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Formulation of Context-Dependent and Target-Specific Strategies of the Impacts of ICT on Development

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Abstract:

Increasing investments in ICT is often premised on the assumption that such investments will lead to improvements in productivity and other aspects of development at the firm and national levels. However, it is reasonable to expect that any such impact will vary depending on the context including the ability to modify and manipulate a chain of intermediate links within the "*investments in ICT* □*outcomes of investments in ICT*" process. In this paper we explore impacts of three constructs of the *Networked Readiness Index* (GIT Report, 2010) on three precursors of GDP - *State of the Labor Market*, *International Trade*, and *Economic Well-Being*.

Keywords: Information and Communication Technology, ICT4D, Data Envelopment Analysis, Networked Readiness Index

1. INTRODUCTION

The role of Information and Communication Technologies (ICT) as of a prominent enabler of sustainable growth has been noted (Greenhill, 2010). It is not surprising, therefore, that the mechanisms and links of "ICT ->impact of ICT" chain have been investigated with the purpose of improving the efficiency and effectiveness of the enabling force (Samoilenko, 2013; 2014). However, the contexts of ICT applications differ greatly, thus, it is only reasonable to expect that the strength of the impact of ICT will vary among the economies of the world. This context-dependency of the impact is worth investigating, for the results

may provide valuable insights and practical implications to those economies that aim to improve their relative levels of effectiveness and efficiency of the impact of ICT.

It is reasonable to assume that in the dynamic global business environment sustainability of the impact of ICT depends on the ability of economies to modify and manipulate a chain of intermediate links within the "*investments in ICT ->outcomes of investments in ICT*" process. This assumption can be expressed in the form of the following general assertion:

> *Sustainability of the impact of a limited resource is dependent on the capability to manipulate the mechanism of the "resource->impact of the resource" process.*

It is also reasonable to consider that under the conditions of the limited availability of the ICT-related inputs and according to the law of diminishing resources sustainability of the impact of ICT will be affected by the ability to innovate. That is, the ability to apply available ICT resources in a novel way to specific targets that allows for "doing more with less". This consideration can be expressed as follows:

> *Sustainability of the impact of a limited resource is impacted by the capability to apply the resource in novel ways.*

Overall, the prerequisites for a sustainable impact of ICT could be outlined as the chain of links depicted in Figure 1.

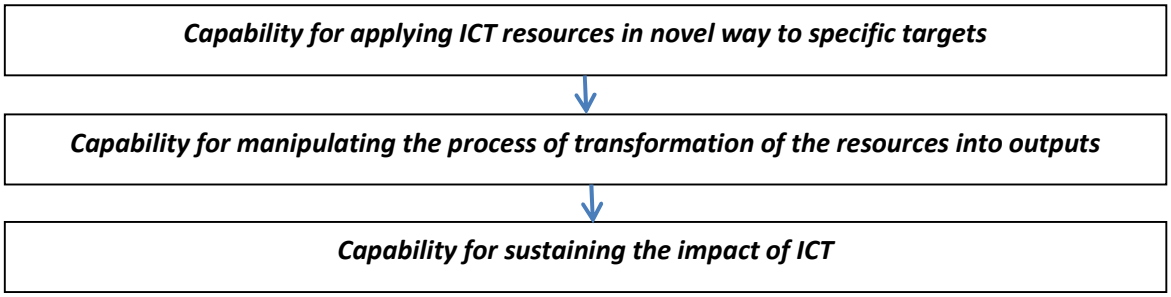

Figure 1. Capabilities for the sustainable impact of ICT

Because our study considers the impacts of various aspects of ICT on specific targets, we argue that obtained insights and implications would contribute to understanding of how to increase the level of sustainability of the impact of ICT, as well as to where innovations in the area of application of ICT would be of most benefit. Specifically, in this investigation we study the impact of ICT within a context of 24 economies of the world representing five groups of countries grouped in accordance with the classification of the International Monetary Fund as of September 2011. Specifically, we look at the impacts of three constructs of the *Networked Readiness Index* (Dutta, Mia, Geiger, and Herrera, 2010) on three precursors of GDP - *State of the Labor Market*, *International Trade*, and *Economic Well-Being* of the population (Samoilenko, 2013; 2014). Given five groups of countries and nine "ICT->impact of ICT" links, we aim to answer the following research questions:

1. *What are the specific characteristics of each group in regard to ICT and the impacts of ICT?*
2. *What areas of ICT may require innovative applications of the available resources for each group?*
3. *What are the areas of strength and weakness in terms of the efficiency of the "ICT->impact of ICT" links for each group?*

Answering these questions allows us addressing the overall objective of this study, formulated as follows:

What are the context-specific factors that differentiate various groups of economies in terms of the impact of ICT?

