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Do information and communication technologies (ICTs) contribute to health outcomes? An empirical analysis

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Abstract This study analyses the relationship between information and communication technology (ICT) and population health. The analysis is based on econometric model of population health in 184 countries using panel data spanning over 1990–2014. The analysis is based on fixed effects method on the basis of Hausman test. Besides, to deal with endogenous nature of ICT two stage least squares and system GMM are used in cross-sectional and panel data, respectively. Health is measured by life expectancy at birth and infant mortality rates. In this study, we measure ICT infrastructure using three proxies namely internet users, mobile cellular subscriptions, and fixed telephone subscriptions. The empirical results show a positive and significant impact of ICT on population health. This study recommends that health care programs need to focus on polices which foster digital inclusion.

Keywords Internet · ICT · Health · Panel data

JEL Classifications I10 · I15 · O32 · L86

1 Introduction

Globally, life expectancy has been improving at a rate of more than 3 years per decade since 1950. Nevertheless, many countries of the world are still lagging behind in attaining better health outcomes. For instance, minimum average score of life expectancy of world population is 39.54 and maximum is 81.49. Similarly, minimum average score of infant mortality is 3.89 and maximum is 147.86.[1] Poor health is becoming a critical issue in terms of global health, with an increasing percentage of the world's population experiencing some type of physical and mental health problem. Given the effect of ill-health

[1] The statistics are calculated over the period 1960–2015.

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as important contributor to disability-adjusted life years (DALYs) and disabling circumstances, there is dire need to understand the ways in which global and national health policies and programs may alleviate this burden.

Does better access to information communication technologies (ICTs) improve health outcomes? The answer to this question has created a policy debate in the recent years. There has been a significant growth in internet access in urban areas. Bukachi and Pakenham-Walsh (2007) point out that health care workers use internet for communication, access to relevant health care information, and international collaboration.

Many academic studies and agency reports have argued that ICTs have the capacity to contribute in health and health care of developing economies (Chetley et al. 2006). The internet can facilitate delivery of services including health care services to expectant and nursing mothers. Moreover it can facilitate communication between patients and health care systems (Bankole et al. 2013). It can improve management and efficiency of government, public utilities (such as mass transit, water delivery). Information and communication technology also helps to health literacy efforts. For instance, the internet provides people with access to near infinite information. Moreover, it allows individuals to actively seek health information, unlike a pro-health advertisement.

However, there have been complaints from some quarters that poor countries need to focus on the provision of basic health services, electricity and clean water rather than ICT infrastructure (Ngwenyama et al. 2006; Morawczynski and Ngwenyama 2007). Policy makers and development practitioners have learned from bitter experience that 'technological fixes' deliver far less than promised. This discrepancy aroused in the presence of chaotic and corrupt health systems in many developing countries. Particularly, concerns on the effectiveness of ICTs are import when initial small scale success does not sustain in the long run. This is important when longer term outcomes depend on complimentary factors such as availability of technical staff, the robustness of sophisticated electronic equipment, an adequate funding to finance routine expenses, maintenance costs, upgrading cost which is an intrinsic feature of ICT systems.

In this paper, we aim to disentangle the relationship between health and ICT using data on three proxies of ICT taken from International Telecommunication Union (ITU 2014) database. These measures are internet users (per 100 people), mobile cellular subscriptions (per 100) and fixed telephone subscriptions (per 100). In this study we try to answer the following two questions: (1) Does ICT usage lead to better health outcomes? (2) Do different measures of ICT impact health equally? To the best of our knowledge, this is the first empirical study of its kind that determines the relationship of health outcomes with ICT for a large number of countries over a long period of time. In addition, this study tries to deal with endogeneity issue between health and ICT using appropriate instruments. Finally, we perform sensitivity analysis to check robustness of the results.

The remainder of paper is organized as follows. Section 2 presents theoretical links of health with ICT. Section 3 illustrates the analytical frame work for the study. Section 4 presents data and variables used in the empirical analysis. Section 5 presents the interpretation and discussion of the results followed by conclusion presented in Sect. 6.

2 Theoretical links: ICT and health

Overall, information and communication technology (ICT) plays a major role in improving health systems of the world. There are number of ways through which technology improves health care and other health outcomes. It improves access for geographically isolated communities, provides support for health care workers, improves data sharing, offers data visual tools to link population and environmental information regarding out broken of a disease, and data storage and management.

Similarly, online health information creates favorable health outcomes through number of mechanisms, some of them are as follows: First, the health information on web improves the knowledge of patients and they better partner with their physicians (Ferguson 2000). Second, web health information can empower the patients and can increase their senses of control over disease by increasing knowledge and self-awareness required to make informed decision to improve their quality of life (Broom 2005; Sharf 1997). Some health professionals have reported that such empowerment of patients help them to observe disease at early stage and encourage them to seek health care (Laing et al. 2004). Third, web health information helps to effective and efficient use of clinic time because basic information has already been processed by the patients and less time is required to process information to make sound decision (Gerber and Eiser 2001).

Wald et al. (2007) provide an excellent review of the relationship of internet with health care system and the physician–patient relationship. There review analysis based on various case studies, implies that internet has the power to improve health systems and population health. In their words "The ''net-friendly'' clinician can be effective by engendering a genuine partnership with patients, thus contributing to quality health care."

Lucas (2008) assesses the potential favorable outcomes of ICT innovations in relation to health systems of developing economies. He considers four broad areas to analyze health outcomes of ICTs. First, improvements in health information systems can be achieved using ICTs systems. Second, computer-aided diagnostics and treatment monitoring can be used to improve health systems. Third, a range of application generally labeled "telemedicine" can be followed. Fourth, the ICT infrastructure can be used to inform general population on health and healthcare. The author concludes that ICTs applications can help to improve the performance of existing health systems.

Blaya et al. (2010) review evolutions of e-health-using information technology to manage patient care-implementations in developing economies. They provide evidence that e-health has a positive impact in developing countries. They argue that ICT systems improve communications between institutions, assist in ordering and managing medications, and facilitate monitoring and detecting patients who might abandon care. Moreover, digital devices such as personal digital assistants and mobile improve data collection time and quality. In a case study of nursing staff in Taiwan, Tsai et al. (2017) provided evidence that e blended e-learning system (BELS), combining face-to-face classes with e-learning modules, improved health education.

