HOW INFORMATION TECHNOLOGY IMPACTS ECONOMIC GROWTH AND HUMAN DEVELOPMENT AT THE COUNTRY-LEVEL

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Abstract: The goal of this document is to understand the differences between two predominately used country-level measures of development, economic growth and human development, and how information and communication technology impacts each. Three studies are employed to gain further understanding of the characteristics of each development measure. The ICT themes of these studies are focused on individual's *freedoms* to have and choose their desired states of well-being, vertical *specialization* within global supply chains, and the *diffusion* of technology across country borders. Within our first ICT theme, *freedoms*, four contextual conversion factors have been found to significantly impact human development: ICT cost, ICT infrastructure, and the interaction effect between e-participation and freedom of expression on the net. Our second theme, *specialization*, we find a partial moderation for the measure of a country's ability to vertically specialize with the direct effects of a country's level of ICT and economic growth. The direct effect weakens and the moderation effect gets stronger after the year 2004. In our last theme, *diffusion*, we investigate the three different channels that technology diffuses across nations: direct trade, foreign direct investment, and R&D spillovers. We find that direct trade has a significantly positive impact on economic growth, whereas foreign direct investment and R&D spillovers have a significantly positive impact on human development, but only with a 1-year and 5-year lag. In summary, economic growth is highly affected by international trade of technological goods and with the aid of ICTs. Human development is more built around social structures and is impacted with social connections and freedoms to have and choose one's own well-being.

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CHAPTER I

INTRODUCTION

ORGANIZATION

Historically, information and communication technology for development (ICT4D) research has utilized development measures without necessarily explaining why they selected their measure or how their measure differs from other development measures. This document is here to explain the differences between two predominantly used measures of development, economic growth and human development, and how they are affected by information and communication technologies. The document is organized in a three-essay format that focus on how ICTs affect each development measure individually and then together within the third essay. Each essay is pulled from separate manuscripts that are currently under review or will soon to be under review for journal submission. This document begins with a brief introduction and literature review over the topics of each essay. The document will end with concluding remarks. References for the introduction are given at the end of this document.

The first essay brings to light the idea of individual freedoms of users. This study used the capability approach to look at opportunity and process freedoms of individuals who must choose to utilize or not utilize a new technology (Sen 1979). Human development was properly chosen as the dependent variable for this study because it is a people-centered focused measure. Conversion factors, moderating variables that impact how technology interacts with development, were identified through Hamel (2010)'s Information and Communication Technology for Development (ICT4D) policy recommendations, and were then tested for their impact on human development. A PLS models with a Gaussian Copula approach was used to test for endogeneity (Hult et al. 2018). A 2SLS model, using instrumental variables, was then utilized to control for endogeneity.

The second essay investigates the unique role of technological progress through global supply chains and on economic growth. This research builds upon the elementary theory of global supply chains to determine how specialized a country is within global supply chain production in relation to their position in the global market over time (Costinot et al. 2013). The Preacher and Hayes method for moderated mediation is used to analyze the direct path of technological progress on economic growth, the indirect path through vertical specialization, and the moderation effect of 20 years of data. All data is gathered through the World Bank databank (WB 2021b).

Finally, the third essay combines ICT-growth and trade-growth research to understand the unique impacts of technological trade on both economic growth and human development. This research pulls from international technological diffusion theory to understand how technological trade diffuses between countries and eventually impacting both economic growth and human development. Data for technological trade was gathered from the United Nation's Commodity Trade statistics databased called World Integrated Trade Solution (WITS 2021). Additionally, R&D spillover effects were significantly associated with human development through trading partners with a one-year and five-year lags, but no significant spillover effects were found within the economic growth model.

LITERATURE REVIEW

A brief literature review is included for each topic. These literature reviews are not all inclusive, but rather an overview what each essay will cover in their subsequent chapters. A more in-depth literature review will be covered within the essays pertaining to their topics.

FREEDOMS

Freedoms in relation to development are focused on opportunities and processes (Sen 1979). The opportunity to choose what people value among alternative capabilities is what Sen refers to as opportunity freedom. The larger the capability set that is present to an individual, the more likely that an optimal choice is available for that individual to obtain a higher well-being. However, opportunity freedom only gives potential to have well-being, not the actual choice (Nyemba-Mudenda and Chigona 2018). This leads to the second freedom, process freedom. Process freedoms gives the individual agency or choice of whether you utilize a capability option or not, even if the option is guaranteed to enhance one's well-being in a particular dimension (e.g., health, education, security, wealth). Both of these freedoms along with the resources that enable capability sets are all affected by the context of the society and environment. These context related factors are called conversion factors and may enable or restrict opportunity and process freedoms (Robeyns 2005). This essay focuses on ICT-specific conversion factors at the country-level that enable or restrict opportunity and process freedoms. The four conversion factors studied are presented from prior policy recommendations (Hamel 2010) which include ICT cost, ICT infrastructure, e-participation, and freedom of expression on the net.

SPECIALIZATION

Global supply chains are becoming increasingly popular. A single product can be partially produced in stages through multiple factories among multiple countries. A unique phenomenon occurs where initial stages of intermediate products are produced in countries with higher probabilities of making mistakes, whereas final products are produced in nations with lower probabilities of making mistakes (Costinot et al. 2013). This phenomenon shapes a vertical specialization that is dependent on a nation's technological progress. Utilizing this elementary theory of global supply chains, this paper seeks to understand how technological progress impacts economic growth when partially mediated by vertical specialization over time. Vertical specialization is measured through the aggregated measure of domestic value added over gross output (Johnson and Noguera 2012). A country that adds more domestic value added in their exports is seen to have a higher specialization than countries with less domestic value added. However, the benefits from technological progress may have diminishing returns over time, according to Nicholas G. Carr (2003). Firms from all over the world have been increasingly spending more on IT over the years, but competitive advantage is lost when all firms are doing the same thing. We investigate the effects of technological progress directly on economic growth and indirectly through vertical specialization with a sample of 62 countries over the years 1995-2014 to better understand how these relations are impacted over time.

DIFFUSION

International technology diffusion is the process in which technology disseminates across countries through trade (Keller 2004). The diffusion channels for international technology are direct trade, foreign direct investments, and knowledge spillovers. Trade has been studied to be a strong driver for export-led economic growth (Singh 2010). Similarly, importing technological goods is seen as improving firm efficiencies, leading to economic growth (Coe and Helpman 1995). Little is known about the effects of international technology diffusion through trade and human development. This essay investigates R&D spillover effects from trading partners as a channel for human development. The present study analyzes all three channels of diffusion with trade of technological goods, foreign direct investments, and R&D spillover effects from trading partners on both our dependent variables, economic growth and human development.

PLAN OF PRESENTATION

The subsequent chapters are copies of research papers that pertain to the topics in the plan above. Chapter 2 identifies four country-level conversion factors and uses the lens of the capability approach to investigate the implications on human development. Chapter 3 uses the elementary theory of global supply chains to investigate how IT impacts economic growth when mediated by vertical specialization. Chapter 4 reviews the implications of international technology diffusion through trade on both economic growth and human development. Chapter 5 will end with closing remarks in regards to how IT impacts economic growth and human development through different channels and in different ways.

CHAPTER II

ICT4D AND THE CAPABILITY APPROACH: UNDERSTANDING HOW CONVERSION FACTORS AFFECT OPPORTUNITY AND PROCESS FREEDOMS AT THE COUNTRY-LEVEL

ABSTRACT

The purpose of this paper is to examine contextual conversion factors that impact the success of information and communication technology for development (ICT4D). Prior macro-level econometric research on ICT4Ds has measured country-level development using resource-based or utilitarian-based approaches. We argue for a people-centered lens by using the capability approach, which reflects the *opportunity* and *process* freedoms from which people must choose. Using the capability approach framework, four key conversion factors of ICTs are identified as enablers/restrictors of either opportunity or process freedoms, and then are hypothesized with relation to human development. Using publicly available archival data and a 2SLS model with instrumental variables, we test ICT cost, ICT infrastructure, and the interaction effect between e-participation and freedom of expression on ICTs to predict a country's human development. Results suggest that both ICT cost and infrastructure significantly affect human development and that e-participation interacts with freedom of expression on ICTs in a way that freedom of expression is only effective when accompanied by high levels of e-participation within a country.

INTRODUCTION

Previous literature has explored the impact of various components of Information and Communication Technologies (ICTs) on development. Recent research suggests that increased investments in information and communication technology infrastructure will increase the well-being of the citizens in a nation through increased social capital, improved crime reporting, transfer of health information, access to educational materials, efficiency in supply chains, and rates for farmer's produce among nations (Ganju et al. 2016). Another macro-level research study has found a significant influence of national information infrastructure on the socio-economic development of nations (Meso et al. 2009). Social networks within a rural village in India were found to have a significant impact on the likelihood of technology use and subsequently increasing income (Venkatesh and Sykes 2013). IT capital and non-IT capital investments to GDP were analyzed between developed and developing countries with the former seeing positive results from IT investments but non-significant results for the latter (Dewan and Kraemer 2000).

The above examples clearly illustrate that previous research has investigated ICTs as instigators of change for human development. However, what is not clearly understood is how people, acting as agents of change with the freedom to choose, utilize those ICTs and subsequently influence human development. If the purpose of ICT4D research is to better understand how lives are changed by ICTs, then research should focus on how people themselves enable change through ICTs. Individuals have the freedom to utilize ICTs; yet, the mere presence of an ICT within a country does not necessarily lead to quality-of-life improvements for citizens. In addition, contextual factors within a country may influence how people interact with ICTs.

In this paper, we apply the Capability Approach (CA) as a human-centric lens to study how the freedom of choice to use ICTs impacts human development. This contrasts with previous literature which uses either a resource-centric or a utility-centric lens. The CA suggests the freedom of individuals to choose what is best for themselves (i.e., acting as agents) is integral to positive outcomes. CA is a theory wherein resources (i.e., ICTs in this research) are a means to an end, rather than an end in themselves (Zheng and Walsham 2008). In other words, resources expand the potential options from which we can choose to meet our goals. The CA argues that development 'is expanding the real freedoms that people enjoy' and 'the removal of major sources of unfreedom' (Sen 1999). In essence, Sen describes development in terms of freedoms for individuals, thereby refocusing the discussion away from national economic measures and toward individual, human-centric measures.

The CA discusses two types of freedoms: opportunity freedoms and process freedoms. Opportunity freedoms look at how many opportunities or capabilities are available. In development, the goal is to address people's practical needs by expanding the opportunities available. Process freedoms are the ability to act in pursuance of the individual's goals. In the CA, resources may enhance one dimension of well-being (e.g., health, education, security, standard of living, etc.) but may also go against what one values. Therefore, process freedom is the choice to either use the resource for one's well-being or act as an agent for oneself and not use the resource out of principle. In the case of development, ICTs act as a resource that can be utilized for information gathering.

However, if the ICT tool is seen to not align with their goals, the individual may act as an agent for themselves and choose not to use it. These freedoms of opportunity expansion and process enactment are then further affected by the context in which the ICT is embedded (Sen 1992). Examples of context-related factors include age, gender, cultural traditions, regulations, infrastructure, etc. In the CA, contextual elements are referred to as conversion factors and include the three categories of individual, social, and environmental.

This paper makes a novel contribution by investigating the impacts of conversion factors of ICT4D on human-centered development as compared to previous research that studied only the impact of ICTs on economic growth or well-being (Chatterjee 2020; Dewan and Kraemer 2000; Ganju et al. 2016; Mayer et al. 2020; Sağlam 2018; Venkatesh and Sykes 2013). Chatterjee (2020 reported the effects of ICT development, mediated by financial inclusion to predict economic growth in 41 countries. Dewan and Kraemer (2000 studied IT and non-IT investments with GDP in 36 countries. Ganju et al. (2016 measured the impacts of ICTs (such as the number of telephone lines, Internet users, and mobile phones) on subjective well-being in 100 countries. Mayer et al. (2020 investigated the effects of broadband infrastructure (fixed broadband penetration, broadband download speed, and years since broadband was introduced) on economic growth in 29 OECD countries. Sağlam (2018 purported the link between ICT diffusion (Internet users per 100 and cellular subscriptions per 100) and R&D investments on economic growth in 34 OECD countries. Venkatesh and Sykes (2013 contributed to family-level generalization by reporting the effects of social networks, mediated by technology use, on economic outcomes for 231 families in India. Using Hamel (2010)'s country-level ICT4D policy recommendations, we have identified two social conversion factors that enable or restrict process freedoms and two environmental conversion factors that enable or restrict opportunity freedoms. Our model includes the interaction effect between e-participation and freedom of expression on ICTs as social factors, as well as ICT cost and ICT infrastructure as environmental factors. Our dependent variable, in accordance with the CA, will use human development as measured through the human development index. Using archival data, the current study seeks to understand how each of these four conversion factors (ICT cost, ICT infrastructure, e-participation, freedom of expression on ICTs) plays a role in a country's human development. The results of this study can help support stakeholders' claims towards ICT4D initiatives. The rest of this paper is organized as follows. The second section of the paper discusses the theoretical framework which includes the capability approach as a basis for our theoretical model and hypotheses. The third section introduces the data collection. The fourth section presents the analysis and results. Finally, the last section summarizes with discussion, limitations, and concluding remarks.

BACKGROUND

HISTORY OF WORLD DEVELOPMENT

Country-level development has a long history and has been studied and measured by the World Bank since the end of WWII in 1946. Loans were initially granted by the World Bank for requests that aided post-war reconstruction in infrastructure (e.g., transport, power, and communications), and education, health, and agricultural loans were continuously granted thereafter. The Bank's focus centered on economic growth (measured through GDP) and later poverty alleviation. By the 1970s, the World Bank realized that a resource-centric approach, as measured through GDP, was an unsatisfactory measure of development as it did not lead to a decrease in poverty. A resource-centric approach focused on what the country, governments included, could achieve and not the citizens. Promoting development by reducing global poverty became the primary concern, and a multidisciplinary focus became necessary, as evident by the first two World Development Reports on Poverty in 1978-79 (IBRD 1978; Mundial 1979).

Another approach that was beginning to appear was the subjective well-being or utility-centric approach for measuring country-level development by accounting for *individuals* within the country. An example of this approach is the Happiness Index. King Jigme Singye Wangchuk first introduced the Happiness Index in 1972 while studying the level of well-being of his people across Bhutan (UN 2012). Other examples of utility-based measures include satisfaction or enjoyment measured through surveys. This approach improves on previous measures by setting the individual as the focal point for measures as opposed to the government. However, some experts argue that utilitarian views of well-being can be swayed through mental conditioning, even during oppressive circumstances. Eventually, people come to terms with deprivation and survival becomes paramount. They also argue that utility contribution is independent of individuals' freedoms to choose what is best for themselves. Examples of this could be parents' families who are living in oppressive circumstances but wish to express happiness to their children or citizens who have little hope in being understood but are being observed by governments to make sure they do not 'step out of line', thus leaving them to live pretend lives. Additionally, utility-based measures can be costly and prohibitive to keep up to date.

There is a belief among scholars that if development is to take place, factors beyond economic growth and subjective well-being should be considered. Factors that promote people's choices (Peet and Hartwick 1999) and account for various dimensions of wellbeing. In 1990, the United Nation's Development Program began publishing its first Human Development Report, which included the annual Human Development Index (Bordé et al. 2009), providing measures for each country and other related topics on Human Development (UNDP 1990). Human development is described as 'building human capabilities—the range of worthwhile things that people can do, and what they can be – and enabling people to shape their own lives' (Alkire 2010). Amartya Sen's conceptualization of development is surrounded by the concept 'freedom of choice'. Sahay et al. (2017) eloquently state:

> Development should enlarge people's choices and remove the power of oppressors. ICT's role is to enhance this freedom by building the capabilities of individuals and the society in which they live. The paradigm is that of human development and the most commonly used theory for human development is the Capability Approach (Sen 1999).

Human development is part of Sen's development paradigm that results from building up capability sets and enabling people to shape their own lives. Human development is thusly the resulting measure from the process of expanding human freedoms.

Mahbub ul Haq, an economist from Pakistan, utilized the capability approach framework and developed the first variation of the HDI used from 1990 to 2009. This variation of the HDI was calculated by averaging three indices of human development: Life Expectancy Index (Savalei and Bentler), Education Index (EI), and Income Index (Kiiski and Pohjola 2002). The three indices were given equal weights in the global calculation of the HDI, showing that each dimension is equally important. In this way, development is measured by increasing three globally agreed-upon human-centered capability dimensions. Several research papers have utilized some form of the human development index as their measure of development (Andoh-Baidoo et al. 2014; Jiménez and Zheng 2018; Meso et al. 2009; Ngwenyama et al. 2006; Nyemba-Mudenda and Chigona 2018). Each of the indices utilizes data from the World Bank to set a maximum and minimum value (goalposts), which are then used to standardize the values. Next, the actual values for the countries are plugged into these indices' formulas, which helps explain where they stand concerning these values, as can be seen below:

$$Dimension\ Index = \frac{\text{Actual Value} - \text{Min}}{Max - Min} \tag{1}$$

By 2010, the UNDP implemented a new approach to calculate the HDI, using a geometric mean of the three indices, HDI = (LEI x EI x II) $^{1/3}$. Also, the Education Index formula, Income Index formula, and all three indices' goalposts were changed to better reflect the indices parameters.

More recently, policy-makers and the World Bank have come to realize the importance of ICTs on human development and development in general (Deloitte 2014; UN-Millennium-Project 2005; UNDP 2012). ICT initiatives have been implemented over the past couple of decades with varying levels of success (Ahmed 2007; Heeks 2002; Keniston 2002; Keniston and Kumar 2004; Lin et al. 2015). Theories of Modernization are overly used to explain economic development within the global South (Qureshi 2015; Zheng 2009). In these predominantly Western-based theories, technologically advanced and developed countries aid lesser developed countries, in hopes that economic development and technological progress will ensue (Escobar 2011; Irwin 1975; Willis 2011).

Additionally, researchers are beginning to study the effects of an individual's personal, social, and environmental conversion factors on their well-being (Frahsa et al. 2021; Hatakka et al. 2020; Nambiar 2013; Nyemba-Mudenda and Chigona 2018). In the conceptualization of the CA, conversion factors enable or restrict a person's ability to convert resources/commodities into an achieved state of well-being (Sen 1999). Three conversion factors exist that enable or restrict a person's desired state of well-being: (a) personal; (b) social; and (c) environmental (Robeyns 2005). Personal factors include characteristics that an individual is endowed with, such as bodily operations (e.g., gender, age, and mobility) and psychological traits (e.g., education and mental well-being). Social factors include social norms, social hierarchies, cultural traditions, and institutional policies. Environmental factors include the physical or built environment (e.g., geography, climate, and infrastructure). Frahsa et al. (2021 utilize conversion factors from the CA to understand the challenges associated with building a framework for transdisciplinary health promotion. Hatakka et al. (2020 showed how the outcomes of study circles using ICTs are dependent upon various conversion factors. Nambiar (2013 focused on conversion factors in a case of a credit cooperative in Malaysia. Nyemba-Mudenda and Chigona (2018 find mediating effects from conversion factors on the use of mobile phones to access health information for women's maternal health in Malawi.

Hamel's (2010) UNDP report on the potentials of ICTs for development points toward four key conversion factors that can enable or restrict a country's human development. The conversion factors include ICT usage cost for individuals, ICT infrastructure to support implemented initiatives, government and citizens' e-participation, and freedom of expression on ICTs in a country. This current study has decided to empirically test these four conversion factors posited by Hamel to understand their relationship on human development. Figure 1 displays the research model and hypotheses.