The significance of the answering this question is intuitive, for *knowing the context- and the impact-specific ICT factors allows for formulating precise policies and implementing custom-tailored practical solutions in the area of Information and Communication Technology for Development (ICT4D)*. The justification for our inquiry is also straightforward- *the heterogeneity of the context of application of ICT4D precludes policy- and decision makers from formulating effective generic solutions.* From a methodological perspective, the goal of this study is to *develop and to test a methodology allowing for identifying relevant to the impact of ICT context-specific factors.*

2. THEORETICAL FRAMEWORK AND THE RESEARCH MODEL

A model of neoclassical growth accounting (Solow, 1957), widely used by researchers to estimate the contribution of ICT to the macroeconomic bottom line of developed, developing and transition economies (Oliner & Sichel, 2000; Schreyer, 2000; Davery, 2000; Jorgenson & Stiroh, 2000; Whelan, 2000; Hernando & Nunez, 2002, Samoilenko & Osei-Bryson, 2008, Samoilenko & Ngwenyama, 2011, Samoilenko, 2013, Samoilenko & Osei-Bryson, 2013.), serves as a grand theory supporting our investigation. The framework allows for decomposing the overall growth of an economy into the contributions from various inputs. A common formulation of neoclassical production function is:

(1) $Y = f(A, K, L)$, where

Y = measure of economic output (most often in the form of GDP);

K = measure of capital, an endogenous variable explaining part of Y,

L = measure of labor, also an endogenous variable explaining part of Y, and

A = total factor productivity (TFP), an exogenous, unexplained by the endogenous components of Y.

Based on the model of neoclassical growth accounting a framework linking ICT to state of the labor market, international trade, and financial well-being of the population was developed by Samoilenko (2013). A theoretical framework of representation of the state of ICT in the form of Network Readiness Index (NRI), consisting of environment, usage, and readiness subindexes, was first outlined in 2003

within Global Information Technology report (Dutta & Jain, 2003). While NRI evolved in terms of the included variables and the methodology for computing the rankings (Dutta, Bilbao-Osorio, & Gieger, 2012) it has remained stable since its introduction.

Overall, the framework of this inquiry, as presented in Figure 2, is an integration of NRI framework and the framework of the microeconomic impact of investments in telecoms (Samoilenko, 2013). The suggested framework is independent of the variables reflecting subindexes of NRI or microeconomic outcomes of Samoilenko (2013); instead, it is expected that the representations of indexes and constructs would change in time to suit the context-dependent needs and to accommodate for the available data.

The benefits of using the proposed framework in this study are two-fold. First, it allows for investigating the efficiency of mechanisms of transformation of the ICT-related resources into the microeconomic outcomes-precursors of the GDP. Specifically, the framework allows for investigating efficiency of target-specific impacts of ICT (e.g. *Does ICT readiness have a greater efficiency of the impact on the Labor Market than on International Trade*?). Additionally, the framework allows for identifying areas of application of ICT that may require innovative application of ICT resources (e.g. *What could be done in the area of ICT usage to improve the efficiency of its impact on Financial Well-Being of the population?*).

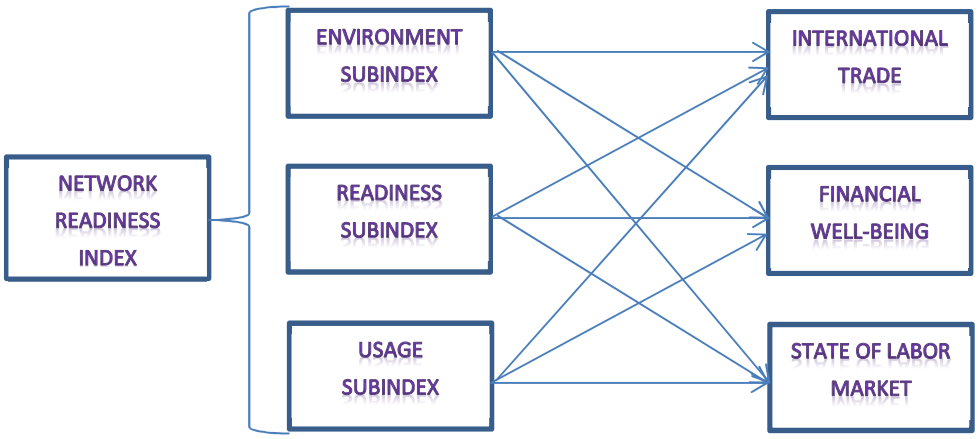

Figure 2 Integrated Theoretical Framework of the Study

3. OVERVIEW ON ANALYTIC METHODS AND THE METHODOLOGY OF THE STUDY

3.1 Overview on Data Envelopment Analysis (DEA)

DEA is a nonparametric method of measuring the efficiency of decision-making units (DMU). Any collection of similar entities could comprise a set of DMUs and be subjected to DEA, as long as the chosen entities transform the same type of inputs into the same type of outputs. Inputs and outputs, taken

together, constitute a common DEA model for all DMUs in the sample. Thus, for all intents and purposes of DEA every DMU in the sample is represented completely by the values of its inputs and outputs of the DEA model. Because some of the inputs or outputs of the DEA model could be more significant than others, DEA offers a decision maker a flexibility of assigning various weights to the inputs and outputs of the model; the equal weighting is commonly utilized as a default.

The empirical foundation of DEA eliminates the need for some of the assumptions and limitations of traditional efficiency measurement approaches. As a result, DEA could be used in cases where the relationships between the multiple Inputs and multiple Outputs are complex or unknown. Consequently, a DEA model is not necessarily comprised of the real inputs that are converted into the real outputs as it is implied by a production process. Rather, a DEA model is better perceived as a collection of the Inputs that in some way or form important to the Outputs of the transformation process under an investigation of a decision maker.