Cole-Lewis and Kershaw (2010) provide a systematic review of phone text messaging as tool for behavior change in disease management and prevention. They observe favorable evidence for weight loss, smoking cessation, and diabetes management. They argue that text messaging can be an important tool to reduce the global burden on health care by providing more effective disease prevention and management support.

Déglise et al. (2012) review case studies from developing economies to analyze SMS-supported interventions for prevention, surveillance, management and treatment compliance of communicable and non-communicable diseases. They provide evidence that mobile phones appear as effective tool for disease control interventions in developing nations. They argue that mobile phones serve as low cost method to address the certain needs of health systems and can bring new opportunities to improve population health of developing economies.

Population of resource-poor countries faces the problems of access to necessary medicines, suboptimal prescribing and use of medicines. People working in health sector lack updated medical information and treatment support. An implementation of ICT infrastructure can help to tackle such problems. The use of ICT among health workers can help health related works such as using ICT to improve ordering, minimizing stock out and use of medicines. Nilseng et al. (2014) conduct a pilot study in 2010–2011 to map the drug distribution chain in Tanzania. Findings of their study show that ICT tools have the potential to improve ordering and stock keeping of drugs among health care workers.

In a recent study, Cole et al. (2016) evaluate the quality of health advice from internet discussion forums. Their analysis shows that there is little evidence of poor quality of health information. They suggest that discussion forum websites may be a useful platform through which people can ask health-related questions and receive answers of acceptable quality.

Other than positive outcomes of on online health information, there are also adverse outcomes, some of these are as follows: First, the quality of information available online can be misleading or misinterpreted which can compromise health behaviors and health outcomes. Kiley (2002) argue that misinformation can cause unnecessary anxiety, preventable morbidity or even mortality. Second, some socioeconomic groups do not have proper access to the Web. In this case Web may aggravate existing socioeconomic health disparities. Third, health information can cause unnecessary visits of the patients consuming the time of physicians. In a survey study of America 39% respondents agreed that the web information causes unnecessary visits to physicians (see Murray et al. 2003).

Similarly, some other studies criticize the applications of ICTs for the improvement of health systems. Bend (2004) found that ‘‘given the number and size of the projects and evaluations that we have examined, we have found a surprisingly small amount of convincing evidence that ICT can deliver greater public value in health.’’

Tanis et al. (2016) conduct a survey of 239 respondents to explore how ‘online health information seeking’ affects the satisfaction with the doctor consultation and what is the role of anxiety to explain it. Their study shows that health anxiety leads to high tendency for seeking online health information, however, the high anxiety is negatively related to satisfaction with doctor consolation. Thus seeking online information is negatively associated with doctor consultation.

A major challenge in optimizing the benefits of ICT is its ‘implementation’ related tasks and challenges in developing countries. There are certain costs such as licensing, upgrading, subscription and replacement costs. Moreover, lack of human capacity and training also hinders its implementation. It is argued in the literature that heavily reliance on external sources does not make a success story in the long run. Furthermore, the tropical climate of the many developing economies damages equipment such as computer hard-drives that need climate-controlled and dust-free environment.

Health outcomes in relation to the implementation of ICT infrastructure have attained considerable attention of research scholars and policy makers in the recent years. However, theoretical relations predict conflicting health outcomes of ICT systems. An empirical assessment of the relationship between health and ICT is thus necessary to have an in-depth understanding of the relationship. The available empirical evidence of health and ICT systems are largely based upon country specific or clinical evidence and cannot be generalized for a larger sample. In this study, therefore, we empirically test the said relationship of ICT tools with health indicators for a large sample of countries over a long period of time.

2.1 Hypothesis to be tested

Present study focuses on the effects of ICT usage on the population health outcomes. The hypothesis to be tested is:

H0 The health outcomes do not depend on the usage of ICT.
H1a The health outcomes depend positively on the usage of ICT.
H1b The health outcomes depend negatively on the usage of ICT.

Since theoretical links of ICT with health outcomes suggest both positive and negative effects, it becomes important to settle it empirically whether positive or negative effects of ICT on health outcomes dominate and to assess whether these effects differ depending upon the measures of ICT used. It could, of course, also possible that our null hypothesis holds and ICT, in some or all dimensions, does not influence our dependent variable.

3 Methodology

A nation's Health Production Function depicts information about health status of that nation. It illustrates the link between inputs and outputs during a specific period. According to Grossman (1972) health is produced by people depending upon their behavior, medical care and the constraints they face. This theoretical Health Production Function is represented in the following way

$$H = f(\textit{inputs to health}) \tag{A}$$

where H is individual health output and inputs are factor that determine health such as income, education, health expenditures, health facilities, environment, and life style. This model was developed to study production function of health at micro level. To convert this model at macro level, inputs to health are represented in per capita form and are reorganized in three categories; social, economic and environmental factors following Fayissa and Gutema (2005).

$$H = f(Y, S, V) \tag{B}$$

where Y, S and V represent vectors of economic, social and environmental variables, respectively. Several variables come under each vector but each study has used different variables because of reliable and sufficient data availability and other limitations.

For our empirical investigation here, the variables in economic factors vector include economic growth and health facilities, variable in social factors vector is restricted to education and variable in environmental factors vector includes carbon dioxide emissions.

$$H = f\left(\textit{Economic Growth},\ \textit{health facilities},\ \textit{Edu},\ CO_2E\right) \tag{i}$$

This study intends to discover the other potential factors which may influence health by focusing on internet. The internet can facilitate delivery of services including health care services to expectant and nursing mothers. Moreover it can facilitate communication between patients and health care systems (Bankole et al. 2013). It can improve management and efficiency of government, public utilities (such as mass transit, water delivery). However, there have been complaints from some quarters that poor countries need to focus on the provision of basic health services, electricity and clean water rather than ICT infrastructure

(Ngwenyama *et al.* 2006; Morawczynski and Ngwenyama 2007). To take into account the effect of ICT on health model, Eq. (i) is extended to include digital inclusion

$$H = f(Growth,\ health\,facilities,\ Edu,\ CO_2E,\ ICT) \tag{ii}$$

In this analysis we have used life expectancy and infant mortality as proxies of health. To measure ICT infrastructure three proxies of ICT-internet users, mobile cellular subscriptions, and fixed telephone subscriptions—are used.

