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The Relationship Between Information and Communication Technologies and the Delivery of Public Health: A Country-level Study

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Abstract:

We empirically investigate the relationship between information and communication technologies (ICTs) and the delivery of country-level public health. Our underlying hypothesis is that ICTs can improve the efficiency and effectiveness of public health delivery mechanisms. In our framework, we include the ICT factors of accessibility, quality, affordability, applications, and institutional efficiency and sustainability. The public health delivery is represented by the changes in the indicators of immunization coverage, TB infection, sanitation, undernourishment, life expectancy, mortality rate, and health care expenses. Results indicate in most cases ICT factors have a significant correlation to a country's delivery of public health over and above a country's income level. The "Accessibility" ICT factor contributes to improved delivery for nearly all of the public health indicators. This is followed by "ICT Applications." Increased ICTs usage leads to increased health care expenditure. Our findings are useful at the country level for informing policy decisions regarding the nature and extent of investment in ICT infrastructure for the delivery of public health. We do caution that merely investing in more ICTs does not imply an automatic improvement in public health. Rather, ICTs have the potential to improve the delivery process.

Keywords: country, E-health, Health Information Technology (HIT) Information and Communication Technologies (ICTs), public health, Public Health Information Network, Public Health Surveillance System, telemedicine.

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I. INTRODUCTION

From personal experience, we know that sustainable health is an important part of the overall well-being of individuals and societies [Bloom, 2007; National Research Council, 1999; Singer and de Castro, 2007]. In 1993, the World Bank said health expenditures can be justified for economic reasons. As World Bank economists point out, improved public health contributes to economic growth in several ways: "It reduces production losses caused by worker illness; it permits the use of natural resources that had been totally or nearly inaccessible because of disease; it increases the enrollment of children in school and makes them better able to learn; and it frees for alternative uses resources that would otherwise have to be spent on treating illness" [World Bank, 1993]. The economic costs of preventable disease cannot be underestimated. Not only does disease negatively impact an individual's household income, carried over an entire citizenry, disease and the inability to work because of illness weaken a country's overall economic health. Furthermore, the report by the Commission on Macroeconomics and Health found that communicable diseases, maternal mortality, and under-nutrition in developing countries affected the poor more deeply than the rich, although all segments of the population were impacted [World Bank, 1993].

Meanwhile, globalization is accelerating the "spread of AIDS, drug-resistant forms of tuberculosis, and other infectious organisms. Industrialization, with its accompanying sedentary life-styles and extended life spans, is creating new epidemics of obesity, diabetes, cancer, and heart disease, among others" [Wells and Woolley, 2008]. Additionally, as these authors point out, the problem is compounded by excessive focus on "crisis and symptom" management versus prevention and cure.

Given that public health is a key determinant of the overall growth and poverty reduction of a country's economy, an expanding library of interdisciplinary literature continues to investigate the effects of good public health on a country's growth (e.g., economic growth, poverty reduction, and sustainability) and the enablers of good public health [World Bank, 1993; World Health Organization, 2001].

The literature suggests that ICT factors—including access, affordability, and applications—have the potential to enable the delivery of good public health by facilitating the timely collection, organization, and communication of health information [Garshnek and Burkle, 1998; Institute of Medicine, 2002; Nordstrom, 2006; Stephens and Woods, 2005]. ICTs provide the infrastructure and resources for the development of large-scale, population-level applications such as health information networks, surveillance systems, and telemedicine [Braa et al. 2004; Chen and Perry, 2006; Dzenowagis and Kernen, 2005; Eysenbach, 2007; Jadad et al. 2000; Kwankam, 2004; World Health Organization, 2006]. Therefore, the potential for positive macro effects of ICTs on public health delivery is great [Kwankam, 2004].

And yet in spite of the array of evidence that ICTs can enable good public health delivery, little empirical research has been conducted to determine whether and what types of ICTs influence the delivery process favorably. In this article we develop a framework for conceptualizing and studying the effects of ICTs on public health delivery at the country level. This exploratory analysis is motivated by various propositions that ICTs have the potential to influence the delivery of public health positively. Put into action, the use of ICTs can enhance the delivery mechanisms, thereby leading to better quality of life, economic growth, alleviation of poverty, and improved mortality leading to overall progress in developing countries [Eysenbach, 2007; World Health Organization, 2006].

Our study is different from other related studies in several ways. First, although prior studies indicate the positive effect of ICTs on health care quality as well as a reduction in costs, their foci are mainly at the health care delivery organization level [Chaudhry et al., 2006; Devaraj and Kohli, 2000; Gans et al., 2005; Khoumbati et al., 2006; Mille et al., 2005]. Our study, on the other hand, looks at the impact of ICTs on public health delivery at the country level.

Second, most studies have focused on ICT implementation (e.g., electronic health records), not its impact [Bates, 2005; Fraser et al., 2005; Jha et al., 2006]. Since ICTs have the potential to impact the delivery of health care to large segments of populations, macro-level impact studies are crucial. This is especially important in that countries have to allocate their limited resources to ICTs infrastructure selection and construction in an optimal way for deriving maximum benefits. Additionally, this focus permits us to document cross-country correlations and variations among the components of ICTs infrastructure and the status of public health delivery and to perform comparative analyses.

Third, most research has focused on evaluating the effectiveness of health information technology (HIT) only in clinical services [Bates, 2005; Chaudhry et al. 2006; Hillestad et al., 2005; Mille et al., 2005], providing a one-dimensional view despite the existence of many ICTs with the potential to impact global health [World Health Organization, 2006]. In addition, the studies have been micro in orientation, that is, they are concerned with "specific aspects" of implementation in "specific organizations, regions or countries" [Andersen et al., 2006; Fraser et al., 2005; MacFarlane et al., 2006; McMurry et al., 2007; Protti, 2007]. Generalizability of the conclusions from these studies is much more difficult, and they fail to address the macro issue of overall public health delivery.

Finally, in terms of methodology, past studies in the ICTs and health care literature are conceptual [Connell and Young, 2007; Raghupathi and Tan, 2002; 2008] or they are case studies of particular countries [Braa et al., 2004; Braa et al., 2007; Madon et al., 2007; Sahay and Walsham, 2006; Tomasi et al., 2004] and across selective countries [Protti, 2007; Tomasi et al., 2004]. While both conceptual studies and case research provide insights, extending the findings to the country level is questionable and does not address the larger picture of how macro-level ICTs can have a positive effect on the delivery of overall public health. Further, we see that quantitative empirical studies on ICTs and their relationship to public health are limited to electronic health records, are relatively few, and are, for the most part, limited to analyzing a particular EHR implementation within a country or countries [Andersen et al., 2006; Fraser et al., 2005; Protti, 2007]. These quantitative studies also do not address macro-level economic issues concerning public health. Likewise, there is a paucity of research at national and cross-country levels even in the field of IT impact [Melville et al., 2004]. Additionally, though there is rich anecdotal evidence, there is an imperative need to conduct large-scale quantitative empirical studies to confirm the relationship between ICTs and the delivery of public health.