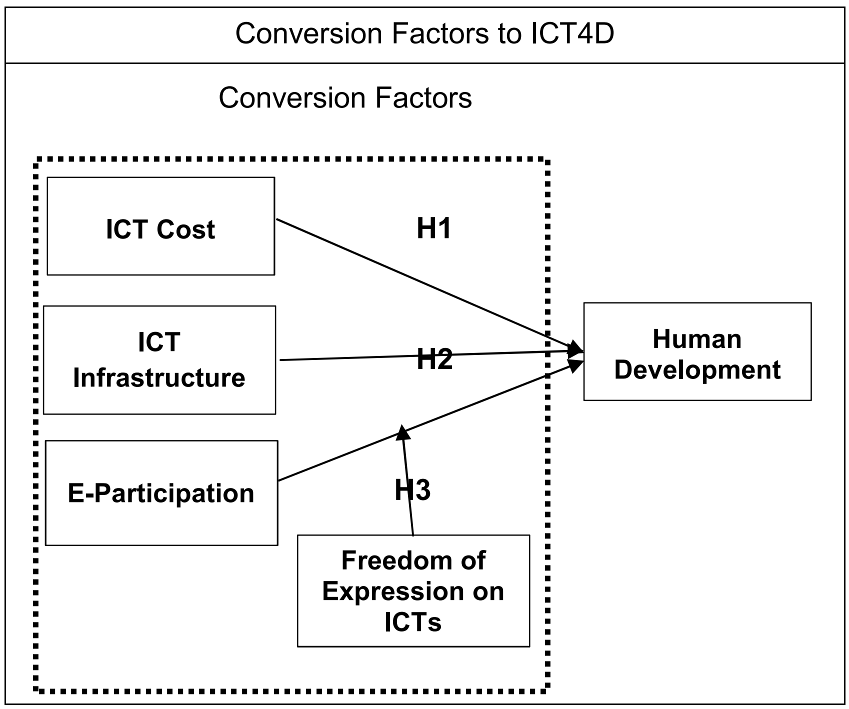

Figure 1. Research Model and Hypotheses

Past country-level panel research has suffered from the lack of theoretical frameworks to help explain why the studied indicators are associated with development. The ICT4D research community often asks *how* and *why* ICTs should be used for development (Andersson et al. 2012), and are often looking for theories to explain such. When discussing ICT4D theory development, Andoh-Baidoo (2017 argues that context is key within the positivist research paradigm. For example, he includes culture, socio-political, and geo-political space to the already established technology, usage, and users contexts from the mainstream IS field (Hong et al. 2014). In Hong et al.'s framework for theory contextualization, two major classes arise. The first is single-context contextualization and the second is cross-context theory replication. Country-level panel research falls within the second classification, cross-context theory replication, where an established theoretical model is replicated in different contexts. As noted before, theoretical frameworks are lacking to explain the *how* and *why* ICTs should be used for development in country-level panel research. We believe that cross-context theory contextualization can address this gap.

Another approach to theory building is using a holistic understanding through utilizing theories to explain each component within ICT4D (Sein et al. 2019). The components are (1) theories to explain the ICT artifact, (2) theories to explain development, and (3) theories to explain the transformative process linking ICT with development. Once again, we find a lack of theoretical frameworks within county-level panel research to adequately explain the third component, transformative processes, linking the ICT artifact with development. This lack of theory presents a gap that deserves attention.

We believe that the CA, although a development theory (the second component), can help explain the *how* and *why* ICTs should be used as a transformative process (the third component) for development in cross country-level panel research. Thus, we want to achieve a holistic understanding by utilizing the CA. We also believe that the CA provides theory contextualization in cross country-level panel research. Transformative processes and theoretical contextualization can be identified through the CA's conversion factors. In particular, social and environmental conversion factors within the CA are inherent contextual factors of a country, and have the potential to enable or restrict the capability and agency of *every individual* within. If we set freedoms as the goal of development, then these conversion factors can be viewed as the enablers that promote or restrictors that inhibit the freedoms of *everyone*. Even if a resource were introduced, conversion factors would help explain how and *why* the presence of a new resource, such as ICTs, can in fact be a source of unfreedom (i.e., when not everyone has access to a resource, or when they do not reflect the lives that people value) (Kleine et al. 2012). In their action research on fair trade value chains, Kleine et al. (2012 stress the importance of participatory practices between ICT4D designers and users. In the same way, the study of social and environmental conversion factors may help us understand how sources of freedoms, or unfreedoms, are present at the country-level.

The CA creates an appropriate framework for this study because it complements human development by guiding public policy to focus on expanding the freedoms in people's lives (Alkire 2010). It can be classified as human-centric (people are the agents of change) as opposed to resource-centric (ICTs are the agents of change). The CA incorporates freedoms of process and opportunity which are independent from a utility-centric approach. While ICTs are important enablers of human development, we argue it is the capacity and agency to use the ICTs by people that leads to human development. It is said that although people's well-being may vary considerably, when we frame development as the enhancement of capabilities and freedoms, we then begin to see that human development and the subsequent human development index are suitable and tangible measures for development (Qureshi 2015; Sein et al. 2019), and we can then assess the ability of a country to adequately provide people with basic 'freedom' (Sen 2001).

CAPABILITY APPROACH

Amartya Sen, an economist working for the World Bank in 1979, developed the capability approach (CA) to allow a multidisciplinary method of defining development (Sen 1979). He argues that development should not only include income but other important aspects of well-being and agency that a person has reason to value. The CA was designed to measure development at the individual's capability level, placing human freedoms in the front and center of analysis instead of ICTs. ICTs are then seen as a means to an end, rather than an end in itself (Zheng and Walsham 2008).

As argued previously, the CA is a human-centric view of development. People are agents who actively use their capabilities to achieve goals. Sen defined human development as follows:

> To expand people's freedoms – the worthwhile capabilities people value – and to empower people to engage actively in development processes... People are both the beneficiaries and the agents of long term, equitable human development, both as individuals and as groups (Alkire 2010).

This core definition is what drives the CA, a normative framework for evaluation and assessment of well-being and social arrangements, as well as policy design in societies (Robeyns 2005). It also incorporates the concept of freedom as the mechanism for development. The capability approach is made up of five core elements: (1) *resources*, (2) *opportunity freedom*, (3) *process freedom*, (4) *functionings*, and (5) *conversion factors* as summarized from the large volume of Sen's work (Nyemba-Mudenda and Chigona 2018; Robeyns 2005; Zheng 2009).

The *resources*, also sometimes called commodities, refer to the goods and services that individuals can turn into real opportunities for a desired well-being. These resources are the means to achieve for an individual. An example of this is a car as a means for mobility. In ICT4D research, the resources are ICTs that possess the characteristic of information. Information derived through ICTs can affect the decision-making process for all dimensions of well-being, making ICTs a strong influencer of human-centric development.

Just the mere presence of a resource does not bring about freedoms or well-being. The CA points to what individuals potentially can achieve. In Sen's definition of development, 'the worthwhile capabilities people value', he refers to *opportunity freedom*. He believed that development took place by expanding people's choices (i.e., capability sets) to obtain their ideal lives. Opportunities are added when resources, such as goods and services, become present. Resources then can expand one's capability set. A capability set refers to all available choices an individual may choose from to increase their well-being. Importantly, this represents that opportunity freedom gives the potential to have well-being, not the actual choice (Nyemba-Mudenda and Chigona 2018).

The third core element is *process freedom*, which 'empower[s] people to engage actively in development processes.' Process freedoms empower people to act as agents on behalf of what matters to them. This means that people can partake in political processes, whether that be through democracy in government, protesting on the streets for something they believe in, or voicing their opinion in a room with alternative viewpoints.

An active agent believes their choices matter for their well-being, as opposed to a passive agent who may be viewed as a beneficiary of a larger organization (e.g., markets or governments). Both active and passive agents derive well-being from their capability sets within opportunity freedoms (Nyemba-Mudenda and Chigona 2018). For process freedoms, well-being is derived from the active selection of capabilities aligned with individual values (Nyemba-Mudenda and Chigona 2018). Thus, passive and active agents derive well-being from opportunity freedoms while active agents may derive well-being from process freedoms.

An example of this would be having two people with nearly identical capability sets. One may choose to live in government-provided housing as a means of safety, while the other chooses to live on the streets for fear of constantly being monitored by their government. This second individual became an active agent for themselves and chose to forgo the safety benefits of government housing in return for what they believe is privacy. Process freedom is then a decision for individuals to either choose opportunities that would maximize their well-being or act as agents for what they believe matters.

After a resource has expanded a person's capability set, that person can then choose to accept or reject the new opportunity to function as their means to well-being. If a capability option is chosen as their means to well-being, we then refer to this as their achieved *functioning*. Examples of functionings include having a good job, being nourished, being safe, expressing oneself, being literate, and being part of a community. For each listed functioning, there is a chosen opportunity derived from a resource to go along with it.

To reiterate, resources are the means to achieve a dimension of well-being, opportunity freedom is the freedom that expands people's capability set, derived through resources. Process freedom empowers individuals by either choosing to accept the capability option that could lead to a desired well-being (i.e. functioning) or choosing to act as an agent for what they believe matters and not choose the capability option, thereby going back and choosing an alternative opportunity option from the capability set. The achieved functioning is then the intended, and sometimes unintended, outcome that is derived from the resource. As such, increasing opportunity and process freedoms becomes the key to development instead of the functionings themselves.

The CA is then affected by the context that individuals are in. Because no country is the same, resources that are implemented in one country will be affected differently through its opportunity and process freedoms than in another country. Resources, such as ICTs, are studied in different contexts to see relations between new capability options introduced and the people's preferred functionings. The CA conceptualizes context as *conversion factors*. Three kinds of conversion factors can enable or restrict an individual's opportunity and process freedoms: personal characteristics which refer to physical condition, biological health, and psychological well-being (e.g., age, gender, metabolism, literacy, religion); social arrangements which refer to social norms, social hierarchies, cultural traditions, and institutional policies (e.g., rules & regulations, gender roles, power relations); and environmental dynamics which refer to physical and organizational environments (e.g., climate, geography, infrastructure) of a country (Robeyns 2005).

Developing capabilities from resources such as goods and services requires conversion factors to be met, otherwise the resource is restricted by the contextual factor. For example, if a person has a physical disability such as a paraplegic man or woman, then a traditional car may not expand the opportunities for that person within their capability set. If a country has laws that restrict certain genders from driving, then a car may not expand one's opportunities. If a country has no road infrastructure, then a car may be restricted in its mobility. Likewise, conversion factors also enable or restrict an individual's choices in process freedoms. For example, some resources, such as the government housing example used earlier in this paper, may increase one dimension of well-being (security) but diminish another dimension of well-being (privacy) due to personal, social, or environmental contextual factors. The government housing could be located at the bottom of a hill, or have thin walls, or require routine check-ups among many other factors. This may lead to a decision to reject the resource based on one's well-being preferences.

In some cases, the conversion factor may be financial-based or require an economic engine to run. Other times, it may require institutional settings and political arrangements to set boundaries. Sometimes the conversion factors are social or cultural practices, social structures, and norms. Individuals' chosen functionings greatly depend on the context, and the context is influenced by these conversion factors. Previous ICT4D research has focused primarily on environmental conversion factors, such as ICT cost and infrastructure, or individual factors, such as age, income, gender, and IT literacy, but little has focused on social factors.[1] Additionally, conversion factors should be analyzed with respect to enabling or restricting opportunity and process freedoms.

The CA operates in the space of resources, opportunity freedoms, process freedoms, functionings, and conversion factors (Robeyns 2005). Resources are introduced, which could be a service or a good, into an environment. These resources add to an individual's capability set, expanding the possible opportunities one has to choose from (opportunity freedom). The individual then decides if the introduced resource is a worthy choice for promoting their well-being or if the individual's morals and/or prior commitments supersede the benefits of the resource (process freedom). If the latter decision is made, then the individual can act as an agent for themselves and choose not to use the resource, thereby restricting the capability option. The chosen opportunity from the capability set is the functioning achieved. Sometimes an achieved functioning can result in both intended and unintended outcomes (Sen 1999). An example of this would be social media addiction as a result of acquiring a mobile phone for the functional benefit of information gathering or mobile banking. Finally, conversion factors enable or

[1] One contribution of this research is applying the Capability Approach to country-level data. While the Capability Approach also includes individual factors (in addition to the social and environmental factors), including these individual factors in the same model would be problematic. Specifically, the Atomistic Fallacy states that one error of aggregation is the error in 'shift of meaning' whereby researchers aggregate individual-level data to 'create' higher-level variables. This, in addition to the Ecological Fallacy, can introduce bias into the analysis whereby country-level decisions are made based on aggregated individual-level data that may not be indicative of the overall country (Tom et al. 1999).

restrict an individual's opportunity and process freedoms by imposing boundary conditions on both resources and the process freedom's choice enactment (see Figure 2).

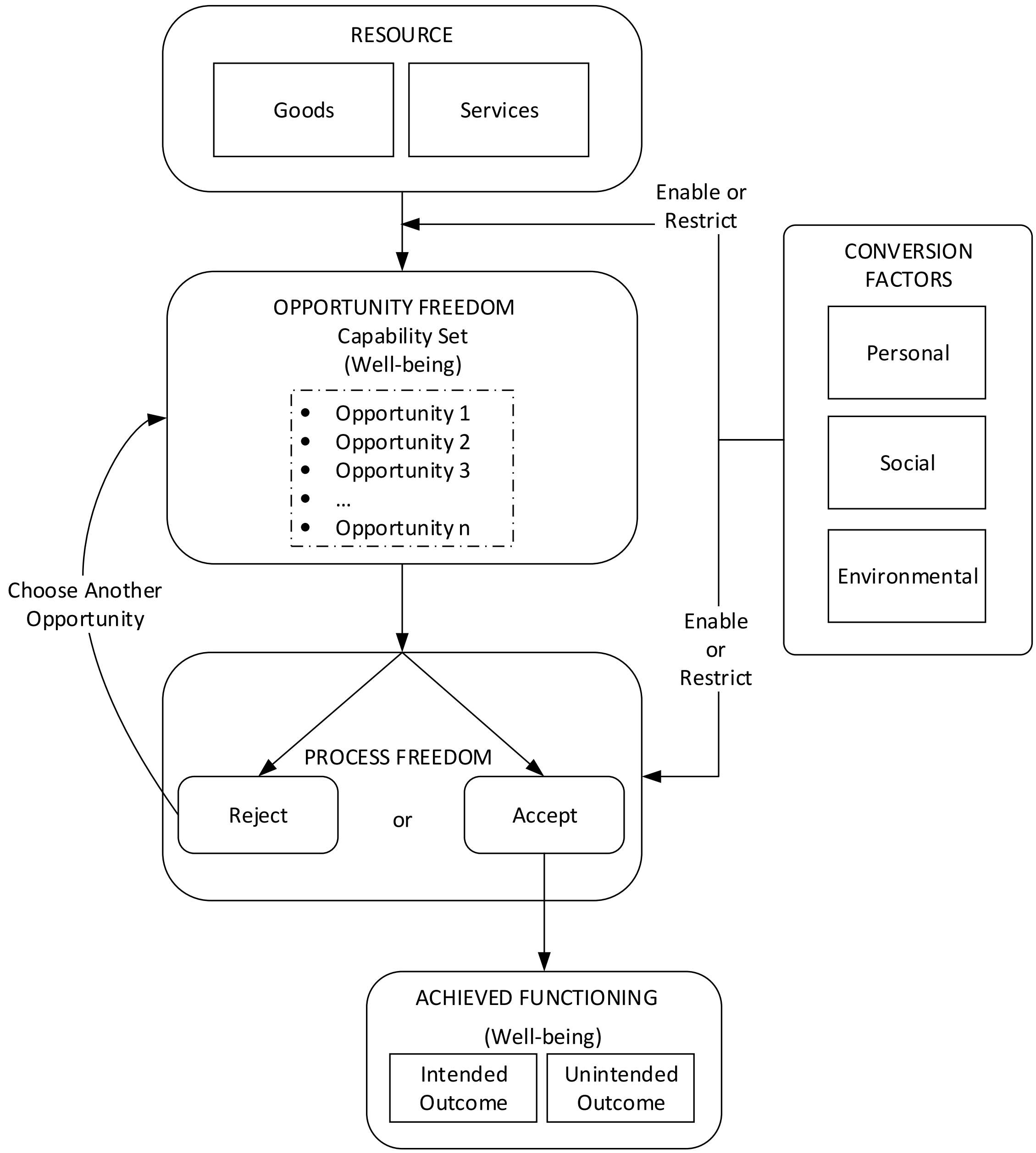

Figure 2. Sen's Capability Approach Framework, adapted from Nyemba-Mudenda and Chigona (2018)

The CA has been utilized increasingly in the ICT4D literature over the past decade as it has gained popularity (Grunfeld et al. 2011; Hatakka et al. 2014; Hatakka and Lagsten 2012; Jiménez and Zheng 2018; Loh and Chib 2019; Nyemba-Mudenda and

Chigona 2018; Rampersad and Troshani 2020). The CA framework is limited in that it cannot explain well-being, inequality, or poverty by itself, but can be used as a tool to conceptualize the ICT4D phenomenon. Additionally, the CA has no variables specified. This intentional omission by Sen allows for an exploratory approach for different contexts. Researchers are free to choose relevant capability dimensions (e.g., health, education, standard of living, security, etc.) to study within the bounds of their research disciplines and contexts (Kiiski and Pohjola 2002).

ICT4D

With new measures of country-level development, the World Bank, along with several country officials, can better judge which country's requests to fulfil by loaning money as a means of reducing poverty. According to the United Nations, implementing Information and Communication Technologies for Development (ICT4D) is important for meeting the expectations of the Millennium Development Goals. The World Bank has primarily focused on various ICTs to decrease the global digital divide, which includes a disparity between nations' information resources such as the Internet and communication devices.

With ICT4Ds as the primary focus for World Bank loans, new claims have been made that ICTs divert development funds away from other, more influential country developments. With several successful and unsuccessful ICTs, trade-offs will need to be justified among competing stakeholders for the limited investment resources. In a United Nations Development Programme report, Hamel (2010 reviews ICT4D research within human development and the CA. His review assessed whether ICTs were appropriate for the human development of the poor in the dimensions of health, education, income, participation, and empowerment. He concluded that ICTs alone cannot improve people's lives, but broader strategies were needed to tailor ICTs towards the people's needs and make the most use of these tools. He also sought to answer the role of government policy and investment decisions towards ICTs as a key means for development, especially in poor countries. The policy recommendations included: (1) ensure that national telecommunication markets are open to competition and aligned with regional and global standards to reduce prices and consequently increase usage; (2) ensure the necessary infrastructure is in place to allow ICTs to be deployed; (3) Create opportunities for citizens to participate, promote transparency of government activities, and become participants themselves; and (4) ensure the networked society is safe by defending the freedom of expression. Each of these policy recommendations represents a conversion factor that ICTs must work through. These conversion factors include the following: ICT usage cost; ICT infrastructure; government and citizen co-participation in ICT; and freedom of expression within ICTs.

In the next few sections, we will map out each policy recommendation to one of the three categories of conversion factors (personal, social, or environmental) along with its association to either enabling or restricting opportunity and/or process freedoms, and hypothesize their relationship with human development.

ICT COST AND HUMAN DEVELOPMENT

Implementing ICTs is not without context. The digital divide is a social and political problem, and not one solely of technology (Hamelink 1999; Weigel and Waldburger 2004). The goal of using ICT with marginalized groups is to further a process of social inclusion (Warschauer 2004). When countries implement an ICT, care must be taken to not discriminate amongst marginalized groups while enhancing others. Such examples can be seen where increased use of ICT contributes to an increase in income inequality by helping the skilled and not the unskilled within (Gasco-Hernandez 2006; Rodriguez and Wilson 2000) such that those who were better off economically and socially took more advantage of the ICT resources (Rogers 2003; Venkatesh and Sykes 2013). This is known as the Matthew Effect (De Haan 2004), where the rich become richer and the poor poorer. In this case, people with more wealth, social status, and technical skills are more likely to take advantage of ICT resources. It is largely up to policymakers and regulators to overcome factors such as marginalization and discrimination.

