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ABSTRACT

Despite the worldwide growth in investments in information and communication technology (ICT), it is not clear whether or not any impacts are the same for countries at different levels of economic development. International organizations, ICT vendors and policy makers have been investigating whether such large investments are worthwhile. ICT investments can be thought of as having four components: Hardware, Software, Internal IS and Telecommunication investment respectively. Of particular interest are the relationships between the interactions of the different components of ICT investment and the dimensions of human development. In this paper we explore the impacts of ICT investments on two dimensions of Human Development (Standard of Living and Health) within three contexts (i.e. High, Medium and Low income countries). Our results suggest among other things that: 1) impact of investments in the ICT components vary with context; 2) impacts are in many cases conditional and complex; and 3) the directions of impacts of investments in ICT on Standard of Living may be different from the corresponding directions of impacts on Health. It is therefore necessary to do in-depth trade off analysis in order to determine an appropriate allocation of ICT investments.

Keywords: Information and Communication Technology, Human Development, Gross Domestic Product, Infant Mortality Rate; Multivariate Adaptive Regression Splines

1.0 INTRODUCTION

In recent decades, investments in information and communication technology (ICT) have grown substantially in both developed and developing countries (Qiang et al., 2004; WITSA, 1998; WITSA, 2008; Bollou and Ngwenyama, 2008; Shiraz, 2010). This rapid growth has brought digital opportunities to many countries, yet it is not clear whether or not any of the impacts are the same for countries at different levels of economic development (e.g. Samoilenko and Osei-Bryson, 2008; Kim et al., 2008; Morawczynski and Ngwenyama, 2007; Bollou, 2006; Shiraz, 2010). Human development (HD) can be considered to be "the process of enlarging people's choices", particularly with regards to choices available for leading "*a long and healthy life*", acquiring knowledge, and having "*access to the resources needed for a decent standard of living*" (UNDP, 2003). The nature of the relationship between the different components of ICT investments, and their impacts on different components of human development is also not fully understood. In this study we will conduct an exploration of these issues using regression splines analysis.

In this paper, investments in an ICT system are considered to have the following major components: hardware (H), software (S), telecommunication (T), and internal IS (I). Our conceptual model involves a production function framework that can be considered to be similar to a translog production function framework (Ko and Osei-Bryson, 2004; Evans et al., 2002; Berndt and Christensen, 1972) in that it allows for interactions between these components. It should be noted that we do not claim nor assume that these ICT Interaction factors are the only or most important determinants of country-level performance with respect to human development. For example, it is reasonable to expect that factors such as the quality of the healthcare system, and the availability and affordability of appropriate nutrition and medication would have a significant impact on *health* outcomes. Similarly, with regards to *Standard of Living*, there are multiple factors apart from ICT including material conditions (e.g. quality of the transportation network), quality of the workforce, and the legal and economic environment that have a significant impact.

For the context in which ICT investments are made, we use the categorization of Kim et al. (2008) that designates each country in a set of 51 as being in the *High* third, *Medium* third, and *Low* third, based on averaged GDP per capita (Current US $) for each country from the years

1993- 2001. Although this categorization does not take into consideration aspects of HD apart from standard of living, we did a preliminary assessment of the suitability of using this categorization in a study that involved other dimensions of HD. This grouping was further validated as being suitable for our data set through Data Envelopment Analysis (DEA) (see Bankole et al., 2011).

Our research approach can be considered to be deductive and exploratory. It is deductive in that it is presumed there is a relationship between ICT investments and dimensions of human development, as has been found in previous studies (Bankole et al., 2011). It can be considered exploratory in that we use regression splines analysis (e.g. Ko and Osei-Bryson, 2004) to explore the relationships between these four components of ICT investments and two dimensions of HD. Although regression splines (RS) have only been used recently in IT studies (e.g. Ko & Osei-Bryson, 2004; Bollou, 2010), RS based analysis has been successfully applied in various fields including software engineering (Briand et al., 2000), engineering (Jin et al., 2000), and finance (Abraham, 2002). It should be noted that if the impact of an independent variable on the dependent variable is conditional, then regression splines can identify such conditions while regression cannot. Thus, some questions cannot be answered using regression since it does not provide a means for exploring those questions. In contrast, regression splines can provide the means for exploring our research questions in greater depth than would have been possible using regression.

The rest of this paper is organised as follows: Section two provides the conceptual background of the study. Section three discusses the overview on regression splines. Section four describes the research methodology, followed by conclusions in section five.

2.0 CONCEPTUAL BACKGROUND

2.1 ICT Investments

Investments in ICT can be thought of as consisting of four facets: hardware, software, internal IS (investments in labour) and telecommunication investments respectively (WITSA, 2008). For the purposes of this study:

- *Hardware* investment is the total computer hardware spending in a country (Kim et al., 2008).

