A Panel Analysis of the Strategic Association between Information and Communication Technology and Public Health Delivery

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ABSTRACT

This exploratory research examines the strategic association over time between Information and Communication Technology (ICTs) and country-level public health. Using data from the World Development Indicators, we construct a panel data set of countries of five different income levels and look closely at the period from 2000 to 2008. The panel data analysis allows us to explore this dynamic relationship under the control for unobserved country-specific effects by using a fixed-effects estimation method. We particularly examine the association of five ICT factors with five public health indicators: adolescent fertility rate, child immunization coverage, tuberculosis case detected, life expectancy, and adult mortality rate. Our results indicate that ICT accessibility has a strong association with effective delivery of public health.

Keywords: Association, information and communication Technologies (ICTs), panel data, public health delivery

1. Introduction

Despite the slow diffusion of ICTs to support public health delivery worldwide as well as the high cost of implementation, global health policy makers and public health officials must focus on key strategic applications of ICTs that deliver high quality public health care at lower costs. These applications may include ICTs-based eHealth, mHealth, situational awareness systems, and 'smart' health systems, among others (Blaya et al., 2010; Bonander & Gates, 2010; Borde et al., 2010; Eysenbach, 2009; GAO, 2009; Gerber et al., 2010; Heinzelmann, 2005; ITU, 2005, 2008, 2010; Kahn et al., 2010; Mars et al., 2010; WHO, 2011). Therefore, understanding the association between ICTs and the nature of public health delivery is important (Raghupathi & Tan, 2008; Raghupathi & Wu, 2011). Public health is a key determinant of a country's overall economic growth and poverty level. Sustainable health is an important part of the overall well being of individuals and societies. An expanding library of interdisciplinary literature investigates the effects of good public health on a country's growth (e.g., economic growth, poverty reduction & sustainability) and identifies the enablers of good public health. ICTs provide the infrastructure and resources for the development of large-scale, population-level applications such as health information networks, surveillance systems and telemedicine. ICTs can improve health outcomes and combat diseases. For example, in rural Niger, following the introduction of a radio ambulance system, the number of emergency evacuations from outlying health centers to the district hospital rose from 10 to 197. Good communications and information sharing help to deliver diagnostic information and drugs and to spread information on reproductive health and communicable diseases. Through the Global Media AIDS initiative, more than 50 broadcast networks are promoting AIDS prevention messages. In the fight against malaria, satellite monitoring identifies and targets mosquito breeding areas for control (World

Bank, 2010). Other examples of ICT-based systems at work include telemedicine networks in Bangladesh; e-pharmacy projects in Malaysia; low-cost sustainable electronic medical records for HIV/AIDS patients in Kenya; and web-based communication tools to address material and child deaths in Peru (Gerber et al., 2010). Reeder et al. (2011) call public health informatics (PHI) the "systematic application of information and computer science and technology to public health practice, research and learning that integrates public health and information technology." Furthermore, Yasnoff et al. (2001) state, PHI needs to use a "systematic and informed approach to the application of information science and technology in order to take full advantage of its potential to enhance and facilitate public health activities." Such activities include:

- the promotion of population health as "opposed to the health of specific individuals";
- the prevention of disease and injury by altering the conditions or environment that put populations at risk;
- the prevention at all vulnerable points in the causal chains leading to disease, injury, or disability but not restricted to particular social, behavioral, or environmental contexts; and,
- the reflection of the "governmental context in which public health is practiced".

In a prior cross-sectional study of 200 countries using the secondary data from World Bank, it is found that in most cases cumulated investment in ICTs is strongly associated with a country's public health delivery (Raghupathi & Wu, 2011). Yet, the nature of the dataset limited the ability to make strong inferences between the two even though the wealth effect was controlled in the analysis. To estimate the extent of the association between ICTs and improved country public health delivery, this study looks at a panel data set of countries representing five different income levels from 2000 to 2008. This association, it has been argued, also leads to economic growth and poverty reduction. The panel data set allows us to explore these dynamic relationships while controlling for unobserved country-specific effects. We use a fixed-effects estimation method to control for unobserved country factors within an income level that may be correlated with countries' public health delivery. We used this method because any unobserved country factor is likely to bias estimated coefficients in a traditional regression model. This method also allows us to examine the wealth effect of different income levels on countries' public health delivery. Overall, this panel analysis delineates the impacts of income level and ICT factors on countries' public health delivery, thus providing more accurate evaluation of the contribution of ICT to public health delivery. The findings will offer strong policy implications to countries in terms of the focus of ICT investment at the macro level to improve public health conditions and advance economic growth. Keeping the rationale for the study in view, we asked two specific research questions:

1. *Do ICTs have a strong association with a country's public health delivery indicators over time?*
2. *Which of the key ICT factors are associated with improvement in public health delivery?*

The rest of the paper is organized as follows. First, we provide the background discussion of the study. We consider the role of ICTs in enabling and improving public health delivery and provide anecdotal examples and case studies as evidence of the positive association between the two. We then outline the conceptual framework and hypotheses and follow these with our methodology, including data collection, measurements and research procedures. A discussion of the key results is next, scope and limitations follow, and finally we offer conclusions and future research directions.

2. Background

The Rockefeller Foundation argues, "health systems around the world face significant challenges in financing and providing affordable, quality health services. The health systems in developing countries—an area frequently referred to as the 'Global South'—operates under increased pressure because of shortages of trained healthcare workers, the growing burden of disease, poor infrastructure, unequal access to healthcare information and research, economic distortions from vertical disease programs, and supply chain inefficiencies. Addressing these challenges requires creative multi-sector approaches that envision delivering health services and information in a fundamentally different way (Rockefeller Foundation (a))." One approach to rationalizing the delivery of public health across all countries is the application of various ICTs, which can level the playing field and make health care more equitable. Take, for example, the collection, management and communication of health information to deliver timely, high-quality health care, one aspect of global public health delivery. Low-income countries often lack the information technology taking root in developed countries to manage health data and work toward evidence-based practice and culture. Partnerships between academic and government institutions in high- and low-income countries can help establish health informatics programs. These programs in turn can capture and manage data that are useful to all partners (Tierney et al., 2010). While a variety of ICTs are applied to support public health delivery, we focus on four key applications to narrow our discussion, namely, eHealth, mHealth, situational awareness systems, and 'smarter' health systems. By and large, these four applications demonstrate the potential of ICTs to enable public health delivery.

2.1 eHealth

The literature is replete with anecdotes and case studies on the potential for eHealth to deliver good quality public health, but despite good intentions, health systems across the globe are unable to deliver high-quality affordable services to all. Thirty thousand children each day die needlessly of preventable diseases. Quality of care in many parts of the world is substandard.

Sick patients who can afford clinic treatment face long waits. Critical health information is buried in thick medical files, and facilities are plagued with severe shortages of medically trained personnel. Inequities in the provision of health care are one of the greatest challenges we face as global citizens, and these demands are only amplified in the developing world. Ill health handicaps people as well as economies and development (Rockefeller Foundation (b)). The WHO recently predicted that countries, particularly those in Africa, will not develop economically and socially without substantial improvements in the health of their people. Experts agree that it will take an unprecedented transformation to reverse the tide of failing health systems, particularly in light of shrinking resources that must now be used more efficiently. Fortunately, support is increasingly available through the breakthrough tools known as eHealth, commonly understood to be the innovative application of emerging ICT in health systems (Rockefeller Foundation (b)).

eHealth, defined as the "use of information and communications technologies (ICTs) in support of health and health-related fields including health-care services, health surveillance, health literature and health education, knowledge and research," can, researchers say, vastly improve public health delivery efficiency, open up diagnosis and treatment of health conditions to larger populations in developing countries, and improve patient outcomes (Blaya et al., 2010). eHealth applications (or, simply, ICT that facilitates health and health care) such as EHRs, computer-assisted prescription systems, and clinical databases, are transforming health today and hold even greater promise for the future. ICTs support clinical care and provide health information to the general public and scientific information to professionals. They equip health care providers with a platform for publishing, disseminating health alerts and supporting administrative functions. Personal digital assistants (PDAs) have already been successful in data collection and in clinical practice in resource-challenged health systems. The European Commission has invested significant resources in the development of wearable computing devices that monitor the health of patients in rehabilitation or for persons working in situations of extreme stress. Short-range mobile transceivers embedded in various devices will collect and process health information and transmit the data between people and medical devices and between devices themselves (WHO, 2005).