Above relationships between "health and ICT" can be written in the form of panel equations as follows. For establishing link between ICT and health log–log functional form is used, because with log it is easy to interpret estimated coefficients.

$$\ln H_{it} = \beta_{it} + \beta_2 \ln Y_{it} + \beta_3 \ln HF_{it} + \beta_4 \ln EDU_{it} + \beta_5 \ln CO_2E_{it} + \beta_6 \ln ICT_{it} + \varepsilon_{it} \tag{iii}$$

where = countries 1, 2, 3 …180, t = Time period 1990 to 2014, *ln* is natural logarithm, *H* is health status measured by life expectancy at birth, total (years), and infant mortality per 1000, *Y* is GDP per capita (constant 2005 US$), *HF* is health facilities (Physicians), *EDU* education [it is Gross enrollment ratio, secondary, both sexes (%)], CO_2E is carbon dioxide emissions (metric tons per capita), *ICT* is information and communication technologies. It is measured by using three proxies (1) Internet users (per 100 people), (2) mobile cellular subscriptions, (3) fixed telephone subscriptions. The empirical analysis is based on following estimation techniques: OLS, Cross-sectional GMM, Pooled OLS, Fixed Effects/Random Effects and System GMM.

4 Data description and sources

The empirical analysis is based upon both cross-sectional and panel data sets. This study covers 184 countries over the period 1990–2014.

4.1 Health status

In this study, life expectancy at birth and infant mortality are used as dependent variables. Life expectancy refers to "life expectancy at birth, total (years)" and infant mortality is measured by "mortality rate, infant (per 1000 live births)". The data on these variables is derived from World Bank's (WDI) online data base 2016.

4.2 ICT

Our focused independent variable is ICT. Data on ICT proxies is obtained from International Telecommunication Union (ITU), (2014). We have measured ICT infrastructure using three proxies (1) internet users (per 100 people), (2) Mobile cellular subscriptions (per 100), (3) fixed telephone subscriptions (per 100).

4.3 Control variables

4.3.1 Economic growth

Economic growth is one of key factors that play an important role in determining health status. Increase in economic growth leads to an increase in individual income, which results in access to adequate diet, housing, education and health services leading better health (Fayissa and Gutema 2005; Bayati et al. 2013; Majeed and Gilani 2017). This study uses log of "GDP per capita (constant 2005 US$)" data from World Bank's (WDI) online database 2016 to measure economic growth. We expect positive (negative) coefficient of economic growth with life expectancy (infant mortality).

4.3.2 Health care facilities

Another important determinant of health is health facilities (Kumar and Singh 2014; Mohapatra 2017). This study uses physicians supply measured by "physicians (per 1000 people)" for life expectancy regression and immunization measured by "Immunization, measles (% of children ages 12–23 months)" for infant mortality regression. If number of physicians is large, then access to health facilities and services will be better, because people have to wait less for treatment and medical attention. Similarly, if number of children's immunized against measles, increases then children's dying before their first birthday will decline. Data sources for these variables are World Bank (WDI) online database 2016. We expect positive sign for physicians and negative for immunization.

4.3.3 Education

Education is assumed to play an important role in improving health status. Well educated people can have good job and thus high income. Besides, educated person is aware of health related information and avoid risky behavior. In addition to men's education, female education also has a vital role in determining child and family health. In our research we have used female education when health is measured by infant mortality and total education when health is measured by life expectancy. Education variable is measured by *"School enrollment, secondary (% gross)"* and is collected from World Bank (WDI) online database 2016. We expect positive coefficient of education for life expectancy regression, while negative for infant mortality.

4.3.4 CO_2 emission

Carbon dioxide pollution results in extensive continuing changes in our environment, which threatens the wellbeing and health of current and upcoming generations. This environmental variable is measured by "CO_2 emissions (metric tons per capita)" and is taken from World Bank (WDI) online database 2016. We expect negative (positive) coefficient of CO_2 emission for life expectancy (infant mortality), because increased air pollution leads to health hazards.

4.4 Instrumental variables

In our model problem of endogeneity is likely to arise due to (1) simultaneous linkages between health and ICT indicators, (2) the ICT measures can be correlated with error terms and (3) there could be problem of omitted variable bias. These problems arise for different reasons however they have common solution that is the use of instrumental variables. In order to deal with potential endogeneity, this study uses two stage least squares in cross-sectional data and System GMM in panel data. Potential endogenous variable (ICT) is instrumented by various suitable internal and external instruments. Instruments used are

Table 1 Cross-section regressions of ICT on population health

Variables	(1)	(2)	(3)	(4)
GDP per capita	0.0272***	0.0344***	0.0165**	0.0211***
	(0.00762)	(0.00621)	(0.00638)	(0.00697)
CO_2 emission	− 0.0174**	− 0.0162*	− 0.0232***	− 0.0206**
	(0.00856)	(0.00884)	(0.00788)	(0.00820)
Education	0.0798***	0.0907***	0.0420*	0.0636**
	(0.0270)	(0.0234)	(0.0247)	(0.0254)
Physician	0.0398***	0.0447***	0.0319***	0.0359***
	(0.00796)	(0.00842)	(0.00865)	(0.00865)
Internet users	0.0199			
	(0.0141)			
Mobile subscription		− 0.00591		
		(0.00960)		
Telephone subscription			0.0493***	
			(0.00985)	
ICT-index				(0.0149)
Constant	3.634***	3.600***	3.824***	3.671***
	(0.120)	(0.110)	(0.112)	(0.108)
Observations	183	183	183	183
R-squared	0.808	0.804	0.834	0.816
Functional form test (hat sq p value)	0.920	0.482	0.179	0.72
Multicolinearity test (mean VIF)	5.83	4.78	6.78	6.82
Heterosecdasticity test (Prob > chi2)	0.0000	0.0000	0.0000	0.0000
Normality test (JB and chi2 value)	4.7e−08	5.7e−08	2.4e−07	2.4e−07

Robust standard errors in parentheses

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

initial values, personal computer (per 100 people), telecommunication investment (% of revenue) and telecommunication revenue (% of GDP). The indicators of personal computers, telecommunication investment and revenue are highly correlated with ICT measures. Moreover, these indicators do not directly influence population health. The data for instrument variables is extracted from ITU (2014).