To our knowledge there is no large-scale empirical study involving many countries that aims to understand the relationship between ICTs and public health. Through this research we hope to contribute to the ICTs and public health research, thereby making the field richer (i.e., to the larger theme of macro-effects of ICTs). Specifically, we analyze the relationships of various ICT factors with country public health indicators in this study. These are captured in the following two distinct-but-related research questions:

1. *Do ICT factors have a positive relationship to a country's public health delivery, controlling for the "wealth effect"?*
2. *Which ICT factors help improve the delivery of public health?*

The rest of the article is organized as follows: First, we provide background. We discuss public health in general and the potential role of ICTs to enable public health delivery. We then outline the research framework and hypotheses. Third, we describe our methodology. Fourth, we discuss the results and implications. And, finally, we offer conclusions and discuss the limitations and future research directions.

II. RESEARCH BACKGROUND

Importance of Public Health

Worldwide, the public health community is faced with difficult new challenges, including bioterrorism, emerging infections, and antibiotic resistant organisms. Add these to such historical challenges as infectious diseases, mortality, malnutrition, and lack of sanitation (see http://www.who.int/topics/en/ for definitions) [World Bank, 1993; World Health Organization, 2001] and there is an urgency to expand the use of information and communication technologies (ICTs) in public health [Koo et al., 2001] and to create "truly effective and efficient public health information systems" [Yasnoff et al., 2001]. According to Yasnoff et al. [2001], these integrated systems have the potential to collect, organize, and disseminate health-related information in real-time from a number of sources, thereby improving the current health status of communities. ICTs—including mobile devices, telephone lines, and the Internet—provide the infrastructure for a range of specific HIT applications. Electronic health record systems, clinical decision support systems, surveillance systems, and telemedicine and other HIT applications—also called e-health applications [Eyesenbach, 2007; Jadad et al., 2000; Kwankam, 2004]—serve the dual purposes of monitoring public health and enabling individual clinical services. Singer and de Castro [2007] emphasize the need to build "integrated human and animal disease surveillance infrastructure and technical capacity in tropical countries on the reporting and scientific evidence requirements of the sanitary and phyto-sanitary agreement under the World Trade Organization" [Singer and de Castro, 2007]. The resulting improvements in health would translate into higher incomes, higher economic growth and reduced population growth [World Health Organization, 2001].

According to WHO [2001], there are three primary ways that disease impedes economic well-being and development. One way is that preventable disease reduces the number of years of healthy life expectancy. Substantial are the economic losses to society caused by early deaths and chronic disability. Second, high infant mortality rates impede parents from investing in their surviving children. Societies with high rates of infant mortality (< 1 year of age) and child mortality (< 5 years of age) have higher rates of fertility in part to compensate for the frequent deaths of children. Large numbers of children in turn reduce the ability of poor families to invest significantly in the health and education of each child. The third way disease impedes economic health is through the depressing effects it has on the returns to business and infrastructure investment, even beyond the effects on individual worker productivity. Whole industries in agriculture, mining, manufacturing, and tourism, as well as important infrastructure projects, could be compromised by a high prevalence of disease. In addition, epidemic and endemic diseases can also undermine social cooperation and even political and macroeconomic stability. The essential interventions needed to eliminate much of the avoidable mortality of low-income countries are not expensive; nor are they free [National Research Council, 1999; World Health Organization, 2001].

Since good health increases the economic productivity of individuals and the economic growth rate of countries, investing in health is one means of accelerating development [National Research Council, 1999; World Bank, 1993; World Health Organization, 2001]. More importantly, good health is a goal in itself. However, while life expectancy has increased and child mortality has decreased over the past decades, new challenges have emerged. The fatalities from childhood and tropical diseases, including AIDS as well as diseases of aging populations, are high. Furthermore, developing countries in particular face budget deficits and limited health expenditures [National Research Council, 1999; World Bank, 1993; World Health Organization, 2001]. Public health programs, therefore, attack directly the health problems of entire populations or population sub-groups [Koo et al., 2001]. Their objective is to prevent disease or injury and to provide information on self-cure and the importance of seeking cures.

The Relationship Between ICTs and Public Health Delivery

Two key roles for ICTs in public health delivery are envisaged: (1) organizing and disseminating health information to health workers and the population at large; (2) educating the public about prevention [World Health Organization, 2006]. Mobile phones, for example, can be used for communicating the upcoming arrival of vaccination teams in remote villages, while the Internet can provide the tools for distance learning and remote monitoring. These two mechanisms have been shown to have a major impact on promoting good public health. Telemetry data helped with the control of onchocerciasis (river blindness caused by a parasitic worm) in West Africa. Likewise, the Internet plays an ongoing role in controlling the SARS outbreak and other viruses via real-time tracking and Web updates (http://www.who.int/csr/outbreaknetwork/en/). The influenza virus is also tracked on the Web (https://www.who.int/fluvirus_tracker). Numerous WHO projects focus on advancing these technologies where they are needed. The Health Internetwork Access to Research Initiative (HINARI—http://www.who.int/hinari/en/), for example, provides health professionals in over 1,200 institutions in developing countries with free or affordable online access to 2,400 of the top scientific journals in the health field, thereby creating a health knowledge community. Several telehealth projects in developing countries are made possible by the rapid proliferation of mobile phones and other wireless devices. In addition, Internet-based medical education offers a partial solution to the human capital flight of health workers from developing countries. The WHO has also set up a global observatory on e-health systems. Its purpose is to track developments in relevant fields by collecting and analyzing data on ICT and health, covering events in research, industry, policy, and practice [Dzenowagis and Kernen, 2005].

Among more advanced initiatives, the European Information Society 2010 supports calls for implementation of such measures as online health services, adoption of health cards, and health information networks between points of care. An EU health portal and EU-sponsored quality criteria for health websites are envisaged for the future. Chronic diseases—heart disease, stroke, cancer, and diabetes—are by far the leading causes of death throughout Europe. Health promotion measures, timely diagnosis, and proper management can delay the onset and mitigate the impact of these diseases, and ICT can facilitate and augment these aspects of care [Tomasi et al., 2004].