Building foundations for eHealth provides a global view that will be particularly useful for governments, policy makers and international organizations in identifying health trends, opportunities and emerging challenges (WHO, 2005). In developing and industrialized countries alike, ICTs have not realized their potential as a means to enhance disease prevention. There is evidence that better tapping of ICT capabilities could result in far more effective and efficient utilization of health services (Chaudhry et al., 2006; Rockefeller Foundation (a); WHO, 2005). Combined, all eHealth applications can narrow health disparities, equip healthcare providers and enable immense leaps in quality of care. For example, using her laptop and mobile phone, a nurse in a remote village can now access information on the world's best treatments, information previously available only to the rich and privileged. These devices also can track and treat her patients using longitudinal health records (Rockefeller Foundation (a)). Illustrations of ICTs at work in poorer and more remote countries and regions include: telemedicine networks in Bangladesh; e-pharmacy projects in Malaysia; low-cost, sustainable electronic health records for HIV/AIDS patients in Kenya; and web-based communication tools to decrease maternal and child deaths in Peru. At an HIV/AIDS clinic in sub-Saharan Africa, care providers can track and treat patients over many years using longitudinal EMRs. Many see e-health as the next breakthrough in health systems improvement in developing nations (Gerber et al., 2010).

In the industrialized world, meanwhile, several national initiatives are underway, such as the creation of an EHR system in Australia, the linking of interoperable HIT in the U.S., and the development of a single EHR for every individual in the U.K (Rockefeller Foundation (b)). To reiterate, eHealth can serve as a vehicle for the transformation of health conditions in the developing world, particularly for those living in rural and remote areas (ITU, 2005, 2008, 2010). eHealth is expanding in developed, developing and least-developed countries, and this ability to transcend sociopolitical boundaries holds the potential to create a borderless world for health systems and health care delivery (Mars & Scott, 2010). The use of eHealth has spread to cities and remote villages worldwide (Dentzer, 2010). Countries such as Rwanda are activating nationwide eHealth networks (Gerber et al., 2010). In fact, Rwanda has emerged as an eHealth leader, its government having prioritized the use of information and communication technology to improve health outcomes. The Rwandan Ministry of Health's comprehensive nationwide e-health plan includes development and implementation of a national interoperable electronic health information system, the rollout of EMRs and other digital systems, and empowerment of community health workers with mobile phone-based communication and reporting capacities (Gerber et al., 2010). Other eHealth initiatives are also becoming linked throughout Africa. The Open Medical Record System (OpenMRS) is a good example. OpenMRS is a multi-institution, non-profit collaborative led by the Regenstrief Institute and Partners in Health to develop and install medical record systems in concert with local users. OpenMRS teams use open-source, non-proprietary strategies in which the software programming code is available for everyone to see, enhance, use and share. To date, OpenMRS has been implemented in South Africa, Kenya, Rwanda, Ghana, Lesotho, Zimbabwe, Mozambique, as well as in Uganda and Tanzania in Africa, and in countries in Central and Latin America (Gerber et al., 2010).

In 2009, IBM helped lead a humanitarian effort to a remote part of Africa that used everyday technology to distribute supplies of medicine to where they were most needed http://www.ibm.com/ibm100/us/en/icons/medicineon-demand/). The project served as an example of how simple, inexpensive technologies used in innovative ways can improve the medicine supply chain and help save lives. Each year in sub-Saharan Africa, almost 250 million people are infected and approximately 800,000 killed by malaria. The mosquito-borne disease is treatable and preventable, and the tools to fight it are available. But medicines do not always reach the patients who need them, particularly in remote areas. In Tanzania, for example, 93% of its mainland population is at risk for malaria infection—especially pregnant women and young children.

In 2008, a team of international students in an IBM internship program called Extreme Blue worked with the pharmaceutical company Novartis to research and refine proposed solutions to the long standing problem of medicine stock-outs in Africa. Given that cell phone service was becoming common, even in remote areas of the continent, the final simple solution for tracking and managing supplies of anti-malarial drugs used a combination of mobile phones, SMS technologies and intuitive websites (http://www-03.ibm.com/press/us/en/pressrelease/29022.wss).

After visits to clinics, hospitals and dispensaries throughout Tanzania in 2009, IBM, Novartis, the mobile phone carrier Vodafone, and the Roll Back Malaria Partnership launched a five-month pilot called SMS for Life, which used simple text messaging and cloud computing to help dispensaries avoid running out of vital stock. The pilot covered 226 villages in different geographic locations across Tanzania. The international team used the cloud-based collaboration and social business tools from IBM Lotus Live to manage the project and share information among multiple organizations (http://www-03.ibm.com/press/us/en/pressrelease/29022.wss). The SMS for Life system sent weekly automated messages to its staff at participating healthcare facilities, prompting them to check their stock of medicines and reply with a text message that included detailed stock levels. The messages were collected and stored on a central website that provided the district medical officers and their users with information about stock levels. This information helped redistribute essential medicines to where they were needed most, as well as set up emergency deliveries when necessary.

Although developed nations have begun to use electronic health information systems to manage information, low-income nations generally lack advanced tools to help them achieve better health outcomes. In countries where per capita spending on health care barely reaches U.S. $10 per year, competition for resources is great and human capital is stretched thin. Yet, some argue that these low-income countries and donors have no choice but to make e-health investments in order to address fundamental health needs (Tierney et al., 2010).

2.2 mHealth

A variation of health information technology applications includes mHealth, or the use of mobile phones and hand held computers to provide health services. These devices can be of enormous value in providing health care in multiple settings. They can support a health worker performing clinician duties where there are no doctors as well as track patients in HIV programs where the loss rate (patients who drop out of treatment) can be as high as 76%. When used to monitor inventories, these systems can save lives and prevent the increase of drug resistance by keeping medicines in stock. In addition, they can provide accurate, timely information for strategic planning, especially in areas where hand-compiled data are often years out of date

(Blaya et al., 2010). The emergent field of mHealth, or mobile health, is characterized by collaborations that take advantage of expanded telecommunications networks and smarter handsets. Particularly in developing countries, mHealth offers a great opportunity to strengthen and transform weak health systems and combat everything from maternal and child illness and mortality to chronic and infectious diseases. Through cell phones and the Internet, the mobile-network infrastructure allows remote and isolated communities to exchange information in real time and in other ways that have not been possible before. Information once available only in specific locations or to specific populations is now broadly available to physicians, health workers and patients. Diagnostic tools delivered at the point of care, by way of a cell phone, a PDA, or a web camera, are expanding the ways people receive treatment. In many countries, private and public organizations are working together to use social networking and other media to encourage healthy behavior, assist patients in monitoring their care, train health care workers, track disease outbreaks, and improve diagnostic and treatment support (Curioso et al., 2010).

Examples reported in the literature include the following:

- An example from South Africa is Project Masiluleke, whose mission includes educating South Africans about HIV and tuberculosis prevention. The project includes large and small organizations based in South Africa and elsewhere, including the mobile phone operator MTN, the South African National AIDS Helpline, the National Geographic Society, and Nokia Systems Networks. The project takes advantage of extra space available in a text message, as when one person sends a “please call me” message via cell phone to another. It automatically inserts a brief message about call centers where people seeking health information about HIV/AIDS can obtain it. The message was intended to appear in one million messages every day for a year. In the five months after it was launched in October 2008, calls to the South African National AIDS Helpline all but quadrupled. The project is ongoing (Curioso et al., 2010);
- Also in South Africa, organizations such as the Praekelt Foundation (which develops innovative mobile technology solutions) and University of Cape Town are partnering to build and deploy platforms for HIV and AIDS prevention and treatment;

- Organizations in India, such as Asia Media Labs, are developing and deploying data collection methods, support tools for community health workers, and gaming systems to promote behavior change;

- The Universidad Peruana Cayetano Heredia in Peru is conducting research and training in biomedical and health informatics

- In Ghana, a program called m-Pedigree is using cell phones to identify and reduce the use of counterfeit drugs;

- A cell phone-based technology called TracNet is helping Rwandan health care workers follow patients and their treatment;

- Mobile health technologies are being used to help rural health workers in the Philippines;

- In Cambodia, the Mekong Collaboration Program has begun using a messaging system known as GeoChat for group communication and developed by Innovative Support to Emergencies, Diseases and Disasters (in-STEADD) (Curioso et al., 2010);

- A cell phone-based system called VidaNET (LifeNet) sends text messages and email to patients in Mexico City, reminding them to take their anti-HIV drugs, keep their doctors appointments, and stay up to date on their lab tests. The system also sends messages about mental health and alerts patients to supplementary resources on a web site explaining side effects from anti-HIV medication (Feder, 2010);

- The VidaNET System, now being rolled out throughout Mexico, is just one of many health-related mobile-phone applications coming into use through the developing world (Feder, 2010);