5 Empirical results

Table 1 shows the result obtained using OLS. The results reported in column 1 shows that when ICT is measured by internet users, it has positive effect on health. However, this effect is statistically insignificant. It means that some other factors such as income, access to health facilities, education and environmental situation account for most of explanation of dependent variable that is life expectancy. Another possible reason could be that dependent variables used in empirical analysis are much broader. For instance, ICT affects mental health, however, this measure has not been employed in the analysis due to the data availability limitations. Similarly, the effect of mobile cellular subscription in column 2 is statistical insignificant. However, when ICT is measured with telephone subscription, it has positive and statistically significant impact on health. The coefficient of telephone in column 3 shows that 1% increase in telephone subscription will cause 0.05% incline in life expectancy. Finally, column 4 reports the results obtained using a combined index of ICT measures. The ICT index is constructed using a simple average of internet users, mobile cellular subscription, and telephone subscription. The parameter estimate on ICT index is positive and significant at 10% percent level of significance implying that overall ICT measures cause favorable impact on health.

Economic growth, education and physician have favorable and statistical significant effect on life expectancy while carbon dioxide emission has adverse and significant effect on life expectancy. The coefficients of economic development, education and physician show that 1 percent increase in development, education and physician leads to 0.03, 0.08 and 0.04% increase in health. While 1% incline in carbon dioxide emission leads to 0.02% decline in life expectancy.

Post-estimation tests of functional form, *multicollinearity*, *heteroscedasticity,* and normality- are reported in the last four rows of Table 1. Following inferences can be drawn: First, using link test of functional form we find that model is correctly specified as *p* value of hat square is greater than 0.05. Second, examination of VIF test indicates that there is no problem of multicollinearity as mean VIF is less than 10. Third, examination of Breusch-Pagan test reveals that there is problem of heteroscedasticity (as probability value is less than 0.05). We have used robust regression to deal with the problem of heteroscedasticity.

There could be problem of endogeneity due to reverse causality, omitted variable biases and measurement error. In presence of endogeneity OLS estimates become inefficient and biased. To address the potential problem of endogeneity and heteroscedasticity, we have applied cross-sectional GMM by incrementing three proxies of ICT on the instruments of (1) telecommunication revenue and (2) personal computer.

Column 1 of Table 2 shows that the internet has positive and significant influence on health indicating that if internet users increase by 1% then life expectancy will increase by 0.05%. This result is consistent with theory that increased knowledge sharing, communication with family and friends and access to health information lead to improved health and longevity. Column 3 shows that the coefficient of telephone causes significant impact on health indicating that 1% increases in telephone subscription will causes 0.043% incline in life expectancy.

Regarding control variables we found that all control variables have expected and significant influence on life expectancy (column1). We have applied post-estimation test that are (1) test of over identification and (2) test of endogeneity. The results from these tests are reported in last two rows of Table 2. Hansen's J test indicate that instruments are valid as probability value is greater than 0.05.

The cross sectional results for second measure of health (infant mortality) have been reported in Table 8 ("Appendix"). First three columns of the Table 8 present results with OLS and columns (4–6) show results with GMM. The parameter estimates on internet and telephone have expected negative signs and statistically significant. It implies that adoption of ICT infrastructure helps to reduce premature deaths of children. The control variable immunization is consistently negative and significant in all regressions. This finding implies that those countries which ensure vaccinations of infants also control premature deaths.

Table 3 shows results when pooled OLS is used. The coefficient of internet in column 1 shows that 1% incline in internet users will lead to 0.002% increase in life expectancy and this result is statistical significant. The coefficient of mobile cellular subscriptions has expected sign and becomes statistical significant indicating life expectancy will increase

Table 2 GMM results using telecommunication revenue and personal computer as instrumental variable

Variables	(1)	(2)	(3)	(4)
GDP per capita	0.0192**	0.0172	0.0193**	0.0185*
	(0.00965)	(0.0167)	(0.00927)	(0.00976)
CO_2 emission	− 0.0199**	− 0.0300**	− 0.0228***	− 0.0226***
	(0.00861)	(0.0136)	(0.00817)	(0.00842)
Education	0.0668**	0.0829**	0.0474	0.0584*
	(0.0322)	(0.0340)	(0.0364)	(0.0336)
Physician	0.0346***	0.0323**	0.0344***	0.0339***
	(0.00879)	(0.0159)	(0.00814)	(0.00883)
Internet users	0.0466*			
	(0.0252)			
Mobile subscription		0.133		
		(0.120)		
Telephone subscription			0.0425*	
			(0.0223)	
				0.0592*
				(0.0316)
Constant	3.688***	3.275***	3.795***	3.683***
	(0.139)	(0.269)	(0.169)	(0.130)
Observations	173	173	173	173
R-squared	0.801	0.640	0.843	0.820
Hansen's J	(p = 0.9655)	(p = 0.5274)	(p = 0.9742)	(p = 0.8978)
GMM C statistic	(p = 0.2044)	(p = 0.1020)	(p = 0.4412)	(p = 0.6757)

Robust standard errors in parentheses

***$p<0.01$; **$p<0.05$; *$p<0.1$

by 0.002% as a result of 1% incline in mobile subscription. The coefficient of telephone shows that 1% increase in telephone subscription causes 0.016% incline in life expectancy and this result is significant at 1% level of significance. The overall impact of ICT measures reported in column 4 is also positive and significant implying that 1% increase in ICT adoption causes 0.005% improvement in life expectancy. Regarding control variables we found that all has expected statistical significant effect on life expectancy.

Table 4 shows the results obtained using fixed effects regression method. In column 1 of Table 4 parameter estimates of internet shows that internet has positive relationship with health implying that 1% increase in internet use increases life expectancy by 0.002% and this effect is statistical significant at 1% level of significance. The parameter estimate of mobile subscription shows that health has positive relationship with mobile subscription implying that 1% increase in mobile cellular subscription increases life expectancy by 0.004% and this effect is statistical significant at 1% level of significance. Similarly, the results reported in column 3 of Table 4 indicate that 1% incline in telephone subscription leads to 0.001% increase in health but this is not statistically significant.