ICTs enable the creation of public health information networks (PHIN) [Detmer, 2003; McMurry et al., 2007; Scotch et al. 2008], a national multi-organizational business and technical architecture for public health information systems in the U.S. [Loonsk et al., 2006]. The goal of PHIN is to expand the functionality of public health applications and integrate them across the span of organizations in and practical needs of public health. There is also an attempt to create a national health information infrastructure (NHII). An NHII provides the underlying information architecture to detect and track global threats to public health by connecting local health providers and health officials to national data systems (e.g., Centers for Disease Control and Prevention), using high-speed networks [Tang, 2002]. A national health information infrastructure must support, among other things, a public health system capable of monitoring, promoting, and protecting the health and safety of the total population (and subpopulations) by sharing tools that enable improved clinical management of populations of patients using vital statistics, population health risks, prompt notifications, and disease registries [Detmer, 2003]. All have the potential for enormous positive effect on delivery of the public health of a country.

ICTs also enable the development of public health surveillance systems whose goal is to collect, analyze, and interpret data about biological agents, diseases, risk factors, and other health events and to provide timely dissemination of collected information to decision makers [Bellika et al., 2007; Chen and Perry, 2006; Lazarus et al., 2008; Sengupta et al., 2008; Tsui et al., 2003; Wagner et al., 2003]. Early detection of a biological attack with agents (anthrax, for example) may be accomplished through surveillance systems that recognize infected individuals early in the disease process. The urgency of the problem is reflected in an explosion of research on new computer-based disease surveillance systems. For example, Wagner et al. [2003] describe the use of surveillance data that track sales of over-the-counter (OTC) health care products, such as cough syrup, purchased by sick individuals early in the course of illness to treat symptoms. They point out that the advent of electronic medical records and health information exchange raises the possibility of expanding public health reporting to detect a broad range of clinical conditions and of monitoring the health of the public on a broad scale [Wagner et al., 2003]. ICTs have the capability to create very large databases of epidemiological data, including but not limited to life expectancy and mortality, malnutrition, immunization level, infection rate, and sanitation level. Some countries have established ICTs-enabled surveillance systems that rely on sentinel districts selected as representative of the country. Data collection systems for cause-specific death rates, vaccine coverage, the effectiveness of vaccines, and the impact of specific health interventions can be monitored. Other systems track pandemics such as the bird flu virus. These systems, when combined with appropriate practices of information use, contribute significantly to increased immunization coverage and consequently to reduced infant and child mortality [Braa et al., 2004].

Another example of the potential of ICTs in public health delivery is telemedicine/telematics. These applications enable a range of activities that include remote care and training, especially in rural areas [Androuchko, 2005; Hu et al., 1999; Jones 1997; MacFarlane et al., 2006; Miscione, 2007; Paul, 2006]. As the WHO (http://www.who.int/eht/eHealthHCD/en/) suggests, it has a primary role of facilitating initial training and continuing education. A study of health telematics projects in fifteen European countries, undertaken by the European Health Telematics Observatory (EHTO), shows that training had a 6 percent share of all health telematics uses [World Health Organization, 2006]. *Health telematics* is a composite term for "health-related activities, services, and systems, carried out over a distance by means of information and communications technologies, for the purposes of global health promotion, disease control, and health care, as well as education, management, and research for health" [World Health Organization, 2006]. This is part of the general trend wherein health care focus is shifting from hospital-based acute care toward prevention, promotion of wellness, and maintenance of function in community and home-based facilities. Telemedicine can facilitate this shift [Jones, 1997]. He reports that the FCC's Advisory Committee on Telecommunications and Health Care also observed that "the convergence of health care and telecommunications technologies offers an extraordinary opportunity to expand the availability and affordability of modern health care."

Finally, ICTs have an impact on the delivery of public health through e-health applications. The potential of e-health to improve life expectancy, literacy, education, and standard of living (all dimensions of "human development") is significant [Eysenbach, 2007]. Over the last decade, the need to develop and organize new ways of providing efficient health care sciences has coincided with major advances in ICTs. The result has been a dramatic increase in the use of ICT applications in health care, collectively known as *e-health* [Jadad et al., 2000; Kwankam, 2004]. Today, the integration and assimilation of e-health into the everyday life of health-care workers is becoming a reality in developed as well as developing countries [Kwankam, 2004]. "E-health is the use, in the health sector, of digital data—transmitted, stored and retrieved electronically—in support of health care, both at the local site and at a distance [World Health Organization, 2007]."

The WHO program on e-health for health care delivery (eHCD) encompasses e-health applications that directly support prevention, patient diagnosis, and patient management and care. These applications include tele-consultations, tele-referrals, forward-storage concepts (e.g., tele-radiology and tele-prescriptions) and electronic patient records (EPR) (http://www.who.int/eht/en/eHealth_HCD.pdf). Through these applications, it is possible to take specialized care to primary health-care centers in remote areas, thereby broadening and improving the quality of services they offer. By connecting primary health workers to primary health-care centers and connecting these centers electronically to departments and referral centers in hospitals for the exchange of data, a significant improvement in access and cost-effectiveness may be affected. Thus, primary health care is the main objective of the eHCD program.

The Research Gap

The potential of ICTs to have a positive association with public health delivery has been discussed extensively [Ferraro, 2008; Nowak, 2008; Rubin, 2008; Ryckman, 2008; Thomas, 2008]. Existing studies have focused on the introduction of specific technologies, such as the cell phone or the Internet, but few have examined empirically the association in detail. Also, most use a case-study method and limit the focus to individual countries [Fraser et al., 2007; Kittler et al., 2004; Kollmann et al., 2007; Patterson et al., 2007; Valenzuela et al., 2007; Verhoeven et al., 2007]. Some examples:

Patterson et al. [2007] examined the referral patterns from an e-mail referral system between doctors in the developing world and specialists in the developed world. Referrals from four countries (Iraq, Afghanistan, Pakistan, Kuwait) and cases from twenty-two other countries were examined, and the authors concluded that e-mail telemedicine could be used in areas of conflict, such as the Middle East.

Valenzuela et al. [2007] reported on the development of a non-commercial open-access Web-based application for tele-consultation, called *Doctor Chat,* in Columbia. Because remote areas remained underserved and access to care limited, the authors suggested tele-consultation might be an effective way to improve access to health care and information.

