, and internet is more common among younger age groups (Pieri & Diamantinir, 2010; Zhou et al., 2011). Our results also show that young age groups from 15 to 44 score significantly higher than old age groups on ICT adoption, keeping other factors constant. Since they have grown up surrounded by computers, smartphones, and the internet, these young people, sometimes known as "digital natives," have been accustomed to using technology on daily basis, as explained by Selwyn (2009).

Coming to socio-economic factors, the income of households is an important factor for ICT inclusion (Reder, 2015; Borg & Smith, 2018). Our results also confirm that earnings of the household significantly play an important role in ICT adoption. As higher-income households can often afford computers, tablets and, as well as high-speed internet. This access helps them leverage technology for career growth, education, and personal development.

On the supply side, ICT infrastructure at the stratum level plays a significant role in driving ICT adoption. Our findings suggest that areas with well-developed ICT infrastructure exhibit a substantially higher likelihood of ICT adoption. This indicates that beyond individual access at home, broader infrastructural factors—such as the availability of high-speed internet, telecommunication networks, and digital service hubs—significantly influence the ICT adoption.

Another important factor that contributes to ICT adoption is the geographical location of the individual. Big cities offer better earning and learning opportunities due to their advanced and developed infrastructure. Further, high competition in these big cities compels workers to enhance their skills and competency level.

Table 2 presents the determinants of digital, in order to address the unobserved heterogeneity bias, we applied the Instrument variable (IV) Probit model given in column 2. To determine whether education is exogenous variable, we conducted the Wald test for exogeneity. The p-value reported in table 2 shows that education is endogenous in ICT literacy model suggesting that innate ability may simultaneously influence both education and ICT literacy. Therefore, the IV probit model, while controlling other variables, is more appropriate for analyzing the causal impact of education on ICT literacy[3].

Table 2: Determinants of ICT Literacy in Pakistan

VARIABLES	(1) Probit Model	(2) IV-Probit Model
Grade ISCED	0.0246***	0.00428***
	(0.000256)	(0.00110)
Male	0.00668***	0.00116**
	(0.00122)	(0.000468)
Age 15-24	0.0318***	0.00553***
	(0.00209)	(0.000518)
Age 25-34	0.0272***	0.00476***
	(0.00201)	(0.000388)
Age 45-44	0.0155***	0.00273***
	(0.00207)	(0.000408)
Age 45-54	0.0116***	0.00202***
	(0.00214)	(0.000379)
Log of Per Capita Earnings	0.00342***	0.000583**
	(0.000498)	(0.000238)
Log of Per Capita Remittances	-1.78e-05	-2.49e-06
	(0.000169)	(2.94e-05)
ICT Access at Home	0.0549***	0.00953***
	(0.00159)	(0.000515)
Internet Access at Home	0.00430***	0.000757***
	(0.00116)	(0.000268)
ICT Infrastructure at Stratum Level	0.0105**	0.000163
	(0.00480)	(0.00108)
Big Cities	0.00268***	0.000504***
	(0.000817)	(0.000148)
Observations	211,683	211,683
Wald test of exogeneity chi2(1)		32.50

[3] The first stage of IV-Probit model is presented in table 6 of the Appendix.

VARIABLES	(1) Probit Model	(2) IV-Probit Model
		Prob > chi2 = 0.000

Note: Standard errors are given in parentheses. The parameters significant at 10%, 5% and 1% levels of significance one indicated by *, ** and *** respectively.

One of the interesting results observed is that of education influence on the ICT literacy, as the coefficient of probit model (in Column 1 of table 2). However, when we incorporate the unobserved heterogeneity bias using IV probit model (presented in table 2), the impact of education becomes much smaller. This suggests that innate ability plays a crucial role in determining ICT literacy and traditional education alone may not be highly effective in enhancing ICT literacy skills. It may also suggest that traditional education systems, particularly in developing countries like Pakistan, often focus on rote learning rather than practical digital skills. Many formal education curricula do not integrate ICT training, meaning that having a higher level of education does not necessarily translate into ICT proficiency.

After incorporating unobserved heterogeneity bias, the gender gap in ICT literacy significantly decreases, indicating that previously observed disparities between men and women in ICT literacy were at least partially driven by unobserved factors rather than gender alone. Similarly, ICT literacy is significantly higher among the younger age group compared to older individuals. These results are consistent with the previous studies i.e. (Shair et al., 2023; Hargittai, 2007). However, when we control innate ability using the IV probit model the impact of age on ICT literacy becomes much smaller. It may suggest that age-related disparities in ICT literacy could be caused by underlying cognitive aptitude, flexibility, and past technology experience rather than just age.