The original DEA model was introduced in 1978 by Charnes, Cooper and Rhodes and it is commonly called the CCR Model. This model allowed representing multiple inputs and outputs of each DMU as a single abstract "meta input" and a single "meta output." Consequently, the efficiency of each DMU could be represented as a ratio of the abstract input to the abstract output, and the resulting efficiency value could then be used for comparison with other DMUs in the set. By using the techniques of Linear Programming (LP), this comparison results in efficiency ranking of each DMU in the given set, where the highest ranking DMU is considered to be 100% *relatively efficient* and is assigned a perfect score of "1." Because multiple DMUs could receive the same score, there could be multiple efficient DMUs in the given set. As a result, DEA envelops the data set with the boundary points represented by the *relatively efficient* DMUs - by connecting the boundary points an investigator could obtain a visual representation of the efficient frontier for a given set of DMUs.

The importance of DEA to our study also lies in its capability to estimate change in efficiency by using the Malmquist Index (MI). The conceptual mechanism of the process of estimating TFP via DEA is straightforward- if the position of the efficient frontier identified by DEA changes over time, the change can be measured by means of MI and decomposed into two components. The first component reflects changes in efficiency (EC) and is depicted as a change in distance between the position of a given decision making unit and the efficient frontier. The second component reflects technological change (TC) and is captured as a change in position of the efficient frontier itself over period of time. An overall positive change in the position of a DMU indicates growth in productivity.

Essentially, the approach is based on performing DEA in two points of time, in our case year 2010 and 2011. Consequently, for a given economy in our sample the period of time 2010-2011 can be represented as the distance between the data point at time 2010 and the data point at time 2011. For each economy in the sample the distance between these data points is reflective of the change in the productivity- this allows us to determine if a given economy became more, or less efficient over period of one year. If the obtained value of MI is greater than 1, then the change is positive, if it is less than 1, the change is negative.

3.2 Overview on Decision Tree (DT) Induction

Few of the data mining tools are as widely used as Decision Trees (DT) for the purposes of classification and prediction. DT got its name because the visual representation of a classificatory or predictive DT model resembles an upside down tree. The process of the creation of the DT model, or "growing of the tree," is called DT induction, and is based on the algorithmic partitioning of the data set into the multiple subsets. There are number of the algorithms that are commonly used in DT induction, and when a given algorithm is applied to a data set, the result is represented in the form of the tree that depicts a path along which the partitioning took place. Structurally, the resultant DT model could be perceived as consisting of the four types of the components, which are root node, leaf nodes, decision nodes and the branches that connect the nodes to form a tree-like model.

At the top of the DT is a root node, which represents the starting point (in the form of the complete data set) from which the building of the DT model begins. Once a DT induction algorithm is applied, the data set becomes gradually partitioned more and more according to the specific splitting rules. The point where each partitioning takes place called a decision node, for it is a point where the "decision" to partition data is made. The variables that are used in top-level splits are considered to be the most important, because top-level splits indicated the major sources of the heterogeneity of the data set.

3.3 Methodology of the Investigation

Our methodology consists of two phases: Data Envelopment Analysis (DEA) and Decision Tree (DT) analysis.

Phase 1: Application of Data Envelopment Analysis (DEA)

The purpose of DEA is to identify relatively efficient economies in regard to the process of conversion of DEA inputs into DEA outputs.

The first phase of our methodology allows us answering the following questions:

1. *What ICT inputs would benefit the most from innovative application of ICT?* We can answer this question by examining the *Relative Efficiency* scores for each DEA model for each group as those

countries that are *relatively inefficient* under the assumption of input-orientation would most benefit from innovation.

2. *What links between ICT inputs and ICT impacts would benefit the most from the changes to the Input-Output Transformation Process?* We can answer this question by analyzing the values of MI and its components as those countries/groups of countries that exhibited negative growth in productivity for a given DEA model would benefit the most from changes to the Input-Output Transformation Process.

For the purposes of this investigation we will create ***I1.O1*** (represented in the form of "*Input.Output*") through ***I3.O3***, with each of these DEA models consisting of a single of the *Input Components* & a single of the *Output Components* described in Table 2 below.

The outcome of the first step of the methodology is 9 scores of the relative efficiency for each economy within its respective group for each year. By running DEA for the purposes of calculating MI we also can determine if a given economy in the sample became more vs. less efficient in the process of conversion of inputs into outputs.

Input Components		**Output Components**	
Label	**Set of Input Variables**	**Label**	**Set of Output Variables**
I1	1. Market environment 2. Political and regulatory environment 3. Infrastructure environment	**O1**	1. Imports of goods and services (% of GDP) 2. Exports of goods and services (% of GDP)
I2	1. Individual readiness 2. Business readiness 3. Government readiness	**O2**	1. Health expenditure, private (% of GDP) 2. International tourism, expenditures (% of GDP)
I3	1. Individual usage 2. Business usage 3. Government usage	**O3**	1. Labor force participation rate, male (% of male population ages 15+) (modeled ILO estimate) 2. Labor force participation rate, female (% of female population ages 15+) (modeled ILO estimate)

Table 2.Description of Input Components & Output Components

Phase 2: Decision Tree based Analysis

The second step of the methodology involves DT analysis. The purpose of the DT induction is to identify the high-level split variable (out of inputs of DEA model) that is used in partitioning of the data set. Specifically, DT analysis will allow for answering the following questions:

1. *What are the differences between the Groups of economies in our sample in terms of ICT-related factors and outcomes for each year?* We can answer this question by identifying the top-splitted variables used in DT induction for years 2010 and 2011.