As you may recall, environmental conversion factors are those environmental conditions that impose boundaries on the conversion of resources to opportunities and process freedom's choices. The environment is made up of physical, climate, and infrastructural characteristics. In the case of ICT usage cost, the boundary condition is part of the economic infrastructure of a country that hinders or promotes commerce and the distribution of goods. ICTs are often priced above the means of marginalized groups within developing countries, thereby negating any benefits that could be brought. Some of the poorest countries only have a single provider (Guida and Crow 2009) and they provide access only to the wealthiest who can afford it. High telecommunications costs that inhibit Internet use are most apparent in these poorest countries (Mann 2003). In a meta-analysis of 253 ICT4D studies, less than 20% reported the costs associated with the interventions, begging the question of 'how much good evidence exists about the impacts, or effectiveness, of ICTD interventions?' (Brown and Skelly 2019). Survey results from 460 respondents identified ICT cost as the second-largest issue to users, just behind electricity, especially in developing nations (Hosman and Armey 2017). Their open-ended responses included the need for finding a 'sweet spot' that balances quality through durability and functionality with the correct expense. Otherwise, marginalized groups get caught in higher long-run expenses associated with charging, connectivity, and repairs of lower-quality items. Simple ICTs, such as mobile phones and broadband Internet, are a means of providing knowledge and information necessary to reduce poverty, reallocate resources, and empower citizens. Mobile phones, for example, have become the most significant ICT to bridge the digital divide in developing countries (Rashid and Diga 2008). ICT costs then become a problem when ICTs are implemented in these often low populated and impoverished communities that may need ICTs the most. ICT usage costs are an environmental conversion factor that can enable or restrict opportunity freedom. The number of opportunities is restricted when prices go above the means of the individual. Lower ICT usage costs enable the individual to utilize the new resource. Therefore, we hypothesize:

H1: Higher levels of ICT usage costs will negatively affect human development in a country.

ICT INFRASTRUCTURE AND HUMAN DEVELOPMENT

A second environmental conversion factor is the infrastructure required to implement ICTs. ICT infrastructure is the requirement for ICTs to operate, and as such are classified as an infrastructural-based environmental factor. Several studies have investigated the impacts of IT infrastructure within initiatives of e-banking in Ethiopia (Borena and Negash 2016), immunization programs in Kenya (Holeman and Barrett 2017), and country-level development (Andoh-Baidoo et al. 2014; Ganju et al. 2016; Meso et al.

2009). All the reported studies above have suggested that lifestyles and living standards are greatly impacted through ICT infrastructure as an enabler of change.

ICT infrastructure is defined here as including the three components of ICT Access (e.g., fixed-telephone subscriptions per 100, mobile-cellular subscriptions per 100, Internet bandwidth bits/s per Internet User, % of households with a computer, % of households with Internet access), ICT Use (e.g., % using Internet, fixed-broadband subscriptions per 100, active mobile-broadband subscriptions per 100), and ICT Skills (e.g., mean years of schooling, secondary gross enrolment ratio, tertiary gross enrolment ratio). A recent literature review for indicators of ICT development has included ICT access and ICT use as shown above (Chatterjee 2020). The concepts of human capital and IT Literacy have been studied as country-level factors that complement ICT access and ICT use (Dedrick et al. 2013; Dewan et al. 2010). Human capital and IT literacy refer to people who know how to use and operate technology. Low literacy, as well, has been shown to present obstacles for ICT4D research (Venkatesh and Sykes 2013). We have decided to include ICT skills, as reported by the International Telecommunication Union, in our ICT infrastructure index to reflect the human-centric IT infrastructure needs (ITU 2019)

Past studies have shown a positive statistical correlation between telephone and Internet access and the success of entrepreneurship, business development, and the incomes of the poor (Forestier et al. 2002). Even more so in developing countries, mobile phones have become the most important ICT in bridging the digital divide (Rashid and Diga 2008). A recent study measures the impact of high-speed broadband on the innovation capabilities of rural firms, showing increased firm performance (Rampersad and Troshani 2020). ICT infrastructure is required for users to gain access to all the benefits of ICT initiatives.

Another dilemma arises when users are not proficient in using ICTs. In a survey of ‘e-skills’ within 17 African countries, the majority of respondents cited that ‘lack of skills’ is the primary reason for not using ICTs (Schmidt and Stork 2009). More so for generations that did not grow up with technologies, literacy can be the roadblock that prevents users from using ICTs. Part of building a good infrastructure for ICT means also investing in education projects and literacy campaigns that will help foster the skills needed for ICT use. The combination of ICT accessibility, use, and e-skills is the core of ICT infrastructure.

ICT infrastructure is rightfully another example of an environmental conversion factor that can enable or restrict opportunity freedom. Without having the core infrastructure needed to support ICT4D initiatives, users are left with little to no alternative options to access the implemented systems within their country, thereby reducing their capability set. Conversely, a nation that has high levels of ICT infrastructure has little worries when implementing a system for its community to access. As such, we hypothesize:

> **H2**: Higher levels of ICT infrastructure positively affect human development in a country.

E-PARTICIPATION, FREEDOM OF EXPRESSION, AND HUMAN DEVELOPMENT

We previously discussed how ICT cost and infrastructure can enable or restrict a resource on a person’s capability set. Expanding an individual’s capability set for which they have to choose from is how we improve opportunity freedom. Participation and freedom of expression are different in the sense that they enable or restrict a person's agency through ongoing processes (i.e., process freedoms). A person may see a benefit to their well-being through e-participation in services offered over online government platforms, but if civil liberties, such as freedom of expression, are limited through these platforms then the person may prefer not to participate (Pirannejad et al. 2019; Shirazi et al. 2010). Social conversion factors include social norms, social hierarchies, cultural traditions, and institutional policies. Of these, e-participation is a social norm that highlights shared expectations that govern a society, whereas freedom of expression is an institutional policy created by policymakers.

Several papers have linked the idea of ICT diffusion with human progress and political freedoms (Baliamoune-Lutz 2003; Lee et al. 2017; Shirazi et al. 2009; Shirazi et al. 2010). As mentioned previously, the CA focuses on freedoms as the means to development. It is also sometimes an approach utilized for policy recommendations. At its core, the CA has the concept of agency that is reflected political freedoms. In this way, we believe that participation and freedom of expression are important enough for us the understand their linkage to development.

Citizen participation is critical in having effective democratic governance (Teorell 2006; Verba et al. 1995). When a citizen participates in governmental decision-making processes, they enhance their capacity to make effective choices and translate the choices to desired actions and outcomes (Alsop and Heinsohn 2005). Tai et al. (2020) refer to E-participation as the 'citizens' use of ICTs to engage with public affairs and democratic processes. E-participation is a way to empower citizens by allowing them to be involved in decision-making processes that they would otherwise not be involved in. ICTs enhance an individual's participation through alternative modes of communication. E-participation is then a supplement to participation in the sense that citizens may already have access to information and democratic processes, but only in person. E-participation opens up the access to those who may live far away and would not likely have the time or money to travel. Higher levels of e-participation give access to higher transparency and public information within governments, provides ways of giving feedback, and allows the opportunity to cooperate with government officials in making policies and services through ICT platforms. E-participation enables all stakeholders, policymakers and citizens alike, to interact and better understand the obstacles that exist in people's lives (Day and Greenwood 2009). Policymakers need feedback from their communities if they are truly going to understand the needs of their citizens, and the citizens are empowered by partaking with public affairs and democratic processes through e-participation. Thus, ICT initiative success will be promoted with higher levels of e-participation between governments and citizens.

We have categorized E-participation as a social conversion factor that enables or restricts people's process freedom. As mentioned, social conversion factors include rules, regulations, and cultural traditions. E-participation enables governmental participation by citizens, creating a culture of inclusion. As E-participation becomes more relevant within a community, people are more likely to share feedback with their government on what truly matters to them.

E-participation alone is not sufficient to generate human development. Freedom of expression also empowers citizens by allowing the means to express alternative views and information. Freedom of expression, defined by article 19 in the United Nations ‘Universal Declaration of Human Rights’ (UN 1948), is the right ‘to hold opinions without interference and to seek, receive, and impart information and ideas through any media and regardless of frontiers.’ The true purpose of freedom of expression is to call attention towards the desired change for what one believes in. Freedom of expression within ICTs is, then, a virtual method of expressing one’s opinion that transcends the confines of physical distances.

We have categorized freedom of expression within ICTs as a social conversion factor that enables or restricts an individual’s process freedom. Freedom to express oneself is deemed as a boundary condition regulated by governing institutions. As freedom of expression on ICTs decrease, actions of agency against using ICT resources increase, thereby restricting the ICT capability option. High levels of freedom of expression on ICTs are less likely to invoke an individual’s agency response to restrict ICT usage.

E-participation and freedom of expression on ICTs are closely tied to each other. Both e-participation and freedom of expression on ICTs are tools to help empower people by allowing them to become agents for themselves and to fight for what they believe matters. E-participation provides a unique potential to citizens who may have no other means of participating in governmental processes, such as access to information or involvement in decision-making processes. Freedom of expression on ICTs is a complement to e-participation whereby the level of freedom of expression moderates e-participation by acting as an enhancer or suppressor of e-participation. Thus, we hypothesize:

H3: The level of e-participation will impact human development in a country depending on the level of freedom of expression on ICTs in a country.

E-participation levels are dependent on the overall levels of freedom of expression on ICTs factors. Freedom of expression can be an enabler of dissent towards authorities when this form of expression is interpreted as a threat toward current administrative governments. This is known as 'the dictator's dilemma', where adoption of ICTs can promote both wealth and influence while also increasing the likelihood of dissent and civil mobilization (Kedzie and Aragon 2002). This situation can sometimes lead to censorship and monitoring, which are fundamental issues related to the use of ICTs (Jordan 1999). Countries may even choose to control the use of ICTs either through physical control or by blocking online networks (Castells 2001). Some public debate has come up over legitimate control on child pornography and terrorism by taking away the anonymity of online users, but advocates for online freedom suggest that these issues are scapegoats utilized for further political control over the people (Slevin 2000). When governments or organizations are suspected to use personal information to harm (physical or non-physical) a user of an ICT, that user is less likely to use said ICT, thereby restricting a person's agency. Given this negative outcome for those in power, a government may choose to limit freedom of expression. This action has a suppression effect whereby the lowering of freedom of expression, concerning ICTs, suppresses the impact of e-participation on human development because citizens will be dissuaded from using government ICTs when they are likely to be censored or blocked. Therefore, we hypothesize the following moderating effect:

H3a: The lower the freedom of expression on ICTs, the less the impact of e-participation on human development in a country.

While lowering the freedom of expression can dampen the effect of e-participation on human development, increasing freedom of expression can have the opposite effect. Freedom of expression is also enhanced through ICTs by giving the citizen's voice a larger microphone to speak through. During the e-participation phase, when a lack of consensus occurs between the current administration and citizens or among citizens themselves, freedom of expression on ICTs can then enhance the citizens' process freedoms by vocalizing their positions and gathering agreement among stakeholders. Freedom of expression on ICTs is then seen to amplify the effects of e-participation's feedback and decision-making processes. At high levels of freedom of expression, increasing e-participation is likely to increase human development because citizens are more likely to get involved with decision-making processes when they are free to speak their opinions. Given this, we hypothesize:

H3b: The greater the freedom of expression on ICTs, the greater e-participation will impact human development in a country.

DATA COLLECTION

Our data was collected from several databases and merged based on country ID. Following previous research on ICT4D, we selected country-level data as our unit of analysis (Andoh-Baidoo et al. 2014; Baliamoune-Lutz 2003; Chatterjee 2020; Dewan and

Kraemer 2000; Ganju et al. 2016; Kiiski and Pohjola 2002; Lee et al. 2017; Leoz et al. 2015; Mayer et al. 2020; Meso et al. 2009; Ngwenyama et al. 2006; Sağlam 2018; Shirazi et al. 2009; Shirazi et al. 2010). This selection allows generalizability to previous research. Our first construct, cost, is collected from the International Telecommunication Union's ICT Prices 2017 report (ITU 2017) which gives consumer costs for four ICT categories in the year 2016. The categories include mobile-cellular, mobile-broadband prepaid, mobile-broadband post-paid, and fixed-broadband. Each of the services' prices corresponds to the least expensive plan offered by the dominant operator who fulfils the usage requirement. The mobile-cellular category includes only voice and SMS, comprising of about 30 calls (approximately 50 minutes each) and 100 SMS messages per month, with the inclusion of both on-net/off-net pricing and peak/off-peak weekend pricing variations. Mobile-broadband pre-paid and post-paid plans are separated with the former having a data allowance of 500 megabytes per month and the latter having one gigabyte per month. For our data selection, we chose to go with the cheaper of the two mobile-broadband options for each country. This was done to exemplify the more practical decision an individual would make within their country. Fixed-broadband values are based on the monthly price for an entry-level fixed-broadband plan with a monthly allowance of one gigabyte and a download speed of 256 kilobits per second. To compare prices between nations with varying income levels, we collected and used the percentage of gross national income per capita (% of GNI p.c.). This measure is the annual utility price in US dollars divided by the GNI p.c. in US dollars for each country.

To measure ICT infrastructure, we used data from the International Telecommunication Union's World Telecommunications/ICT database (ITU 2019).

There we pulled data on 176 countries for the 2016 ICT Development Index, which gives data on ICT access, use, and skills of a population for each country. The specific measures used for ICT access were fixed-telephone subscriptions (per 100 inhabitants), mobile-cellular subscriptions (per 100 inhabitants), Internet bandwidth (bits/s) per Internet user, percentage of households with a computer, and percentage of households with Internet access. The measures used for ICT use include the percentage of individuals using the Internet, fixed-broadband subscriptions (per 100 inhabitants), and active mobile-broadband subscriptions (per 100 inhabitants). Finally, ICT skills were measured from mean years of schooling, secondary gross enrolment ratio, and tertiary gross enrolment ratio. The three sub-indexes are combined using a weighted scale of 40/40/20, with ICT skills as the latter. This lower weight on ICT skills is due to the use of proxy indicators. All scales were normalized before combining them. The final score for the ICT Development Index is reported as a value between zero and ten that we then standardized between zero and one with the latter having the highest level of development. Hamel (2010 notes that electrification is another important infrastructure measure, but we decided not to include access to electricity due to the other infrastructure measures acting as a proxy for electricity. Scores are then normalized for analysis testing.

Measuring e-participation required us to find data on e-government, and more specifically, governments participating with the community through electronic platforms. We used data from the United Nations' department of economic and social affairs (UN 2020). They measure citizen engagement with governments through ICTs. There we pulled data on 191 countries for the 2016 E-Participation Index. The index is comprised of E-information: enabling participation by providing citizens with public information and access to information without or upon demand; E-consultation: engaging citizens in contributions to and deliberation on public policies and services; and E-decision-making: empowering citizens through co-design of policy options and co-production of service components and delivery modalities. This index adequately measures our intended participation construct as it measures the level of information shared between governments and citizens, along with the agency component that empowers citizens to be involved in policy discussions and decisions. Values were standardized between zero and one for analysis.

The last measure, freedom of expression, is pulled from Freedom House's 2016 Freedom on the Net report (Kelly et al. 2016). They give a score for Internet Freedom to 65 countries around the world based on obstacles to access, limits on content, and violations of user rights. An aggregated score of the three mentioned measures is used for their freedom on the net score. To obtain this data, a 21-question survey is administered to a trained researcher (or organization) within each country. Following the survey is a two-day rating review meeting, held with the rater to critique and adjust the draft scores following the project's comprehensive research methodology. Careful attention is paid to current events, laws, and practices. A final score is then submitted after extensive review and fact-checking from Freedom House staff. Obstacles to access are measured by infrastructural and economic barriers, legal and ownership control over ISPs, and independence of regulatory bodies. Limits on content are measured by legal regulations on content, technical filtering and blocking of websites, self-censorship, vibrancy, and diversity of online news media, and the use of digital tools for civic mobilization. Violations of User Rights are measured by laws that give governments power to survey, infringe on privacy, and penalize users for online speech and activities through imprisonment, extra-legal harassment, or cyberattacks. We decided to drop the obstacles to the access category as the questions directly related to our infrastructure measures. Limits on content and violations of user rights were then aggregated for a max score of 75, instead of the previous 100 score range which included obstacles to access questions. Scores are then inverted, as following with the 2019 Freedom on the Net report, to align with other development indexes, normalized, and standardized between zero and one for further analysis. This means that higher scores now represent more freedom of expression.

Matching all datasets and excluding countries with missing data, we total 63 countries for use in the analysis. Of the 63 countries, 22 were classified as developed and 41 were classified as developing countries by the United Nations Development Programme (UNDP 2018). A post-hoc analysis was run on the final model by including an independent variable indicating whether the country was developed or developing. Results show that this independent variable is not a significant predictor of HDI above and beyond the variables in the theoretical model, providing greater credence to the generalizability of the results. It is important to note that if we were to only use the first three independent variables (i.e., exclude freedom of expression), the sample size becomes 186 countries. We felt the importance of including freedom of expression on ICTs, and its interaction with e-participation, warranted the smaller dataset. This is in accordance with other country-level research given the limited sample size. Given this, the ratio of a sample size to the number of items within our study is 13:1, which still exceeds recommendations from previous research of 5:1 (Gorsuch 1983), 6:1 (Cattell

1978), and 10:1 (Everitt 1975). More recent research uses ratios similar to those previously recommended:

- (Chatterjee 2020):
  - Model 1: n = 41, 9 variables (5:1)
  - Model 2: n = 41, 8 variables (5:1)
  - Model 3: n = 41, 10 variables (4:1)
  - Model 4: n = 41, 9 variables (5:1)
  - Model 5: n = 41, 7 variables (6:1)
- (Dewan et al. 2010): n = 26, 3 variables (9:1)
- (Ganju et al. 2016): n = 94, 9 variables (10:1)
- (Lee et al. 2017): n = 102, 3 variables (34:1)

ANALYSIS AND RESULTS

Econometric methods were used to test the relationship between the independent and dependent variables in the proposed research model. We controlled for potential endogeneity using instrumental variables. This method has been utilized in previous research involving ICT and well-being (Ganju et al. 2016).

INSTRUMENT VARIABLES

To address possible endogeneity, several country-level characteristics were identified as instruments. These instrumental variables are identified through previous research as correlated with the dependent variable but not correlated with the independent variable. The instrumental variables include ICT competition level, terrain ruggedness, e-skills, and the freedom of expression and information index. Further details on each instrumental variable are written below.

The International Telecommunications Union has advocated for increased levels of competition within ICT markets as the best means to lower costs (ITU 2008). Monopolies on ICT infrastructure and services keep prices in several developing countries above the viable range of many users, thereby keeping demand low and limiting the impacts derived from such markets. Therefore, we argue that the level of competition in ICT markets will impact the infrastructure and service costs of ICT, but not correlated with the level of human development in a country. We utilize competition data from ITU's World Telecommunications/ICT Database (ITU 2019). The data given is categorical (Monopoly, Duopoly, Partial competition, and Full competition). The variables chosen were mobile cellular, mobile broadband, and fixed wireless broadband. Inputs were converted to an ordinal scale (i.e., 1, 2, 3, 4) and standardized.

Prior studies have argued that the extent of the sloping terrain in a country will impact the difficulty of providing ICT services (Ganju et al. 2016; Kolko 2012). Also, hilly terrains are argued to reduce the broadcasting range in mobile devices (Arokiamary 2009). We argue that slope ruggedness will impact a country's ability to provide ICT infrastructure, but the ruggedness is not correlated with human development. Slope ruggedness data is obtained from (Nunn and Puga 2012). We specifically used the population-weighted ruggedness variable to capture the importance of areas that are more densely populated. The variable is then standardized.