- Diable-Diaro, which roughly translates into Diabetes Diary, is an ambitious mobile health project. It will help users track their basic health indicators, including their blood sugar levels, and will coach them on adherence and healthy living (Feder, 2010); and

- With CardioNET, a typical message texted to a user underscores facts like the importance of exercise: “Regular physical activity can be done almost anywhere, and helps on your road to health: at home, at the office, on an airplane, while watching television, while waiting in line, just to name a few opportunities.” The system also features a risk-assessment tool to give users instant feedback on their proneness to serious illness due to obesity. It asks users for their height and weight, for their blood pressure and cholesterol levels and whether they smoke or have diabetes. It then calculates the risk that the user will have a heart attack in the next ten years, and provides links to resources to help patients live a healthier lifestyle (Feder, 2010);

- In the United Kingdom, use of text-message reminders at a sexually-transmitted infection clinic had two important benefits: decreasing time to treatment for chlamydia, and decreasing appointment no-show rates (and the added benefit of increased revenue from rebooking far exceeding implementation cost) (Kahn et al., 2010);
- In Hangzhou, China, text message and telephone reminders improved appointment attendance by 7%, and messaging cost less than telephone reminders (Kahn et al., 2010);
- A recent randomized controlled trial of patients with chronic diseases in Malaysia found that non-attendance rates were about 40% lower in the text-messaging and phone groups than in controls (Kahn et al., 2010).
- In Zambia, Population Services International uses m-health for several aspects of male circumcision services. The circumcision service sends fifteen text messages as postoperative reminders to patients to encourage proper wound healing. It also conducts service satisfaction surveys. New messaging services include a referral system, appointment scheduling and addressing patients' clinical questions (Kahn et al., 2010).
- Begun in response to post-election violence in Kenya in 2007, Ushahidi (http://ushahidi.com) gained broad recognition and acclaim as an important resource for citizens and responders in the aftermath of the earthquake in Port-au-Prince, Haiti, on 1/12/10 (Freifeld et al., 2010). The system provides an open-source platform for collecting individual reports from users through SMS, web and email and provides tools for translating, classifying and geo-referencing these reports; the newest version of the platform further allows for submission via voice message, essential for illiterate users. Aggregated information is presented on a map-based interface accessible via web and mobile phone. Regarding the Ushahidi deployment in Haiti, Craig Clark of the United States Marine Corps said, "I cannot overemphasize to you what the work of the Ushahidi/Haiti has provided. It is saving lives every day . . . I say with confidence that there are hundreds of these kinds of [success] stories". Ushahidi has also been deployed in several other countries, including Afghanistan, Uganda, Malawi and Zambia (reported in Freifeld et al., 2010).

Because mobile phones and other mobile technologies require fewer infrastructures than other eHealth systems, scale-up of mHealth may be the most promising investment in developing countries. It can be used to support remote health workers and to reach people anytime or anywhere. Mobile phone use continues to increase, expanding the networks of those connected through this medium (Friefeld et al., 2010; Kahn et al., 2010; WHO, 2011). More sophisticated 3G networks, mobile broadband, and smart phones suggest that opportunities to exchange information will continue to emerge (Curioso et al., 2010). Developing countries face steady growth in the prevalence of chronic diseases, along with a continued burden from communicable diseases, and these mobile technologies can be used to manage diseases and lower healthcare costs. For years, telehealth (Heinzelmann, 2005) has provided clinical services for individuals who lacked physical access, such as farmers in remote communities, soldiers near the battlefield, and prison inmates. Now these technologies have demonstrated the ability to benefit almost any individual (PwC, 2010). In short, the key applications for mHealth in developing countries are: education and awareness, emote data collection, remote monitoring, communication and training for healthcare workers, disease and epidemic outbreak tracking, and diagnostic and treatment support (Vital Wave Consulting, 2009).

Not surprisingly, governments are expressing greater and greater interest in mHealth as a complementary strategy for strengthening health systems and achieving the health-related Millennium Development Goals (MDGs) in low- and middle-income countries. This interest has manifested into a series of mHealth deployments worldwide that are providing early evidence of the potential for mobile and wireless technologies. mHealth is being applied in maternal and child health, and reducing the burden of the diseases linked to poverty, including HIV/AIDS, malaria, and tuberculosis (TB). mHealth applications are being tested in such diverse scenarios as improving timely access to emergency and general health services and information, managing patient care, reducing drug shortages at health clinics, enhancing clinical diagnosis and treatment adherence among others (Hersh et al., 2010; WHO, 2011).

2.3 Situational Awareness Systems

There has never been as great a challenge to public health than the threat of epidemics facing global communities and governments today. Globalization, economic migration, and tourism have resulted in large numbers of people traveling internationally, often through major transport hubs or open borders. As a result, epidemics and pandemics may pose immediate and acute threats to a nation's health system, economy, and political stability (Oracle, 2009). The recent emergence of new strains of influenza and the rapid rate of dispersion of these infectious agents worldwide has demonstrated just how exposed national security is to these invisible threats. No government can afford to ignore the possibility of repeat threats. Policy makers face the challenges of transforming outdated, inadequate public health surveillance systems and seek opportunities for leveraging newly emerging technologies that will make this transformation possible (Oracle, 2009; Orion Health, 2009).

Situational awareness is another ICT application of potentially great value to public health delivery. Public health situational awareness is the knowledge of key components needed to prepare for and respond to disease outbreaks and other public health emergencies. The electronic public health situational awareness network involves strategies for nationwide health information exchange, coordinated biosurveillance, and health security. These components include, but are not limited to, health-capacity, environmental threats, public awareness and jurisdictions in the country. Creating and maintaining situational awareness involves an active, continuous, and timely data-oriented loop that enhances the ability of public health officials to make decisions leading to successful mitigation of emerging threats, better use of resources in preparing for and responding to emergencies, and better health outcomes for the population. The use of ICTs to collect and share this information electronically among public health entities can aid in creating the situational awareness needed to enable early detection of and effective response to emerging events (GAO , 2011; Orion Health, 2009).

ICTs provide the data needed by public health entities to enhance situational awareness of emergencies and potential emergencies, an essential role. For more than a decade, federal, state and local public health organizations, private companies and academic institutions in the U.S. have been developing systems for collecting and analyzing electronic surveillance data from hospital emergency departments, clinical laboratories, pharmacies, and other sources. These systems support emergency preparedness by providing near real-time information needed to detect disease outbreaks and other public health emergencies. Electronic biosurveillance systems collect and provide data—lab test results and complaints from emergency department patients, for example—to public health officials. These surveillance techniques are employed not only to detect initial signs of emerging threats but also to track the spread of syndromes, diseases and other biological events throughout the duration of public health emergencies. Additionally, geographic information systems and mapping tools that support emergency response to events are useful to public health officials because they provide visual and quantitative data such as maps of available hospital facilities and bed capacity, the location of electrical grids, and regional population information during a disease outbreak or other public health emergency (Oracle 2009; Orion Health, 2009; GAO, 2011).

Recent domestic public health events provide examples of department of Health & Human Services's (HHS) use of ICTs in preparation for and response to emerging public health events. During the Deepwater Horizon oil spill in 2010, the Center for Disease Control (CDC), in coordination with state and local health departments, conducted surveillance for related health effects across the five U.S. states bordering the Gulf of Mexico. As part of this effort, the CDC used BioSense, a syndromic surveillance system, and the National Poison Data System to maintain a situational awareness of more than 20 health conditions related to the eyes and skin and the respiratory, cardiovascular, gastrointestinal and neurological systems of citizens affected by the spill. Further, the Secretary's Operations Center at HHS employed geographic information systems and Internet-based mapping tools to track the spread of the oil and manage response efforts during the event (GAO, 2011).

ICTs also played a role in providing situational awareness for the early detection of influenza-like illnesses during the 2009-2010 H1N1 influenza outbreaks. During these outbreaks, the CDC, in partnership with the Public Health Information Institute and the International Society for Disease Surveillance, used another surveillance system called Distribute to collect, analyze and share surveillance information from local emergency surveillance systems throughout the affected areas and across multiple public health jurisdictions. Similarly, during the public health emergency that occurred as a result of the earthquake in Haiti, the CDC used Internet-based mapping tools to identify available medical facilities and open transportation routes for delivering medical supplies (GAO, 2011)

HHS officials have identified key ICTs that support early event detection through the analysis of electronic data collected from various sources. Biosurveillance systems such as BioSense and Distribute, collect, analyze and share data from such sources as state and local public health departments, public health laboratories and health care facilities. These systems are intended to enhance public health entities' ability to detect disease outbreaks and other public health emergencies by enabling simultaneous sharing of information produced by the systems. In another sector, officials with the FDA reported using a web-based system called the Electronic Laboratory Exchange Network (elEXNET) to collect, analyze and share electronic food safety laboratory data among federal, state and local agencies to help detect the potential for outbreaks of food-borne illnesses (GAO 2011).