2. *What are some of the differentiating characteristics of the Relatively Efficient and Inefficient economies?* We can answer this question by creating a target variable *Efficiency* with the domain of values *Efficient* and *Inefficient* and running a DT analysis as the top-splitted variables would indicate the factors that differentiate the efficient economies from the inefficient ones.

4. DESCRIPTION OF THE DATA

We obtained the data from two sources- the database of the World Development Indicators (WDI) and Global Information Technology Reports of 2010 and 2011. Important changes took place in 2012 - that was the year when the representation of NRI has partially changed in terms of the number and representation of the "pillars" of three sub-indexes of NRI. Because the data for 2013 was largely unavailable, it is not possible to assess the multi-year changes associated with the new representation of NRI. Thus, we decided not to consider year 2012 in this study; however, as more data becomes available we will analyze the performance of the revised index vs. the original one. Overall, we compiled the data on 24 economies of the world representing five groups according to the classification of the International Monetary Fund (2011). Membership of each group is provided in Table 1.

Advanced Economies	**Central and Eastern Europe**	**Commonwealth of Independent States and Mongolia**	**Middle East and North Africa**	**Sub-Saharan Africa**
Estonia	Hungary	Armenia	Morocco	Kenya
Slovenia	Latvia	Kazakhstan	Tunisia	Ghana
Czech Republic	Poland	Moldova	Algeria	Senegal
Slovak Republic	Lithuania	Kyrgyz Republic	Oman	Namibia
Spain	Montenegro	Tajikistan		Nigeria

Table 1. Groups of Countries (based on IMF classification of 2011) and Membership of each Group

Because NRI framework does not split the set of the countries into the various subgroups when assigning scores to the pillars representing sub-indexes, we also combine the five groups of the countries into a single set. The limited number of the economies of this study is due to exploratory nature of the investigation- once the methodology is developed and tested we will increase the sample size and conduct the follow-up study in a large context. The variables that represent the constructs of the framework and were used in the analysis are provided in Table 2. The representation of the state of ICT is in accordance to the representation used by Global Information Technology reports 2011 and 2012. The representation of the impact of ICT on development is based on the representation of the constructs developed in Samoilenko (2013, 2014).

State of ICT		**Impact of ICT on Development**	
Subindexes of NRI	**Representing Pillars**	**Impacts**	**Representation**
Environment	1. Market environment 2. Political and regulatory environment 3. Infrastructure environment	**International Trade (Trade)**	1. Imports of goods and services (% of GDP) 2. Exports of goods and services (% of GDP)
Readiness	1. Individual readiness 2. Business readiness 3. Government readiness	**Financial Well-being (Income)**	1. Health expenditure, private (% of GDP) 2. International tourism, expenditures (% of GDP)
Usage	1. Individual usage 2. Business usage 3. Government usage	**State of Labor Market (Labor)**	1. Labor force participation rate, male (% of male population ages 15+) (modeled ILO estimate) 2. Labor force participation rate, female (% of female population ages 15+) (modeled ILO estimate)

Table 2. Representation of the Constructs of the Research Model

5. RESULTS OF THE DATA ANALYSIS

5.1 Results from Phase 1: Application of Data Envelopment Analysis (DEA)

In Table 3 we report the Relative Efficiency scores for each country in our sample for each DEA model for the years 2010 & 2011. An examination of these results offers a few points to consider. First, the *Relative Efficiency* scores of the countries differ significantly, but in general for a given model the Relative Scores for a given country in 2011 is not much different from what it was in 2010. Second, we can observe a clear pattern where a consistent group of economies stays relatively efficient – 18 countries received a perfect score of "1" for the same set of Input-Output models for both years (e.g. Moldova, Estonia, Slovenia, Senegal, Tunisia, and Oman). The data in Table 3 offers us the opportunity to answer the question of *What ICT inputs would benefit the most from innovative application of ICT?* In order to do so we identify the model with the lowest averaged score of the relative efficiency, for each year. In our case, for both years, it is a model I1.O1, and the corresponding input is *Environment*. Consequently we can answer the question as follows:

> *Market environment, Political & Regulatory environment, and Infrastructure environment are the inputs that would benefit the most from the innovative application of ICT.*