In studying e-participation, researchers have utilized e-skills as an instrumental variable (Tai et al. 2020). The difference between participation and e-participation being the use of ICTs for online participation versus offline participation. Citizens need knowledge of electronic skills to participate in society online. We argue that e-skills will impact e-participation, but e-skills alone are not correlated with human development. The level of e-skills is collected from the ITU's World Telecommunication/ICT Database (ITU 2019). E-skills are made up of mean years of schooling, secondary gross enrolment ratio, and tertiary gross enrolment ratio. Values range from zero through ten. The variable is then standardized.

Freedom of Expression and Information is an index reported by the Fraser Institute's Human Freedom Index report (Vásquez et al. 2018). The Freedom of Expression and Information index specifically targets press freedoms and access to their reported information. The press are considered citizens of a nation and are, therefore, given similar rights as other citizens within a nation (e.g., freedom of expression). This index correlates with a citizen's freedom of expression in the sense that the press is considered to be arbiters of information and pushback on government mismanagements. We argue that press freedoms influence human development only through the freedom of expression given to all citizens of a nation, and therefore press freedoms are not directly correlated with human development. The index is then standardized. Table 1 below includes the descriptive statistics for all the used standardized variables and standardized instrumental variables.

Table 1. Descriptive Statistics

Variable	Maximum	Minimum	Mean	Std Dev
HDI	0.936	0.456	0.730	0.137
Cost	1	0	0.086	0.169
ICTDI	0.888	0.135	0.494	0.221
Epart	1	0.068	0.598	0.233
FOTN	0.933	0.067	0.538	0.209

rugged	0.473	0.001	0.093	0.079
eskills	0.998	0.186	0.649	0.233
FOEI	0.980	0.184	0.729	0.174

ANALYTICAL METHODS

We utilize two-stage least squares (2SLS) to analyze our model using SAS. This decision is based on previous work in the ICT literature using simple least squares and regression at the country level (Andoh-Baidoo et al. 2014; Baliamoune-Lutz 2003; Chatterjee 2020; Dewan and Kraemer 2000; Ganju et al. 2016; Kiiski and Pohjola 2002; Lee et al. 2017; Leoz et al. 2015; Loh and Chib 2019; Mayer et al. 2020; Ngwenyama et al. 2006; Sağlam 2018; Shirazi et al. 2009; Shirazi et al. 2010). One alternative in the literature is PLS (Meso et al. 2009; Venkatesh and Sykes 2013), though it is rarely used. We note that while Meso et al. (2009 analyzed data at the country-level, Venkatesh and Sykes (2013 analyzed the family-unit-level; thus, PLS is given little attention to analyzing country-level data.[2]

Two-stage least squares (2SLS) modeling was utilized to test for endogeneity. Regression analysis has been utilized previously in related research and also offers generalizability

[2] Endogeneity within PLS has received little attention in the literature. While no software specifically includes endogeneity in the models like 2SLS, recently researchers have developed scripts to use in combination of PLS and R (Hult et al. 2018). Upon inspection, IS has not yet utilized this method in its research. Given this, we have included an Appendix utilizing this method both to corroborate our results using 2SLS as well as provide impetus for utilizing the method in future IS research.

with this research (Andoh-Baidoo et al. 2014; Chatterjee 2020; Dewan and Kraemer 2000; Ganju et al. 2016; Lee et al. 2017; Ngwenyama et al. 2006; Shirazi et al. 2010). Preliminary analysis was performed to first identify if endogeneity was truly present or if traditional ordinary least squares (Hölscher and Tomann) modeling would be sufficient. The Hausman test was used with a significant result indicating endogeneity is present (Hausman 1978). Results in Table 1 show that while Cost and Infrastructure displayed no significant endogeneity, e-participation showed substantial endogeneity and ICT freedom of expression showed marginally significant endogeneity. Given this, 2SLS modeling was utilized to control for this endogeneity.

Table 2. Endogeniety Analysis

Independent Variable	Instrumental Variable	Hausman Test
ICT Cost	Competition Level	0.21 (p = 0.91)
ICT Infrastructure	Terrain Ruggedness	0.16 (p = 0.92)
E-participation	E-skills	51.94 (p < 0.001)
ICT Freedom of Expression	Freedom of Expression and Information	5.02 (p = 0.08)

The 2SLS model was evaluated using the equations below.

$$HDI_i = \beta_0 - \beta_1 cost_i + \beta_2 infr_i + \beta_3 epart_i + \beta_4 ICTfoe_i + \beta_5 epart_i * ICTfoe_i + \epsilon_1 \quad (2)$$

$$infr_i = \beta_6 + \beta_7 rugged_i + \epsilon_2 \quad (3)$$

$$epart_i = \beta_8 + \beta_9 eskills_i + \epsilon_3 \quad (4)$$

$$ICTfoe_i = \beta_{10} + \beta_{11} foei_i + \epsilon_4 \quad (5)$$

Equation 1 specifies the primary model of country-level human development for country I (Bordé et al.) regressed on ICT Cost, ICT Infrastructure (infr), E-participation (epart), ICT Freedom of Expression (ICTfoe), and the interaction of E-participation and ICT Freedom of Expression (epart*ICTfoe). Equations 2-4 specify each of the endogenous variables regressed on their respective instrumental variable. Ruggedness, while found not significant for endogeneity using the Hausman test above, was still conservatively included as an instrumental variable of ICT Infrastructure given the extensive analysis in previous research purporting such (Ganju et al. 2016).

RESULTS

Overall the model is highly significant ($F_{(5,57)} = 138.30$, $p < 0.001$), explaining over 92 percent of the variance in HDI ($R^2 = 0.924$). The 2SLS results are shown in Table 2. One-tailed t-tests show that ICT Cost negatively impacts HDI, and ICT Infrastructure positively impacts HDI, supporting H1 and H2 respectively. While E-participation and ICT Freedom of Expression do not significantly impact HDI, the interaction of the two does positively impact HDI, supporting H3.

Table 3. 2SLS Regression Results

Hypos	Independent Variable	Estimate	t-value	p-value	Supported
H1	ICT Cost	-0.09	-2.16	0.02	YES
H2	ICT Infrastructure	0.57	1.73	0.04	YES
	E-participation	-0.01	-0.02	0.49	
	ICT FoE	-0.04	-0.30	0.38	
H3	E-part * ICT FoE	0.10	2.33	0.01	YES

For the analysis, an alpha level threshold of 0.05 was used for the hypothesized single-sided tests. The estimates for E-participation and ICT FoE are not hypothesized given the interaction effect that supersedes these main effects in H3.

Looking more closely, at the interaction of E-participation and ICT FoE, a simple slope analysis was conducted to analyze simple main effects within the interaction. Figure 3 graphs this interaction. Simple main effects show that, when ICT FoE is low, the level of E-participation has no significant impact (β = 0.56, p = 0.21), supporting H3a. Conversely, when ICT FoE is high, the level of e-participation is magnified such that higher levels of e-participation have a more significant impact as compared to lower levels (β = 0.22, p = 0.04), supporting H3b.

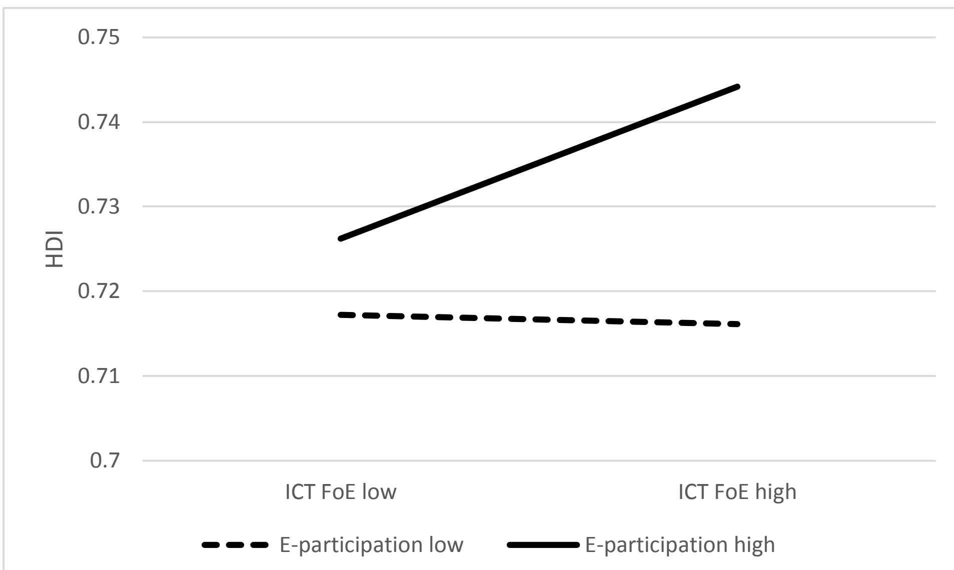

Figure 3. Impact of Interaction of E-participation and ICT FoE on HDI

POST-HOC ANALYSIS

To provide greater support for our findings, the data were also analyzed using Partial Least Squares path modeling. The same model was used whereby ICT Cost, ICT Infrastructure (infra), and E-participation (epart) directly impact Human Development

(Bordé et al.), with Freedom of Expression on ICT's (FoE) moderating the impact of epart.

Before analysis, endogeneity was assessed for the independent variables in the model. Endogeneity within PLS models has only recently been addressed in the literature (Hult et al. 2018). This novel Gaussian Copula approach involves a multi-part assessment of the independent variables in the model both for their ability to detect endogeneity if it exists, and subsequent testing if appropriate. First, the data was modeled according to the base model outlined above. Using SmartPLS (Hair Jr et al. 2016), the latent variable scores from the PLS algorithm are extracted from the output. Second, the R code provided for the method (see Hult et al., 2018) is used to run the Kolmogorov–Smirnov test with Lilliefors correction (Sarstedt and Mooi 2014) to assess the normality of each independent variable where non-normality is required to further consider the variable for endogeneity in the model. Results found that cost ($p = 0.002$) and FoE ($p = 0.037$) were significantly different from a normal distribution and, therefore, these variables could be further assessed for endogeneity. Third, Copulas were created for each of these variables, and bootstrapped standard errors were used to calculate corrected p-values for the original model with each of the Copulas included for each of the variables individually. Results (see Table 3) did not find a significant corrected p-value for any of the tested variables. Given this, the results of this analysis would suggest using the original model as no endogeneity is present.

Table 4. M1 includes the Copula for cost (c_cost) and M2 the Copula for FoE (c_FoE).

	Original		**M1**		**M2**	
	beta	p-value	beta	p-value	beta	p-value

epart	-0.08	0.49	-0.06	0.75	-0.08	0.64
FoE	-0.18	0.18	-0.14	0.51	-0.19	0.51
infra	0.78	< 0.001	0.73	< 0.001	0.78	< 0.001
cost	-0.16	< 0.001	-0.10	0.30	-0.16	0.07
FoE*epart	0.30	0.06	0.27	0.38	0.30	0.28
c_cost			-0.09	0.34		
c_FoE					0.01	0.93

Given the differing results regarding endogeneity between the traditional 2SLS instrumental variable approach and the Gaussian Copula approach, an important question is which is better suited for this research? First, the Gaussian Copula approach only enabled the assessment of endogeneity for two of the variables given its requirement that variables have a non-normal distribution to be tested. This left out both epart and FoE, both of which showed significant endogeneity using the Hausman test in the 2SLS model, which does not have these distributional restrictions. Another consideration is that, while the 2SLS instrumental variable approach is highly accepted and is an established assessment within econometrics, marketing, and other disciplines, the Gaussian Copula approach is relatively novel and somewhat rarely used, affecting the comparability of the study to previous studies using these methods. Finally, this study utilizes an interaction term in the base model. Currently, research does not yet have an accepted metric for assessing endogeneity in a PLS model that includes interaction terms (Hult et al. 2018), and researchers recommend instead using a 2SLS approach utilizing instrumental variables (Sande and Ghosh 2018) until greater research into this area with PLS has been carried out. Overall, the 2SLS approach is preferable as a tried-and-true method for measuring endogeneity as well as the inability of PLS to work with endogeneity when interaction terms are involved. This 2SLS approach utilizing instrumental variables is what is utilized in this paper.

Even with the drawbacks of using PLS, when comparing the results of the two approaches (2SLS and PLS), the overall picture is highly similar. In both studies, there is a significant impact of cost, infrastructure, and the interaction of FoE and epart on HDI. Furthermore, the overall R^2 of both models is almost identical (0.92 in the 2SLS model and 0.91 in the PLS model). From this perspective, both methods point towards the same independent variables significantly affecting the dependent variable, with the explained variance around 91-92 percent.

DISCUSSION AND CONCLUSIONS

This paper seeks to measure the effects of the four conversion factors on human development as recommended by Hamel's (2010) report on the potentials of ICTs on human development and the CA. Hamel's (2010) policy recommendations were considered conversion factors that can enable or restrict the ICTs capability set expansion within opportunity freedoms, and the agency/well-being decision within the process freedoms.

Findings show an interaction of e-participation and freedom of expression on ICTs. As noted previously, the ICT4D literature has not come to any consensus on how development should be measured or understood (Avgerou 2003). It is divided between economic prosperity, subjective well-being, and human development. Our study builds upon the human-development framework to measure development by utilizing the capability approach and identifying key country-level conversion factors that enable or restrict opportunity and process freedoms (Dedrick et al. 2013; Dewan et al. 2010). Policymakers could take note of these particular country-level conversion factors and refocus ICTs on expanding freedoms as a means to development.

It is important to note that the ICT infrastructure conversion factor has the greatest overall impact on human development (Forestier et al. 2002; Rampersad and Troshani 2020; Rashid and Diga 2008). With the inter-connectedness of systems, ICT infrastructure is crucial to develop for accessing systems of information and communication technologies, although the infrastructure is constantly changing and new technologies are constantly obsoleting older ones. For example, Google is launching hundreds of satellites into orbit to give marginalized groups an alternative for accessing the Internet, thereby bypassing previously required ICT infrastructures and reducing the global digital divide (Barr and Pasztor 2014; Novet 2021).

Another key finding is the interacting effect between the two social conversion factors, e-participation and freedom of expression on ICTs. Citizens are not likely to use new ICTs if they believe the government is restricting their use and freedoms on said ICTs (Kedzie and Aragon 2002). However, when governments and citizens cooperate through e-participation, there are reinforced reasons to believe freedoms of expression exist, such that government ICTs (e.g., e-government programs) and the-like are more likely to succeed. Policymakers must take note that allowing freedom of expression on ICTs may also increase public organization and dissent for governments when there is not a lot of participation, on- or off-line, happening between citizens and government.

A final finding was the ability of the overall model to explain a high amount of variance in the dependent variable, human development. Comparing our results to that of previous research (Meso et al. 2009), our model showed a significant improvement in variance explained of 92%. This provides a stable foundation for future research using a model that predicts almost all the variance in human development and provides authors with a solid starting point from which to undertake their research.

An interesting surprise from our results is no significant difference was found between developing and developed countries. The extant research has found differences, especially when technology plays a central role. A few such examples include the following:

- For developing countries, national information infrastructure influences the quality of governance as well as the level of socio-economic development (Meso et al. 2009).
- Less developed countries derive increases in well-being primarily from mobile devices while more developed countries via any ICT (Ganju et al. 2016).
- For lower-middle-income countries, the diffusion of mobile devices enhances the economic freedom of citizens whereas for upper-middle-income countries the diffusion of mobile devices not only enhances economic freedom, but civil liberties and political rights (Lee et al. 2017), and in the high-income group fixed-line broadband diffusion enhances civil liberties, political rights, and economic freedom.
- The complementarity of the diffusion of PCs and the Internet is greater for developing countries compared to developed ones (Dewan et al. 2010).

- In developing countries, the lack of banking education in the populace prevents stronger growth and diffusion of mobile and internet technology (Chatterjee 2020).
- For developing countries, income and government trade policies influence ICT diffusion; ICT diffusion fosters economic development and enhances political rights and civil liberties (Baliamoune-Lutz 2003).

While we performed a post-hoc test to verify that the inclusion of this variable did not significantly impact HDI above and beyond the primary model, future research should be performed to provide a more in-depth assessment of the developed nature of a country and the impact not only on HDI but more nuanced impacts concerning the individual theoretical relationships within the model.

It must be noted that there are limitations to our study. Notably, the number of countries analyzed. To have the most robust results, we took out countries with missing data. This limited our sample to 63 countries. However, our study has a good sample of countries from all levels of development. The 2016 HDI values are categorized into low, medium, high, and very high development categories. The value thresholds for each are below 0.55, 0.55-0.699, 0.7-0.799, and 0.8 and above. In our dataset, we count nine low-developed, 13 medium-developed, 19 high-developed, and 22 very-high-developed countries This limits bias that can be taken from a skewed dataset.

Another limitation of our study is the use of external data sources to run our analysis. Using indexes that were collected and stored by third parties can have implications with not knowing exactly how the data was collected. We performed our due diligence and researched the methodologies used to collect all external data sources used for this paper. Appropriate indexes were selected based on the criteria used to collect for each variable. Indexes were also standardized across all variables in the model to ensure no bias in one variable over another. Furthermore, an added PLS analysis was run to add credence to our use of these indexes in the primary analysis. Endogeneity is also an issue with using secondary data sources. We used several instrumental variables to check for and correct if any endogeneity was observed. We included instrumental variables that have been used in previous research. Additional econometric specifications could be examined in future research.

A third limitation is the selected ICTs used for this study do not capture all possible ICTs with regard to both ICT cost and ICT infrastructure. We measured the cost of mobile-cellular, mobile-broadband prepaid, mobile-broadband post-paid, and fixed-broadband, as well as infrastructure related to mobile cellular, mobile broadband, and fixed broadband as our collective ICT measures. This does not account for all possible ICTs, such as radio, television, and more, though current research in the area has also utilized these same measures providing some justification for their use.

A final limitation can be attributed to the lack of management between the data-gathering entities. Due to the non-overlapping nature of the collected datasets, our study utilizes a cross-sectional analysis of country-level data. Going forward, it may be beneficial for the various groups and entities that collect this data to better coordinate their years of collection to enable longitudinal analyzes to uncover potential trends in the data.

IMPLICATIONS

Previously within this area, research has investigated environmental utility conversion factors (e.g., ICT infrastructure) as a mechanism for improving human development. While important, social conversion factors also impact this human development. Given this, it is pertinent to look at the social, or human, side of these factors as countries shouldn't just focus on implementing ICTs but also how they will provide the individuals within the country opportunities to use them. We demonstrate how two of these social factors, e-participation and Freedom of Expression in IT, provide a joint impact on human development within the country such that high amounts of both are needed to positively impact human development. Countries should examine their strategies concerning these social conversion factors to more positively serve their constituencies.

As a practical implication, our findings suggest the combination of e-participation and freedom of expression are integral to human development. Contrary to previous research that investigated e-participation and freedom of expression individually, both must exist in tandem to receive improvements in human development. Specifically, both high freedom of expression and high e-participation are needed to jointly impact human development, where a high degree on only one will not impact human development.

Methodologically, while our use of 2SLS increases comparability by providing a mechanism for comparing this research with previous research, our post-hoc analysis using PLS provides implications for future research. Specifically, we introduce a recently established method for assessing endogeneity within PLS models utilizing a Gaussian Copula approach (Hult et al. 2018). This novel method has yet to be utilized within IS research and provides a much-needed mechanism for addressing the potential for endogeneity within these more complex modeling techniques. Future research within our field should utilize and further examine this method, especially the yet-to-be-solved problem of interactions within this context. Given this, we still encourage future reviewers to exercise caution regarding the use of PLS. Specifically, the Gaussian Copula approach for assessing endogeneity is quite novel and has not been extensively tested. This is especially true when assessing endogeneity in a PLS model that includes interaction terms where researchers still recommend the use of 2SLS (Hult et al. 2018; Sande and Ghosh 2018). More generally, PLS has been shown to have drawbacks in other areas. First, given the biased estimators in PLS (Savalei and Bentler 2007) due to model errors not being taken into account (Marcoulides et al. 2009), the models are maximized for prediction of endogenous variables as opposed to explaining what is happening within a theory, as is needed in this research (Fornell and Bookstein 1982; Mathes 1993; McDonald 1996; Noonan and Wold 1982). Second, the PLS bias (Hair et al. 2014) which yields biased estimates due to the lack of explicit modeling of measurement error (Goodhue et al. 2012; Goodhue et al. 2013; Marcoulides et al. 2009), the results produce different outcomes for each research context thereby limiting the accuracy of the theoretical model and also the ability to compare results to previous research (Dijkstra 1983; McDonald 1996), which we do in this study.