Verhoeven et al. [2007] carried out a systematic literature review to study the benefits and deficiencies of tele-consultation and videoconferencing on the clinical, behavioral, and care coordination outcomes of diabetes treatment. Tele-consultation programs involving daily monitoring of clinical data, education, and personal feedback proved to be most successful in realizing behavioral change and reducing costs. Videoconferencing was found to benefit education and cost reduction efforts, although it also aided in monitoring disease.

Fraser et al. [2005] report on several projects in which cell phones were used to assist in patient follow-up and to provide access to medical data, such as laboratory tests. Rwanda's Partners-in-Health, for example, sends messages using short message service (SMS) to clinical staff warning of abnormal lab results. Cell phones have also been used in South Africa to encourage patient compliance with TB treatment and in Peru to monitor medication side effects for treatment of sexually transmitted infections. Systems in Peru and Rwanda, set up by Voxiva Inc., allow staff to send data on patient care to a Web-based reporting system through a phone system. The Rwandan government uses this system to facilitate national reporting of HIV outcomes.

Fraser et al. [2007] assessed the role of medical information systems in tracking patients with HIV or MDR-TB, ensuring they are cared for promptly, their progress (and compliance) aided by regular follow-up. Preliminary data showed the benefits of tracking patients, of providing access to key laboratory data, and of using this data to improve the timeliness and quality of care.

Kollmann et al. [2007] suggest that mobile phones can assist in daily diabetes management, enabling tele-medical interaction between patients and health care professionals. In particular, they evaluated the feasibility of a mobile phone-based data service to assist diabetes mellitus (DM1) patients on intensive insulin treatment. Outcome measures focused on patients' adherence to the therapy, availability of the monitoring system, and the effects on metabolic status. The service was well accepted by the patients (no dropouts), and data transmission via mobile phone was successful on the first attempt in 96.5 percent of cases.

Kittler et al. [2007] evaluated the use of the Internet in accessing information related to the 2001 anthrax scare in the U.S. and strategized about the best use of the Internet during times of public health crises. The results indicated that traditional media (e.g., TV, radio) were the first source of information on the health emergency, but survey respondents said they also searched the Internet for information on anthrax and bioterrorism. The authors concluded that information found online could positively influence behavioral responses to health crises.

The above review indicates a dearth of empirical studies in this area. The limited available literature is more often micro leveling in scope. From a methodological perspective, sample sizes are relatively small. Generalizability, therefore, is limited. Empirical in orientation, our study aims to fill the gap by examining the relationship between ICTs and public health delivery at the macro level. Plus, our sample is large enough to enable some generalizability.

III. RESEARCH FRAMEWORK

The current body of work and the substantive number of publications at the WHO (e.g., World Health Organization, 2001) and the World Bank (e.g., World Bank, 1993) indicate the potential relationship between ICTs and public health delivery process. We add to the literature with this study that attempts to determine empirically the extent of the relationship between the two. We develop our framework drawing from the literature cited in Sections I and II and the WHO and World Bank data, as shown in Figure 1. Since our study is at the macro level, we chose key aggregate indicators representative of public health [National Research Council, 1999]; http://go.worldbank.org/SDHOTB92H0). Case studies and anecdotes cited in the previous section indicate that ICT-enabled applications such as health information networks, public health surveillance systems, telemedicine, and e-health have a positive impact on key public health indicators: they have the potential to increase immunization coverage, reduce infection (e.g., TB), improve sanitation, minimize undernourishment, increase life expectancy, reduce the mortality rate [World Health Organization, 2001, p. 52], and increase health care expenses (indicating an investment in public health) by supporting the underlying health care delivery mechanisms (e.g., communication and dissemination of health information in a timely fashion). Immunization coverage is increased by the use of mobile technologies to inform the population that vaccination teams are scheduled to arrive on a particular day. Infection rates are reduced when diseases are monitored and treated in a timely fashion and when preventive measures are taken based on information in public health information networks and surveillance systems. Likewise, sanitation is improved and undernourishment minimized via ICT-enabled education, such as the use of telemedicine and tele-training. The overall effects include an increase in life expectancy and decrease in mortality through better quality public health delivery. E-health applications, for example, can provide services at the clinical level, thereby preventing needless deaths. We also hypothesize that an investment in ICTs results in increased health care expenditure due to infrastructure investment.