Disease surveillance is based on counting. That said, active and accurate surveillance relies on proactive efforts by public health officials to identify and report cases of disease. Usually this involves assigning public health staff to hospitals or clinics to review medical charts in order to identify new cases. Active surveillance reporting is typically timely, inclusive and complete. With few exceptions, though, public health agencies lack the resources to conduct active, widespread, and comprehensive disease surveillance. But new automated technologies offer the promise of transforming the tasks of data collection, data analysis, and data reporting as seen in:

- The emergence of electronic health record systems, hospital information systems, and laboratory information systems that capture the information required for electronic public health case reporting;
- New software tools that can integrate and analyze these disparate data sources using sophisticated rules and algorithms designed specifically for extracting public health case reports; and
- Tools that transform the multiple data coding and formats commonly seen in these source data systems into a standard electronic format that is then securely transmitted to appropriate public health agencies (Oracle, 2009).

ICTs offer the possibility that surveillance system automation will transform data collection, data analysis, and data reporting and thereby result in dramatic increases in surveillance system sensitivity and specificity (Oracle, 2009). When available, health officials and government leaders now rely on situational awareness systems to better understand when a public health threat is growing or decreasing; whether it is expanding into different geographic areas; and whether the threat is becoming more or less serious to the community or population. This knowledge influences decisions ranging from the deployment of additional or specialized resources to respond to the threat; to implementing plans to provide mass vaccinations or treatments; and to decisions that affect the movement of people within a community (Oracle, 2009; Orion Health, 2009).

The hallmarks of situational awareness systems are the use of new, novel sources of data that are combined to increase system sensitivity. These disparate data sources are securely transmitted using standardized vocabulary and message structures, to both state and national laboratories in near real time. Their power lies in the ability to quickly identify potential new health threats or to closely track changes in the characteristics of an existing outbreak or epidemic (Freifeld et al., 2010; Oracle, 2009).

2.4 Smarter Public Health Delivery

We briefly discuss the emergence of 'smarter' health care delivery associated with the use of analytics and health intelligence applications. Rising costs, limited access, high error rates, lack of coverage, poor response to chronic disease and the lengthy development cycle for new medicines could be addressed by the linking of diagnosis to drug discovery to healthcare providers to insurers to employers to patients and communities. Today, the components, processes and participants that comprise the vast healthcare system are not connected, although large amounts of life-saving information are available (IBM, 2011). Duplication and handoffs are rampant. A smarter healthcare system starts with better connections, better data and faster and more detailed analysis. It involves integrating our data and centering it on the patient so each person 'owns' his or her information and has access to a networked team of collaborative care. It means moving away from paper records, in order to reduce medical errors and improve efficiency. And it means applying advanced analytics to vast amounts of data to improve outcomes.

Smarter healthcare is instrumental, so our health systems can automatically capture accurate, real time information. Implanet, a French orthopedics manufacturer, is using RFID technology to track surgical implants from manufacturers until they're inside patients. And healthcare providers in Denmark are using predictive health systems with advanced telemetry to monitor elderly patients in their homes, sharing data instantly (IBM, 2011).

Smarter healthcare is interconnected so doctors, patients and insurers can share information seamlessly and efficiently. Sainte-Justine, a research hospital in Quebec, is automating the gathering, managing and updating of critical research data, which is often spread across different departments. They're applying analytics to speed childhood cancer research and improve patient care while drastically lowering the cost of data acquisition and enhancing data quality. Servicio Extremeno de Salud, a public healthcare service in Spain, has built a regionally integrated system that lets a patient go to any health center within a region and have confidence the doctor there will have the patient's complete, up-to-date records for faster and more accurate treatment (IBM, 2011).

Smarter healthcare is intelligent, applying advanced analytics to improve research, diagnosis and treatment. Geisinger Health Systems is merging clinical, financial, operational, claims, genomic and other information into an integrated environment of medical intelligence that helps doctors deliver more personalized care. This enables them to make smarter decisions and deliver higher quality care because they can easily turn information into actionable knowledge.

Smarter health care systems hold promise beyond their particular communities, patients and diseases. The smart ideas from one can be replicated across a system. This should result in lower costs, better quality care and healthier people and communities (IBM, 2011).

3. Conceptual Framework

In developing countries, lack of access to health care and inefficient delivery methods is the norm. Poor health care is characterized by high infant, female (pregnancy & birth mortality) and adult mortalities, low immunization rates, death from diseases, and low life expectancies. The shortage of health care is worsened by the inability of governments to devote adequate funding to their respective health care sectors, and the shortage is exacerbated by the multiple crises in finance, food and energy. Unsuccessful reform efforts, combined with little funding, have left billions without the ability to tap into basic health care services. Most health care ministries in developing countries are aware of the inequities between urban and rural communities, but efforts to decrease this divide have fallen short. Cost effective reform initiatives are needed to ensure greater access and higher quality of basic health care through the use of ICTs. A number of initiatives, as discussed above, have demonstrated where ICTs proved critical in improving access and health services to underserved populations.

Most health care providers look to eHealth and mHealth as advantageous solutions because they are personal, ubiquitous and already connected. Intelligent, and multitasking mobile phones have become indispensable in much of the developing world: 64% of mobile users are in emerging markets, and it is estimated that by 2012, 50% of individuals in remote areas of the world will have them. According to the WHO, technology has always been at the backbone of improving medical services to prevent, diagnose and treat illness and disease (Borde et al., 2010). As outlined in background, the typical measures of public health delivery have been the numerous millennium development goals for health care. Three of the eight MDGs were designed to improve global health:

1. Reduce child mortality (MDG 4): reduce by 2/3rds between 1990 and 2015, the under-five mortality rate;
2. Improve maternal health (MDG 5): reduce by three quarters between 1990 and 2015, the maternal mortality ratio; and
3. Combat HIV and AIDS, malaria and other diseases (MDG 6): have halted by 2015 and begun to reverse the spread of HIV/AIDS; have halted by 2015 and begun to reverse the incidence of malaria and other major diseases (Vital Wave Consulting, 2009).

These three MDGs can be achieved best through a coordinated approach of public, private and civil institutions. There is a need for ICT programs to work synergistically with other existing policy initiatives or strategies, such as national poverty reduction strategies or as part of national health policies. With specific regard to MDGs 4, 5, and 6, ICTs have the capability to increase remote access and support of specialists to caregivers in rural locales. They also enhance basic training for healthcare workers, increasing their ability to monitor and access information, such as statistics on disease and famine. Unfortunately, though, despite the broad economic advances of this decade, the 2008 UN report on progress toward meeting the MDGs indicates dire conditions in crucial public health areas (Vital Wave Consulting, 2009) continue to hamper progress. For example,

- "a child born in a developing country is over 33 times more likely to die within the first five years of life than a child born in an industrialized country, even though the leading causes of death (pneumonia, diarrhea, malaria, and measles) are preventable through basic services and vaccinations;"

- "every minute, at least one woman dies from complications related to pregnancy or childbirth; and, for every woman who dies in childbirth, approximately 20 more suffer injury, infection, or disease —nearly 10 million each year;"

- "an estimated 2.5 million people were newly infected with HIV in 2007;" and

- "communicable, and entirely avoidable diseases such as tuberculosis (TB) and malaria continue to claim lives due to preventable factors such as lack of access to proper drugs and medical treatment. By current estimates, meeting the target MDG of halving the TB prevalence rate by 2015 is unlikely (Vital Wave Consulting, 2009)."

The ability of developing countries to overcome these serious challenges is hindered by several core obstacles, among them a global shortage of healthcare workers. Mobile communication offers an effective means of bringing healthcare services to citizens in developing country. For example, mobile technology can enable health workers to provide real-time health information and diagnoses in rural and marginalized areas where health services are often scarce or absent altogether (Vital Wave Consulting, 2009).

The use of ICTs for health today represents one of the key instruments for health care delivery and public health (WHO, 2005, 2011). "Efficient and robust eHealth solutions have already demonstrated their value—particularly in facing new global health challenges such as emerging epidemics or the health consequences of natural disasters—towards achievement of the MDGs. "It is the health community's common responsibility to increase the implementation of eHealth, particularly in developing countries" (WHO, 2005, 2011).