- *Software* investment refers to total country spending on software packages, database systems, utility software and programming tools.
- Investment in *Internal IS* refers to the total national amount spent on software customization, human capital development and other miscellaneous IT related expenses.
- *Telecommunication* investments spending refer to annual local and long distance landline and wireless communication investments in a country (ITU, 2007; WITSA, 2008).

It is known that computer *Hardware* cannot be effective without appropriate installed software and vice versa. This software could be externally developed (*Software*) or internally developed (*Internal IS*). Spending on externally developed software may in some cases be more efficient and effective than spending on internally developed software. In other cases there may be the need for internally developed software (*Internal Spending*) to customize externally developed software. So in some cases external developed software may be a substitute for internal developed software; in other cases the relationship between the two could be complementary.

While other studies have explored the impacts of pair wise interactions of investments in *Hardware*, *Software* and *Internal IS* on GDP (e.g. Kim et al., 2008), they have typically excluded an exploration of the impact of the interaction of *Telecommunication* and *Internal IS*. However, several studies (Wolde-Rufael, 2007; Beil et al., 2005) have explored the impact of investments in Telecommunications on GDP, and have come to different conclusions. While most of such studies are in agreement that there is a high degree of correlation between GDP and investments in *Telecommunications*, some concluded that the impacts are bi- directional (e.g. Wolde-Rufael, 2007) while others concluded that there is only a uni-directional impact from GDP on Telecommunication investments (Beil et al., 2005).

2.2 Human Development

The Human Development Index (HDI) is used to assess the quality of life in a nation, and is based on three components: *Standard of Living*, *Knowledge Acquisition*, and *Health*. For assessing standard of living, gross domestic product per capita (GDP per capita) is used; for assessing knowledge acquisition capability (education), national literacy rates and levels of school enrolment are used; and for assessing health, Infant mortality rate (IMR) and longevity (life expectancy at birth) are typically used (UNDP, 1990, 1991, 2006).

In this study, the focus is on the *Standard of Living* and *Health* dimensions of HD. For the *Standard of Living* dimension, GDP per capita is used as in other studies (e.g. Morawczynski and Ngwenyama, 2007). For the *Health* dimension, while previous studies (e.g. Ngwenyama et al., 2006) tend to use *Life Expectancy Rate* (*LER*) as the indicator, we use a parallel measure of *Infant Mortality Rate* (*IMR*) as indicator, primarily because it appears that *IMR* is more likely than *LER* to be impacted by the relatively short-term use of ICT than longevity. For example, major reasons for infant mortality (IM) include dehydration, diarrhoea and pneumonia. It is already known that the dissemination of information on preventative and curative methods to mothers can result in a significant decrease in IM. ICTs can be used to facilitate the distribution of such information and to support other aspects of patient care management. Since *IMR* is the number of infant deaths (one year of age or younger) per 1000 live births, then a parallel measure is the infant survival rate (ISR), where ISR = (1000 – IMR). Therefore, ISR is used in this study.

2.3 Impact of ICT Investments on Human Development

ICT investments are referred to as second-order investments that, for example, create opportunities for people to overcome conditions of poverty and marginalization (Servon, 2002; Morawczynski & Ngwenyama, 2007). International organizations such as the International Telecommunication Union (ITU), World Bank and International Monetary Fund (IMF), among others, have highlighted ICT as a potential tool for development in poor nations. For example, it can be used to rationalize the delivery of services, including health care delivery services to expectant and nursing mothers and to facilitate communication between patients and the health care system. It can also be used to improve the management of government, public utilities (e.g. mass transit, water delivery), and enable and empower business organizations including small and medium enterprises. There have been protests from some quarters, however, that poor nations should be utilizing their limited resources on basic amenities like building schools and making provision for basic health, electricity and clean water, rather than ICT infrastructure (Ngwenyama et al., 2006; Morawczynski and Ngwenyama, 2007). Unraveling the impact of ICT investments on human development has therefore been receiving attention among policy makers, ICT practitioners and governments (UNDP, 2003).

Typically studies in this domain have investigated the economic impact of ICT investments (Jalava and Pohjola, 2002; Daveri, 2002; Stiroh, 2002). Generally, findings point to the positive influence of ICT investment on economic development across a range of different contexts, but particularly in developed and newly developed nations (Oulton, 2002, Wang, 1999, Colecchia and Schreyer, 2002; Kuppusamy and Santhapparaj, 2005). Less research has investigated these impacts in developing and the least developed countries (Mbarika et al., 2005; Bollou, 2006). There are even fewer studies looking at the impact of ICT investments on other facets of human development, such as education and health (Ngwenyama et al., 2006).