Economy/ Model (2010)	**I1.O1**	**I1.O2**	**I1.O3**	**I2.O1**	**I2.O2**	**I2.O3**	**I3.O1**	**I3.O2**	**I3.O3**
Algeria	0.31	0.38	0.31	0.13	0.15	0.13	0.67	0.71	0.65
Armenia	0.41	0.50	0.43	0.68	0.84	0.68	0.69	0.85	0.72
Czech Republic	0.77	0.95	0.87	0.41	0.51	0.5	0.89	0.98	**1.00***
Estonia	**1.00***	**1.00***	**1.00***	0.85	0.97	**1.00***	**1.00***	**1.00***	**1.00***
Hungary	0.99	0.96	**1.00***	0.55	0.61	0.63	0.76	0.67	0.79
Kazakhstan	0.40	0.44	0.44	0.31	0.35	0.42	0.85	0.94	0.96
Kyrgyz Republic	0.74	0.68	0.76	**1.00***	**1.00***	**1.00***	0.75	0.64	0.76
Latvia	0.61	0.66	0.59	0.65	0.63	0.65	0.76	0.85	0.81
Lithuania	0.81	0.79	0.84	0.50	0.51	0.60	0.81	0.79	0.88
Moldova	0.83	**1.00***	0.75	**1.00***	**1.00***	**1.00***	0.51	0.68	0.52
Morocco	0.42	0.43	0.45	0.74	0.68	0.66	0.78	0.72	0.83
Nigeria	0.21	0.26	0.23	0.80	0.88	0.69	0.65	0.72	0.69
Namibia	0.67	0.55	0.58	0.86	0.62	0.59	0.86	0.70	0.82
Poland	0.48	0.52	0.48	0.41	0.45	0.39	0.75	0.76	0.77
Slovenia	0.94	0.92	0.82	0.68	0.75	0.73	**1.00***	0.97	0.91
Slovak Republic	0.91	0.98	0.97	0.71	0.69	0.74	0.80	0.78	0.85
Spain	0.38	0.42	0.43	0.57	0.65	0.78	0.92	0.95	**1.00***
Senegal	0.40	0.48	0.44	0.44	0.50	0.43	0.92	**1.00***	**1.00***
Tajikistan	0.46	0.50	0.56	0.66	0.81	0.78	0.70	0.72	0.89
Tunisia	0.60	0.94	0.66	0.64	0.95	0.75	0.81	**1.00***	0.85
Oman	0.62	0.69	0.58	0.57	0.74	0.47	**1.00***	0.96	0.9
Montenegro	0.76	0.88	0.73	0.6	0.64	0.59	0.75	0.87	0.73
Kenya	0.36	0.46	0.42	0.48	0.55	0.49	0.72	0.91	0.91
Ghana	0.43	0.45	0.43	0.51	0.50	0.42	0.81	0.86	0.88
Average	***0.60****	***0.66***	***0.62***	***0.61***	***0.67***	***0.63***	***0.80***	***0.83***	***0.84***
Economy/ Model (2011)	**I1.O1**	**I1.O2**	**I1.O3**	**I2.O1**	**I2.O2**	**I2.O3**	**I3.O1**	**I3.O2**	**I3.O3**
Algeria	0.25	0.37	0.29	0.12	0.14	0.12	0.6	0.78	0.66
Armenia	0.35	0.53	0.41	0.63	0.76	0.66	0.66	0.88	0.73
Czech Republic	0.71	0.87	0.79	0.42	0.46	0.47	0.87	1.00	0.94
Estonia	**1.00***	**1.00***	**1.00***	0.85	0.92	**1.00***	**1.00***	**1.00***	**1.00***
Hungary	0.87	0.9	0.98	0.58	0.54	0.66	0.72	0.70	0.78
Kazakhstan	0.39	0.54	0.44	0.29	0.33	0.41	0.84	**1.00***	0.94
KyrgyzRepublic	0.58	0.97	0.65	**1.00***	**1.00***	**1.00***	0.69	**1.00***	0.74
Latvia	0.54	0.71	0.60	0.63	0.58	0.75	0.71	0.85	0.78
Lithuania	0.78	0.81	0.85	0.46	0.41	0.57	0.82	0.83	0.9
Moldova	0.64	**1.00***	0.73	**1.00***	**1.00***	**1.00***	0.43	0.60	0.49
Morocco	0.44	0.42	0.44	0.84	0.82	0.73	0.80	0.76	0.81
Nigeria	0.25	0.28	0.27	0.68	0.69	0.66	0.64	0.69	0.67
Namibia	0.54	0.51	0.47	0.85	0.64	0.57	0.86	0.81	0.75
Poland	0.41	0.47	0.45	0.38	0.4	0.44	0.72	0.81	0.77
Slovenia	0.79	0.84	0.75	0.66	0.61	0.77	0.91	0.95	0.86
Slovak Republic	0.83	0.83	0.83	0.55	0.50	0.68	0.80	0.77	0.82
Spain	0.34	0.38	0.35	0.59	0.59	0.82	0.91	0.96	0.93
Senegal	0.36	0.42	0.41	0.42	0.53	0.42	0.95	**1.00***	**1.00***
Tajikistan	0.49	0.59	0.59	0.65	0.76	0.68	0.69	0.83	0.78

Tunisia	0.54	0.85	0.60	0.65	0.98	0.74	0.83	**1.00***	0.91
Oman	0.68	0.75	0.58	0.49	0.69	0.46	**1.00***	**1.00***	0.97
Montenegro	0.62	0.79	0.64	0.63	0.69	0.6	0.66	0.80	0.67
Kenya	0.38	0.46	0.43	0.48	0.53	0.49	0.78	0.95	0.89
Ghana	0.45	0.46	0.43	0.53	0.5	0.44	0.93	0.94	0.88
Average	***0.55****	***0.66***	***0.58***	***0.60***	***0.63***	***0.63***	***0.78***	***0.87***	***0.82***

Table 3. Relative Efficiency Scores (Model with Smallest Average Relative Efficiency Score)***

We also obtained the scores of Malmquist Index- this allows us to evaluate the changes in productivity that took place over time, as well as to identify the dominant component of MI. The results are presented in Table 4.