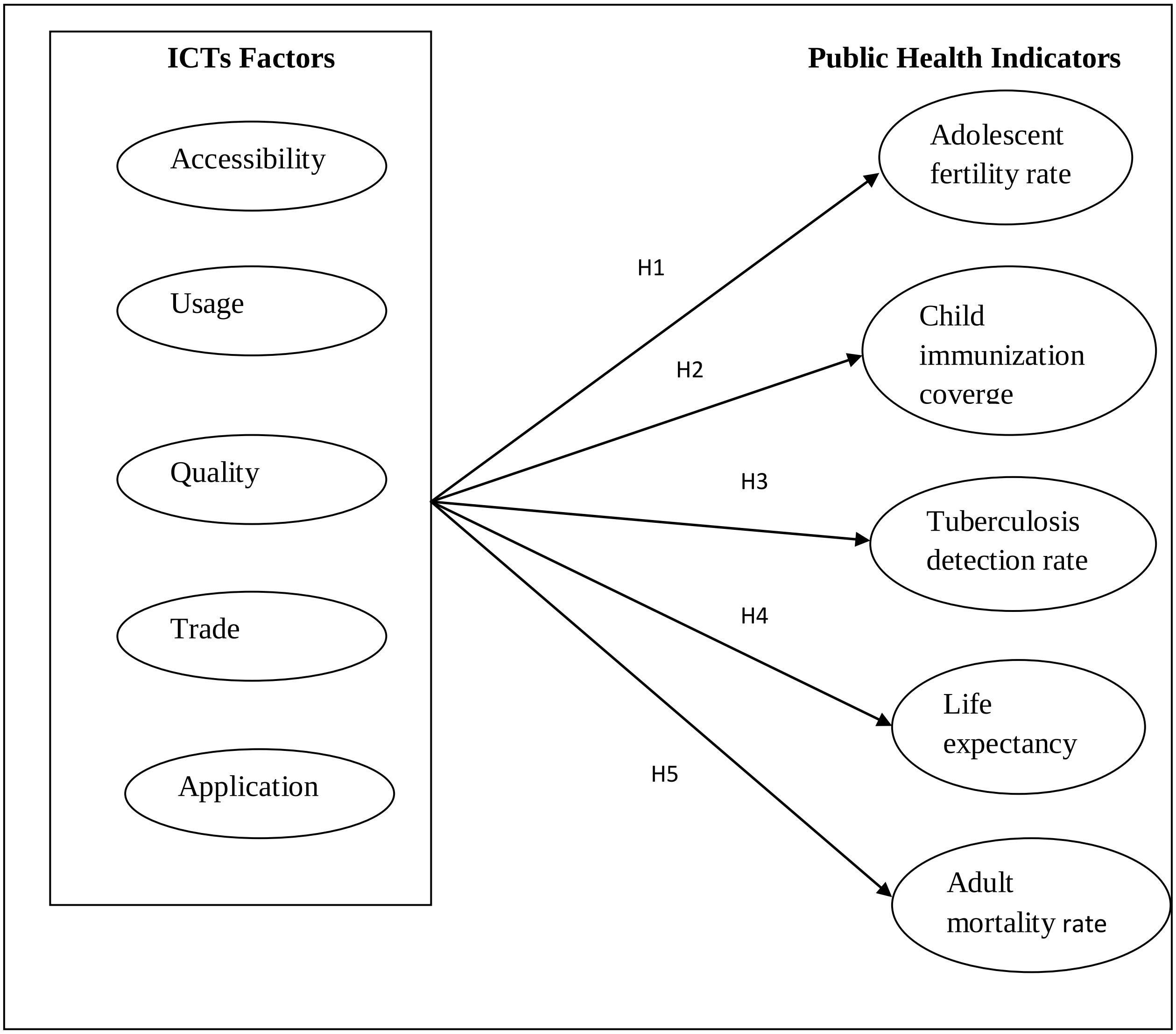
The MDGs placed health at the heart of development. At the time, countries were unprepared for the acceleration of the HIV/AIDS epidemic, the emergence and resurgence of infectious diseases, and the rising threat of terrorism. What has also changed in the years since the MDGs were ratified is the awareness of the importance of ICTs in meeting health targets. And while ICT diffusion was one MDG target, it was not linked to health in any substantive way. Today, health is increasingly seen as a driver for, as well as a beneficiary of, ICT development in countries (WHO, 2011).

The panel data study described in this paper is an adaptation of the conceptual framework developed in an earlier paper (see Raghupathi & Wu, 2011, for comprehensive literature review) and the numerous papers cited in the background section, as well as the publications at the International Telecommunication Union (2005, 2008, 2010), WHO (2005, 2011) and World Bank (2010). We also draw on the substantive health information technology literature that is reviewed in Raghupathi & Wu, 2011, and in the recent special issues of JAIS (Payton et al., 2011) and JSIS (Newell, 2011).

Both anecdotal evidence and various surveys indicate a potential association between ICTs and country-level public health delivery. eHealth and mHealth applications—including but not limited to telemedicine, electronic health record systems, public health surveillance systems, health information networks—have a positive relationship to key public health indicators. They have the potential to reduce adolescent fertility rates, increase child immunization coverage, improve tuberculosis detection rates, increase life expectancy, and reduce adult mortality rates by supporting health data collection, analysis (diagnosis & treatment), as well as communication & dissemination (Raghupathi & Wu, 2011).

As discussed above, among other ICTs, eHealth and mHealth play significant roles in making public health service accessible to all. **Figure 1** shows our framework. We chose for our macro level study the significant aggregate indicators related to public health (World Bank 2010) at http://data.worldbank.org/data-catalog/world-development-indicators/.

Figure 1. Conceptual Framework



While proposing these associations we recognize the reality that high-income countries would have better ICT infrastructure and better public health. That is, ICTs may not have an association with global public health delivery; wealth may provide the association. To obviate this possibility, the wealth effect is controlled so as to obtain accurate and reliable estimates. Therefore, we develop the following hypotheses:

H1. Information & communication technologies (ICTs) are associated with a reduction in the adolescent fertility rate at the country level.

H2. Information & communication technologies (ICTs) are associated with an increase in child immunization coverage at the country level.

H3. Information & communication technologies (ICTs) are associated with an increase in the tuberculosis case detection rate at the country level.

H4. Information & communication technologies (ICTs) are associated with an increase in the life expectancy at the country level.

H5. Information & communication technologies (ICTs) are associated with a reduction in the adult mortality rate at the country level.

4. Methodology

4.1 Data collection and measurements

The data used to test our hypotheses came from two World Bank databases for more than 200 countries during 2000 to 2008. The World Bank ICT at-a-Glance database classifies the major ICT sector performance variables into six factors, namely a*ccessibility, usage, quality, affordability, trade,* and *applications*. The detailed measurement variables are summarized in **Table 1**. Some measurement variables suffered from a high proportion of missing values and were not included in the later analysis. Unfortunately, all three measurement variables for the affordability factor had high missing values and this factor was not included in the later analysis. Since the measurement variables were in different scales, they were first standardized with a mean of zero and standard deviation of one and then averaged to extract the corresponding factor scores. Data for the public health indicators were extracted from the World Development Indicators database, which includes *adolescent fertility rate, child immunization*, *tuberculosis case detection rate, life expectancy,* and *adult mortality rate*. The definitions of these indicators are summarized in **Table 2**. Child immunization consists of two variables: immunization against DPT and that against measles. Likewise, adult mortality rate contains two variables: mortality rates for females and males. All the variables were normalized and the values of child immunization and adult mortality rate were calculated as the averages of their two measurement variables respectively.

Table 1. Measurement Items for ICT Sector Performance

ICT factors	***Measurement variables***
Accessibility	*Telephone lines (per 100 people)* *Mobile cellular subscriptions (per 100 people)* *Fixed Internet subscribers (per 100 people)* *Personal computers (per 100 people)* **Households with a television set (%)*
Usage	**International voice traffic (minutes/person/month)* *Mobile telephone usage (minutes/user/month)* *Internet users (per 100 people)*
Quality	**Population covered by mobile cellular network (%)* *Fixed broadband subscribers (% of total Internet subscribers)* *International Internet bandwidth (bits/second/person)*
Affordability	**Residential fixed line tariff (US$/month)* **Mobile cellular prepaid tariff (US$/month)* **Fixed broadband Internet access tariff (US$/month)*
Trade	*ICT goods exports (% of total goods exports)* *ICT goods imports (% of total goods imports)* *ICT service exports (% of total service exports)*
Applications	*ICT expenditure (% of GDP)* **E-government web measure index* *Secure Internet servers (per 1 million people)*

Note: Adapted from World Bank – ICT at a Glance 2009 (http://data.worldbank.org/data-catalog/ICT-table).