2.4 Context

Kim et al. (2008) investigated the impact of different facets of ICT investment (hardware, software and internal spending) on economic development in 51 countries with the largest ICT markets (see Table 1). These 51 countries grouped into *High*, *Middle* and *Low* groups countries, based on GDP per capita. The first 17 countries above the two-third percentile of GDP per capita are defined as *High* group countries and the second 17 countries within the one- third percentile are defined as *Medium* group. The last 17 countries below the one- third percentile are defined as *Low* group countries.

Table 1: Countries under Assessment (Kim et al., 2008)

Income Group	**List of Countries**	**Avg. Index of HD Components**			**Population**
		GDP	**Health**	**Avg. Size**	**%Urban**
High	Japan, Switzerland, Norway, Denmark, USA, Sweden, Germany, Austria, Singapore, Netherlands, Belgium, France, Hong Kong, Finland, UK, Ireland, Canada	95%	89%	43 Million	60% - 100%
Medium	Australia, Italy, Israel, New Zealand, Spain, Taiwan, Greece, Portugal, South Korea, Slovenia, Argentina, Saudi Arabia, Czech Republic, Mexico, Hungary, Chile, Brazil	86%	83%	36 Million	40% – 92%
Low	Malaysia, Venezuela, Poland, Slovakia, South Africa, Turkey, Egypt, Colombia, Thailand, Russia, Romania, Bulgaria, Philippines, Indonesia, China, India, Vietnam	74%	72%	200 Million	26% - 94%

2.5 Conceptual Framework

Our conceptual framework can be considered to have similarity to a translog production function framework (Ko and Osei-Bryson, 2004; Evans et al., 2000; Berndt and Christensen, 1972) in that it allows for pairwise interactions between the components of ICT. It can be considered to have the following form where *D* represents one of the human development (HD) dimensions:

$$\log(\mathbf{D}) = \alpha_0 + \alpha_{HS}\log(H)*\log(S) + \alpha_{HI}\log(H)*\log(I) + \alpha_{SI}\log(S)*\log(I) + \alpha_{TI}\log(T)*\log(H) + \alpha_{TI}\log(T)*\log(S) + \alpha_{TI}\log(T)*\log(I) + \xi$$

It should be noted that we do not claim nor assume that these ICT components and their pairwise interactions are the only or most important determinants of country-level performance with respect to human development. For example it is reasonable to expect that factors such as the quality of the healthcare system, the availability and affordability of appropriate nutrition and medication would be significant impact on *health* outcomes. Similarly, with regards to *Standard of Living*, there are multiple factors apart from ICT including material conditions (e.g. quality of the transportation network), quality of the workforce, and the legal and economic environment that have a significant impact.

3.0 OVERVIEW ON REGRESSION SPLINES

Multivariate Adaptive Regression Splines (MARS) is a technique for discovering, evaluating and describing the causal links between factors. While ordinary regression equations attempt to model the relationship between outcome and predictor variables using a single function (the regression splines approach models the relationship between the target (e.g. independent) variable and predictor variables as a linear combination of piecewise polynomial *basis functions (**BF**)* that are joined together smoothly at the knots, where a *knot* specifies the end of one region of data and the beginning of another.

MARS uses both simple and complex BFs. Simple BFs involve a single variable and come in pairs of the form $(x - t)_+$ and $(t - x)_+$ where t is the knot, $(x - t)_+ = \underline{(x - t)}$ if $x > t$, and 0 otherwise; and $(t - x)_+ = \underline{(t - x)}$ if $x < t$, and $\underline{0}$ otherwise (Hastie and Tibshirani 1990). Complex BFs have the form: $h_k(\mathbf{x}) = \Pi_{ij} f_{ij}(x_i)$ where $x_1, \ldots x_q$ are the independent variables, f_{ij} is a spline BF for the i^{th} independent variable x_i at j^{th} knot. The function generated using the MARS approach can be described as follows:

$$Y = \beta_0 + \sum_{k=1}^{K} \beta_k h_k(\mathbf{x}) \qquad (4)$$

Where β_0 is the coefficient of the constant BF, β_k (k = 1, K) are the coefficients of the BFs, K is the number of basis functions (**BF**) in the model. The coefficient of each BF (i.e. β_k) is estimated by minimizing the sum of square errors, which is similar to the estimation process of linear regression, but involving local data for the given region. MARS provides the analysis of variance (ANOVA) decomposition, which identifies the relative contributions of each of the predictor variables and the interactions between variables, and handles missing values.

Generation of a MARS model involves 2 phases. In the *Forward Phase* BFs are added, allowing the model to become more flexible but also more complex, and terminating when a user specified maximum number of BFs is reached; in the *Backward Phase* BFs are deleted in order of least contribution to the model until an "Optimal" model is found, with the selection of the "Optimal" model being based on the Generalized Cross Validation (GCV) measure. The GCV measure plays a trade-off role between accuracy and simplicity in the generation of MARS models as that played by the Akaike Information Criterion (AIC), Bayes Information Criterion (BIC), and Shwartz Bays Criterion (SBC) measures play in traditional regression.