Economy/ Model	**I1.O1"Environment-> Trade"**			**I1.O2 "Environment -> Financial Well-Being"**			**I1.O3 "Environment -> State of Labor Market"**		
2010-2011	**MI**	**EC**	**TC**	**MI**	**EC**	**TC**	**MI**	**EC**	**TC**
Algeria	1.02	0.80	1.28	0.91	0.93	0.98	1.02	0.90	1.13
Armenia	1.07	0.85	1.26	0.97	0.93	1.05	1.04	0.96	1.09
Czech Republic	1.16	0.91	1.27	1.04	1.02	1.02	1.07	0.98	1.09
Estonia	1.19	1.00	1.19	1.05	1.00	1.05	1.03	1.00	1.03
Hungary	1.18	0.87	1.35	1.03	1.05	0.98	1.11	0.95	1.17
Kazakhstan	1.16	0.98	1.19	0.94	0.96	0.98	1.04	0.98	1.06
Kyrgyz Republic	1.01	0.79	1.28	1.07	1.00	1.07	1.02	0.93	1.10
Latvia	1.14	0.89	1.28	0.95	0.97	0.98	1.00	0.93	1.08
Lithuania	1.28	0.96	1.34	0.9	0.92	0.99	1.14	1.01	1.13
Moldova	1.09	0.78	1.41	0.97	1.00	0.97	1.02	0.85	1.19
Morocco	1.14	1.07	1.07	1.12	1.14	0.98	1.01	1.03	0.98
Nigeria	1.17	1.15	1.02	0.83	0.85	0.98	0.92	0.99	0.92
Namibia	0.95	0.81	1.17	0.97	1.00	0.98	1.00	1.01	0.99
Poland	1.11	0.85	1.31	0.91	0.94	0.97	1.06	0.96	1.10
Slovenia	1.14	0.84	1.36	0.96	0.97	0.99	1.04	0.91	1.13
Slovak Republic	1.05	0.91	1.16	0.76	0.78	0.98	1.00	1.01	0.99
Spain	1.19	0.9	1.33	1.00	1.03	0.98	1.10	0.98	1.12
Senegal	0.99	0.92	1.07	0.95	0.97	0.98	0.96	1.03	0.93
Tajikistan	1.27	1.07	1.18	0.96	0.98	0.98	1.00	0.99	1.01
Tunisia	1.05	0.90	1.17	1.00	1.02	0.98	1.03	1.03	1.00
Oman	1.1	1.09	1.01	0.95	0.87	1.09	1.03	1.00	1.03
Montenegro	1.04	0.81	1.28	1.03	1.05	0.98	0.96	0.88	1.09
Kenya	1.12	1.04	1.08	0.98	1.01	0.98	0.99	1.08	0.91
Ghana	1.11	1.04	1.06	1.02	1.03	0.98	1.03	1.14	0.90
Average	***1.11****	*0.93*	*1.21*	***0.97***	*0.98*	*1.00*	***1.03****	*0.98*	*1.05*
Economy/Model	**I2.O1 "Readiness -> Trade"**			**I2.O2 "Readiness -> Financial Well-Being"**			**I2.O3"Readiness -> State of Labor Market"**		
2010-2011	**MI**	**EC**	**TC**	**MI**	**EC**	**TC**	**MI**	**EC**	**TC**
Algeria	1.12	0.98	1.15	0.95	0.97	0.98	1.06	1.11	0.95
Armenia	1.20	1.07	1.12	1.07	0.90	1.18	1.16	1.04	1.11
Czech Republic	0.96	0.92	1.04	0.89	0.90	1.00	0.91	1.02	0.89
Estonia	1.10	1.00	1.10	1.00	0.95	1.05	0.95	1.00	0.95