Turning to socio-economic variables, like per capita earnings of household, our estimates using the IV probit model show their much smaller impact on ICT skills and the impact of per capita remittances of household indicates that these also do not play a significant role in enhancing digital skills.

Whereas, ICT facility at home and internet availability at home significantly improves the likelihood of ICT literacy. Having ICT facilities at home—such as internet access, computers, and smart devices—significantly enhances ICT literacy (Aesaert et al., 2015; Fraillon et al., 2020). It provides an environment where individuals can consistently engage with technology, learn digital skills, and integrate ICT into their daily lives. However, in terms of supply-side factors, ICT infrastructure at stratum level has no significant role on ICT literacy. On the other hand, individuals who belong to big cities tend to have significantly better ICT skills as compared to those of smaller cities, through the overall effect remains minimal.

To assess the strength of the instruments, although the IV-Probit model does not provide post-estimation diagnostics, however the F-statistic from the first-stage regression reported in Appendix. Table 6 indicates that our instruments are valid, consistent with the approach used by Liu et al. (2023).

Table 3 presents the determinants of ICT transformation at individual level the p-value of the Wald test for exogeneity indicates that education is endogenous variable in this context.

Table 3: Determinants of ICT Transformation in Pakistan

VARIABLES	(1) Probit Model	(2) IV Probit Model
Grade ISCED	0.0172***	0.00965***
	(0.000331)	(0.00235)
Male	0.0729***	0.0404***
	(0.00213)	(0.00401)
Age 15-24	0.133***	0.0739***
	(0.00291)	(0.00608)
Age 25-34	0.127***	0.0699***
	(0.00286)	(0.00679)
Age 45-44	0.111***	0.0611***
	(0.00296)	(0.00620)
Age 45-54	0.0501***	0.0276***
	(0.00311)	(0.00331)
Log of Per Capita Earnings	0.00422***	0.00248
	(0.000785)	(0.00156)
Log of Per Capita Remittances	-0.000140	-8.72e-05
	(0.000245)	(0.000137)
ICT Access at Home	0.127***	0.0704***
	(0.00223)	(0.00758)
Internet Access at Home	0.170***	0.0943***
	(0.00181)	(0.00714)
ICT Infrastructure at Stratum Level	0.0461***	0.0525***
	(0.00840)	(0.00781)
Big Cities	0.00179	0.000365
	(0.00127)	(0.000834)
Observations	211,683	211,683
Wald test of exogeneity		38.16 Prob > chi2 = 0.0000

Note: Standard errors are given in parentheses. The parameters significant at 10%, 5% and 1% levels of significance one indicated by *, ** and *** respectively.

The result for education indicates that by accounting the unobserved heterogeneity bias, its impact on ICT transformation capability remains minimal. This finding aligns with the results in table 2, which highlights the limited role of education in enhancing ICT literacy. This implies that a person's capacity to successfully accept and use ICT is not just influenced by their level of formal education but may show that some individuals possess a natural ability to understand and adapt to new technologies more quickly than others.

The impact of age on ICT transformation is consistent with ICT literacy, as younger individuals are more likely to integrate and utilize ICT effectively in education and the workplace. Similarly, the impact of socio-economic status of household plays no significant role for ICT transformation. Turning to ICT facilities at home indicates that individuals with ICT and internet have significantly more (7%9.4% respectively) chance of transforming ICT capabilities as, compared to those without access.

5. Conclusion

This study assessed the level of ICT inclusion in Pakistan's districts by measuring it through three dimensions: ICT adoption, ICT literacy and ICT transformation and analyzed the key determinants of ICT inclusion in Pakistan from both demand and supply side perspective, using the data of PSLM 2019-20. It has been concluded that digital divide remains a major challenge, with marginalized areas like Baluchistan and underprivileged communities experiencing lower ICT inclusion rates. It might indicate that these areas lack broadband and cellular coverage due to the high cost of infrastructure deployment. Moreover, Baluchistan has one of the lowest literacy rates in Pakistan, making digital literacy even more challenging. Establishing digital literacy and skills development centers in these regions, along with tailored programs designed for low-education households and older workers, may help reduce disparities more effectively. Targeting these specific demographic and geographic segments can support more cost-efficient and impactful policy implementation aligned with the evidence presented in this study.