4.0 RESEARCH METHODOLOGY

In this study, we conduct exploratory research, using archival quantitative data concerning ICT investments and human development. Our methodology consists of the following major steps:

1. Data Collection
2. Regression Splines Analysis

4.1 Data Collection

The 51 countries included in this study involve the largest ICT markets around the world (Kim et al., 2008). Countries were grouped into *High, Middle* and *Low* groups countries as per Kim et al. (2008). The data on ICT investments and human development (HD) for each country were collected for the period 1994-2003 from four different sources - the UN and World Bank (for GDP, literacy rates and schools enrolment), the ITU (for telecommunication investment data), and the WITSA databases (for IT investment data, i.e. hardware, software and internal spending). The period 1994 to 2003 was chosen as complete data sets on both ICT investment and human development for the 51 countries were available for this period only. Table 1 displays a summary of the logarithm of the minimum and maximum values for each ICT component variable in the given sample dataset for each group. We report the logarithm because as previously stated our conceptual model involves a production function framework that has some similarity to the translog production function

Table 1: Range of Log Values of the Variables

Variable	***High*** **Group**		***Medium*** **Group**		***Low*** **Group**	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**
Software (S)	4.84	13.09	3.43	8.63	1.95	8.04
Internal IS (I)	5.3	12.45	4.74	9.57	3.62	8.11
Hardware (H)	5.98	12.01	4.93	9.27	4.39	10.12
Telecommunication (T)	7.44	13.09	5.02	10.34	4.80	10.68
GDP (G)	0.89	0.99	0.41	0.99	0.21	0.98
Infant Survival Rate (ISR)	6.81	6.90	6.81	6.90	6.84	6.91

4.2 Regression Splines Analysis

The data was analysed using Salford System's MARS software (Version 6.6). We explored six regression splines models: three where *Standard of Living* (as measured by GDP) was the dependent variable and three where *Health* (as measured by ISR) was the dependent variable. For the forward phase modeling, we set the Maximum Number of Basis Functions (BFs) parameter to 16, and allowed for two-way interactions.

4.2.1 Impacts of ICT on Standard of Living

It is known that no single component of an ICT system can by itself produce gains. For example, it is known that computer *Hardware* cannot be effective without appropriate installed software and vice versa. This software could be externally developed (*Software*) or internally developed (*Internal IS*). Spending on externally developed software may in some cases be more efficient and effective than spending on internally developed software. In other cases there may be the need for internally developed software (*Internal Spending*) to customize externally developed software. So in some cases external developed software may be a substitute for internal developed software; in other cases the relationship between the two could be complementary.

Table 2 presents 3 separate regression splines models, each describing the impacts of the ICT component variables on *Standard of Living* (as measured by *GDP*) for the relevant group. Our results suggest that there are indeed interactions between the 4 ICT components that determine their impacts on GDP. For example, an examination of Table 2 indicates that for the *High* group 5 of its 9 BFs involves interactions, and for the *Medium* and *Low* groups all of the BFs involve interactions. Further for each group, the relevant BFs suggest that the impact of each ICT component is conditional, depending on both the value of the given ICT component and at least one other ICT component.

Table 2: Regression Splines Models - Impacts of ICT investments on Standard of Living

Group	BF	Coefficient	Expression
High	BF2	-0.061	Max {0, Log(9.08 - Log(S)}
	BF3	-0.198	Max {0, Log(I) - 6.9}
Adj R^2 = 0.394	BF5	-0.146	Max {0, Log(I) – 10.57) }* Max {0, Log(S) - 9.08}
	BF8	0.039	Max {0, 9.96 - Log(H)}
	BF9	0.078	Max {0, Log(I) - 7.39)}* Max {0, Log(9.08 - Log(S)}
	BF10	-0.018	Max {0, 7.39 - Log(I)} * Max {0, Log(9.08 - Log(S)}
	BF12	0.057	Max {0, Log(S) - 6.92)}* Max { 0, Log(I) - 6.9}
	BF14	0.047	Max {0, Log(I) - 8.61}
	BF18	-0.815	Max {0, Log(T) - 10.52)} * Max {0, 10.57 - Log(I)}}
Medium	BF5	0.109	Max {0, Log(I) - 7.52)}* Max {0, Log(S) - 5.95}
	BF9	-0.546	Max {0, Log(H) – 6.82)}* Max {0, 5.95 - Log(S)}
Adj R^2 = 0.549	BF11	-0.139	Max {0, Log(I) - 7.6)} * Max {0, log(T) - 8.52}
	BF12	-0.478	Max {0, 7.6 - Log(I)} * Max {0, log(T) - 8.52}
	BF13	-0.046	Max {0, Log(I) - 4.74)} * Max {0, 5.95 - Log(S)}
	BF14	-0.174	Max {0, Log(S) - 7.02)}* Max {0,7.94 - Log(H)}
	BF16	0.024	Max {0, Log(S) - 3.43)} * Max {0,7.94 - Log(H)}
Low	BF6	-0.693	Max {0, 6.07 - Log(I)} * Max {0, log(T) - 6.14}
	BF7	0.228	Max {0, Log(H) - 8.15)} * Max {0, Log(S) - 5.86}
Adj R^2 = 0.567	BF8	0.829	Max {0, 8.15 - Log(H)} * Max {0, Log(S) - 5.86}
	BF9	-0.163	Max {0, Log(S) - 5.61)} * Max {0, log(T) - 6.14}
	BF10	-0.176	Max {0, 5.61 - Log(S)} * Max {0, Log(T) - 6.14}
	BF11	0.049	Max {0, Log(H) - 7.6)} * Max {0, Log(T) - 6.14}
	BF12	0.139	Max {0, 7.6 - Log(H)} * Max {0, Log(T) - 6.14}