In summary, our findings provide a strong variance explained model for ICT conversion factors that affect human development at both the levels of opportunity freedoms and process freedoms. We mapped out the whole capability approach theory and explained how conversion factors are associated with different parts of the model. We have also highlighted an interesting interaction effect between e-participation and freedom of expression in the ICT4D literature. Our model shows how policymakers can further increase the success rate of ICT initiatives within their countries. Moreover, future country-level research can focus on additional conversion factors as ways to improve human development.

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CHAPTER III

THE ROLE OF TECHNOLOGICAL PROGRESS IN VERTICAL SPECIALIZATION AND ECONOMIC GROWTH

ABSTRACT

Vertical specialization refers to where a country lies within a global supply chain. At lower levels of the global supply chain, firms in a country focus more on raw materials to produce intermediate goods. At higher levels of the global supply chain, firms in a country can focus more on technical processes. Technological progress can then help a country to vertically upgrade within the global supply chains. Likewise, prior literature has studied the connections between information technologies and development within a country. Technological progress enhances a country's ability to gather information, innovate, and increase economic growth. The current paper seeks to explain how technological progress can positively enhanced a country's vertical specialization and economic growth using data from 62 countries over the years 1995-2014. The regression results will inform key stakeholders on the possibilities of vertically upgrading their country.

INTRODUCTION

Global value chains are becoming increasingly popular. A single product can be partially produced in stages through multiple factories among multiple countries. A unique phenomenon occurs where initial stages of intermediate products are produced in countries with higher probabilities of making mistakes, whereas final products are produced in nations with lower probabilities of making mistakes (Costinot et al. 2013). This phenomenon shapes a vertical specialization that is dependent on a nation's technological progress. Vertical specialization refers to where a country or firm participates along the global value chain.

Vertical specialization was initially studied to explain the inequalities in the earnings of labor. The relative wage and employment ratio of nonproduction to production workers in 56 years of U.S. manufacturing shows an increasing wage gap and an increasing shift of employment in favor of nonproduction workers (Feenstra 2017). Nonproduction workers are considered skilled workers who have college experience while production workers are considered less-skilled. On a demand curve, the rising wage disparity between nonproduction and production workers should have seen a decrease in employment toward nonproduction workers, but the reverse is true. A widely accepted explanation for this trend is the outward shift in demand for skilled workers through global value chains. Less-skilled job activities are outsourced to countries with lower production costs, thereby increasing the wage gap with relatively fewer production worker jobs in the reporting country. The firm can focus more on skilled labor positions.

Likewise, prior literature has analyzed and found a positive relation of technological progress with economic growth and well-being over time (Chatterjee 2020; Hatakka et al. 2020; Loh and Chib 2019). What has not been studied is how technological progress interact with vertical specialization and economic growth of countries. Thus, the research question that the authors of this paper propose: Is the level of economic growth in a country dependent upon how technological progress interacts with vertical specialization over time? This helps address the gap in the ICT4D literature that has yet to investigate how vertical specialization plays a role in the growth of a country. We seek to answer this question by utilizing input output trade tables and technological progress indexes from 62 countries for the years 1995-2014 to estimate economic growth, as seen in Figure 4.

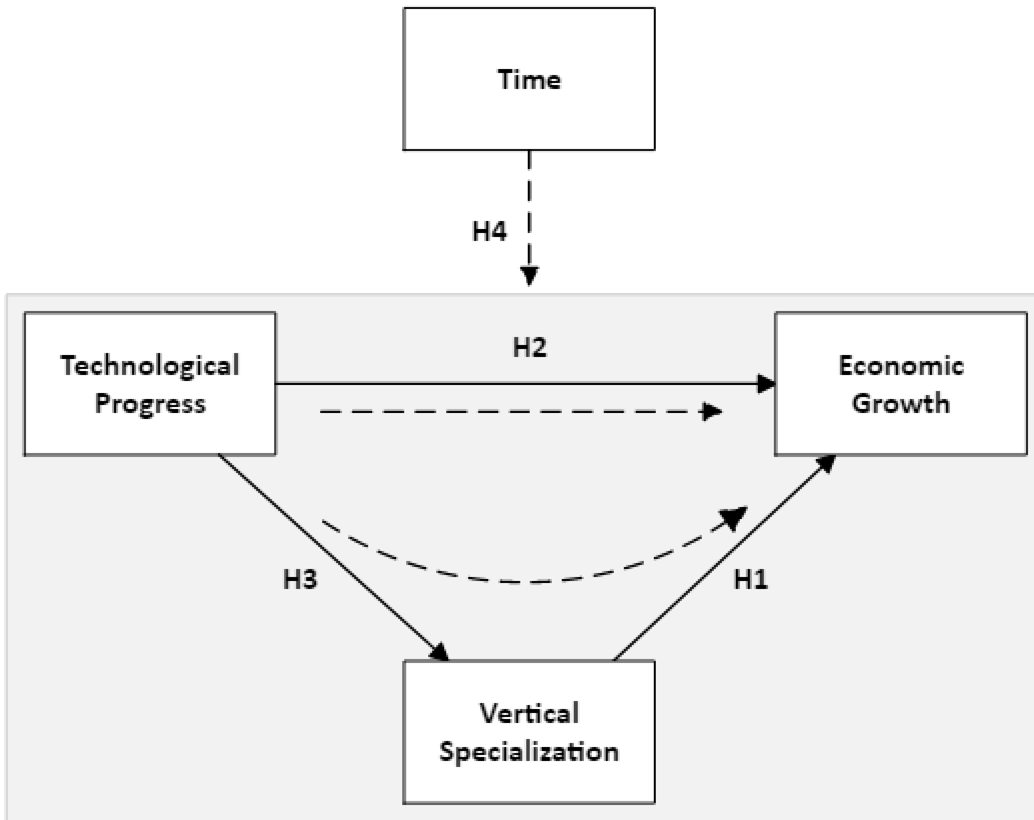

Figure 4. The Vertical Specialization & Technological Progress Growth Model.

LITERATURE REVIEW

VERTICAL SPECIALIZATION AND ECONOMIC GROWTH

Fragmentation of work processes has been a growing trend across the globe. Final products must go through several work processes, requiring intermediate goods and labor at each stage of production. Producing one unit of intermediate good requires one unit of intermediate good and one unit of labor at a previous stage in production. Increasingly, these stages of production have been outsourced to different firms domestically and internationally, allowing the firm to focus and excel on the stages they expertise in. Fragmentation may also be referred to as offshoring, vertical specialization, global factory, global value chains, or global supply chains. We will refer to this phenomenon as vertical specialization (VS) henceforth.

It is important to understand that as more and more processes of production are divided up, there becomes more and more trade activity to go along with it. VS theory attempts to explain the ever-growing trade across countries using traditional Ricardian comparative advantage (Jones 2000). This comparative advantage explains why a firm would outsource a production process for a product when the cost of production is cheaper elsewhere. This then allows the firm to focus on stages of production where they have a comparative advantage instead. A country could be especially good at producing a particular intermediate product over other countries, thereby reinforcing the specialization of that particular stage of production and reducing the price of the final product that utilizes the intermediate product.

Final products can differ in their assembly framework. The first framework is referred to as a snake which takes on a linear path of assembly (Baldwin and Venables 2010). The assembly process for a snake could take place domestically, internationally, or even within the firm itself. Each stage is sequential, building upon what the previous stage gave. The other framework is referred to as a spider which has multiple limbs that branch off from the main body. In this second framework, a firm may outsource the assembly of multiple parts and bring them together for the finished product. As with snakes, spiders can also occur domestically, internationally, or within the firm itself. In many cases, production processes take on both frameworks, making empirical linkages of production hard to value-added difficult to trace.

Since outsourced production processes can take place both domestically and internationally, researchers have investigated methods of measuring participation in VS and value-added. A first generation measure for the extent of foreign outsourcing utilized the share of imported intermediate inputs relative to total nonenergy costs (Feenstra and Hanson 1999). This measure is limited in its scope as it did not measure vertical specialization's impact on real values, such as wages. Second generation measures came about to measure vertical specialization with three requirements: (1) a good is produced in two or more sequential stages, (2) two or more countries provide value-added during the production of the good, and (3) at least one country must use imported inputs in its stage of production process, and some of the resulting output must be exported (Hummels et al. 2001). The VS measurement for country k is

$$VS_k = \left(\frac{imported\ intermediates}{\text{gross output}}\right) \cdot exports \quad (1)$$

where the first term in the equation is the VS share of exports, or the share of imported inputs into gross production. This is multiplied by total exports to provide a dollar value for the imported share of exports. This is also known as foreign value-added in exports or backward global value chain participation.

Looking again at the three requirements for VS, one may notice that a value chain has to begin in some origin country. This origin country would not have imports of intermediate goods when they are at the beginning of the VS chain. This is known as forward global value chain participation, or VS1, when a country's exports are embedded in a second country's export goods (Hummels et al. 2001).

$$VS1_k = \left(\frac{imported\ intermediates \cdot exports}{\text{gross output}}\right) \quad (2)$$

This is also referred to as domestic value-added in exports and can be difficult to calculate globally (Los et al. 2016). Domestic value-added is the inverse of foreign value-added (1-VS) in gross exports, though not all domestic value-added is going to be sent oversees to be processed and resent to a third country. Some of the domestic value-added will be absorbed within the first exported country. This does not follow with Hummel et al.'s third requirement of VS.

There is a well-known issue within Hummels et al.'s method of calculating VS. In two-way trade, a first country's exports of intermediate goods can potentially be imported back from other countries within value chain, thereby overestimating the value added from these additional countries. This 'double-counting' problem (Los et al. 2016), where value added is aggregated at every border crossing, has led researchers to come up with the VAX ratio (Johnson and Noguera 2012). The VAX ratio is the portion of domestic value added in gross exports, and can be measured at the sector or aggregate level for a country.

$$VAX_k = \left(\frac{domestic\ value\ added}{\text{gross output}}\right) \qquad (3)$$

Vertical specialization, and value-added in general, has been studied on both developed and developing countries to understand how it may affect a country's economic growth. A study on India's tariff liberalization shows a positive impact on imported intermediate goods and domestic product expansion (Goldberg et al. 2010). Another study of tariffs looks at multiple countries imported capital inputs and intermediate goods tariff laws, finding a potential of about 1% growth in GDP per year, especially for poor countries who are net importers of intermediate goods and mostly net importers of intermediate goods (Estevadeordal and Taylor 2013). The concept of vertically upgrading was introduced by (Jiang and Milberg 2012) as an additional form of economic upgrading within a sector. Vertical upgrading is defined as the structural reduction of foreign inputs per unit of exports. They explain that when reliance of foreign inputs is replaced with domestic inputs, then domestic value-added increases through a higher competitive advantage. They analyze VS on five countries (U.S., China, India, Brazil, and South Africa) in the years 1995, 2000, and 2005 to see how changes in exports containing import content per sector.

In an attempt to understand the determinants (i.e., education, population density, GDP, proximity, trade policy, exchange rate policy, and political environment) for companies to engage in VS, (Clark 2010) surprisingly found that educational attainment of the workforce has a positive effect on VS in developed countries, but found a negative effect with developing countries. This is likely due to how more specialized tasks are conducted in countries where there is an abundance of skilled workers and technological progress while simple tasks are offshored to low labor costing countries with relatively fewer skilled workers. Labor cost share of intermediate goods increase as countries move up the chain.

In studying income differences of 35 developed and developing countries, Jones (2011) found no correlation between intermediate goods share and per capita GDP. The average intermediate goods share is about 52.6% and a standard deviation of about 6%, but income differences are larger in the presence of intermediate goods with income in richer countries benefitting more from highest productivity firms and income in poorer countries depend on the productivity of the weakest firms. From the above studies, we can definitively say that intermediate goods share is not a factor for economic growth, but rather how specialized a country is along multiple sectors that can determine their economic growth. We propose:

H1: *The level of specialization in a country is positively associated with economic growth.*

TECHNOLOGICAL PROGRESS AND ECONOMIC GROWTH

A large majority of the VS research analyzes income disparity, mainly through skilled labor differences across countries. Another large impacting factor that is mentioned in almost all the VS literature is technological progress, but little is theorized other than the mere mentioning of technology as a contributing factor. Fortunately, another body of research, information and communication technology for development (ICT4D), has extensively studied how information technology can enhance development such as economic growth (Adeleye et al. 2021; Adeleye and Eboagu 2019a; Chatterjee 2020; Dewan and Kraemer 2000; Mayer et al. 2020; Sağlam 2018; Seck 2012).

One such study analyzed indicators of ICTs (i.e., Internet usage, mobile subscriptions, and fixed telephone subscriptions) within 54 African countries between 2005 to 2015, finding a significantly positive relationship with economic growth (Adeleye and Eboagu 2019a). A similar study also found that ICTs within 52 African nations are linked with increased trade, improving both GDP and human development (Adeleye et al. 2021). A study on mobile banking usage found a positive correlation with GDP per capita in 41 countries (Chatterjee 2020). Another such study found that broadband infrastructure plays an important role with economic growth in 29 OECD countries (Mayer et al. 2020). In the case of innovations, economic growth is significantly related to foreign R&D capital stock, foreign direct investment, and both IT and non-IT capital investments (Dewan and Kraemer 2000; Seck 2012), especially with higher levels of ICT diffusion (Sağlam 2018). Therefore, we propose:

H2: *Technological progress is positively associated with a country's economic growth.*

TECHNOLOGICAL PROGRESS AND VERTICAL SPECIALIZATION

According to Costinot et. Al.'s theory of global supply chains, "production is sequential and subject to mistakes" (Costinot et al. 2013). Countries that have a lower probability of mistakes tend to be higher up in stages of production. Technological change can then determine if a country moves up or down within these stages of production. They note in particular that countries at or near the top of the chain will always benefit from moving up through the help of technological progress, whereas countries at or near the bottom of the chain may move up or down, depending on the type technological progress. Additionally, richer countries near the bottom of a chain are disproportionately benefitting from moving up than poorer countries. This could be due to economy of scales within the richer countries or even unique endogenous barriers within the poorer countries. Therefore, we propose:

H3: T*echnological progress is positively associated with a country's level of specialization.*

TIME MODERATION

Thus far, we have introduced how both vertical specialization and technological progress are related to the growth of a country, and how technological progress impacts a country's vertical specialization. However, we are also interested in how these relationships are affected over time. Our model suggests that there is a partial mediation between technological progress and economic growth. We are interested in how this mediation possibly changes over time.

In the famous article "*IT Doesn't Matter"* by Nicholas G. Carr (2003), firms from all over the world have been increasing spending towards IT because of the valuable resource it gives. However, the competitive advantage is being lost as every firm now has IT capabilities. You can only gain an advantage when nobody else can do it. In the meantime, firms are still pouring millions of dollars into IT. Carr suggests that this diminishing advantage would be better off spent by competitors, while your firm waits for the spillovers from IT innovations.

As proposed earlier, we believe there is a direct effect between technological progress and economic growth. We believe that the direct effect is strongest in the earlier years, where IT brought a competitive advantage to countries. The early 2000's would include up to and a little past the dot-com bubble, where ecommerce was rapidly developed with the help of IT. In the later 2000's, the majority of businesses had online commerce setup, removing the competitive advantage from the initial online pioneers. We believe that the direct path of technological progress on economic growth becomes weaker in these later years. However, the partially mediated indirect path, through vertical specialization, becomes stronger. IT could enhance a country's production specialization to be more efficient or some other added value, if they are still willing to spend money to remain competitive. Thus, we propose:

H4: *The impact of technological progress on economic growth varies with time such that in the late nineties and early 2000's technological progress will have a direct impact on economic growth while in the late 2000's and early 2010's technological progress will have an indirect effect on economic growth through vertical specialization.*

DATA & METHODOLOGY

DATA

The data was collected among a few databases and merged based on country ID. We chose to analyze country level data instead of sectoral data to get a generalized sense of the model. Future research could look at individual sectors of countries to gain further insight. All of our variables come from the World Bank's database (WB 2021b). Our dependent variable, economic growth, is commonly measured through GDP (current US$) of a country. Vertical specialization is measured through the aggregated VAX ratio, calculated as domestic value-added over output of a country. Finally, our measures for technological progress in a country are measured through common ICT indicators: Individuals using the Internet (% of pop.) and mobile cellular subscriptions (per 100 people). To best observe the longitudinal trends, we collected multiple years for the data. The years 1995 through 2014 were collected based on availability. Our sample size consists of 62 countries. Table 5 below shows the descriptive statistics for our variables.

Table 5. Descriptive Statistics

Variable	Mean	Maximum	Minimum	Standard Deviation
VS	74.402	97.69	39.77	11.07777053
GDP	26.118	30.505	22.143	1.66162571

NET	36.464	98.16	0	29.6412213
YEARNUM	10.503	20	1	5.765934443
NETXYEAR	509.481	1963.2	0	516.9964797

METHODOLOGY

This study will be using moderated mediation method to analyze each hypothesis (Preacher et al. 2007) with the use of Mplus. Moderated mediation helps to explain the when and under what conditions an effect occurs, that is the strength of the mediating effect based on the moderator. A mediator is a variable that provides the mechanism through which one variable influence another. The moderator, in this instance, influences the strength and direction of the mediation. In a behavioral research study, open sourcing of ideas for new products and services utilizes moderated mediation, where perceived ease of use mediates the relation between the online evaluation mechanism and the decision quality of the users, but is also moderated by both idea readability and perceived task variability (Blohm et al. 2016). Economic research, too, utilize moderated mediation to understand how female membership in microfinance institutions improves the performance of the institution through debt repayment, especially under adverse cognitive and regulatory institutional moderated conditions (Boehe and Cruz 2013).

Models four through six below capture the effects of specialization, technological progress, and the partial mediation of technological progress through specialization on economic growth, in that order. Model seven captures the direct effect of technological progress on specialization. These models are written as:

$$GDP_{it} = \beta_1 + \tau_1 X_{VS_{it}} + \varepsilon_1 \quad (4)$$

$$GDP_{it} = \beta_2 + \tau_2 X_{IT_{it}} + \varepsilon_2 \quad (5)$$

$$GDP_{it} = \beta_3 + \tau_3 X_{IT_{it}} + \tau_4 X_{VS_{it}} + \varepsilon_3 \quad (6)$$

$$VS_{it} = \beta_4 + \tau_4 X_{IT_{it}} + \varepsilon_4 \quad (7)$$

Where the dependent variables GDP and VS are economic growth and specialization for country *i* and year *t*. X_{VS} is the independent variable measures for specialization. X_{IT} is the independent variable measure for technological progress. The β's are the estimates for the intercepts in each model. The $\boldsymbol{\tau}$'s are the model estimates. The $\boldsymbol{\varepsilon}$ terms captures any extra noise related to, but not directly specified within the model.

RESULTS

The model was analyzed using multilevel regression. Given the nested nature of measures for each country across several years, multilevel modeling controls for bias by nesting observations by country. Additionally, given the panel nature of the data, the impact of year was also deemed significant for the research model. Given this, a multilevel moderated mediation analysis was run to address the impact of year on the relationships in the model.

The Preacher and Hayes method for moderated mediation was used to assess the model (Preacher et al. 2007). Specifically, year was used as a moderating variable to assess the research model. Year was first assessed as a moderator for each path, with only the direct path of IT on GDP moderated by year. Results found that IT has a significant negative impact on vertical specialization such that the more connected a country, the less vertical specialization ($\beta = -0.20$, $p = 0.002$), contrary to H3. Also, the level of vertical specialization of a country has a significant positive impact on GDP, supporting H1. Year was found to moderate the relationship between IT and GDP such that the earlier the year the more significant this positive relationship ($\beta = -0.19$, $p = 0.029$), partially supporting H2. Table 6 and Figure 5 show the model with standardized weights.