*Measurement items are not included in the later analysis due to high missing values.

Table 2. Measurement Items for Public Health Indicators

Variables	*Definition*
Adolescent fertility rate	The number of births per 1,000 women ages 15-19
Child immunization	The percentage of children ages 12-23 months who received vaccination against diphtheria, pertussis, and tetanus (DPT) as well as measles.
Tuberculosis case detection rate	The ratio of newly notified tuberculosis cases (including relapses) to estimated incident cases (case detection, all forms).
Life expectancy	The number of years a newborn infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life.
Adult mortality rate	The probability of dying between the ages of 15 and 60 (per 1000 female adults) – that is, the probability of 15-year-od dying before reaching age 60, if subject to current age-specific mortality rates between those ages.

Note: Adapted from World Bank Indicator 2009 9http://data.worldbank.org/products/data-books/WDI-2009)

The dataset of ICT factors and public health indicators were merged based on the unique identification information of country name (or code). The final dataset contained data for 200 countries.

4.2 Research method

The primary analysis method in this study is panel data analysis, which is an increasingly popular form of longitudinal data analysis among social and behavioral science researchers. A panel is a cross-section or group of people who are surveyed periodically over time. With repeated observations of enough cross-sections, panel analysis permits the researcher to study the dynamics of change with short time series. The combination of time series with cross-sections can enhance the quality and quantity of data in ways that would be impossible using only one of these two dimensions. Specifically, the panel data allow us to control for variables that we cannot observe or measure in each group (e.g., culture) and also help to control for unobservable variables that change over time but not across entities (e.g., economic development level).

With panel data one can include variables at different levels of analysis. In this study, we could choose each country as the level of analysis, but we set the level of analysis at an aggregate level—groups of countries based on their income. The primary reason for this choice is that the missing values of all the interested variables across 200 countries result in a substantial reduction of the dataset. Following World Bank classification, all the countries are divided into five income groups: high-income group, upper-middle-income group, middle-income group, lower-middle-income group, and low-income group.

The following fixed effect model is set up to explore the relationship between ICT factors performance and public health delivery indicators within each group of countries, as we assume that something within a country group may impact or bias the predictor or outcome variables and that this needs to be controlled in the model. The key insight is that if the unobserved variables do not change over time, then any changes in the outcome variable must be due to influences other than these fixed characteristics. As such, once the effect of those time-invariant characteristics from the predictor variables is removed, we can assess the predictors' net effect on outcome variables.

There are two ways to build the fixed effect model, and we chose to use the one with binary variables because we could separate the association of ICT factors and income levels from public health delivery indicators. Since we have five entities (five groups of countries), to generate binary (dummy) variables, only four entities are included in the model.

$$Y_{it} = \beta_0 + \beta_k X_{it}^k + \gamma_n E_n + \mu_{it}$$

where Y_{it} is the dependent variables where *i* = entity (group of countries) and *t* = time,

X_{it}^k $(k = 1, 2, \dots 5)$ represent five independent ICTs variables

β_k $(k = 1, 2, \dots 5)$ is the coefficient for the corresponding independent variable

$E_n(n = 1, 2, 3, 4)$ is the binary entity.

$\gamma_n (n = 1, 2, 3, 4)$ is the coefficient for the binary entities

μ_{it} is the error term

5. Key Results and Discussion

The association between the ICTs' factors and the five public health indicators are summarized in **Table 3**. Three similarities across the public health indicators are observed. First, overall ICTs' factors substantially improve a country's public health delivery on the top of wealth effect, lending support to all the hypotheses. Second, among all the ICTs' factors, accessibility is the only one that is associated with improvements in all aspects of public health delivery, while the contributions from the usage, quality, and applications are negligible. ICTs' accessibility factor is associated with a considerable extension to life expectancy and reduced adult mortality rate. Third, all entity-specific factors are significant in each model, indicating that countries' economic development level does influence their public health delivery. **Figures 2** through **6** plot the ICTs' accessibility factor against each public health indicator for each group of countries. Overall, high income countries enjoy higher ICTs accessibility and better health condition whereas low income countries have low accessibility and poor health condition. Thus, wealth effect is confirmed.

Table 3. Associations between ICTs' factors and public health delivery indicators

Independent variables	*Adolescent fertility rate*		*Child immunization*		*Tuberculosis detection*		*Life expectancy*		*Adult mortality rate*	
	Coefficient	*p-value*	*Coefficient*	*p-value*	*Coefficient*	*p-value*	*Coefficient*	*p-value*	*Coefficient*	*p-value*
Accessibility	-0.28	<0.001	0.64	<0.001	0.86	<0.001	0.30	0.03	-0.35	<0.001
Usage	-0.03	0.32	0.14	0.16	0.20	0.07	-0.004	0.89	-0.04	0.30
Quality	<0.001	0.05	<-0.001	0.21	<-0.001	0.06	<-0.001	0.13	<0.001	0.84
Trade	-0.15	0.01	0.90	<0.001	1.37	<0.001	-0.07	0.52	0.01	0.88
Application	-0.05	0.15	-0.06	0.61	0.04	0.76	0.14	0.15	0.05	0.35
Lower middle income countries	-1.33	<0.001	-3.73	<0.001	-5.13	<0.001	1.54	0.01	-1.72	<0.001
Middle income countries	-1.39	<0.001	-2.67	<0.001	-3.82	<0.001	1.57	0.002	-1.63	<0.001
Upper middle income countries	-1.18	<0.001	-0.70	0.09	-2.06	<0.001	1.78	<0.001	-1.28	<0.001
High income countries	-1.98	<0.001	-1.94	0.005	-3.45	<0.001	2.31	0.01	-2.40	<0.001
Constant	1.12	<0.001	2.10	<0.001	3.31	<0.001	-1.46	0.003	1.38	<0.001
F test that all U_i=0	76.86	<0.001	38.51	<0.001	19.05	<0.001	113.91	<0.001	38.36	<0.001