In order to demonstrate the conditional impacts of the ICT component variables, we present a more detailed analysis of the direction of the impacts of two of the ICT component variables: *Telecommunications* and *Software* variables in Tables 4a & 4b. The use of these two variables here should not be interpreted as indicating that that this study is not concerned about the impacts of the other two ICT component variables: *Hardware* (**H**) and *Internal IS* (**I**). Rather the reader will observe that typically at least one of these two variables play a conditioning role on the ***Direction of Impact*** of *Telecommunications* and *Software* variables. It should be noted that in some cases we do not present all of the conditions under which the given variable may have a *Positive* or *Negative* impact, as the main purpose is to demonstrate that it is possible for impacts to be in different directions.

The data in Tables 4a and 4b are obtained using the basis functions that include the relevant variable (see Table 2). For example, if we consider the impact of the *Telecommunications* (**T**) variable for the *High* group, only BF18 (i.e. Max {0, log (**T**) - 10.52} * Max {0, 10.57 - log (**I**)}) applies, and the relevant knot is log (T) = 10.52. The knots are used to specify the relevant intervals, and the relevant ***Contribution Expression*** can then be specified for each interval. Since there is only one knot (i.e. log (T) = 10.52) then the relevant intervals are: log (T) ≤ 10.52 and log (T) > 10.52, and there are two *Contribution Expression*s (see Table 3). Each ***Direction of Impact Expression*** is then obtained by taking the first derivative with respect to the log of the given ICT component variable (e.g. log (T)) of the corresponding ***Contribution Expression*** (see Table 3). In this example, the ***Direction of Impact*** of *Telecommunications* (**T**) is: 0 if log(**T**) ≤ 10.52; (-0.815 * (10.57 - log(**I**)) if (log(**T**) > 10.52) & (log(**I**) < 10.57) ; and 0 if (log(**T**) > 10.52) & (log(**I**) ≥ 10.57). In other words this suggests that there could be *No* impact or a *Negative* impact, and that the actual impact is determined by the values of ***T*** & ***I***.

Table 3: Development of Direction of Impact Expressions

Interval: log(T)	**Contribution Expression**	**Direction of Impact Expression**
≤ 10.52	-0.815 * 0 * Max{0, 10.57 - log(**I**)} = 0	0
> 10.52	-0.815 * (log(**T**) - 10.52) * Max{0, 10.57 - log(**I**)}	-0.815 * Max{0, 10.57 - log(**I**)}

The results displayed in Table 4a suggest that the impact of *Telecommunications* (**T**) varies depending on the given context (i.e. *High*, *Medium*, *and Low*), the value of the *Telecommunications* variable and the value of at least one other ICT component variable. For example, for the *High* group if log (T) > 10.52 then the impact of investments in *Telecommunications* is *Negative* if log (**I**) < 10.57, otherwise it has no impact. Thus for the High group, the direction of impact of *Telecommunications* investments is dependent on both the amount invested in *Telecommunications* (T) and the amount invested in *Internal IS* (S).

Interestingly these results suggest that, depending on the context and condition of ICT investments, the impact of investment in *Telecommunications* could be *Positive, Negative,* or *Non-existent*. To some extent the suggestion of conditional impact may help to explain the seemingly contradictory results of previous studies (e.g., Wolde-Rufael, 2007; Beil et al., 2005) on the impact of *Telecommunication* investments on *GDP*. The reader may observe that the condition under which *Telecommunications* (T) has a positive impact on GDP for the *High* group is different from that for the *Low* group. This suggests that the relative impacts of ICT components vary according to the context (i.e. *High*, *Medium*, or *Low* group).