Regarding control variables, we find that increased economic growth leads to improved health, implying that individual will have better health if he/she has more income to spend on quality food, health care, and housing. CO_2 emissions have adverse influence on health with both proxies of health. Education has favorable influence

Table 3 Pooled OLS result of health and ICT

Variables	(1)	(2)	(3)	(4)
GDP per capita	0.0299***	0.0299***	0.0258***	0.0294***
	(0.00188)	(0.00180)	(0.00189)	(0.00190)
CO_2 emission	− 0.00744**	− 0.00720***	− 0.00950***	− 0.00856***
	(0.00297)	(0.00278)	(0.00257)	(0.00299)
Education	0.0696***	0.0712***	0.0663***	0.0652***
	(0.00755)	(0.00690)	(0.00684)	(0.00797)
Physician	0.0304***	0.0288***	0.0245***	0.0307***
	(0.00346)	(0.00319)	(0.00309)	(0.00351)
Internet users	0.00201***			
	(0.000713)			
Mobile subscription		0.00160**		
		(0.000626)		
Telephone subscription			0.0156***	
			(0.00322)	
ICT-index				0.00473***
				(0.00108)
Constant	3.706***	3.699***	3.720***	3.723***
	(0.0342)	(0.0312)	(0.0305)	(0.0354)
Observations	1353	1419	1563	1322
R-squared	0.758	0.753	0.786	0.748

Robust standard errors in parentheses

***$p<0.01$; **$p<0.05$; *$p<0.1$

on health because educated people have greater chance to get good job, high income besides having capability to practicing healthy diet and avoid unhealthy behavior. Physicians has statistical significant positive effect on life expectancy, indicating that if physicians supply increases, life expectancy will increase because of less waiting time, increased availability and accessibility. Similarly, immunization has negative and significant effect on infant mortality. Immunization reduces risk associated with neonatal, post-neonatal and infant mortality.

All ICT indicators also significantly help to reduce health outcomes in terms of infant mortality (see Table 9). Since education of mothers plays a central role in managing health care of infants (see Khan and Raza 2014; Impicciatore and Dalla Zuanna 2017), we have used females' education in infant mortality model. The parameter estimates on female education are robustly significant with negative signs at 1% level of significant. It implies that investing in the education of females can substantially help to reduce infant mortality.

Table 5 shows the results obtained using random effect regression method. We obtain same results regarding sign and significance of coefficients as with fixed effects method. All three proxies of ICT (internet, mobile and telephone subscription) has expected and statistical significant relationship with health indicating that 1% increase in internet users, mobile subscription and telephone subscription lead to 0.002, 0.003, 0.003 and 0.005% incline in health respectively with effect of telephone being insignificant. All control variables have same result in random effect as in fixed effect (Table 6).

Table 4 Fixed effects result of health and ICT

Variables	(1)	(2)	(3)	(4)
GDP per capita	0.0549***	0.0383***	0.0672***	0.0438***
	(0.00389)	(0.00349)	(0.00344)	(0.00375)
CO_2 emission	− 0.0137***	− 0.00484*	− 0.0152***	− 0.00478
	(0.00312)	(0.00284)	(0.00320)	(0.00316)
Education	0.0636***	0.0572***	0.0837***	0.0550***
	(0.00408)	(0.00362)	(0.00414)	(0.00398)
Physician	0.00989***	0.00358**	0.00919***	0.00599***
	(0.00206)	(0.00165)	(0.00220)	(0.00189)
Internet users	0.00204***			
	(0.000339)			
Mobile subscription		0.00390***		
		(0.000324)		
Telephone subscription			0.00102	
			(0.00204)	
ICT-index				0.00493***
				(0.000519)
Constant	3.528***	3.686***	3.339***	3.644***
	(0.0368)	(0.0334)	(0.0284)	(0.0360)
Observations	1353	1419	1563	1322
R-squared	0.628	0.697	0.568	0.665
Number of id	159	163	166	159

Robust standard errors in parentheses

***$p<0.01$; **$p<0.05$; *$p<0.1$

To deal with endogeneity problem we have used instrumental variables technique 2SLS. However, this technique is inappropriate in the presence of heteroscedasticity. In this situation it is appropriate to use Generalized Method of Moments (GMM) as it cares for both endogeneity and heteroscedasticity. Here we have used system GMM introduced by Arrelano and Bond. We have taken 1st lag of endogenous variable as independent variable and instrument used for endogenous variable are lag of endogenous variable, personal computer, telecommunication investment and telecommunication revenue.

Table 7 shows the results obtained from system GMM. The coefficients of internet users, mobile cellular subscription and telephone subscription show that ICT has expected positive and significant relationship with life expectancy. Regarding control variables we found that economic development, CO_2 emission and Physicians have expected statistically significant relationship with life expectancy. However, education has expected coefficient only when ICT is measured by internet users.

Table 5 Random effects result of health and ICT

Variables	(1)	(2)	(3)	(4)
GDP per capita	0.0509***	0.0408***	0.0574***	0.0431***
	(0.00323)	(0.00298)	(0.00304)	(0.00321)
CO_2 emission	− 0.0117***	− 0.00246	− 0.0161***	− 0.00292
	(0.00287)	(0.00269)	(0.00282)	(0.00291)
Education	0.0659***	0.0606***	0.0858***	0.0578***
	(0.00399)	(0.00358)	(0.00404)	(0.00391)
Physician	0.0130***	0.00703***	0.0117***	0.00910***
	(0.00192)	(0.00159)	(0.00206)	(0.00179)
Internet	0.00211***			
	(0.000297)			
Mobile subscription		0.00342***		
		(0.000287)		
Telephone subscription			0.00298	
			(0.00201)	
				0.00470***
				(0.000462)
Constant	3.546***	3.635***	3.406***	3.629***
	(0.0302)	(0.0282)	(0.0262)	(0.0303)
Observations	1353	1419	1563	1322
Number of id	159	163	166	159

Robust standard errors in parentheses

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

Table 6 Choice between fixed effects and random effects models

Model	Outcome	Conclusion
Model with internet	chi2(5) = 29.66	Fixed effects
	Prob > chi2 = 0.0000 (V_b–V_B is not positive definite)	
Model with Mobile	chi2(5) = 54.75	Fixed effects
	Prob > chi2 = 0.0000 (V_b–V_B is not positive definite)	
Model with telephone	chi2(5) = 59.83	Fixed effects
	Prob > chi2 = 0.0000	