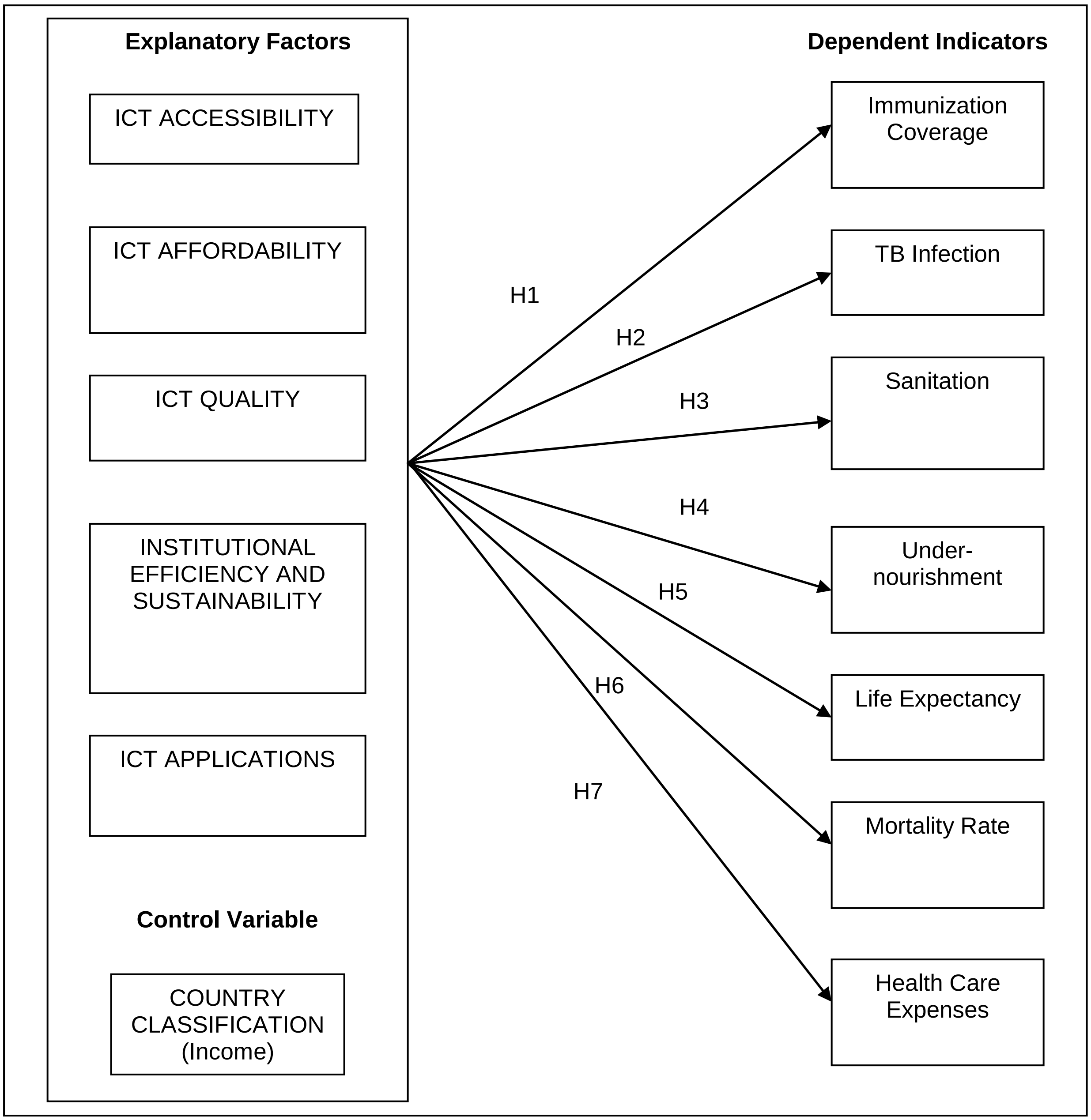

Figure 1. ICTs—Public Health Delivery Research Framework

While proposing these relationships in Figure 1, we also recognize the possibility that richer countries have better ICT infrastructure and better public health. That is to say, ICTs may not have a direct relationship to public health delivery. It is the third common factor (i.e., wealth) that makes them correlate. To preclude this explanation, the wealth effect must be controlled so as to obtain accurate and reliable estimates. As such, we formulate the following hypotheses:

H1. Information and communication technologies (ICTs) are positively related to the coverage of immunization in a country controlling for the wealth effect.

H2. Information and communication technologies (ICTs) are negatively related to the TB infection cases in a country controlling for the wealth effect.

H3. Information and communication technologies (ICTs) are positively related to the sanitation condition of a country controlling for the wealth effect.

H4. Information and communication technologies (ICTs) are negatively related to the undernourishment in a country population controlling for the wealth effect.

H5. Information and communication technologies (ICTs) are positively related to the life expectancy of a country population controlling for the wealth effect.

H6. Information and communication technologies (ICTs) are negatively related to the mortality rate of a country population controlling for the wealth effect.

H7. Information and communication technologies (ICTs) are positively related to the health care expenses per capita of a country controlling the wealth effect.

IV. METHODOLOGY

Datasets

In order to estimate the extent of the relationship between ICTs and public health delivery, we extracted data from several World Bank databases for 2004, the latest year for which complete data was available. The country income data was obtained from the World Development Indicators database (WDI), and the country classifications (high, middle, or low) were obtained from The World Bank (http://go.worldbank.org/CWTURYIPS0). The data for the twenty-one information and communication technologies' variables was extracted from The World Bank ICT at-a-Glance country database (http://go.worldbank.org/FDTYJVBR60). Based on World Bank ICT at-a-Glance database, these twenty-one information and communication technologies' variables are classified into five factors (Table 1). The five factors are Accessibility, Quality, Affordability, ICT Applications, and Institutional Efficiency and Sustainability.

Data for the public health indicators was extracted from the World Development Indicators database at the World Bank website for 2004 (http://go.worldbank.org/VXW7J2NON0). These variables include Immunization coverage, TB infection, sanitation, undernourishment, life expectancy, mortality rate, and health care expenses (Table 2).

The dataset of ICT factors and public health indicators (WDI) were merged based on the unique identification information of country name (or code). The final dataset contained data for 200 countries. The control variable refers to country classification into one of three groups, namely, low, middle, or high income. An index that averages each ICT factor's measurement items was also created. The factor scores, as well as the control variable (country income level), were used to explain the variance of public health across the countries.

Research Method

Hierarchical linear regression (HLR) was conducted to test each hypothesis in SPSS, the statistical software. HLR is a theory-driven testing technique that allows groups of variables to be introduced in the regression model sequentially. The order in which the predictor variables are entered is not a statistical decision, but based on theoretical or logical assumptions on which the hypothesis is based. This is an important difference between HLR and stepwise regression where the software determines the order of entry of the variables.

Our hypotheses consider the impact of two groups of variables on public health: wealth factor and ICT factors. Consequently, there are two steps for each hypothesis testing. In the first model (Model 1), a regression of public health indicators on country income level was performed. In the second model (Model 2), a regression of public health indicators on both country income level and the five ICT factors was performed. Because Model 1 is nested in Model 2, we can compare the change in R-square and the associated F statistics and p-values to assess whether the more complex model can significantly improve the goodness of fit of the model.

Table 1: ICT Factors	
ICT factors	**Measurement items**
Accessibility	Telephone mainlines (per 1,000 people) International voice traffic (minutes per person) Mobile phone subscribers (per 1,000 people) Population covered by mobile telephony (%) Internet users (per 1,000 people) Personal computers (per 1,000 people) Households with television (%)
Quality	Telephone faults (per 100 mainlines) Broadband subscribers (per 1,000 people) International Internet bandwidth (bits per person)
Affordability	Price basket for residential fixed line (US$ per month) Price basket for mobile (US$ per month) Price basket for Internet (US$ per month) Telephone average cost of call to US (US$ per three minutes)
ICT applications	Information and communication technology expenditure (% of GDP) Secure Internet servers (per 1 million people) Schools connected to the Internet (%) E-government readiness index (scale 0-1)
Institutional efficiency and sustainability	Telecommunications revenue (% GDP) Telephone subscribers per employee Telecommunications investment (% of revenue)

Table 2: Public Health Indicators	
Indicator	**Measurement items**
Immunization coverage	Immunization, DPT (%)
TB infection	Incidence of tuberculosis (per 100,000 people)
Sanitation	Improved sanitation facilities (% of population with access)
	Improved water sources (% of population with access)
Undernourishment	Prevalence of undernourishment (% of population)
Life expectancy	Life expectancy at birth, total
Mortality rate	Mortality rate, infant (per 1000 live births)
Health care expenses	Health care expense per capita