Table 4a. Impact of Investments in Telecommunication on Standard of Living

Group	Interval: log(T)	BFs	Direction of Impact	
			Expression	**Assessment**
High	≤ 10.52	None	None	○ *None*
	> 10.52	BF18	-0.815 * Max {0, 10.57 - Log(I)}}	○ *Negative* if log(**I**) < 10.57 ○ *None* if log(**I**) > 10.57
Medium	≤ 8.52	None	None	○ *None*
	> 8.52	BF11 BF12	-0.139* Max {0, Log(I) - 7.6)} - 0.478* Max {0, 7.6 - Log(I)})	○ *Negative*
Low	≤ 6.14	None	None	○ *None*
	> 6.14	BF6 BF9 BF10 BF11 BF12	(-0.693* Max {0, 6.07 - Log(I)} -0.163 * Max {0, Log(S) - 5.61)} -0.176 * Max {0, 5.61 - Log(S)} + 0.049* Max {0, Log(H) - 7.6)} + 0.139* Max {0, 7.6 - Log(H)})	*Conditional*: ○ Could be *Positive*, *Negative* or *Non-existent* depending on values of ***H, I*, *S***

In Table 4b we only report results for the *High* and *Medium* groups. These results suggest that complex conditional impacts hold for the relationship between investments in *Software* (**S**) and *Standard of Living* (as measured by GDP). The reader may observe that the condition under which *Software* (**S**) has a positive impact on GDP for the *High* group is different from that for the *Low* group. This suggests that the relative impacts of ICT components depend on the context.

Table 4b. Impact of Investments in Software (S) on Standard of Living

Group	Interval: log(S)	BFs	Direction of Impact	
			Expression	**Assessment**
High	< 6.92	BF2 BF9 BF10	0.061 + 0.078* Max {0, log(***I***) - 7.39)} - 0.018*Max {0, 7.39 - log(***I***)}	○ *Positive* if log(***I***) > 7.39 - (0.061/0.018) = 4.002 ○ *Negative* otherwise
	(6.92, 9.08)	BF12 BF2 BF9 BF10	0.061 + 0.078* Max {0, log(***I***) - 7.39)} - 0.018*Max {0, 7.39 - log(***I***)} + 0.057* Max {0, log(***I***) - 6.9}	○ *Positive* if log(***I***) > 6.204 ○ Otherwise could be *Positive, Negative* or *None* depending on value of ***I***
	> 9.08	BF12	0.057* Max {0, log(***I***) - 6.9}	○ *Positive* if log(***I***) > 6.92 ○ *None* otherwise
Low	< 5.61	BF10	0.176 * Max {0, log(***T***) - 6.14}	○ *Positive* if log(***T***) > 6.14 ○ *None* otherwise
	(5.61, 5.86)	BF9	-0.163 * Max {0, log(***T***) - 6.14}	○ *Negative* if log(***T***) > 6.14 ○ *None* otherwise
	> 5.86	BF9 BF7 BF8	-0.163* Max {0, log(***T***) - 6.14} + 0.228*Max {0, log(***H***) - 8.15} + 0.829*Max {0, 8.15 - log(***H***)}	○ *Positive* if log(***T***) ≤ 6.14 ○ Otherwise could be *Positive, Negative* depending on relationship between ***H*** & ***T*** values

4.2.2 Impacts of ICT on Standard of Health

Table 5 presents three separate regression splines models, each describing the impacts of the ICT component variables on *Health* (as measured by *ISR*) for the relevant group. The results in Tables 6a & 6b below are obtained from the results in Table 5 in a manner similar to that used to obtain the results in Tables 4a and 4b from the results displayed in Table 2.

Table 5: Regression Splines Models - Impacts of ICT investments on Health (ISR)