The findings highlight that ICT adoption, being one of the components of ICT inclusion, is significantly influenced by education, income levels, ICT access at home, and urbanization. Whereas formal education positively correlates with ICT literacy and its transformation, however its impact becomes minimal when accounting for unobserved heterogeneity bias, suggesting that innate ability and self-learning play a crucial role and these are the problem-solving skills that help people to effectively navigate ICT challenges. Many ICT skills are acquired outside of traditional educational settings through online courses, self-study, practical experience, or exposure to the workplace.

Our result shows that women have limited ICT inclusion so there is a need to implement targeted programs to increase female participation in ICT fields and reduce disparities in digital access. So government should subsidize ICT access for low-income households, implement financial assistance programs to ensure that disadvantaged groups can afford ICT tools and internet connectivity. Further there is a need to revise curricula to include practical ICT training, coding, and digital literacy from an early age to enhance technology adoption. Moreover, there is need to invest in broadband expansion and affordable internet services to reduce regional disparities in ICT access. Similarly, internet-based learning program should be introduced to enhance digital literacy among populations with limited ICT access.

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Appendix

Table 4: Construction of Variables

Variables	**Description**
Dependent Variables ICT Adoption	
Digital Adoption	Digital adoption is =1 if the individuals have used laptop/tablet/ desktop, Smart phone and Internet, "0"otherwise.
Digital Literacy	Digital literacy =1, if an individual has known two or more skills as defined in PSLM which if the following activates have you carried out and "0" otherwise.
Digital Transformation	Digital Transformation =1 if he can transform any two or more activities knows is assigned the value "1" and "0" otherwise., as defined in PSLM for which purpose did you use internet and "0" otherwise.
Explanatory Variables	
Demand Side Factors	
Education Attainment ISCED Education level	Education attainment level defined by International Standard Classification of Education (ISCED).
Gender	1 for Male, 0 for Female
Age	Age is taken as a categorical variable from 15 to 60 years with five years age group 15-24, 25-34,… 45-65.
Log of Per Capita Earnings	A continuous variable measure by total earnings of household divide by household size.
Log of Per Capita Remittances	A continuous variable which shows the amount of remittances received from outside Pakistan.
ICT-Access at home	A dummy variable that takes the value =1 if the individual has ICT facilities such as computer/ laptop/Smart phone at home, and "0" otherwise
Internet Access at home	1 for individuals have access to Internet at home and "0" otherwise
Supply Side factors:	

ICT Infrastructure at Stratum Level	Percentage of households that have internet facility in given area at stratum level
Big Cities	A dummy variable that takes the value =1 if the individual belongs tobig city define by PSLM, and "0" otherwise. Big cities is used as proxy of urbanization as urbanization plays an important role for ICT inclusion

Table 5: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
ICT Adoption	0.21	0.40	0	1
ICT Literacy	0.04	0.20	0	1
ICT Transformation	0.07	0.25	0	1
Grade ISCED	1.61	1.79	0	7
Male	0.50	0.50		
Age	32.44	12.62	15	60
Per Capita Earnings	5957.01	10313.62	0	800000
Log of Per Capita Earnings	8.41	0.85	2.70	13.69
Per Capita Remittances	2238.25	22534.56	0	7500000
Log of Per Capita Remittances	9.84	1.42	0	15.83
ICT-Access at home	0.41	0.49	0	1
Internet Access at home	0.36	0.48	0	1
ICT Infrastructure at Stratum Level	0.32	0.06	0.09	1
Big Cities	0.31	0.46	0	1
Average ISCED at Stratum	2.77	0.18	1.53	5.81
Unemployment rate at age 14	3.71	2.15	0.40	7.83

Table 6: First Stage Result of IV Probit Model

Variables	Coefficients
Average ISCED at Stratum	0.6142*** (0.0231)
Unemployment rate at age 14	-0.0095*** (0.0017)
Male	0.4604*** (0.0094)
Age 15-24	0.4400*** (0.0142)
Age 25-34	0.8022*** (0.0143)
Age 45-44	0.7724*** (0.0144)
Age 45-54	0.3913***

Variables	Coefficients
	(0.0146)
Log of Per Capita Earnings	0.4503***
	(0.0042)
Log of Per Capita Remittances	-0.0017***
	(0.0014)
ICT Access at Home	1.0802***
	(0.0119)
Internet Access at Home	0.4238***
	(0.0122)
ICT Infrastructure at Stratum Level	-0.4905***
	(0.0771)
Big Cities	0.1787***
	(0.0075)
Constant	-5.2534***
	(0.0626)
Observations	211,683
Prob > F	0.0000
R-squared	0.3019

Note: Standard errors are given in parentheses. The parameters significant at 10%, 5% and 1% levels of significance one indicated by *, ** and *** respectively.