V. RESULTS AND DISCUSSION

Figure 2 shows the average value of ICT factors across countries at different income levels. High income countries on average have higher ICT investment than low and middle income countries except in ICT institutional efficiency and sustainability. The graph in Figure 3 shows the average public health delivery situation in countries at different income levels. For instance, high income countries have higher immunization coverage and better sanitation than low and middle income countries. They also have lower mortality rate, undernourishment and TB infection. The regression results of Models 1 and 2 are presented in Table 3. Hypotheses 1, 2, 3, 4, and 7 are supported, whereas Hypotheses 5 and 6 are rejected. Overall, we report four major findings:

First, as shown, a country's income level (high, middle or low) appears to have a significant relationship to its public health situation, with one exception—life expectancy at birth. This finding largely confirms the presence of the wealth effect. This exception can be explained from three aspects. One, life expectancy at birth does not follow normal distribution, which could affect the efficiency and bias of the estimates. Two, the sample size is relatively small (48) compared to the sample sizes for the other sets of regressions of public health indicators (typically sample size is greater than 110). Third, the correlation between *Accessibility* and country income level is quite high (0.86). As such, the explanatory power by country income level is largely deprived by *Accessibility* factor. These three reasons come from the statistical analysis perspective; currently we do not have sound theoretical explanations. Future research is definitely desirable to see whether this is essentially a sample problem.

Second, in most cases ICT factors have a significant association with a country's public health delivery mechanisms over and above a country's income level. We found that *the change of F* statistics are significant at $p<0.05$ when ICT factors are added in the regression with the control variable, except for life expectancy and birth mortality. The