Table 6. Model Estimates and Fit

	Estimate	S.E.	Two-Tailed P-Value
GDP (R2 = 0.179)			
VS	0.39	0.106	0
IT	0.392	0.172	0.023
YEARNUM	0.054	0.114	0.637
IT X YEAR	-0.193	0.088	0.029
VS (R2=0.040)			
NET	-0.2	0.063	0.002

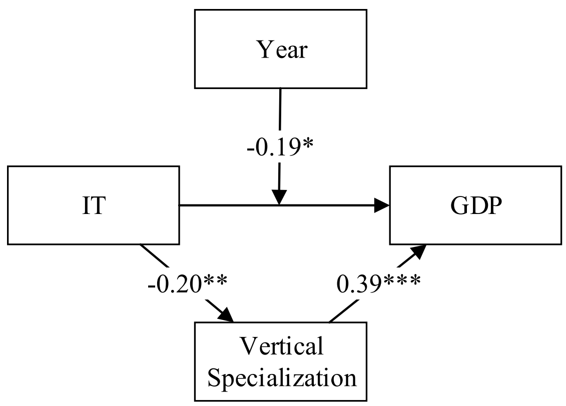

Figure 5. Vertical Specialization & Technological Progress Model Results.

To better understand the moderating relationship of year, the model was separated by year range. The moderated mediation analysis found that the direct relationship of IT on GDP was significant for earlier and middle years but not for more recent years. Given the range of 1995 until 2014, 2008 was chosen as the cutoff to analyze the two ranges. Findings show partial mediation for the years 1995-2008 with IT having significant direct ($\beta = 0.25$, $p = 0.002$) and indirect ($\beta = -0.07$, $p = 0.038$) effect on GDP. Conversely, a full mediation effect is found for years 2009-2014 with the impact of IT on GDP fully mediated by vertical specialization ($\beta = -0.08$, $p = 0.0475$). Figure 6 shows the results for the two-year ranges.

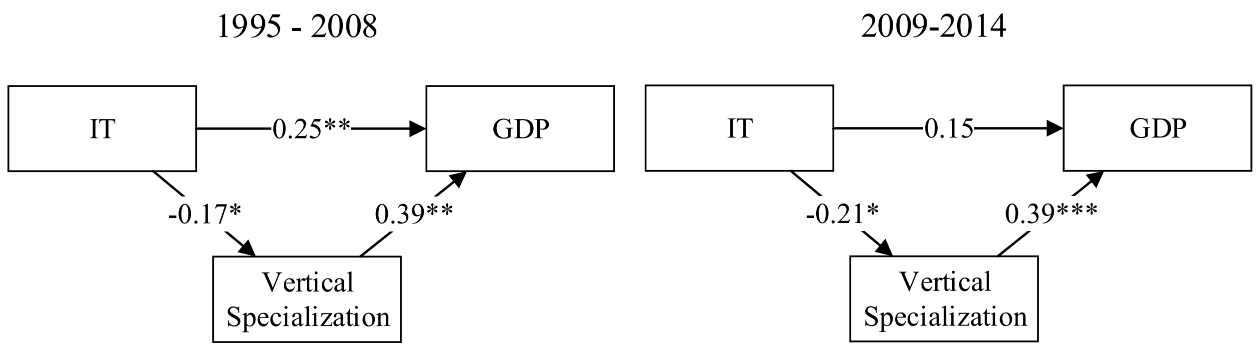

Figure 6. Model for Years 1995-2008 and 2009-2014.

DISCUSSION

To understand the negative correlation between technological progress and vertical specialization, we turn to the works of Friedman (2007). According to Friedman, globalization is causing the world to become flatter, where historical and geographical borders are becoming less relevant and the world seems smaller within the global economy. In other words, the world's economic playing field is being leveled out as access to the world economy becomes easier to reach. Access to the world economy is enabled through technological progress and new forms of collaboration, thus allowing countries, businesses, and people to interact from anywhere in an ever-shrinking world. All of a sudden, more people were able to connect and collaborate with more and more people than ever before.

In his third edition of "The World is Flat", Friedman expounds upon the flat world with ten world *flatteners* within the 21st century. (1) Windows-powered PCs – individuals now had the ability to create their own content and connect to one another with a graphical interface for word processing and through a global phone network. (2) Netscape – expanding the audience for the Internet. (3) Workflow software – allows machines to communicate with other machines through protocols. (4) Uploading – online projects, such as open source software, enabled people to collaborate. (5) Outsourcing – services and manufacturing could now be split in the most efficient way. (6) Offshoring – Lowers the cost of operations by outsourcing manufacturing or other processes to less costly foreign land. (7) Supply-chaining – streamlined shipping and distribution. (8) Insourcing – Utilizing services of a company for other businesses. (9) Information – Providing access to information (e.g., search engines and information repositories) so readily and easily to the public. (10) Voice over IP and file sharing – content becoming virtual and being sent at fast speeds and large volumes at a time. These world flatteners work together and reinforce each other, irrespective of geography, time, and language, to help bring the world closer together.

As the world becomes flatter and as more countries get involved with globalization, the global markets increasingly pressure countries to specialize in only production processes where there is a competitive advantage, thereby decreasing their overall domestic value added in exports (or VAX ratio) to only what the global market deems efficient and profitable. Technological progress enables countries to connect with the global market, but as the global market expands with more and more players being added, fragmentation of manufacturing processes take place more and more often. This leads to countries becoming less diverse and only specialized in a few production processes rather than many within global supply chains. Pahl and Timmer have identified a decrease in VAX-D ratios, domestic value added for direct use, for all countries over time (Pahl and Timmer 2019). In Friedman's book, he emphasizes the need for countries, companies, and individuals to continually remain competitive in a global market as a hedge against the flattening world.

Our model sheds some light on how globalization is affecting various world economies. Although, IT is an enabler in many different ways, it appears that globalization focuses a country to a specific task along global supply chains for each industry. More profitable countries tend to be at the top end of supply chains, whereas developing nations tend to be near the bottom where cost of labor is low. If the goal is economic growth for developing nations, then finding a way to move up a vertically specialized supply chain is important. Vertically upgrading, however, is difficult.

Vertical upgrading, as proposed by Jiang and Milberg (2012) is one type of economic upgrading along with process upgrading, product upgrading, functional upgrading, and intersectoral upgrading (Humphrey 2004; Humphrey and Schmitz 2002). Process upgrading is increased value-added in production through improvements in the production process. Product upgrading results from changing to a higher value-added product within the same supply chain. Functional upgrading involves moving into higher value-added aspects of a given production process. Intersectoral upgrading is shifting to a completely new product with a higher value-added. Vertical upgrading is then the non-reliance of imported intermediate inputs in production processes. In essence, this is an upgrading strategy to increase the proportion of domestically value-added components in production processes.

Vertical upgrading can be achieved by improving one's position in the global value chain through technological progress. China enhanced its technological capabilities through 'domestic innovation', through a national science and technology program in 2006, to alleviate its dependence on foreign technology and become more involved in ICT global value chains (Grimes and Yang 2018). Innovation processes in developed countries are based upon frequent incremental innovation and absorption of knowledge and technologies, whereas developing countries experience wildly radical and new changes. These developing countries utilize well-functioning information systems to facilitate partner relations in value chains, thereby exchanging complementary knowledge and reducing complexity of transactions (Pietrobelli and Rabellotti 2011). As developing countries participate more in VS, they obtain more knowledge spillovers that can also cross-over into other sectors (Seck 2012; Unel 2010). However, vertically upgrading to higher value-added functions can be difficult with a lack of technical and R&D scientists and engineers, along with underdeveloped high-tech and R&D infrastructures, such as in Malaysia and Mexico (Rasiah 2007). In these cases, Malaysia and Mexico initially generated improved economic growth from global market participation, but lacked the technological progress to enter higher value-added segments in the value chains.

What we see here is that technological progress enables countries to participate in global markets, thereby receiving immediate economic growth. It is then up to the individual countries to remain competitive by continuously innovating and vertically upgrade to see continued economic growth. Using the co-evolutionary theory, IT has been shown to in fact 'matter' when used to foster a competitive advantage (Luse and Mennecke 2014). Otherwise, the countries will remain stagnant or even vertically downgrade within global markets.

A limitation in our study is the bias that inherently comes from the sample of countries taken. According to the United Nations Development Program, our sample has 24 very high, 30 high, 7 medium, and 1 low developed countries. Although, we would like to generalize our findings, this sample distribution creates a bias in our results towards more highly developed countries. Another limitation in our study is the number of countries available for our analysis. We are limited to 62 countries because of availability of archival data. However, 62 countries are sufficiently adequate for this level of analysis. As seen from the brief review of papers in Table 7 below. Although not a comprehensive list, prior ICT4D research has had similar sample sizes.

Table 7. Brief Review ICT4D Sample Sizes.

Title	Authors	Number of Countries
Financial Inclusion, Information and Communication Technology Diffusion, and Economic Growth: A Panel data Analysis	Chatterjee (2020)	41 countries
Information Technology and Productivity: Evidence from Country-Level Data	Dewan and Kraemer (2000)	36 countries
ICT Diffusion, R&D Intensity, and Economic Growth: A Dynamic Panel Data Approach	Sağlam (2018)	34 countries

Broadband and Economic Growth: A Reassessment	Mayer et al. (2020)	29 countries
International Technology Diffusion and Economic Growth: Explaining the Spillover Benefits to Developing Countries	Seck (2012)	55 countries
Evaluation of ICT Development and Economic Growth in Africa	Adeleye and Eboagu (2019a)	54 countries
The Criticality of ICT-Trade Nexus on Economic and Inclusive Growth	Adeleye et al. (2021)	53 countries

CONCLUSION AND POLICY RECOMMENDATIONS

This paper attempts to link technological progress with vertical specialization and economic growth. The inclusion of the VS model into ICT for development research is an attempt to respond to the call for papers to include more theory within the ICT4D context. We utilized 20 years of archival data of 62 countries to build our model. We analyzed how technological progress directly and positively impacted economic growth from 1995 to 2004, and then indirectly, through vertical specialization, from 2005 to 2014. This is important in understanding how technological progress is a driving factor in the growth and development of a country, through its connections with the global economy. There is initial and direct economic growth by using technological progress to engage in the global economy, and then additional economic growth by using technological progress further to vertically upgrade and specialize in the global supply chains.

Policy-makers who are interested in economic growth may want to consider strategies for how to vertically upgrade within their own countries. Supporting domestic innovation, such as the case with China’s national science and technology programs, or even engaging more in the global markets for knowledge and technical spillovers, such as several developing countries have seen, can help a country to vertically upgrade. Future research may benefit from investigating the spillover effects from partner countries.

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CHAPTER IV

INTERNATIONAL TECHNOLOGY DIFFUSION, TRADING PARTNER SPILLOVERS, AND DEVELOPMENT

ABSTRACT

The purpose of this paper is to expand ICT4D literature by investigating the associations between international trade of technological goods and development across countries. Using the theory for international technology diffusion and utilizing a spatial dynamic panel data (SDPD) model of 229 countries from 2000 to 2019, we examine the effects of both imports and exports of technology driven trade and foreign direct investment on two measures of development, GDP and socio-economic development. Additionally, we investigate R&D spillovers through the import channels of reporting countries and discover a significantly positive effect from foreign R&D on development.

INTRODUCTION

This paper investigates the effects of both exports/imports of technological goods and foreign direct investment on development. Prior literature has explored various components of technology, mainly information and communication technologies (Ganju et al. 2015), and their related factors such as IT cost (Hosman and Armey 2017), IT investments (Dewan and Kraemer 2000; Ngwenyama et al. 2006), IT infrastructure (Andoh-Baidoo et al. 2014; Dewan et al. 2010; Meso et al. 2009), IT access (Baliamoune□Lutz 2003; Loh and Chib 2019; Rampersad and Troshani 2020) on development. In relation to trade, ICTs have been studied along with trade policies (Baliamoune□Lutz 2003) and openness to trade (Adeleye et al. 2021). The dependent variable, development, at the country-level has primarily been studied through economic growth, as measured through gross domestic product or GDP per capita, and through socio-economic development, as measured through the human development index (Bordé et al. 2009).

A Similar stream of literature also looks at technology diffusion, bridging the gap between the haves and the have nots, as a means of reducing global poverty. The rate of technology diffusion differs within each social group. Diffusion rate is dependent upon many social factors such as cost, accessibility, and familiarity with technological change, but sometimes technology diffuses across international borders as well. We can define international technology diffusion as the diffusion of technology across international borders and into new social systems, where we view technology as knowledge (Keller 2004). International technology diffusion is dependent upon knowledge attainment of a foreign technology and the use of technologies invented abroad. Trade and foreign direct investments (FDI) are often seen as the driving mechanisms for international technology diffusion. Our first research question is: “how is development, both economic growth and socio-economic development, impacted from international technology diffusion through trade and foreign direct investments?” We begin our research by using a technology diffusion lens to guide our hypotheses of international trade of technological goods and foreign direct investment on both economic growth and socio-economic development, as seen in Figure 7.

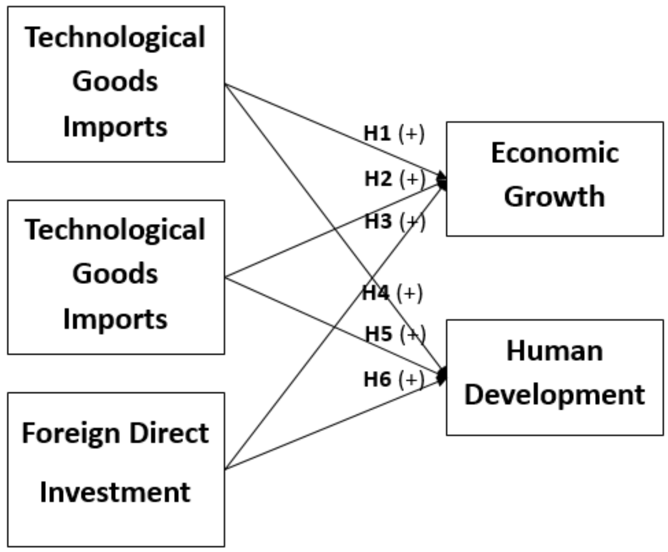

Figure 7. Trade of Technological Goods & Foreign Investment Development Model.

Additionally, trade dependencies can present a bias that affects the diffusion of technologies and development of a nation. As the world becomes more and more interconnected, bi-lateral trade flows have evolved to include more and more intermediate products (de Soyres and Gaillard 2020), especially technological goods. They noted that when two countries have similar industrial structures, their trade in inputs is more closely associated with higher GDP. In regards to division of production processes, Adam Smith quotes:

> One man draws out the wire, another straights it, a third cuts it, a fourth points it, a fifth grinds it at the top for receiving the head; to make the head requires two or three distinct operations; to put it on, is a peculiar business, to whiten the pins is another; it is even a trade by itself to put them into the paper; and the important business of making a pin is, in this manner, divided into about eighteen distinct operations, which, in some manufactories, are all performed by distinct hands, though in others the same man will sometimes perform two or three of them. (Smith 1776)

Today, production processes are being exported to other countries at a growing rate. Global supply chains are increasingly connecting countries and creating systemic interdependence above and beyond direct trade partners. This means that a single product could go through more than two countries from raw materials to final product. These trade dependencies present a bias that need to be accounted for within development models that include bilateral trade. Prior literature has investigated development spillover effects due to spatial (geographical) bias (Pick et al. 2021; Yu Ho et al. 2013). In their study, (Pick et al. 2021) noted a limitation and call for future research to investigate independent variables based on trade dependencies. That is, spatial bias, also known as spillovers, within trade networks. This leads to our second research question: "do bilateral trade spillovers have a significant contribution toward development?"

Our paper explores the gap in the literature by looking at both imports and exports of technological goods, foreign direct investments, and R&D spillovers through the imports channel of technological goods on both economic growth and socio-economic development. Prior ICT4D research has investigated how technologies may promote trade-growth within a country (Adeleye et al. 2020), and how ICT diffusion is linked with R&D intensity in creating economic growth (Sağlam 2018), but very little is mentioned about the spillover effects from R&D intensity of trading partner countries and foreign direct investment (Valery Samoilenko 2013). The International Technology Diffusion literature has made more ground with studying the spillover effects of R&D from partner countries, through geospatial, bilateral import channels, and foreign direct investment channels (Amidi and Fagheh Majidi 2020; Costantini and Liberati 2014; Ertur and Koch 2011; Keller 2004; Seck 2012; Servén and Abate 2020; Yu Ho et al. 2013). This research utilizes new growth theories, such as Schumpeterian growth theory, which suggests that innovation is the major source of technological advance, and in turn drives growth. However, in these primarily economic disciplined papers, the IT component is missing, suggesting that endogenous technological progress is synonymous with knowledge accumulation.

For this, we use 20 years of country-level archival data of both imports and exports of technological goods and foreign direct investment as predictors of economic growth and socio-economic development. Additionally, we investigate the significance of international spillovers from R&D through the imports channel of technological bilateral trade on both economic growth and human development by including a spatially weighted term in our model. Within the last few decades, there has been a phenomenon of increased trade over growth. This is likely due to global supply chains exchanging more and more intermediate products than final goods as production processes are segmented more and more. These segmented processes are taking place internationally, requiring technological progress with all countries within the supply chain.

The rest of the paper is organized as follows. The second section of the paper will discuss the literature review and hypotheses development. The third section will give further details on the data and the methodology used. The fourth section will report the analysis and results. Finally, the last section will include discussion, limitations, and conclusion.

LITERATURE REVIEW

INTERNATIONAL TECHNOLOGY DIFFUSION

Early growth theories viewed technology as a major source of economic growth, but it was underwhelmingly assessed within models. The neoclassical growth model considered technological progress as exogenous, leaving no room for economic policy to enhance a country's R&D sector or to promote the absorption capacity for foreign R&D. However, the importance of R&D spillovers was still noted as reason for why developing countries were not keeping up to countries at or near the technological frontier. With the advent of new growth theories, such as

Schumpeterian model, technology development could be understood as an endogenous process. In such a technologically driven growth model, technology can diffuse through trade and foreign direct investments. International trade supplies new goods with foreign knowledge, and can promote both quality of existing intermediate inputs or capital goods and increase the variety of differentiated inputs. Foreign direct investment creates a partnership with a technologically advanced country, allowing access for more efficient production processes. Additionally, foreign firms that do business domestically will increase the competition, thereby forcing competing domestic firms to either imitate the foreign firm's production processes or acquire the technology inputs themselves (Holmes and Schmitz Jr 2001). Foreign direct investment can also bring over knowledgeable workers from the technology-advanced foreign firm. Spillovers can transfer directly from employee interaction.

Even within early growth theories, R&D spillovers were noted to benefit a country's or industry's "process-oriented" and/or "product-oriented" innovations. The former innovation typically refers to new production methods that lower the costs of operation. The latter refers to innovations of new goods or better-quality goods. Following with these two types of innovations are two types of R&D spillovers, "rent spillover" and "knowledge spillover". Rent spillovers refer to as knowledge-embodied inputs, purchased lower price than the quality improvement of the input. This type of spillover has nothing to do with capital equipment, but rather an improved price-quality ratio. Knowledge spillovers refer to the benefits a country gains from the R&D practices of another country. These types of spillovers don't require the purchase of capital inputs. Knowledge spillovers can be broken down to two type: "imitation-enhancing" and "idea-creating". Imitation-enhancing is the knowledge gained and imitated by other competitors, whereas idea-creation is accumulation of foreign knowledge to produce a new idea.