Figure 2. Impact of ICTs accessibility on adolescent fertility rate

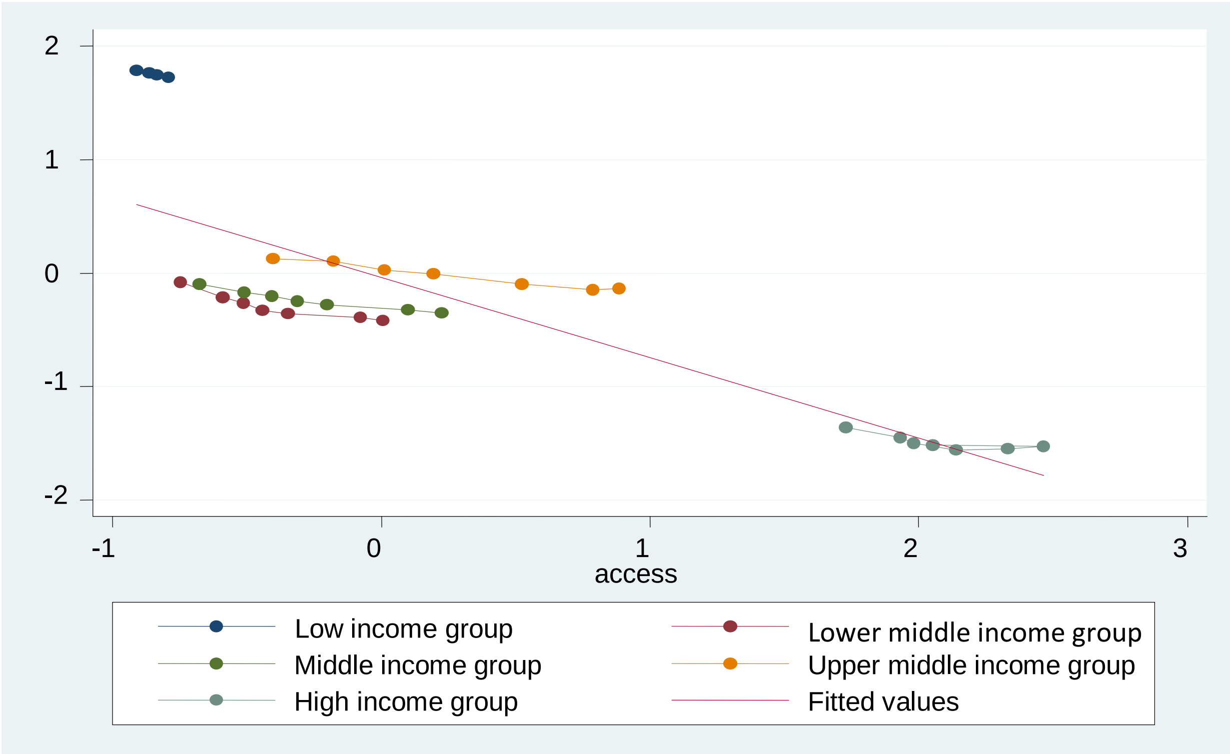


Figure 3. Impact of ICT accessibility on child immunization coverage

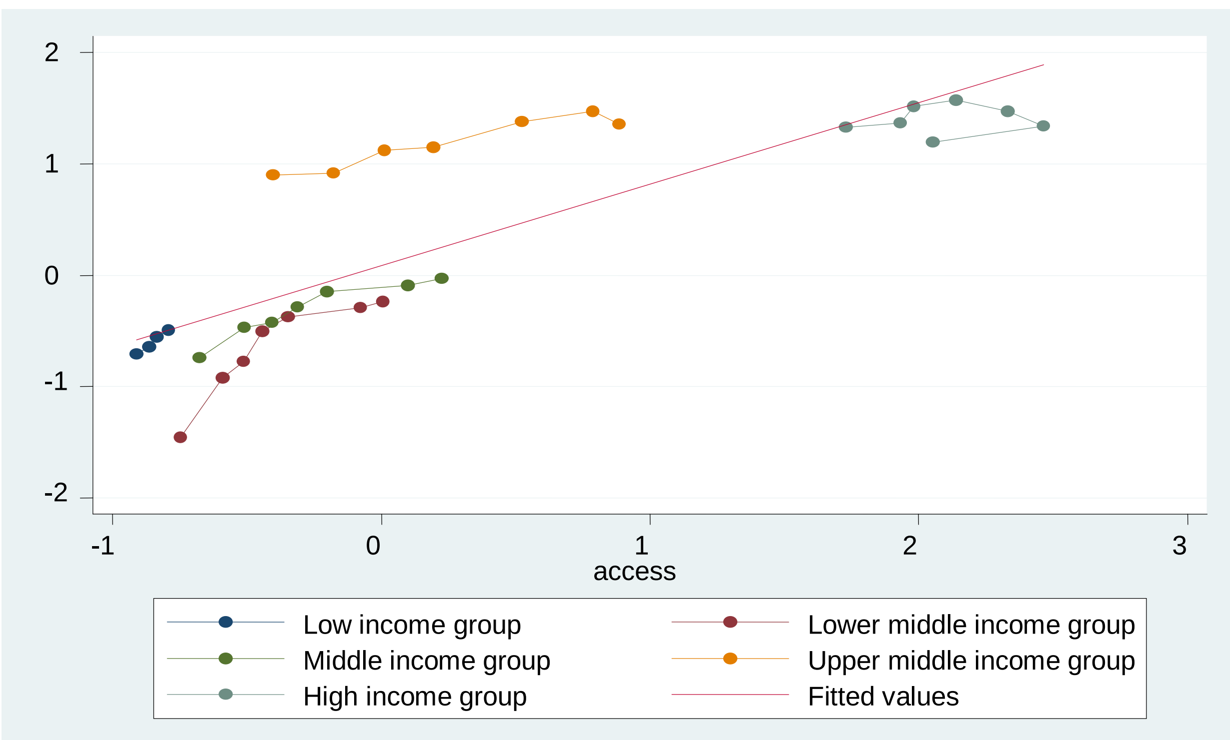


Figure 4. Impact of ICTs accessibility on Tuberculosis case detection rate

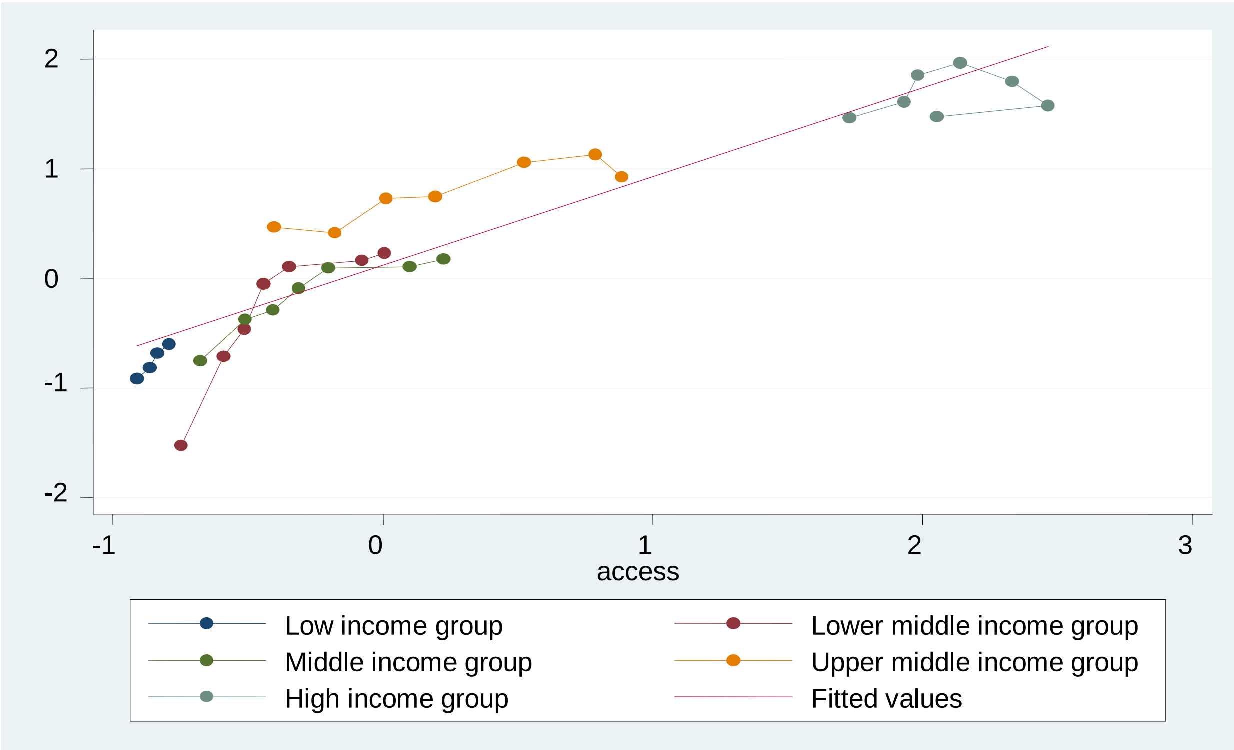


Figure 5. Impact of ICTs accessibility on life expectancy

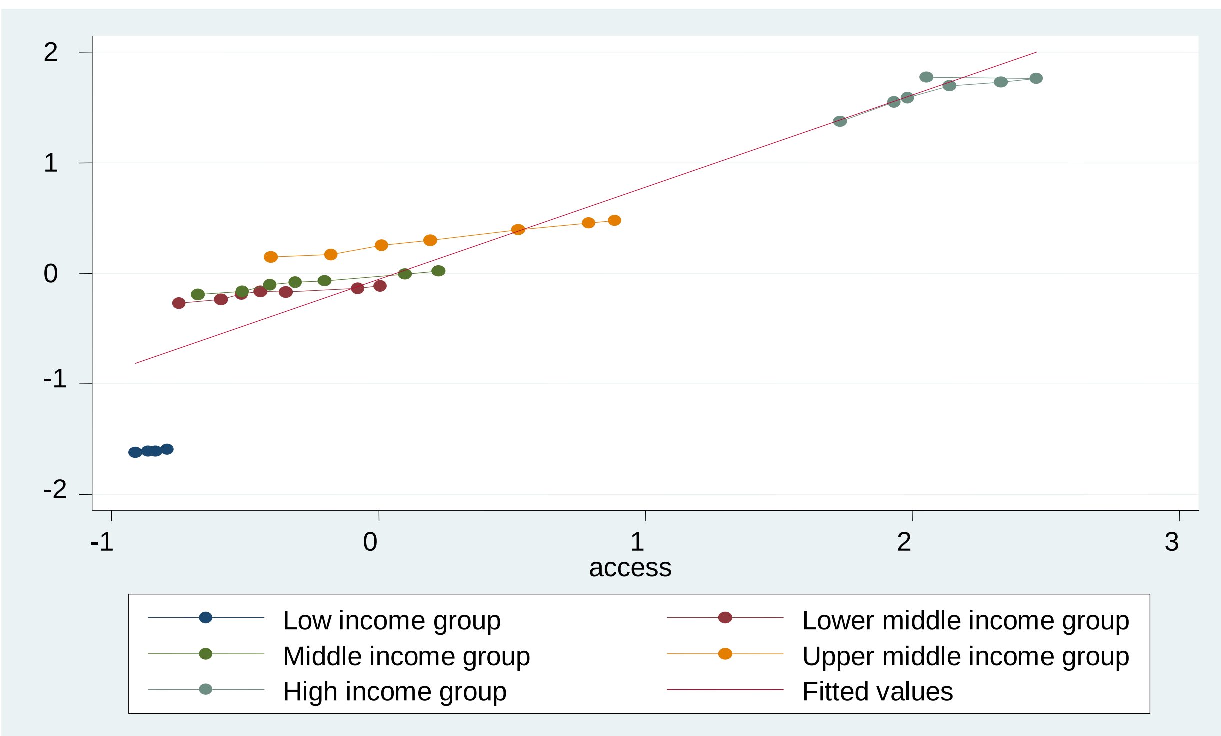
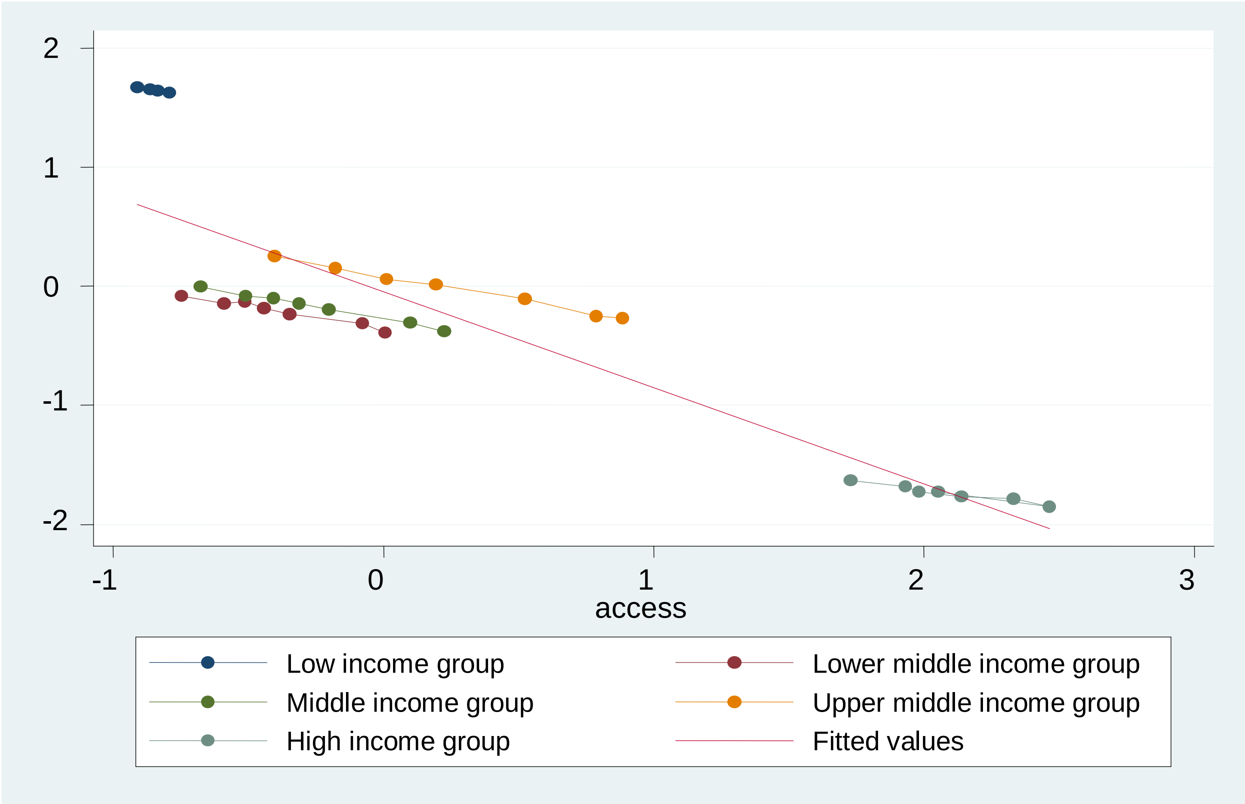


Figure 6. Impact of ICTs accessibility on adult mortality rate



The analysis suggests that in almost all areas studied countries in the higher-income groups have progressed further in the adoption of actions and provision of services than those in the lower-income groups. This finding is not surprising; it confirms that the 'digital divide' includes eHealth. Our common goal should be, therefore, to lessen this divide with concerted action (WHO, 2005): First, by investing in ICTs target to public health, the delivery of public health is enhanced. Second, although the effect of wealth is acknowledged, the cumulative investment in ICTs will improve public health delivery irrespective of the development stage of a country. Third, accessibility has the greatest association with positive delivery of public health vis-à-vis the other ICT factors. Therefore, enabling accessibility ought to be the top priority in ICT infrastructure investment, particularly in developing countries.

The contributions of this study are several. For one, by further studying the association between ICTs and public health indicators empirically (using panel data analysis), we contribute to the sparse literature in this particular area. Note that we acknowledge the portfolio of general research that has emerged in health information technology—see special issues of Journal of the Association for Information Systems (Payton et al., 2011) & Journal of Strategic Information Systems (Newell, 2011). The findings can help global policy makers strategize on ICTs' health resource allocation and invest in technologies that would maximize the population health benefits.

6. Scope and Limitations

Since countries report data to the World Bank database and the International Telecommunications Union in lagged fashion, further longitudinal studies that use updated data and more recent years is necessary. It is also important to note that the study does not show a direct causality between ICTs and public health delivery. In other words, the study does not say that by using ICTs, health improves. Rather, we conclude that there is a strong association in the relationship between certain ICTs and how public health is delivered. In this regard, the findings support the anecdotal and case studies evidence reported in the literature. Further longitudinal studies in the linkages between specific ICT applications (e.g., introduction of a telemedicine project) and health indicators (e.g., reduction in the number of hospital visits) may address causal relationships. But large 'big data' sets are needed for this type of study. Another limitation is we only considered income as an extraneous variable. Other country-level variables may change the view. Furthermore, the data acquired from the World Bank data sets is secondary in nature.