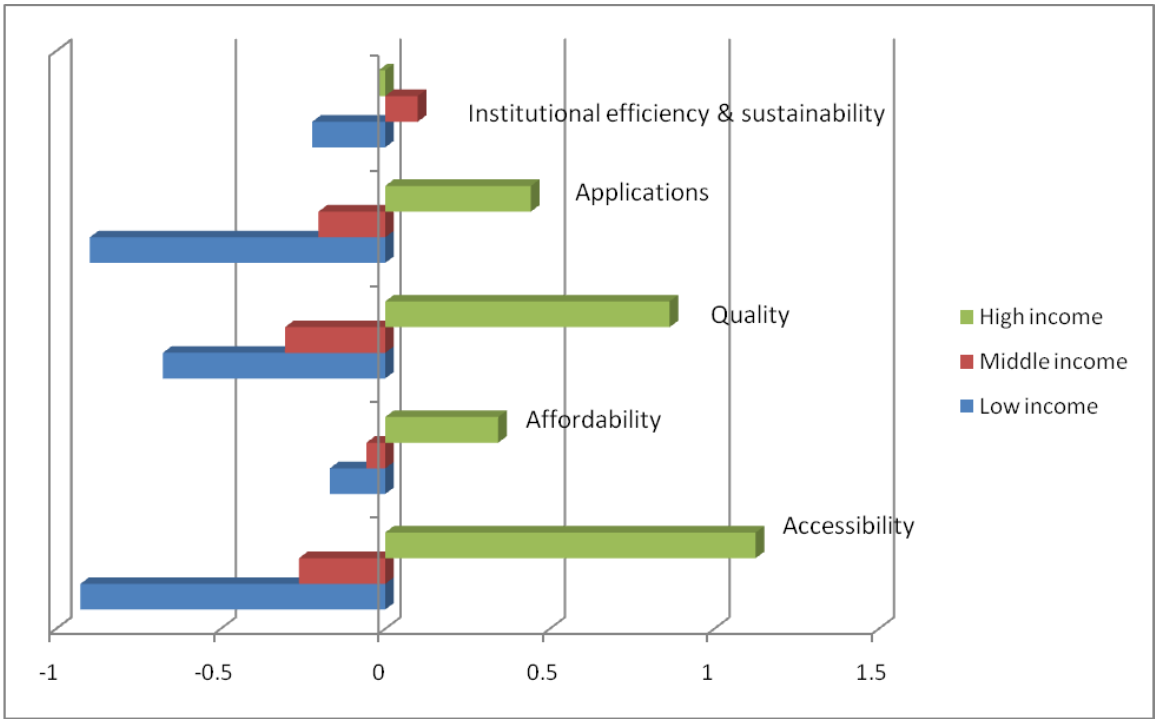

Figure 2. ICT Factors Mean Values Comparison Across Country Types

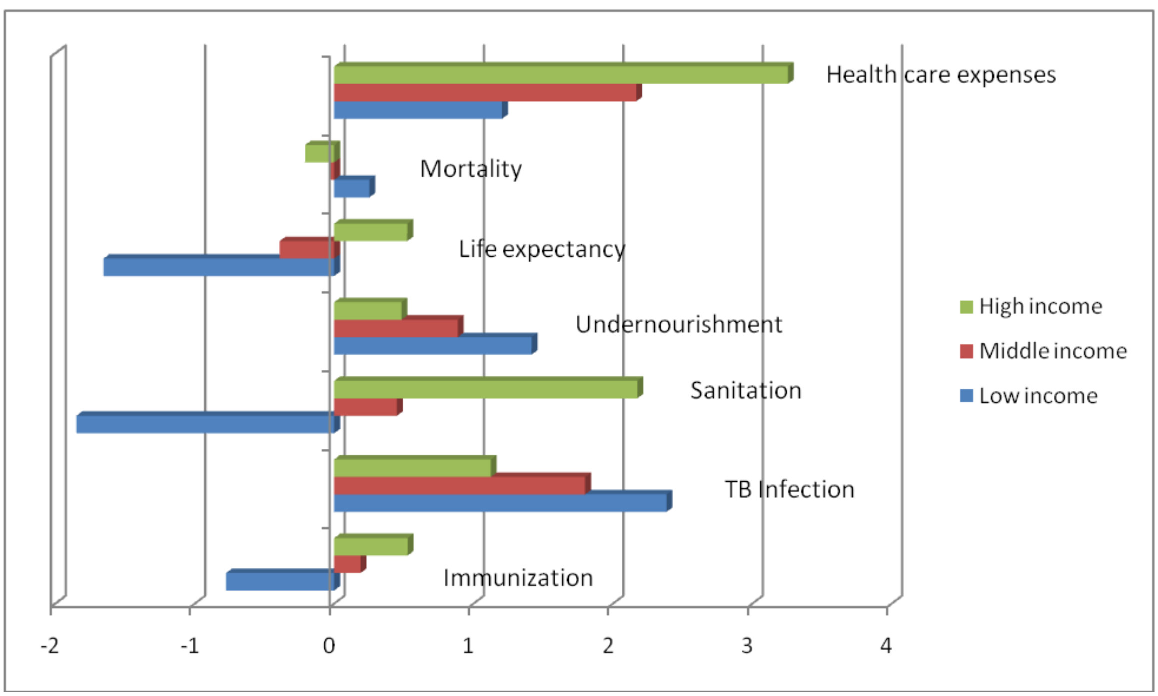

Figure 3. Public Health Indicators Mean Value Comparison Across Country Types

Table 3: Regression Results

Explanatory factors	Immunization coverage Model 1	Immunization coverage Model 2	TB infection Model 1	TB infection Model 2	Sanitation Model 1	Sanitation Model 2
Income group	0.42**	0.12	-0.77**	-0.36**	0.76**	0.47**
Access		0.41*		-0.51**		0.32*
Quality		-0.22		0.09		-0.13
Affordability		-0.10		-0.02		-0.17**
Applications		0.16		-0.04		0.21
IES		0.05		0.06		-0.07
ΔR^2	0.18	0.08	0.59	0.05	0.58	0.10
ΔF	25.10	2.20	165.58	3.36	129.20	5.80
Sig. of ΔF	<0.001	<0.05	<0.001	<0.01	<0.001	<0.001

Dependent Indicators (continued)

Explanatory factors	Undernourishment Model 1	Undernourishment Model 2	Life expectancy Model 1	Life expectancy Model 2	Mortality rate Model 1	Mortality rate Model 2	Health care expenses Model 1	Health care expenses Model 2
Income group	-0.77**	-0.40**	0.63**	0.31	-0.83**	-0.85**	0.92**	0.40**
Access		-0.36*		0.66*		-0.01		0.45**
Quality		0.03		0.03		-0.15		0.02
Affordability		0.02		-0.02		-0.01		0.12**
Applications		-0.13		-0.40*		0.22		0.12**
IES		0.03		-0.11		0.04		-0.16
ΔR^2	0.59	0.06	0.39	0.11	0.68	0.03	0.84	0.09
ΔF	155.73	3.19	30.53	1.89	67.20	0.45	593.86	26.80
Sig. of ΔF	<0.001	<0.001	<0.001	0.12	<0.001	0.79	<0.001	<0.001

Note: The table reports the standardized regression coefficients. Regression coefficients significant at p < 0.05 are marked by *, significant a p < 0.01 are marked by **. Applications—ICT applications; IES—Institutional efficiency and sustainability

results are reasonable because improving life expectancy and reducing birth mortality take much longer than, say, increasing immunization coverage. On the one hand this finding implies the persistence of the wealth effect on the delivery of public health with respect to some of the public health indicators and it may take a few generations for ICTs to have a favorable association. On the other hand, the results do indicate that ICTs have stronger influence on the delivery of near-term oriented public health indicators. Due to the limitation of the data, we cannot test this argument currently. Overall, developed countries tend to have better health conditions than developing countries, yet improvements in ICTs still contribute substantially to improve the delivery of public health. This implies ICTs can be useful leverages to vastly improve the delivery of public health, say, in a developing country.

Third, not all ICT factors are equally important in improving the delivery process. Indeed, *Accessibility* turns out to be the only ICT factor that contributes to improving the delivery for nearly all of the public health indicators. This is followed by *ICT Applications*. On the other hand *Institutional Efficiency and Sustainability* seems to have no relationship to the indicators. This phenomenon can be explained by the fact that contemporary investments in telecommunications is in mobile technologies rather than land lines. There is anecdotal evidence that in developing countries in Africa and Asia, mobile technologies have caught on, bypassing traditional telecommunications, such as land lines. This finding has a direct bearing on public health policy. As discussed previously, considering the limited resources at the disposal of countries, particularly developing countries, policy makers must choose among the different ICT factors to serve particular goals. For example, instead of implementing clinical services applications, such as a specific clinical decision support system that serves a small number of individuals, ICTs that might include health information networks and surveillance systems may be directed toward population-based health services.

Fourth, increased ICTs usage leads to increased health care expenditure. This is interesting because one would expect a decrease in expenses with the use of technology. It can be argued that when more ICTs are used (e.g., use of mobile phones to publicize vaccination schedules), the resulting health care interventions (e.g., purchase of more vaccines due to more demand) to increase immunization, reduce infection, decrease mortality and increase life expectancy, and so on, cost money and naturally will lead to an increase in overall expenditures. The plausible explanation is a “rebound effect” in additional investment due to effects of ICTs. The argument can be extended to suggest that ICTs lead to a positive increase in public health care expenditure. But over the long term, the expenditure may decrease due to preventive measures.

Our findings send out an encouraging message for countries to improve their public health delivery mechanisms. Although it is unlikely a country can change its income level in a short period, carefully chosen investments in ICTs could have a high payoff with the improvement in public health delivery. A study by WHO confirms the variations in e-health introduction vis-à-vis the income level. Countries in the high- and upper-middle income groups were more advanced in their e-health development than those in the lower-middle and low-income groups [World Health Organization, 2006]. However, by carefully choosing applications that cost less but have high payoffs, the low income countries can make effective use of ICTs. Since 2003, AED-Satellite Center for Health Information and Technology, for example, has distributed 600 PDAs to health workers in remote areas of Uganda. It has also launched a second program in Mozambique. Clinicians use the PDAs to collect public health data. They then upload that data and e-mail what they need to a caching server at a rural health facility. The server sends the data and messages over the cell network to a server in Kampala, Uganda's capital, which then routes the information to the appropriate recipients. In turn, messages, data, and other information that clinicians need are sent back. The system is believed to improve the accuracy and speed with which public health data is collected (reported in Ferraro, 2008). The article goes on to say that the information dissemination aspect of the system is being examined to support continuing medical education for clinicians who practice far away from any medical school.