For this paper, we will focus on knowledge spillovers, and primarily imitation-enhancing spillovers through imports of technological goods. Product-oriented innovations are more likely to be imitated through trade than process-oriented innovations, and R&D activity heavily favors product-oriented innovations (Verspagen and Los 2007). We realize that our data cannot fully separate out knowledge spillovers from rent spillovers, and this is considered a limitation with our data.

Additionally, some countries lack the capability to assimilate foreign knowledge, and continue to lag behind countries near or at the technological frontier. Within the international technology diffusion literature, there is a notion about a country's absorptive capacity. Absorptive capacity refers to the characteristics of a country to absorb knowledge from foreign R&D. The two most commonly used absorptive capacities are human capital, measured through level of education, and institutional capital, measured through political indexes. Absorptive capacity implies that if a country does not have sufficient absorption capabilities for new knowledge, then spillover effects will not take place (Westphal et al. 1985). Our study has a second limitation due to data constraints. Human capital is highly correlated with our dependent variable, socio-economic development, and therefore we decided not to include it. Institutional capital measures are quite limited to the number of countries available and the dates available, mostly high-income countries in more recent years are available.

DEVELOPMENT – ECONOMIC GROWTH

The World Bank has taken on the task of studying country-level development starting near the end of World War II in 1946. The task initially began as an effort to bolster post-war reconstruction, and progressed beyond infrastructure to educational, healthcare, and agricultural needs. Loans were given out to countries to help in these efforts. Economic growth, measured through GDP, was their first measure of country-level development. Economic growth, then, is a comparison of a country's economy on the international market.

ICTS & ECONOMIC GROWTH

Researchers are beginning to study the effects of ICTs and development of a country. Policy-makers and the World Bank alike are reviewing the importance of ICTs on development (Deloitte 2014; UN-Millennium-Project 2005; UNDP 2012). IT capital and non-IT capital investments to economic growth were analyzed between 36 developed and developing countries with the former seeing positive results from IT investments but non-significant results for the latter (Dewan and Kraemer 2000). Financial inclusion, supported by ICT development, has shown improved economic growth in a study of 41 countries in a fixed-effects panel data model (Chatterjee 2020). Improved broadband network penetration and speed has been found to significantly and positively impact economic growth in countries with low penetration and speeds (Mayer et al. 2020).

The arguments above support the claim that more ICT development in a country would improve its economic engine. Sometimes ICT development can be improved domestically, but for a lot of under-developed countries this may not be the most efficient strategy. International trade of technological goods can help support the deficiencies of a country's ICT infrastructure. International trade in technology has been positively associated with product variety, volume of trade, and national income between countries (Spulber 2008).

TECHNOLOGICAL TRADE & ECONOMIC GROWTH

Technology diffusion plays an important role for ICTs and development. Technology diffusion, also known as diffusion of innovation, is a theory that represents the adoption of new innovations within a defined social system. The rate of diffusion is determined through the time that an adopter or non-adopter takes to reflect upon the innovation's social influence in their lives. International technology diffusion is then the diffusion of technology across international borders and into new social systems. The two driving mechanisms for international technology diffusion are (1) direct learning about foreign technological knowledge and (2) employing specialized and advanced intermediate products that have been invented abroad (Keller 2004). Technological knowledge is considered the design for a new intermediate product.

Technology helps explain the disparity of income levels across countries. Human capital and physical capital also help to explain income levels, but lack in explaining the differences between countries (Easterly and Levine 2001; Prescott 1998). Technological change does indeed differ across countries and impacts the distributions of incomes. For example, United States firms have invested nearly $4 trillion into technology in 2019 alone and have one of the highest per capita incomes in the world. Many poorer countries are less likely to spend capital on domestic technological investments. They rely heavily upon foreign sources of productivity growth. Spillover effects occur when non-domestic technological knowledge and products are obtained without incurring the initial IT investments in the R&D process.

Research has shown that imports of ICT goods leads to increases in productivity and growth through an international diffusion of technology (Benhabib and Spiegel 1994; Coe and Helpman 1995; Eaton and Kortum 1994; Eaton and Kortum 1996; Parente and Prescott 1994). Technology is first manufactured in the inventor’s country, and then exported and diffused to trade partner countries (Coe and Helpman 1995). A new model for innovation and international diffusion of technology was made by Eaton and Kortum (1996) to help explain the relative productivity and growth among OECD countries. In their model, productivity is dependent on a country’s ability to innovate or adopt new technology. Import new technologies are used as intermediate inputs of production, thereby increasing the partner country’s productivity.

More recently, researchers have been studying the “leapfrogging” hypothesis (Steinmueller 2001). This hypothesis states that development stages can be skipped when a radically new innovation permits usage without the need to go through prior development stages. A study on the relationship between three ICT indicators and economic growth in Africa from 2005-2015 shows that mobile subscriptions are leapfrogging internet and fixed telephone subscriptions and their importance for growth (Adeleye and Eboagu 2019a). Adeleye et al. (2020) investigated the effects of mobile and fixed phone subscriptions and found an interaction effect with trade on economic growth. Similarly, using a GMM estimator, researchers study the effects of digitalization on economic growth in 74 Sub-Saharan African and OECD countries, showing that digitalization is the primary driver of economic growth (Myovella et al. 2020). In another longitudinal study of 192 countries from the years 1990-2007 show that mobile telecommunications increased GDP by 0.11% for low-income countries and 0.20% for high-income countries (Gruber and Koutroumpis 2011). With imports of new ICT innovations, countries can leap-frog development stages and increase their productivity, measured through GDP. Therefore, we hypothesize:

Hypothesis 1: Imports of technological goods are positively correlated with economic growth.

Economic growth has a long stream of literature with international trade. Singh (2010) surveyed the literature on growth and trade and reports mixed support and evidence for their interaction. Trade openness and economic growth were in-fact negatively correlated a century ago; not correlated during the interwar period (Foreman-Peck 2006; O'Rourke and Williamson 1999; Vamvakidis 2002); and significantly correlated within recent decades (Clemens and Williamson 2004; Vamvakidis 2002). However, correlation does not imply causation. Duel hypotheses were challenged with 'export-led growth' versus 'growth-led export'. Early in the literature, it was hypothesized that trade served as the 'engine of growth', but only for developed countries in the nineteenth century (Nurkse 1961). This claim was countered by Kravis (1970) when growth was examined in the 1950s and the 1960s for developing countries, asserting that favorable internal factors led to growth with external demand stimulating these factors.

Lots of empirical evidence from time-series models backs up the ‘export-led growth’ hypothesis (Balassa 1978; Balassa 1984; Bodman 1996; Emery 1967; Fajana 1979; Feder 1983; Freund and Bolaky 2008; Greenaway and Sapsford 1994; Heller and Porter 1978; Henriques and Sadorsky 1996; Jung and Marshall 1985; Kavoussi 1984; Keho 2017; Kong et al. 2021; Kpomblekou and Wonyra 2020; Maizels et al. 1968; Michaely 1977; Moschos 1989; Ram 1987; Salahuddin and Gow 2016; Tyler 1981; Voivodas 1973; Williamson 1978); some had limited support for ‘export-led growth’ hypothesis (Boltho 1996; Calderón et al. 2004; Chang et al. 2009; Chen and Tang 1990; Chow 1987; Kugler 1991); and some others had mixed findings (Eriș and Ulașan 2013; Kunst and Marin 1989; Manwa et al. 2019; Nishimizu and Robinson 1984; Oxley 1993; Tybout 1992; Were 2015; Zahonogo 2016).

Cross-country models also show a significantly positive relationship between export and growth (Balassa 1985; Ram 1987). It is noted that export expansion leads to higher total factor productivity (TFP) growth, growth that is not by input changes in labor and capital, while import substitution leads to lower TFP growth. Research on the productivity effects of trade began to include trade-induced convergence in income per capita and growth across countries, showing significant and positive effects of trade on productivity and growth (Alcalá and Ciccone 2004; Ben-David 1993; Ben-David 1996; Dollar 1992; Edwards 1998; Harrison 1996; Sachs et al. 1995; Vamvakidis 1999). Based on the previous section’s literature on ICTs and development and the above argument for exports and growth, we hypothesize:

Hypothesis 2: Exports of technological goods are positively correlated with economic growth.

FOREIGN DIRECT INVESTMENT & ECONOMIC GROWTH

There is an increasing body of literature that has found a positive role for foreign direct investments as a potential path for knowledge transfer (Hu and Jaffe 2007; Saggi 2002; Seck 2012), and its role in influencing economic growth (Hansen and Rand 2006). Foreign direct investment is recognized as the primary channel for diffusion in developed countries, whereas developing countries diffuse knowledge primarily through trade flows by expanding the variety of intermediate goods for domestic production and disseminating knowledge about product design, production processes, and managerial methods (Coe et al. 1997). We do not yet know all of the intricacies involved with foreign direct investment on growth. What we do know is FDI can encourage the adoption of foreign technology for production processes. Advanced production processes create inner firm efficiencies that enhances its competitive advantage. Additionally, FDI can promote knowledge transfer from foreign skilled workers, alternative managerial practices, and better organizational arrangements (Hansen and Rand 2006). Based on the above, we hypothesize:

Hypothesis 3: Foreign direct investments are positively correlated with economic growth.

DEVELOPMENT – HUMAN DEVELOPMENT

By 1990, the first Human Development Report was published, which included the annual Human Development Index (Bordé et al.). Human development is a people-centered approach to measuring development based on 3 globally agreed upon dimensions of human progress (i.e., health, education, and income). Many countries have since adopted the human development as a measure of a country's individual-level of development.

ICTS & SOCIO-ECONOMIC DEVELOPMENT

Previous literature has investigated the effects of ICTs on development. Research in ICTs of 100 countries have led researchers to believe that investments in ICT infrastructure will increase well-being of citizens through increased social capital, improved crime reporting, transfer of health information, access to educational materials, efficiency in supply chains, and rates for farmer's produce (Ganju et al. 2015). Similarly, a study of 144 countries' national information infrastructure, a broader spectrum than just traditional ICTs that includes all computerized networks, applications, and services, has a significantly positive influence on socio-economic development within nations (Meso et al. 2009). These social factors relate to development at the individual level. Human progress can be measured in multiple ways or dimensions that reflect societies development.

Socio-economic development is a more recent metric for development than economic growth, and thus research on it is more limited. Recent qualitative research has analyzed how participants at technology and innovation hubs in Africa are given more opportunities for not just economic growth, but as participants of a community as well (Jiménez and Zheng 2018). Ngwenyama et al. (2006) studied the relationship between investments in ICT, in education, and in healthcare of 5 African nations between 1993-2003 and found the former 2 have a positive impact on socio-economic development. Similarly, studying the effects of mobile phone penetration and innovations in 49 sub-Saharan African countries between years 2000-2012 shows improvements to socio-economic development, despite the country's level of income, legal origins, religious orientation and state of the nation (Asongu 2020). ICTs help bring knowledge to users that they may not otherwise receive. More knowledge can lead to better decisions in all facets of life, as measured partially by socio-economic development.

TECHNOLOGICAL TRADE & SOCIO-ECONOMIC DEVELOPMENT

As part of a gap in research, little is known about the effects of technological trade and socio-economic development. One study looks at the impact of mobile and fixed telephone indicators in 53 African countries from 2005-2015 as enhancers of the trade openness on growth (measured through both GDP and HDI) (Adeleye et al. 2020), but this study does not capture the impact of imports or exports of technological goods on socio-economic development. Other research that also studied trade openness and socio-economic development, countries who are more open have a higher level of socio-economic development and a higher rate of improvement in socio-economic development over time (Eusufzai 1996). Using data of a 5-year average on 47 developing countries in the years 1965-1990, Nourzad and Powell (2003) find that trade openness is positively related to economic growth and socio-economic development. However, Adeyemi et al. (2006) did not find any significant relation between the international trade of 41 Sub-Saharan Africa countries and socio-economic development in the year 2003. Looking at only 11 oil rich countries form 1998-2009, Razmi and Yavari (2012) found a significantly positive relation between trade openness and socio-economic development. Another study looking at 38 Organization of Islamic Council (OIC) countries for the years 1980-2005 and find a positive relationship between trade and socio-economic development, but insignificant relationship with only the health and education portions of the HDI (Hamid and Mohd Amin 2013). In a time-series analysis of Pakistan's aggregated and disaggregated international trading from years 1980-2013, exports of primary and manufactured goods as well as imports of capital goods were shown to improve socio-economic development (Jawaid and Waheed 2017).

The above studies show mixed findings for trade openness and socio-economic development. What is not looked at is the trade of just technological goods and its relation with socio-economic development. As noted before, technology improves all facets of life through knowledge attainment and better decision planning. Some countries have little to no investment in

IT, and thus international technological diffusion is key to acquiring technological knowledge and employing specialized and intermediate products to enhance socio-economic development. Thus, we hypothesize:

Hypothesis 4: Imports of technological goods are positively correlated with socio-economic development.

In Jawaid and Waheed (2017)'s study on Pakistan's aggregated and disaggregated exports and imports on socio-economic development, the disaggregated portions did not solely look at technological trade. The authors here believe that economic growth and socio-economic development share the relation of income per capita, and thus any increase in economic growth through exports would share some relation with the individual income portion of socio-economic development. In other words, as a country's exports increase, the incomes of individuals working for the exporting firms within the country also increase. Incomes is only a third of the HDI, so the relationship between exports of technological goods and socio-economic development would be weaker, but still significant. We hypothesize:

Hypothesis 5: Exports of technological goods are positively correlated with socio-economic development.

FOREIGN DIRECT INVESTMENT & SOCIO-ECONOMIC DEVELOPMENT

Although technology diffusion has been concentrated on economic growth, some incite has been revealed to the lesser studied socio-economic growth with regards to foreign direct investment. Knowledge stock, channeled through FDI, can be stored up as public knowledge, thereby disseminating itself very rapidly and used in multiple locations simultaneously (Costantini and

Liberati 2014). Knowledge stored up in the public sector is also highly dependent on the absorptive capacity of the country. Developed countries are more likely to receive knowledge spillovers through FDI for this reason. We hypothesize:

Hypothesis 6: Foreign direct investments are positively correlated with socio-economic development.

TRADING PARTNER SPILLOVERS

There are two bodies in the economics literatures that suggest international trade influences the growth of nations. The first body includes the empirical works suggesting exports or outbound movements across countries with varying frequencies promote growth. The second includes the degree of foreign knowledge transferred through importing goods such as technological progress. In this second body of research, domestic productivity is found to be impacted by the import share weighted sum of R&D expenditure among trading partner countries, thereby suggesting that knowledge and technology transfer is enabled through trade (Coe and Helpman 1995). Thus, global interdependence, as a result of trade, needs to be addressed in growth models. As Yu Ho et al. (2013 eloquently states:

> In neoclassical growth theory, economies are assumed to be independent, and they do not interact with each other. However, technological advances in one economy might be transmitted to other economies. Also, international trade connects economies, thus creating output co-movement among countries with large trade volume. Consequently, the closed economy assumption might not be valid, and we need to take into account possible spatial correlation (Yu Ho et al. 2013).

In econometrics, when the sample has correlation within itself, the independency assumption is violated and statistical outcomes become unreliable. When dealing with international trade networks, explanatory variables of one country are often correlated with the same variable of a neighboring country or trading partner. When this phenomenon occurs, we call it a spillover effect. An example would be a supply chain incorporating a new automation system for tracking orders. The trading partners would benefit from the system, freeing up time from manually inputting tracking information. The general consensus is that technology transfer through spatial spillovers do exist, but relevant empirical literature is lacking (Ditzen 2018; Grossman and Helpman 2015; Jones 2016). To capture these spillover effects related to bilateral trade, a spatial autoregressive term must be added either for cross-sectional data (Ertur and Koch 2011) or for panel data (Amidi and Fagheh Majidi 2020; Kohansal and Hamidehpour 2019; Servén and Abate 2020; Yu Ho et al. 2013). In their (2011) research, Ertur & Koch show how a Schumpeterian growth model performs better than a neoclassical growth model when international R&D spillovers are accounted for. This model was extended to include a spatial time lag term and tested with 26 OECD countries from 1971-2005, showing a positive spillover through bilateral trade on economic growth from a country to its trading partners (Yu Ho et al. 2013). More recent research included several ECO countries along with the OECD countries into the model from 2001-2015, showing that only physical capital contributed to growth in developing countries whereas physical capital, human capital, and trade contributed to developed countries' growth (Kohansal and Hamidehpour 2019). Spatial spillovers from geographical distance and bilateral trade of 25 developed countries were also discovered to be key economic growth determinants for the years 1992-2016 (Amidi and Fagheh Majidi 2020). In the same year, Servén & Abate analyzed 117 countries over the years 1970-2016, and included global shocks summarized by a latent common factor along with the spatial spillovers from geographical distance and bilateral trade linkages into the model (Servén and Abate 2020). They found that openness to trade and the degree of commodity specialization within the economies is positively related to a country's exposure to global shocks.

Similar studies look at the impacts of technology spillovers from R&D investments in developing countries, finding that their total factor productivity increases when there is more openness to trade, especially from foreign R&D capital (Coe et al. 1997; Coe et al. 2009; Seck 2012). Developed countries were seeing a 120 percent return from R&D investments, and their trading partners were seeing an additional 30 percent (Coe and Helpman 1995). Conversely, Seck (2012) sought to answer the impact for a developing country's productivity and found more than a two percent increase in total factor productivity from a ten percent increase in the country's foreign R&D capital stocks . These investments are attributed with "process-oriented" innovation and "product-oriented" innovation that in return reduces a country's cost of production and increases innovation of current or new products (Griliches 1979). These product- and process-oriented innovations are also documented as a type of knowledge spillover. Knowledge spillovers are obtained when a country or industry benefit from the R&D practices from another country or industry (Seck 2012). For example, if a firm purchase and employs a newly developed technology, that firm has benefited from knowledge spillovers. In these studies, researchers find that developing countries, those who are least likely to afford R&D investments, are likely to benefit from technology diffusion through trade as an opportunity for economic growth.

This paper seeks to understand how both international technology diffusion, foreign direct investment, and knowledge spillovers from the R&D intensities of partner countries leads to development, both economic growth and socio-economic development. More developed countries are typically associated with higher volumes and usage of innovative technologies (Adeleye and Eboagu 2019b; Ganju et al. 2016; Loh and Chib 2019; Mayer et al. 2020; Meso et al. 2009). These nations have firms who already poured lots of money into R&D. As these firms expand beyond country borders, knowledge spillovers are obtained. As a firm expands into new countries, the necessary infrastructure is needed, along with purchases of newly developed technology for the supply chain to operate and be efficient. A country that has a higher volume of technological trade is likely to have firms who've invested more in R&D over time. We propose that partner countries who have a higher volume of technological trade are then likely to create knowledge spillovers to the countries they trade with, thereby creating higher process- and product-oriented innovations and economic growth for a country. Both

DATA AND METHODOLOGY

Our data was collected from a few databases and merged based on country ID. As our hypotheses deal with international trade, we selected country-level data as our unit of analysis. The technological trade data comes from the United Nation's Commodity Trade statistics database called World Integrated Trade Solution (WITS 2022). We collected annual international import and export technological trade value data using the ISIC 2-digit code, ISIC revision 3 nomenclature with the 1996 harmonized system. The ISIC 2-digit import and export product codes used were 30 (manufacture of office, accounting and computing machinery), 31 (manufacture of electrical machinery and apparatus N.E.C.), and 32 (manufacture of radio, television and communication equipment and apparatus) for the years 2000 – 2019. We then aggregated the three collected codes for total technological imports and exports between countries. Country GDP and inbound foreign direct investment data comes from The World Bank (WB 2021a). Finally, socio-economic development is measured through the human development index (Bordé et al.), and is collected from the United Nations Development Programs' Human Development Report (UNDP 2020).