Robust standard errors in parentheses

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

Table 7 System GMM result of health and ICT

Variables	(1)	(2)	(3)	(4)
Life expectancy (t-1)	1.041***	1.027***	1.030***	1.025***
	(0.00122)	(0.00156)	(0.00148)	(0.00115)
GDP per capita	0.00182***	0.00221***	0.00199***	0.00188***
	(5.53e−05)	(0.000137)	(0.000158)	(6.15e−05)
CO_2 emission	− 0.00866***	− 0.00388***	− 0.00825***	− 0.00490***
	(0.000256)	(0.000243)	(0.000179)	(0.000133)
Education	0.00267***	− 0.0175***	− 0.00648***	0.00232***
	(0.000568)	(0.000698)	(0.000409)	(2.81e−05)
Physician	0.00103***	0.00332***	0.00232***	− 0.00950***
	(4.62e−05)	(6.90e−05)	(8.50e−05)	(0.000399)
Internet users	0.000146***			
	(1.54e−05)			
Mobile subscription		0.000650***		
		(2.33e−05)		
Telephone			0.00250***	
Subscription			(0.000239)	
				0.000686***
				(2.71e−05)
Constant	− 0.186***	− 0.0499***	− 0.110***	− 0.0745***
	(0.00458)	(0.00458)	(0.00714)	(0.00445)
Observations	689	729	770	674
Number of id	122	124	126	120
Number of instrument	107	107	107	107
AR1 (Pr > z)	0.053	0.022	0.028	0.042
AR2 (Pr > z)	0.139	0.808	0.843	0.158

Table 7 (continued)

Variables	(1)	(2)	(3)	(4)
Hansen test of overid	Prob > chi2 = 0.66	Prob > chi2 = 0.56	Prob > chi2 = 0.62	Prob > chi2 = 0.64
GMM instruments for levels	Prob > chi2 = 0.61	Prob > chi2 = 0.46	Prob > chi2 = 0.71	Prob > chi2 = 0.47
Hansen test excluding group difference	Prob > chi2 = 0.60	Prob > chi2 = 0.63	Prob > chi2 = 0.39	Prob > chi2 = 0.74
iv(L.linter/L.lmobper/L.ltelper pc tinv tr)	Prob > chi2 = 0.67	Prob > chi2 = 0.65	Prob > chi2 = 0.61	Prob > chi2 = 0.58
Hansen test excluding group difference	Prob > chi2 = 0.38	Prob > chi2 = 0.13	Prob > chi2 = 0.51	Prob > chi2 = 0.76

Robust standard errors in parentheses

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

6 Conclusion

In this study we attempt to extend the existing literature on determinants of health by empirically investigating the impact of ICT on population health using estimation techniques suitable in cross-sectional and panel data which deal with endogenous nature of ICT. We have employed theoretical model given by Grossman (1972) using environmental and socioeconomic factors as inputs to health. Data on several proxies of variables of interest is taken for 183 developing and developed countries over time period 1990–2014. In this study, life expectancy at birth and infant mortality are used as dependent variables. We have measured ICT infrastructure using three proxies (1) internet users (per 100 people), (2) mobile cellular subscriptions (per 100), (3) fixed telephone subscriptions (per 100). Several conclusions which can be drawn from this study are summarized below.

This study confirms that increased ICT improves population health in terms of increasing life expectancy and decreasing infant mortality. It is because digital inclusiveness leads to good relationships and healthy behaviors among people, thereby improving their health and longevity. In addition, we find that all control variables have expected and statistically significant impact on health indicating that economic growth, education and health facilities have favorable effect on health, while CO_2 emission has adverse impact on health. The results of sensitivity analysis reveal that not all measures of ICT are robust to inclusion of other determinants of health. Our study reveals that besides other determinants of health, ICT plays an essential role in determination of population health.

This study undergoes certain limitations: First, in this paper life expectancy is used as measures of health while chronic diseases are ignored. Life expectancy does not consider quality of life but consider only quantity of life. Thus, there is need to construct a single and comprehensive measure of health. Second, the role of non-state (private sector) health care services is not considered in this study due to data limitations. Third, ICT not only influences physical health but also mental health, however, health indicators used as dependent variables in this study are much broader than measures of mental illness. The data availability limitations restricted the analysis for broader measures of population health. Future research can use different measures of health outcomes such as maternal health, mental health and different diseases.

The present study is limited to two measures of health outcomes that are life expectancy and infant mortality. Future research can use different measures of health outcomes such as maternal health, mental health and different diseases. Finally, findings of this study need to be considered with caution as these findings are based on cross-country analysis which may not be valid for a specific country. Whereas the findings of this study can be generalized globally, heterogeneity across countries can also limit the implications of these findings. Future research may extend this analysis to country specific case studies to have an in-depth understanding of the links between ICT and health outcomes and to take care of potential heterogeneity of a country.

Findings of this study suggest important policy implications. Policy makers need to design polices which ensure inclusive ICT usage in the society because it improves population health by improving health literacy, spreading health information to prevent diseases, facilitating health care services, and improving communication between patient and health care systems. Policies which control environmental degradation and facilitate inclusive education can also produce better health outcomes.

Appendix

See Tables 8, 9, 10, 11, 12, 13, 14.