In another example described by Thomas [2008], field workers in rural Southern Africa faced a problem. Sending the data they had collected about animal health to governments was slow because there was no connection to the Internet or even the national grid. According to Phil Fong, a regional data information co-coordinator for the United Nations' Food and Agriculture Program, it took about three months for information collected in the field to get to their national office. Trying to make decisions with old information was challenging and was particularly problematic when trying to spot early warning signs of an epidemic. A solution provided by Xcallibre, a subsidiary of the South African company Data World, used digital pen and paper technology from Anoto that could collect data as workers wrote it down and transmit it over the mobile network to a central server. An eighteen-month pilot, which received funding from the South African government, was run with thirty-five field workers in Namibia, Zambia, Malawi, Mozambique, and Tanzania. The swift dissemination of data has been a crucial development for countries where veterinary skills at a local level are in short supply. For example, according to Mr. Fong, Malawi had no trained veterinarians in the regions. A single trained veterinarian in the head office interprets and acts on data he receives. If action is needed, officials can send immediate instructions to field workers on mobile phones. The pilot program brought rapid benefits, according to Mr. Fong. In one case in Tanzania, an animal health technician noted signs of a disease he had observed in an animal and made a tentative, but incorrect, diagnosis. Once the vet in the national office saw the description of the symptoms, he was able to diagnose a case of Rift Valley fever (a viral disease that can be passed to humans), and take action to stop it from spreading. The African Development Bank is now funding the use of the technology in Mozambique, Malawi, Zambia, Tanzania, and Angola [Thomas, 2008]. These and other examples indicate the rapid deployment of ICTs in developing countries to promote the delivery of public health.

V. CONCLUSIONS, LIMITATIONS, AND FUTURE RESEARCH

In this study, we empirically confirm the association between ICTs and public health delivery while controlling for the wealth effect. Some of the associations are positive while others are negative. In addition, we identify the most important ICT factors that would improve public health delivery. Our results provide empirical evidence to support the anecdotal stories and other articles that examine the potential of ICTs by WHO, World Bank, and other researchers. By choosing carefully and investing in ICT initiatives, countries can improve their delivery mechanisms (e.g., communication and dissemination) for public health, that is, achieve higher immunization rates, reduce infection and malnutrition, improve sanitation, increase life expectancy and reduce mortality rates. E-health, health information networks, surveillance systems, and telemedicine are key applications that can play a critical role. The resultant good public health can, in turn, lead to greater economic growth, reduction in poverty, and improved quality of life. Challenges remain. Globalization, an era of limited resources, the need for privacy and security, lack of infrastructure and political support may hinder advances.

Scope and Limitations

Our study is not without limitations. First, we acknowledge that our study is a snapshot in time. Given the nature of cross-sectional data, our study does not indicate a direct causal relationship between ICTs and public health. Rather, we conclude that there is an association relationship between ICTs and public health delivery. As the databases are updated and complete data become available for additional years, longitudinal studies can be undertaken to further test the potential for causal relationships. In addition, our study shows ICTs have the potential to improve the delivery process, for example, via timely communication and dissemination of health information and providing the ability to reach larger segments of the population (e.g., telemedicine). Yet, the current dataset does not allow us to further explore how ICTs may improve public health delivery. But it is definitely a crucial question to study the mechanism of realizing the positive effects of ICTs investment.

Second, other intervening variables such as country characteristics may change the long view. Also, our data acquired from the World Bank data set is secondary in nature. The explanatory ICT factors and the health indicators are aggregated from multiple models and sources. Moreover, because many of the country characteristics are interrelated (as also in ICT and public health delivery) our regression results are likely to be affected by (omitted) correlated variables.

Finally, additional studies may be conducted to address the nonlinear effects of ICTs on public health delivery (e.g., a curve-linear relationship in the event ICTs are overused). We expect that future research into the effects of ICTs (and technology in general) on public health delivery will be enhanced by more complete theories and databases. Ultimately, effective public health programs supported by ICTs are the key to good health.

Contributions

While limitations are recognized, this study is extensive enough to make important contributions to the ICT and public health delivery literature and policy making process at a country level. First, most studies on the effects of ICTs are limited to organizational or individual patient level analysis. There is a need for understanding the impact of ICTs at the national as well as global level [Melville et al., 2004]. By studying the relationship of ICT factors with country-level public health indicators, our study contributes to the sparse literature on the association between ICTs and public health delivery at the country-level. The findings can help global policy makers strategize on health resource allocation and invest to maximize the population health benefits.

Second, we show that ICTs are not the only instruments benefiting public health delivery. A country's income level, to a large extent, explains the level of public health. It seemed obvious that poor countries had greater health problems. Indeed, poor health has particularly negative effects on economic development in Sub-Saharan Africa, South Asia, and areas of high disease and intense poverty elsewhere [World Bank, 1993]. The high burden of disease and its effects on productivity, demography, and education have certainly played a role in Africa's poverty. High prevalence of diseases such as malaria and HIV/AIDS are also associated with persistent and large reductions of economic growth rates [World Bank, 1993; World Health Organization, 2001]. Donor countries, global institutions and nonprofit agencies and foundations can make better choices in terms of investments. In addition, while ICTs may make substantive contributions to the delivery of public health beyond the wealth effect, some of the effects may take longer to be observed (e.g., increase in life expectancy, decrease in birth mortality). Some of the insignificant results should not be viewed disappointingly. These results could indicate that poor countries need continued investments over time to realize greater benefits.

Third, most studies in this area have been surveys or case studies. This study is an incremental step in the direction of more robust quantitative studies. Moreover, we make novel use of publicly available fee-based databases to enhance our understanding about the relationship between ICTs and the public health indicators. This can be viewed as a contribution from a methodology perspective. Finally, we can talk about the contribution to policy making, especially in developing countries. This point is very important since that is the key practical implication from this study.

To summarize, our study contributes to the literature in several ways. One, this is most likely the first interdisciplinary study integrating information technology with public health. Second, we derive empirical findings as opposed to the largely anecdotal and case studies that are prevalent in ICTs and public health publications. Third, our article provides the most comprehensive literature review. Fourth, we contribute to incremental theory building by presenting an original framework to describe the relationship between ICTs and public health. Fifth, we present a macro perspective which is essential to the understanding of public health delivery at the macro, population level. Specifically, our findings confirm what is indicated in the literature in ad hoc fashion in cases and anecdotes, that is, a relationship exists between key ICT factors and improved public health. Additionally, our study provides generalizability, therefore, the findings can be applied at country level wherein large scale investments are made to deal with public health issues.

Future research may focus on cross-country and regional as well as longitudinal studies. Other variables relating to education and environment may reveal additional correlations and effects. Others may research the diffusion of ICTs for effective public health delivery in developing countries and the development of global strategic models of ICT integration and use. While empirical work in ICTs and how they may improve the delivery of public health is at a nascent stage, these types of studies can accelerate its maturing process.

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