All datasets were matched by the reporting economy's three-digit code. The year 2018 was the most recent that all datasets had available. The sample is 229 countries. Using R, our analysis utilizes spatial autocorrelation regression based upon spillover effects relating to bilateral trade. A spatial weight matrix is implemented using ones and zeros for trade partner or non-trade partner of technological goods. Moran's I is measured to check for autocorrelation between trading countries. A p-value at or below 0.05 suggests there is autocorrelation happening. A spatial dynamic panel data (SDPD) model is appropriately utilized to model growth spillover effects of a country from the growth of the trading partners. Spatial econometric models account for spatial autocorrelation and/or spatial heterogeneity which can cause inaccurate interpretations in the association between independent and dependent variables (Anselin 1988; Anselin et al. 1996; Voss et al. 2006). Spatial dependence causes a bias and unreliability for ordinary least squares estimators (Anselin and Bera 1998; LeSage and Pace 2009). Our models allow the growth from knowledge spatial spillovers of trading partners trading activity to be estimated by including lagged independent variables. The base SDPD model is written as:

$$lnGDP_{i,t} = \beta_1 lnI_{i,t} + \beta_2 lnE_{i,t} + \beta_3 lnFDI_{i.t} + \beta_4 W_i^{IMP} R\&D_{j,t} + \gamma_i + \delta_t + \varepsilon_{it} \quad (1)$$

$$HDI_{i,t} = \beta_0 + \beta_1 lnI_{i,t} + \beta_2 lnE_{i,t} + \beta_3 lnFDI_{i.t} + \beta_4 W_i^{IMP} R\&D_{j,t} + \varepsilon_{it} \quad (2)$$

where $lnGDP_{i,t}$ represents the natural log of the gross domestic product for country i and time t. $HDI_{i,t}$ is the squared proxy for socio-economic development for country i at time t. lnI represents the natural log of imports of technological goods at time t, whereas lnE represents the natural log of exports of technological goods at time t. FDI is our measure for foreign direct investments, where lnFDI is the natural log of FDI divided by GDP to get the ratio of FDI to GDP of the country. W^{IMP} represents the import weight matrix for country i and multiplied by the R&D intensities from country j at time t and this value is then normalized by dividing by the mean and then squaring this value. Finally, γ_i country fixed effects and δ_t represents yearly fixed effects.

RESULTS

MODELING ECONOMIC GROWTH

First, to verify the need for panel data, the data was analyzed for heteroscedasticity. The Breusch-Pagan test shows that there is heteroscedasticity in the data and therefore traditional OLS regression is not appropriate ($BP_4 = 307.02$, $p < 0.001$). Next, to test whether this heteroscedasticity is due to time, the Lagrange Multiplier Test using Breusch-Pagan for unbalanced panels shows that panel effects do exist in the data ($\chi^2_1 = 13{,}119$, $p < 0.001$), providing credence to our use of panel analysis methods. Next, given the spatial/network context of the trading partners within the dataset, cross-sectional dependence was tested. The Breusch-Pagan LM test for cross-sectional dependence shows significant cross-sectional dependence in the data ($\chi^2_{13522} = 65{,}939$, $p < 0.001$). Given this, identifying the source of this cross-sectional dependence is key. Given the network effects within our data, the presence of cross-sectional dependence warrants the inclusion of these network-based effects. With the need for panel analysis established, the use of a fixed vs. random effects model was investigated. The Hausman Test found that the fixed model is significantly different from the random effects model, supporting use of the fixed effects model ($\chi^2_4 = 137.4$, $p < 0.001$). With the fixed model established, tests were run to verify the need for unit and/or time fixed effects. The Lagrange Multiplier test found a significant need for both unit and time effects to be included in the model (93.85, $p < 0.001$).

Running the base model (Model1), we found that imports ($\beta = ^{0.144}$, $t = 23.36$), exports ($\beta = 0.007$, $t = 3.27$), and R&D spillovers ($\beta = 0.085$, $t = 4.59$) have a significant impact on GDP, resulting in an R^2 of 0.22. After running this model, we tested for serial correlation in the base panel model. The Breusch-Godfrey/Wooldridge test for serial correlation in panel models shows that there is error in the time series from one period to another and therefore lags are warranted ($\chi^2_2 = 1586.6$, $p < 0.001$). Model2 was run by including a one-year lag for each variable in the model. Results show that, in addition to current imports, exports, and R&D spillovers, imports (β = 0.085, t = 9.82), exports (β = 0.006, t = 2.55), and R&D spillovers (β = 0.079, t = 3.55) from one year prior also significantly impact GDP. This impact is even more apparent in the R^2 value increase to of 0.30. A third model was run to examine both a one and five-year lag. These results showed that the imports (β =0.042, t = 6.25) and R&D spillovers (β = 0.079, t = 3.49) from five years prior again predicted a significant amount in GDP, beyond those already predicted by the current year. However, this five-year lag did not explain an increased amount of variance with an R^2 of 0.30. Table 8 shows the model statistics.

Table 8. GDP Model Statistics

	Model1		Model2		Model3	
	β	t	β	t	β	t
imports	0.144	23.36***	0.091	10.28***	0.089	9.52***
exports	0.007	3.27**	0.006	2.39*	-0.002	-0.82
FDI	0.005	0.35	-0.002	-0.17	-0.001	-0.11
W x R&D	0.085	4.59***	0.050	2.66**	0.046	2.48*
$imports_{t-1}$			0.085	9.82***	0.067	7.26***
$exports_{t-1}$			0.006	2.55*	0.006	2.62**
FDI_{t-1}			0.005	0.41	-0.006	-0.54
W x $R\&D_{t-1}$			0.079	3.55***	0.037	1.66
$imports_{t-5}$					0.042	6.25***
$exports_{t-5}$					0.004	1.85
FDI_{t-5}					0.003	0.24
W x $R\&D_{t-5}$					0.079	3.49***
Year F.E.	Yes		Yes		Yes	
Country F.E.	Yes		Yes		Yes	
R^2	0.22		0.30		0.30	

MODELING SOCIO-ECONOMIC DEVELOPMENT

First, to verify the need for panel data, the data was analyzed for heteroscedasticity. The Breusch-Pagan test of shows that there is heteroscedasticity in the data and therefore traditional OLS regression is not appropriate (BP_4 = 185.91, p < 0.001). Next, to test whether this heteroscedasticity is due to time, the Lagrange Multiplier Test using Breusch-Pagan for unbalanced panels shows that panel effects do exist in the data (χ^2_1 = 20,803, p < 0.001), providing credence to our use of panel analysis methods. Next, given the spatial/network context of the trading partners within the dataset, cross-sectional dependence was tested. The Breusch-Pagan LM test for cross-sectional dependence shows significant cross-sectional dependence in the data (χ^2_{13522} = 79,461, p < 0.001). Given this, identifying the source of this cross-sectional dependence is key. (Chudik et al. 2011) delineate a distinction between weak and strong forms of cross-sectional dependence by identifying whether this dependence is based on spatial/network patterns or unobserved common factors. With regard to spatial components, previous research has demonstrated the effect these spatial patterns can have within panel data (Holly et al. 2010; Holly et al. 2011). Given the network effects within our data, the presence of cross-sectional dependence warrants the inclusion of these network-based effects. With the need for panel analysis established, the use of a fixed vs. random effects model was investigated. The Hausman Test found that the fixed model is not significantly different from the random effects model, supporting use of the random effects model (χ^2_4 = 4.13, p = 0.39).

Running the base model (Model1), we found that imports (β = 0.051, z = 41.20), exports (β = 0.002, z = 4.24), and R&D spillovers (β = 0.011, z = 8.29) have a significant impact on HDI, resulting in an R^2 of 0.53. After running this model, we tested for serial correlation in the base panel model. The Breusch-Godfrey/Wooldridge test for serial correlation in panel models shows that there is error in the time series from one period to another and therefore lags are warranted (χ^2_2 = 1176.7, p < 0.001). Model2 was run by including a one-year lag for each variable in the model. Results show that both imports (β = 0.01, z = 5.82) and R&D spillovers (β = 0.083, z = 44.27) account for a substantial impact one year prior to the focal year. This impact is even more apparent in the R^2 value of 0.76. A third model was run to examine both and one and five-year lag. These results showed that imports (β = 0.008, z = 6.44) and R&D spillovers (β = 0.060, z = 26.31) from five years prior again predicted a significant amount in; however, the loss of years due to the extra time lag showed only a minimal improvement in R^2 to 0.77. Table 9 shows the model statistics.

Table 9. HDI Model Statistics

	Model1			Model2			Model3		
	β	z		β	z		β	z	
Intercept	-0.215	-8.84	***	0.092	3.96	***	0.144	5.35	***
imports	0.051	41.2	***	0.014	8.47	***	0.013	7.54	***
exports	0.002	4.24	***	0.001	1.27		-0.001	-1.17	
FDI	-0.005	-1.36		-0.002	-0.68		-0.003	-1.50	
W x R&D	0.011	8.29	***	-0.010	-9.92	***	-0.006	-6.95	***
$imports_{t-1}$				0.010	5.82	***	0.004	2.51	*
$exports_{t-1}$				0.001	1.11		0.000	1.02	
FDI_{t-1}				-0.004	-1.47		-0.005	-2.41	*
W x $R\&D_{t-1}$				0.083	44.27	***	0.018	7.15	***
$imports_{t-5}$							0.008	6.44	***
$exports_{t-5}$							0.000	0.64	
FDI_{t-5}							-0.001	-0.29	
W x $R\&D_{t-5}$							0.060	26.31	***
R^2	0.53			0.76			0.77		

DISCUSSION

Economic growth and socio-economic development are two distinct measures for development. Economic growth measures a countries productivity level, whereas socio-economic development is more of an individual measure. We discover in our analysis that economic growth and socio-economic development are fueled by different parts of an economy, where the former is highly dependent on trade intensity, both imports and exports, the latter is more dependent on knowledge spillovers, over time, through the import channel of technological goods. Neither economic growth nor socio-economic development are dependent on foreign direct investment except with the 1-year lag in the 3rd model for socio-economic development.

Within the economic growth models, we can see that both imports and exports play an important role in determining growth. When introducing the lag effects, the direct impact from exports diminish over time. This is likely due to the continuous splintering of production processes and reduced competitive advantages across the globe. It is better for parts of production processes to be outsourced when other countries can produce them at lower costs. This means that an increase in both the imports intermediate goods and exports of intermediate or final goods have a strong immediate influence on economic growth. In our particular study, we focused on the trade of technological goods, which can also be absorbed by a country to increase production processes even further than just the aggregation of all imports and exports.

Country and year fixed effects within the GDP model were analyzed to understand how they impacted the regression. For the year fixed effects, the only year that was slightly significant when calculating the difference from the overall mean was 2002 (p=0.9), with all other years insignificant. Additionally, years 2000-2007 showed positive estimates, but the signs changed to negative every year until 2019 within the year fixed effects model. A possible explanation for this change was 2008 marked the beginning of a global recession that lasted a long time. For country fixed effects, the vast majority of the countries were significant, and only 16 countries in the sample had no significance. Additionally, looking at the country fixed effects, developing countries were much more likely to have negative estimates within the model.

Within the international technology diffusion literature, R&D investments are not confined to the local country. These investments can spillover to foreign countries with strong economic ties. The R&D spillovers play a significant role in both economic growth and socio-economic development models, giving credence to the beneficial effects of R&D spillovers through the imports channel of technological trade. R&D spillovers are significant in models 1-3 for both measures of development, giving credence to the immediate and lagged impacts of foreign research spilling over to trade partners. Often times, poor countries who have little money to invest in their own R&D projects can reap the rewards from other countries' R&D investments, provided they develop significant absorption capabilities like human capital. A limitation to our research is the lack of well-defined absorption capabilities like human and institutional capital.

A key takeaway for socio-economic development is the impact it receives from importing technological goods in the same year and with one- and five-year lags, whereas exports become insignificant within the lagged models. Within the ICT4D literature, the information and communication technologies are often viewed as a means to an end rather than an end in themselves. Added resources are viewed as expanding potential options to choose from to meet our goals. In this current research, our resources are the imported technological goods that both firms and individuals of a country have chosen and purchased to meet their goals. ICTs are often used for their information gathering abilities. As individuals are able to gather more information in their lives, they are able to make better informed decisions. With the one- and five-year lagged effects on imports, information has enough time to can disseminate among the population for a societal benefit. Exports show significance for the immediate year, showing the relationship between individual's income and levels of exports.

Additionally, foreign direct investment shows no significant correlation with economic growth and only in the five-year lagged model for socio-economic development. Foreign direct investment is an additional means for knowledge spillovers to take place. FDI enables a host country to develop a relation with the more technologically advanced partner country. This relation could bring about other spillover effects towards socio-economic development that this particular study was not able to capture. Such an example could be with overseas skilled labor moving into a host country to help with new production operations. Educational knowledge spillovers could occur between the skilled laborer and his/her social network in the host country. Regrettably, our models were not able to incorporate spillover effects from FDI due to lack of dyadic relational FDI data available. However, our inclusion of FDI as a direct effect showed potential for socio-economic growth over time.

Finally, the lagged models of both economic growth and socio-economic development outperform the non-lagged model by having higher R^2 values. This helps us understand how economic growth and socio-economic development do not change rapidly from importing technological goods and knowledge spillovers. It can take time for new knowledge to disseminate throughout a country and for production processes to ramp up.

Our study has several limitations, such as the previously mentioned lack of absorptive capacity. In order for us to collect data on 229 countries, we had to utilize secondary databases in our research. This inherently can cause issues with accuracy of the data. Additionally, several countries may not have reported their data during many years. This leads to an omission bias. Finally, our foreign direct investment variable did not measure R&D spillovers like the imports channel due to lack of countries reporting bilateral FDI data. FDI could play a larger role than what we were able to analyze with our current data.

CONCLUSION

This research sought to understand how international technology diffusion impacts development for both importing and exporting countries. Utilizing prior ICT4D research and the international technology diffusion literature, we developed a twenty-year longitudinal model based on archival data of 229 countries. Our work recognizes the intersecting point between the ICT4D and international technology diffusion literatures. We attempt to bridge these research topics by utilizing the theory for international technology diffusion along with the aggregated trade of technological goods using the ISIC 2-digit codes to explain both economic growth and socio-economic development. Our research discovers that knowledge spillovers through the imports of technological goods channel are highly significant with both economic growth and socio-economic development. This is key to understanding policy strategies for developing countries who are less likely to invest in R&D themselves because they are constantly playing catchup to those countries who are at or near the technological frontier. We also find that both imports and exports are a significant driver of economic growth in all three models, but the significance of exports drops off in the lagged socio-economic models. This is not surprising to hear when we talk about the importance of global supply chains utilizing intermediate inputs from countries who have competitive advantage for different parts of production processes.

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CHAPTER V

CONCLUSION

The goal of this paper is to understand the differences between two predominantly used measures of development, economic growth and human development, and how they are affected by information and communication technologies. The three previous chapters were paramount into understanding how information and communication technologies' impact these different measures for development. The three essays each covered distinct themes: individual opportunity and process *freedoms*, vertical *specialization* within global supply chains, and international technology *diffusion*.

The first essay introduced the concepts of opportunity and process freedoms. Individuals benefit from expanded opportunities along with their process to select among their preferred option. These freedoms are impacted through country-specific conversion factors that play a crucial role in the country's adoption of ICTs. The four conversion factors include ICT cost, ICT infrastructure, e-participation, and freedom of expression on the net, and were analyzed using a regression, showing all conversion factors significantly impact a country's human development.

The second essay presented a novel model with vertical specialization partially mediating technological progress, measured by internet usage and cellular phone subscriptions indicators, on economic growth. In the earlier years, from 1995 to 2004, of our sample, we see a significantly positive direct relation between technological progress and economic growth. In the later years, from 2005 to 2014, we see technological progress significantly impacting economic growth through the partial mediation of vertical specialization. Economic growth is greatly impacted when countries become more involved in global markets through the help of ICTs, but in later years we see economic growth requiring ICTs to vertically upgrade within global supply chains.

Finally, the third essay utilized international technology diffusion theory to investigate the impacts from importing and exporting technological goods, foreign direct investments, and R&D spillovers from partner countries on both economic growth and human development. Our findings show that in the economic growth model, both imports and exports of technological goods and the R&D spillovers contributed significantly and positively towards economic growth, but foreign direct investment had no impact. However, with the human development model we lose significance with exports in the lagged models, but foreign direct investments showed significance with a 1-year lag within 5-year lagged model. This study gives credence to different policy measures for economic growth and human development.

Synthesizing these three essays, we can see how economic growth focuses on the wealth of a nation, but not the wealth of individuals within a nation. Economic growth is highly dependent on international trade, both imports and exports, to generate wealth. Also, economic growth does not well reflect the wealth of citizen within a nation. Human development, on the other hand, reflects more of the social aspects of the citizens. It reflects the multiple dimensions of well-being and the choices people may have or choose towards well-being. Both economic growth and human development benefit from knowledge spillovers, by improving logistical trade and by providing credible and knowledgeable resources to the individual. Policy-makers may be more interested in economic growth measures if the goal is to vertically upgrade in the global marketplace or increase taxable revenue. If policy-makers are more interested in improving citizen’s well-being or understand social ties, then human development would be a better measure for studies.

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APPENDICES

APPENDIX A

In order to provide greater support for our findings, the data was also analysed using Partial Least Squares path modelling. The same model was used whereby ICT Cost (cost), ICT Infrastructure (infra) and E-participation (epart) directly impact Human Development (Bordé et al.), with Freedom of Expression on ICT's (FoE) moderating the impact of epart.

Prior to analysis, endogeneity was assessed for the independent variables in the model. Endogeneity within PLS models has only recently been addressed in the literature (Hult et al. 2018). This novel Gaussian Copula approach involves a multi-part assessment of the independent variables in the model both for their ability to detect endogeneity if it exists, and subsequent testing if appropriate. First, the data was modelled according to the base model outlined above. Using SmartPLS (Hair Jr et al. 2016), the latent variable scores from the PLS algorithm are extracted from the output. Second, R code provided for the method (Jawaid and Waheed)Hult et al., 2018) is used to run the Kolmogorov–Smirnov test with Lilliefors correction (Sarstedt and Mooi 2014) to assess the normality of each independent variable where non-normality is required to further consider the variable for endogeneity in the model. Results found that cost ($p = 0.002$) and FoE ($p = 0.037$) were significantly different from a normal distribution and, therefore, these variables could be further assessed for endogeneity. Third, Copulas were created for each of these variables and bootstrapped standard errors were used to calculate corrected p-values for the original model with each of the Copulas included for each of the variables individually. Given this, the results of this analysis would suggest using the original model as no endogeneity is present.

Given the differing results regarding endogeneity between the traditional 2SLS instrumental variable approach and the Gaussian Copula approach, an important question is which is better suited for this research? First, the Gaussian Copula approach only enabled the assessment of endogeneity for two of the variables given its requirement that variables have a non-normal distribution to be tested. This left out both epart and FoE, both of which showed significant endogeneity using the Hausman test in the 2SLS model, which does not have these distributional restrictions. Another consideration is that, while the 2SLS instrumental variable approach is highly accepted and is an established assessment within econometrics, marketing, and other disciplines, the Gaussian Copula approach is relatively novel and somewhat rarely used, affecting the generalizability of the study in its comparison to previous studies using these methods. Finally, this study utilizes an interaction term in the base model. Currently, research does not yet have an accepted metric for assessing endogeneity in a PLS model that includes interaction terms (Hult et al. 2018), and researchers recommend instead to use a 2SLS approach utilizing instrumental variables (Sande and Ghosh 2018) until greater research into this area with PLS has been carried out. This 2SLS approach utilizing instrumental variables is what is utilized in this paper. When comparing the results of the two approaches, the overall picture is highly similar. In both studies there is a significant impact of cost, infrastructure, and the interaction of FoE and epart on HDI. Furthermore, the overall R^2 of both models is almost identical (0.92 in the 2SLS model and 0.91 in the PLS model). From this perspective, both methods point towards the same independent variables significantly affecting the dependent variable, with the explained variance around 91-92 percent.

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