Hungary	0.95	0.94	1.02	0.87	0.89	0.98	0.94	1.05	0.89
Kazakhstan	1.32	1.23	1.07	0.91	0.93	0.98	1.10	1.07	1.03
Kyrgyz Republic	1.57	1.44	1.09	1.30	1.00	1.30	1.57	1.56	1.01
Latvia	1.27	1.08	1.17	0.94	0.93	1.01	1.06	0.99	1.07
Lithuania	1.15	1.03	1.12	0.78	0.8	0.98	1.02	1.05	0.97
Moldova	1.10	1.00	1.10	0.97	1.00	0.97	1.01	0.88	1.15
Morocco	1.05	0.99	1.06	1.18	1.21	0.98	0.95	1.06	0.90
Nigeria	1.07	1.06	1.00	0.77	0.78	0.98	0.84	0.96	0.88
Namibia	0.99	0.93	1.06	1.02	1.04	0.98	1.04	1.16	0.90
Poland	0.99	0.92	1.08	0.86	0.89	0.97	0.97	1.06	0.91
Slovenia	1.02	0.91	1.12	0.80	0.81	0.98	0.93	0.97	0.96
Slovak Republic	0.89	0.84	1.06	0.70	0.72	0.98	0.88	0.99	0.89
Spain	0.96	0.91	1.06	0.89	0.92	0.98	0.90	1.01	0.89
Senegal	0.96	0.89	1.08	1.04	1.06	0.98	0.95	1.00	0.95
Tajikistan	1.31	1.17	1.11	0.91	0.94	0.98	1.10	1.17	0.94
Tunisia	1.07	0.91	1.18	1.00	1.03	0.98	1.02	1.00	1.02
Oman	1.17	1.09	1.07	0.99	0.93	1.07	1.03	1.04	0.99
Montenegro	1.03	0.89	1.16	1.04	1.07	0.98	0.96	0.91	1.05
Kenya	1.11	1.00	1.11	0.95	0.97	0.98	0.99	1.05	0.95
Ghana	1.15	1.02	1.13	0.98	1.00	0.98	1.07	1.10	0.97
Average	***1.10****	*1.01*	*1.09*	***0.95***	*0.94*	*1.01**	***1.02***	*1.05*	*0.97*
Economy/Model	**I3.O1 "Usage -> Trade"**			**I3.O2 "Usage -> Financial Well-Being"**			**I3.O3"Usage -> State of Labor Market"**		
2010-2011	**MI**	**EC**	**TC**	**MI**	**EC**	**TC**	**MI**	**EC**	**TC**
Algeria	1.12	0.98	1.15	0.95	0.97	0.98	1.06	1.11	0.95
Armenia	1.20	1.07	1.12	1.07	0.90	1.18	1.16	1.04	1.11
Czech Republic	0.96	0.92	1.04	0.89	0.90	1.00	0.91	1.02	0.89
Estonia	1.10	1.00	1.10	1.00	0.95	1.05	0.95	1.00	0.95
Hungary	0.95	0.94	1.02	0.87	0.89	0.98	0.94	1.05	0.89
Kazakhstan	1.32	1.23	1.07	0.91	0.93	0.98	1.10	1.07	1.03
Kyrgyz Republic	1.57	1.44	1.09	1.30	1.00	1.30	1.57	1.56	1.01
Latvia	1.27	1.08	1.17	0.94	0.93	1.01	1.06	0.99	1.07
Lithuania	1.15	1.03	1.12	0.78	0.80	0.98	1.02	1.05	0.97
Moldova	1.10	1.00	1.10	0.97	1.00	0.97	1.01	0.88	1.15
Morocco	1.05	0.99	1.06	1.18	1.21	0.98	0.95	1.06	0.90
Nigeria	1.07	1.06	1.00	0.77	0.78	0.98	0.84	0.96	0.88
Namibia	0.99	0.93	1.06	1.02	1.04	0.98	1.04	1.16	0.90
Poland	0.99	0.92	1.08	0.86	0.89	0.97	0.97	1.06	0.91
Slovenia	1.02	0.91	1.12	0.80	0.81	0.98	0.93	0.97	0.96
Slovak Republic	0.89	0.84	1.06	0.70	0.72	0.98	0.88	0.99	0.89
Spain	0.96	0.91	1.06	0.89	0.92	0.98	0.90	1.01	0.89
Senegal	0.96	0.89	1.08	1.04	1.06	0.98	0.95	1.00	0.95
Tajikistan	1.31	1.17	1.11	0.91	0.94	0.98	1.10	1.17	0.94
Tunisia	1.07	0.91	1.18	1.00	1.03	0.98	1.02	1.00	1.02
Oman	1.17	1.09	1.07	0.99	0.93	1.07	1.03	1.04	0.99
Montenegro	1.03	0.89	1.16	1.04	1.07	0.98	0.96	0.91	1.05
Kenya	1.11	1.00	1.11	0.95	0.97	0.98	0.99	1.05	0.95

Ghana	1.14	1.00	1.14	1.04	1.06	0.98	1.06	1.00	1.06
Average	***1.10****	*0.95*	*1.15*	***1.00***	*1.00*	*1.00*	***1.01****	*0.98*	*1.03*

Table 4 Results of DEA- MI and its Components (*denotes overall growth in Productivity)

The results presented in Table 4 also offer a few insights. First, we can identify those "*ICT ->Impact of ICT*" paths that, overall, exhibited growth in productivity. This means that most of the economies, as time passes, become more efficient in converting the inputs into outputs along those paths. Models I1.O1, I1.O3, I2.O1, I2.O3, I3.O1, and I3.O3 all demonstrated averaged growth in productivity.

Surprisingly, none of the models with the output "Financial Well-Being" exhibited growth in productivity, thus, it would be reasonable to suggest that the attention of the policy and decision makers should be directed to the models I1.O2, I2.O2, I3.O2. Furthermore, the important insight is offered by the dominant component of MI in the case where the growth in productivity took place- in all cases heavy lifting was done by the changes in technology. This means that the improvements in productivity came from technology, and not from the more efficient utilization of technology.

By analyzing the information summarized in Table 4 and identifying the links that have exhibited lowest growth in productivity (e.g., the lowest value of MI) we can answer the following question:

> *What links between ICT inputs and ICT impacts would benefit the most from the changes to the Input-Output Transformation Process?*

The lowest values of MI are associated with three paths leading to the construct *Financial Well-Being*; consequently, we answer the questions as follows:

> *The links leading from ICT inputs to Financial Well-Being would benefit the most from the changes in the Input-Output Transformation Process.*

We can also summarize, for each economy, those paths that demonstrated growth in productivity and those paths that did not. We present the summary in Table 5.