Group	BF	Coefficient	Expression
High Adj R^2 = 0.701	BF1	-0.035	Max {0, Log(I) - 7.79}
	BF2	0.148	Max {0, 7.79 - Log(I)}
	BF3	-0.019	Max {0, Log(S) - 9.54}
	BF4	-0.020	Max {0, 9.54 - Log(S)}
	BF5	0.010	Max {0, Log(I) - 7.25)} * Max {0, 9.54 - Log(S)}
	BF6	-0.057	Max {0, 7.25 - Log(I)} * Max {0, 9.54 - Log(S)}
	BF7	-0.388	Max {0, Log(S) - 6.42)} * Max {0, 7.79 - Log(I)}
	BF8	0.031	Max {0, 6.42 - Log(S)} * Max {0, 7.79 - Log(I)}
	BF9	0.037	Max {0, Log(T) - 9.54)} * Max {0, Log(I) - 7.79}
	BF10	0.030	Max {0, 9.54 - Log(T)} * Max {0, Log(I) - 7.79}
	BF11	-0.033	Max {0, Log(T) - 10.11)} * Max {0, Log(I) - 7.79}
	BF13	0.039	Max {0, Log(H) - 7.04)} * Max {0, 7.79 –Log(I)}
Medium Adj R^2 = 0.476	BF4	-0.138	Max {0, Log (H) - 7.94}
	BF6	0.033	Max {(0, Log (H) -7.41)} * Max {0, Log (S) - 4.91}
	BF7	0.022	Max {(0, 7.41 - Log (H)} * Max {0, Log (S) - 4.91}
	BF8	0.018	Max {(0, log (T) - 8.29)} * Max {0, Log (I) - 4.74}
	BF10	-0.017	Max {0, Log (S) - 4.82)} * Max {0, Log (I) - 4.74}
	BF12	-0.036	Max {0, log (T) - 8.2}
	BF15	-0.101	Max {(0, 7.11 - log (H)} * Max {(0, log (T) - 8.2)}
	BF16	0.008	Max {(0, log(H) - 4.93)} * Max {0, log(I) - 4.74}
Low Adj R^2 0.509	BF2	-0.053	Max {0, 4.89 – Log(H)}
	BF3	-0.010	Max {(0, Log(S) - 5.51)} * Max {0, Log(H) - 4.89}
	BF4	0.010	Max {0, 5.51 - Log(S)} * Max {0, Log(H) - 4.89}
	BF7	0.007	Max {0, Log(S) - 3.96}
	BF8	0.013	Max {0, 3.96 - Log(S)}
	BF9	0.032	Max {0, log(T) - 9.04}
	BF11	-0.063	Max {(0, log(H) - 7.33)} * Max {0, 9.04 - log(T)}
	BF13	0.017	Max {(0, log(I) - 6.68)}
	BF15	0.035	Max {(0, log(S) - 6.22)}

The results in Table 6a suggest that complex conditional impacts hold for the relationship between investments in *Telecommunications* (**T**) and *Health* (as measured by *ISR*). The reader may observe that the condition under which *Software* (**S**) has a positive impact on *ISR* for the *High* group is different from the condition for the *Low* group. This suggests that the relative impacts of ICT components depend on the context. A comparison of these results with those displayed in Table 4a, suggests that the conditions under which *Telecommunications* (**T**) has a positive impact on *GDP* are different from those under which *Telecommunications* (**T**) has a positive impact on *ISR*.

Table 6a. Impact of Investments in Telecommunication (T) on Health (ISR)

Group (based on average GDP per capita (1993-2001)	**Interval: log(T)**	**BFs**	**Direction of Impact**	
			Expression	**Assessment**
High	≤ 9.54	BF10	-0.030 * Max {0, log(I) - 7.79}	○ *Negative* if log(I) > 7.79 ○ *None* otherwise
	(9.54, 10.11]	BF9	0.037 * Max {0, log(I) - 7.79}	○ *Positive* if log(I) > 7.79 ○ *None* otherwise
	> 10.11	BF9, BF11	0.037 * Max {0, log(I) - 7.79} - 0.033 * Max {0, log(I) - 7.79} = 0.004 * Max {0, log(I) - 7.79}	○ *Positive* if log(I) > 7.79 ○ *None* otherwise
Medium	≤ 8.2	None	None	○ *None*
	(8.20, 8.29]	BF12 BF15	-0.036 - 0.101*Max {0, 7.11 - log (H)})	○ *Negative*
	> 8.29	BF8 BF12 BF15	0.018 * Max {0, log (I) - 4.74} -0.036 - 0.101*Max {0, 7.11 - log (H)})	○ *Positive* if log(***I***) > 6.74 & log(***H***) > 7.11 ○ *Negative* if log(***I***) < 4.74 or log(***H***) < 7.11 ○ Varies otherwise
Low	≤ 9.04	BF11	0.063 *Max {0, log(H) - 7.33}	○ *Positive* if log(H) > 7.33 ○ *None* otherwise
	> 9.04	BF09	0.032	○ *Positive*

In Table 6b we only report results for the *High* and *Medium* groups. These results suggest that complex conditional impacts hold for the relationship between investments in *Software* (**S**) and *Health* (as measured by *ISR*). The reader may observe that the condition under which *Software* (**S**) has a positive impact on *ISR* for the *High* group is different from that for the *Low* group. This suggests that the relative impacts of ICT components depend on the context. A comparison of these results with those displayed in Table 4b, suggests that the conditions under which *Software* (**S**) has a positive impact on *GDP* are different from those under which *Software* (**S**) has a positive impact on *ISR*.