7. Conclusions and Future Research

ICTs have the potential to radically transform the delivery of public health. There are others, but the key strategic applications are eHealth and mHealth. The findings of this study will help government officials and public health policy makers to formulate strategic decisions regarding the best ICT investments and deployment. For example, the study shows that providing accessibility ought to be a critical focus. While the use of ICTs is one among several strategies in improving global public health, the delivery of public health cannot be replaced or underplayed. The actual carrying out of immunizations and vaccinations and preventive health measures, health education, hygiene, clean water and sanitation are vital factors in promoting public health. In the long term, better public health can improve productivity, contribute to poverty alleviation, and enhance quality of life overall.

Several research directions are possible. The emerging field of health analytics can be applied to 'big health data' sets for more robust analysis resulting in richer insight and informed decision making. While most governmental and NGOs (e.g., World Bank, WHO, Rockefeller Foundation) report and publish surveys, there is a paucity of quantitative analysis of the raw data, or aggregated data. The application of health analytics techniques will enrich findings. While this is a study done at the aggregate level, it is important to continue case studies of specific applications and deployments in various countries to gain insight into the socio-technical dimensions of the role of ICTs in health care. These include social, cultural, and political aspects of what works and what doesn't. The lessons learned can be shared with characteristically similar countries so as to avoid costly investment mistakes. Thus, knowledge creation and sharing is important. Also, future research may continually monitor and update the variables and data sets in real time and perform cross-country and cross-regional research as well as additional longitudinal studies. Other variables and development indicators may reveal additional associations and effects. An important issue to address is the 'reverse effect' or 'rebound effect.' What are the negative consequences of using or overusing technology? Carpel tunnel syndrome, for instance, is symptomatic of repeated use of the keyboard. Excessive cell phone use or constant staring at electronic screens or monitors also may have adverse effects. Going beyond quantitative studies, one may research the diffusion of ICTs for public health purposes and consider additional concepts and models, such as the introduction of key 'disruptive technologies' into health care, the 'leap frog' effect, the alleviation of the 'digital divide' with regard to health care, 'local innovation,' and new health care delivery designs and models. Additionally, new resource allocation & investment models and strategies of ICTs may emerge. Their adoption and assimilation may be studied. Globally, the application of ICTs such as eHealth and mHealth is rapidly, if unevenly, proliferating. Much needs to be done to provide universal and equitable health care to all.

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