Table 8 Cross sectional pooled OLS result of health (infant mortality) and ICT

Variables	(1) Infant Mor. OLS	(2) Infant Mor. OLS	(3) Infant Mor. OLS	(4) Infant Mor. GMM	(5) Infant Mor. GMM	(6) Infant Mor. GMM
GDP per capita	− 0.522***	− 0.565***	− 0.465***	− 0.442***	− 0.678***	− 0.432***
	(0.0425)	(0.0408)	(0.0435)	(0.0795)	(0.0934)	(0.0759)
CO_2 emission	0.234***	0.228***	0.253***	0.228***	0.190***	0.270***
	(0.0479)	(0.0496)	(0.0456)	(0.0518)	(0.0657)	(0.0471)
Education of Females	− 0.0957	− 0.130	0.0159	0.231	− 0.0348	0.306*
	(0.108)	(0.108)	(0.0997)	(0.169)	(0.149)	(0.183)
Physicians	− 0.178***	− 0.206***	− 0.136***	− 0.149**	− 0.225***	− 0.121*
	(0.0444)	(0.0407)	(0.0484)	(0.0597)	(0.0769)	(0.0621)
Immunization	− 0.694***	− 0.799***	− 0.444*	− 0.714**	− 0.913***	− 0.450
	(0.248)	(0.215)	(0.236)	(0.354)	(0.333)	(0.301)
Internet	− 0.0930			− 0.457**		
	(0.0670)			(0.214)		
Mobile subscription		0.0898			0.503	
		(0.0753)			(0.588)	
Telephone subscription			− 0.240***			− 0.438**
			(0.0639)			(0.195)
Constant	10.82***	11.21***	9.061***	9.785***	10.73***	8.007***
	(1.095)	(0.975)	(1.079)	(1.680)	(1.080)	(1.907)
Observations	177	177	177	167	167	167
R-squared	0.865	0.865	0.877	0.832	0.830	0.874

Table 9 Pooled OLS result of health (infant mortality) and ICT

Variables	(1)	(2)	(3)
GDP per capita	− 0.503***	− 0.513***	− 0.499***
	(0.0131)	(0.0131)	(0.0137)
CO_2 emission	0.129***	0.159***	0.185***
	(0.0187)	(0.0188)	(0.0160)
Education of Females	− 0.151***	− 0.222***	− 0.125***
	(0.0393)	(0.0399)	(0.0345)
Physicians	− 0.166***	− 0.171***	− 0.136***
	(0.0171)	(0.0165)	(0.0169)
Immunization	− 0.176**	− 0.262***	− 0.303***
	(0.0807)	(0.0817)	(0.0605)
Internet	− 0.0405***		
	(0.00583)		
Mobile subscription		− 0.0291***	
		(0.00545)	
Telephone subscription			− 0.118***
			(0.0219)
Constant	8.335***	9.103***	8.961***
	(0.387)	(0.387)	(0.305)
Observations	1287	1342	1457
R-squared	0.868	0.859	0.867

Table 10 Fixed effects and random effects result of health (infant mortality) and ICT

Variables	(1) Fixed effects	(2) Fixed effects	(3) Fixed effects	(4) Random effects	(5) Random effects	(6) Random effects
GDP per capita	− 0.537***	− 0.553***	− 0.906***	− 0.528***	− 0.529***	− 0.729***
	(0.0296)	(0.0297)	(0.0252)	(0.0218)	(0.0218)	(0.0217)
CO_2 emission	0.103***	0.0990***	0.162***	0.0932***	0.0986***	0.240***
	(0.0231)	(0.0238)	(0.0227)	(0.0203)	(0.0208)	(0.0199)
Education of	− 0.0268	− 0.0524*	− 0.226***	− 0.0482*	− 0.0710***	− 0.250***
Females	(0.0270)	(0.0270)	(0.0256)	(0.0259)	(0.0258)	(0.0259)
Physician	− 0.0650***	− 0.0834***	− 0.103***	− 0.0872***	− 0.101***	− 0.0861***
	(0.0150)	(0.0141)	(0.0153)	(0.0135)	(0.0128)	(0.0145)
Immunization	− 0.111***	− 0.109***	− 0.196***	− 0.126***	− 0.134***	− 0.235***
	(0.0407)	(0.0421)	(0.0390)	(0.0402)	(0.0414)	(0.0402)
Internet	− 0.0537***			− 0.0523***		
	(0.00260)			(0.00216)		
Mobile		− 0.0520***			− 0.0515***	
Subscription		(0.00282)			(0.00229)	
Telephone			− 0.0197			− 0.0467***
Subscription			(0.0147)			(0.0148)
Constant	7.833***	8.139***	12.17***	8.003***	8.194***	10.90***
	(0.303)	(0.316)	(0.231)	(0.243)	(0.251)	(0.220)
Observations	1287	1342	1457	1287	1342	1457
R-squared	0.787	0.781	0.702			

Table 11 Descriptive statistics of variables

Variable	Observations	Mean	SD	Min	Max
Life expectancy	207	68.05918	9.441058	41.75435	81.49474
Infant mortality	192	37.18019	31.88567	3.028	132.284
GDP per capita	199	11200.94	17783.21	161.9164	121293.9
CO_2 emission	199	4.697698	6.413147	.0268648	53.10504
Education	193	70.95926	30.08341	7.35304	142.8768
Education of females	191	71.28891	32.26167	4.63442	142.3347
Physician	202	1.493827	1.654384	.0199571	15.6165
Immunization	191	82.59667	14.72365	32.44	99
Internet	204	19.48356	16.33097	.4274932	69.66689
Mobile subscription	208	44.26732	23.7706	2.820298	151.9117
Telephone subscription	208	19.40025	19.7921	.0152318	103.293

Table 12 Correlation matrix of variables

Variables		[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]
Cross sectional data												
Life expectancy	[1]	1.0000										
Infant mortality	[2]	− 0.9422	1.0000									
GDP per capita	[3]	0.5931	− 0.5382	1.0000								
CO_2 emission	[4]	0.4813	− 0.4829	0.6931	1.0000							
Education	[5]	0.8485	− 0.8551	0.5838	0.5186	1.0000						
Education of females	[6]	0.8524	− 0.8667	0.5652	0.5081	0.9921	1.0000					
Physician	[7]	0.6829	− 0.6565	0.5112	0.4560	0.7407	0.7267	1.0000				
Immunization	[8]	0.6970	− 0.7660	0.3195	0.3875	0.7246	0.7471	0.5378	1.0000			
Internet	[9]	0.7726	− 0.7535	0.8121	0.5961	0.7907	0.7776	0.6464	0.5620	1.0000		
Mobile subscription	[10]	0.6605	− 0.6737	0.5320	0.4801	0.6888	0.6851	0.5606	0.5596	0.7386	1.00	
Telephone subscript.	[11]	0.7613	− 0.7355	0.8148	0.5216	0.7892	0.7715	0.6851	0.5058	0.9172	0.69	1.00
Variables		[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]
Panel data												
Life expectancy	[1]	1.0000										
Infant mortality	[2]	− 0.9180	1.0000									
GDP per capita	[3]	0.6143	− 0.5561	1.0000								
CO_2 emission	[4]	0.4592	− 0.4890	0.6421	1.0000							
Education	[5]	0.7852	− 0.8292	0.5981	0.4994	1.0000						
Education of females	[6]	0.7807	− 0.8327	0.5858	0.4962	0.9928	1.0000					
Physician	[7]	0.6186	− 0.6125	0.4424	0.3362	0.6556	0.6447	1.0000				
Immunization	[8]	0.5100	− 0.6106	0.1707	0.2854	0.5118	0.5275	0.3547	1.0000			
Internet	[9]	0.5096	− 0.4494	0.5569	0.3318	0.4663	0.4507	0.3712	0.3058	1.0000		
Mobile subscription	[10]	0.4101	− 0.3868	0.3352	0.2527	0.3762	0.3647	0.2843	0.3213	0.8276	1.00	
Telephone subscript.	[11]	0.7234	− 0.7208	0.8067	0.4953	0.7518	0.7381	0.5598	0.2732	0.4845	0.29	1.00