Table 6b. Impact of Investments in Software (S) on Health (ISR)

Group	Interval: log(S)	BFs	Direction of Impact	
			Expression	**Assessment**
High	< 6.42	BF4 BF5 BF6 BF8	0.020 - 0.010 * Max {0, log(I) - 7.25)} + 0.057 * Max {0, 7.25 - log(I)} - 0.031 * Max {0, 7.79 - log(I)}}	○ *Positive* if log(***I***) < 9.25 ○ *Negative* if log(***I***) > 9.25
	(6.42, 9.54)	BF4 BF5 BF6 BF7	0.020 - 0.010 * Max {0, log(I) - 7.25)} + 0.057 * Max {0, 7.25 - Log(I)} - 0.388 * Max {0, 7.79 - Log(I)}	○ *Positive* if log(***I***) > 7.75 & < 9.25 ○ *Negative* otherwise
	>9.54	BF3 BF6	-0.019 + 0.057 * Max {0, 7.25 - Log(I)}	○ *Negative* if log(***I***) > 7.25 ○ *Positive* if log(**I**) < 7.25 – (0.019/0.057)
Low	< 3.96	BF4 BF8	-0.010* Max {0, log(H) – 4.89) - 0.13	○ *Negative*
	(3.96, 5.51)	BF4 BF7	-0.010* Max {0, log(H) – 4.89) + 0.007	○ *Positive* if log(**H**) < 4.89 + (0.007/0.010)
	(5.51, 6.22)	BF3 BF7	-0.010* Max {0, log(H) – 4.89) + 0.007	○ *Positive* if log(**H**) < 4.89 + (0.007/0.010)
	>6.22	BF3 BF7 BF15	-0.010* Max {0, log(H) – 4.89) + 0.007 + 0.035	○ *Positive* if log(**H**) < 4.89 + (0.042/0.010)

4.2.3 Further Comparison of Contexts and Dimensions

Many predictive modeling techniques (e.g. regression, regression splines, decision tree induction) provide the means for determining the order of importance of the variables in the generated predictive model. This is represented in the form of a variable importance vector (see Tables 7 & 8) where the most important variable in the model is assigned a relative score of 100%, and each variable that was not established to be a predictor is assigned a score of 0%.

Table 7: Impact of ICT investments on Standard of Living: Relative Importance of Variables

	High **Group**	***Medium*** **Group**	***Low*** **Group**
Software (S)	**100.000**	71.180	89.459
Internal IS (I)	68.443	**100.000**	27.162
Hardware (H)	34.254	45.998	78.847
Telecommunication (T)	27.134	83.960	**100.000**

Table 7 displays for each group (i.e. *High*, *Medium*, or *Low*), the relative importance of each ICT component variable as a predictor of *Standard of Living* (as measured by GDP). Table 7 provides similar information but for *Health* as the independent variable. An examination of the results in this pair of tables again suggests that the relative impacts of the four ICT components depend on the context (i.e. *High*, *Medium*, or *Low* group). For example with regards to the predictors of Standard of Living, for the *High* group, *Software* is the most important predictor, while for the *Low* group it is *Telecommunications* that is the most important predictor

These results suggest again that the relative impacts of the four ICT components depend on the HD dimension (i.e. Standard of Living, or Health). For the High group, if the focus is on *Standard of Living* then *Software* (S) is the most important predictor (see Table 7) but if the focus is on *Health* (as measured by ISR) then *Internal IS* (I) is the most important predictor (see Table 8).

Table 8: Impact of ICT investments on Health: Relative Importance of Variables

	***High* Group**	***Medium* Group**	***Low* Group**
Software (S)	85.689	**100.000**	71.895
Internal IS (I)	**100.000**	93.049	42.242
Hardware (H)	29.177	96.016	**100.000**
Telecommunication (T)	57.501	57.443	72.033

5.0 CONCLUSION

In this paper we explored the impacts of ICT investments on two dimensions of Human Development (*Standard of Living*, *Health*) within three contexts. Other researchers have also addressed topics of this type. In this paper we extend this line of inquiry in two ways. Firstly in addition to investments in *Hardware*, *Software* and *Internal IS*, our study also considers *Telecommunication* investments. Secondly, in addition to considering the impact of these ICT investments on *standard of living*, our study seeks to explore the impact of these ICT investments on *health*. As with Kim et al. (2008), we consider these impacts in high, middle and low group countries respectively. Our results suggest among other things that:

- The impact of investments in the ICT components varies with context.
- The impacts are in many cases conditional and complex, with the impact of a given component being affected not only by the level of investments in that component but also by at least one other component.
- The directions of impacts of investments in ICT on *Standard of Living* may be different from the corresponding directions of impacts on *Health*.

It is therefore necessary to do in-depth tradeoff analysis in order to determine the appropriateness of any allocation of ICT investments. Future research could include the education index, in addition for a more holistic view of ICT impact on human development.

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