Table 13 Pooled OLS result of health and ICT with regional effects

Variables	(1)	(2)	(3)	(4)
GDP per capita	0.0369***	0.0367***	0.0319***	0.0370***
	(0.00159)	(0.00154)	(0.00161)	(0.00161)
CO_2 emissions	− 0.0181***	− 0.0175***	− 0.0193***	− 0.0203***
	(0.00290)	(0.00280)	(0.00272)	(0.00292)
Educations	0.0445***	0.0458***	0.0442***	0.0378***
	(0.00822)	(0.00747)	(0.00629)	(0.00859)
Physicians	0.0182***	0.0200***	0.0168***	0.0187***
	(0.00289)	(0.00272)	(0.00272)	(0.00291)
Internet	0.00355***			
	(0.000528)			
Mobile subscription		0.00347***		
		(0.000530)		
Telephone subscription			0.0188***	
			(0.00274)	
ICT-index				0.00676***
				(0.000835)
Europe and Central Asia	0.00612	− 0.00295	− 0.0253***	− 0.00394
	(0.00953)	(0.00895)	(0.00870)	(0.00899)
Middle East and North	0.0307***	0.0225***	0.00851	0.0204**
Africa	(0.00896)	(0.00847)	(0.00799)	(0.00855)
East Asia and Pacific	0.0321***	0.0248***	0.00598	0.0220***
	(0.00857)	(0.00835)	(0.00814)	(0.00814)
Sub-Saharan Africa	− 0.131***	− 0.126***	− 0.127***	− 0.143***
	(0.0133)	(0.0130)	(0.0113)	(0.0136)
Latin American	0.0330***	0.0239***	0.00600	0.0213***
Countries	(0.00845)	(0.00806)	(0.00780)	(0.00792)
North America	0.0234**	0.0170*	− 0.00867	0.0151
	(0.00995)	(0.00957)	(0.00946)	(0.00954)
Constant	3.766***	3.765***	3.791***	3.798***
	(0.0336)	(0.0304)	(0.0270)	(0.0346)
Observations	1353	1419	1563	1322
R-squared	0.849	0.840	0.857	0.844

Table 14 List of countries

1	Afghanistan	40	Cyprus	79	Kyrgyz Republic	118	Russian Federation
2	Albania	41	Czech Republic	80	Lao PDR	119	Rwanda
3	Algeria	42	Denmark	81	Latvia	120	Samoa
4	Angola	43	Dominica	82	Lebanon	121	Sao Tome & Principe
5	Antigua and Barbuda	44	Dominican Republic	83	Lesotho	122	Senegal
6	Argentina	45	Ecuador	84	Liberia	123	Serbia
7	Armenia	46	Egypt, Arab Rep.	85	Lithuania	124	Seychelles
8	Australia	47	El Salvador	86	Luxembourg	125	Sierra Leone
9	Austria	48	Equatorial Guinea	87	Macedonia, FYR	126	Singapore
10	Azerbaijan	49	Estonia	88	Madagascar	127	Slovak Republic
11	Bahamas, The	50	Ethiopia	89	Malaysia	128	Slovenia
12	Bahrain	51	Fiji	90	Maldives	129	South Africa
13	Bangladesh	52	Finland	91	Mali	130	Spain
14	Barbados	53	France	92	Malta	131	Sri Lanka
15	Belarus	54	Gambia, The	93	Mauritius	132	St. Kitts and Nevis
16	Belgium	55	Georgia	94	Mexico	133	St. Lucia
17	Belize	56	Germany	95	Moldova	134	St. Vincent & Grenad.
18	Benin	57	Ghana	96	Mongolia	135	Sudan
19	Bhutan	58	Greece	97	Morocco	136	Suriname
20	Bolivia	59	Grenada	98	Mozambique	137	Sweden
21	Bosnia and Herzegovina	60	Guatemala	99	Namibia	138	Switzerland
22	Botswana	61	Guinea	100	Nepal	139	Syrian Arab Republic
23	Brazil	62	Honduras	101	Netherlands	140	Tajikistan
24	Bulgaria	63	Hungary	102	New Zealand	141	Tanzania
25	Burkina Faso	64	Iceland	103	Nicaragua	142	Thailand
26	Burundi	65	India	104	Niger	143	Togo
27	Cabo Verde	66	Indonesia	105	Nigeria	144	Trinidad and Tobago
28	Cambodia	67	Iran, Islamic Rep.	106	Norway	145	Tunisia
29	Cameroon	68	Ireland	107	Oman	146	Turkey
30	Canada	69	Israel	108	Pakistan	147	Uganda
31	Central African Republic	70	Italy	109	Panama	148	Ukraine
32	Chile	71	Jamaica	110	Papua N Guinea	149	United Arab Emirates
33	China	72	Japan	111	Paraguay	150	United Kingdom
34	Colombia	73	Jordan	112	Peru	151	United States
35	Congo, Dem. Rep.	74	Kazakhstan	113	Philippines	152	Uruguay
36	Congo, Rep.	75	Kenya	114	Poland	153	Vanuatu
37	Costa Rica	76	Kiribati	115	Portugal	154	Venezuela, RB
38	Cote d'Ivoire	77	Korea, Rep.	116	Qatar	155	Yemen, Rep.
39	Croatia	78	Kuwait	117	Romania	156	Zambia

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