2010-2011	I1.O1	I1.O2	I1.O3	I2.O1	I2.O2	I2.O3	I3.O1	I3.O2	I3.O3
Algeria	+	-	+	+	-	+	+	-	+
Armenia	+	-	+	+	+	+	+	+	+
Czech Rep	+	+	+	-	-	-	-	-	-
Estonia	+	+	+	+	-	-	+	-	-
Hungary	+	+	+	-	-	-	-	-	-
Kazakhstan	+	-	+	+	-	+	+	-	+
Kyrgyz Rep	+	+	+	+	+	+	+	+	+
Latvia	+	-	-	+	-	+	+	-	+
Lithuania	+	-	+	+	-	+	+	-	+
Moldova	+	-	+	+	-	+	+	-	+
Morocco	+	+	+	+	+	-	+	+	-
Nigeria	+	-	-	+	-	-	+	-	-

Namibia	-	-	-	-	+	+	-	+	+
Poland	+	-	+	-	-	-	-	-	-
Slovenia	+	-	+	+	-	-	+	-	-
Slovak Rep	+	-	-	-	-	-	-	-	-
Spain	+	-	+	-	-	-	-	-	-
Senegal	-	-	-	-	+	-	-	+	-
Tajikistan	+	-	-	+	-	+	+	-	+
Tunisia	+	-	+	+	-	+	+	-	+
Oman	+	-	+	+	-	+	+	-	+
Montenegro	+	+	-	+	+	-	+	+	-
Kenya	+	-	-	+	-	-	+	-	-
Ghana	+	+	+	+	-	+	+	+	+

Table 5 A Summary of the Best (+) and the Worst (-) models per Economy

At this point we can calculate the average Relative Efficiency of each country group, per model. This allows us to determine which group may be chosen as a benchmark for each model. The results are displayed in the table below.

Group/Model (2010)	**I1.O1**	**I1.O2**	**I1.O3**	**I2.O1**	**I2.O2**	**I2.O3**	**I3.O1**	**I3.O2**	**I3.O3**
Advanced Economies	**0.734***	**0.784***	**0.744***	0.614	0.616	0.748	**0.898***	**0.936***	**0.910***
Central and Eastern Europe	0.644	0.736	0.704	0.536	0.524	0.604	0.726	0.798	0.780
Commonwealth of Independent States	0.490	0.726	0.564	**0.714***	**0.770***	**0.750***	0.662	0.862	0.736
Middle East and North Africa	0.478	0.598	0.478	0.525	0.658	0.513	0.808	0.885	0.838
Sub-Saharan Africa	0.396	0.426	0.402	0.592	0.578	0.516	0.832	0.878	0.838
Group/Model (2011)	**I1.O1**	**I1.O2**	**I1.O3**	**I2.O1**	**I2.O2**	**I2.O3**	**I3.O1**	**I3.O2**	**I3.O3**
Advanced Economies	**0.750***	**0.818***	**0.773***	0.593	0.650	0.688	**0.903***	**0.920***	**0.940***
Central and Eastern Europe	0.730	0.762	0.728	0.542	0.568	0.572	0.766	0.788	0.796
Commonwealth of Independent States	0.568	0.624	0.588	**0.730***	**0.800***	**0.776***	0.700	0.766	0.770
Middle East and North Africa	0.488	0.610	0.500	0.520	0.630	0.503	0.815	0.848	0.808
Sub-Saharan Africa	0.414	0.440	0.420	0.618	0.610	0.524	0.792	0.838	0.860

Table 6 Average Relative Efficiencies, per Group, per DEA Model (*- the most relatively efficient group)

The calculated results allow us to conclude that the group of Advanced Economies is the most efficient group in terms of the impact of *ICT Environment* and *ICT Usage* on *Trade*, *Labor Market*, and *Financial Well-Being* of the population. The Commonwealth of Independent states is the most efficient group in translating *ICT Readiness* into the impacts of *Trade, Labor,* and the level of *Disposable Income.*

Group/Model (MI)	**I1.O1Environment-> Trade**			**I1.O2Environment-> Income**			**I1.O3Environment-> Labor**		
	MI	**EC**	**TC**	**MI**	**EC**	**TC**	**MI**	**EC**	**TC**
Advanced Economies	**1.135**	0.890	1.280	0.940	0.950	0.993	1.053	0.970	1.083
Central and Eastern Europe	1.150	0.876	1.312	0.964	0.986	0.980	**1.054**	0.946	1.114
Commonwealth of Independent States	1.120	0.894	1.264	0.982	0.974	1.010	1.024	0.942	1.090
Middle East and North Africa	1.078	0.965	1.133	**0.995**	0.990	1.008	1.023	0.990	1.035
Sub-Saharan Africa	1.068	0.992	1.080	0.950	0.972	0.980	0.980	1.050	0.930
Group/Model (MI)	**I2.O1 Readiness-> Trade**			**I2.O2Readiness-> Income**			**I2.O3Readiness-> Labor**		
	MI	**EC**	**TC**	**MI**	**EC**	**TC**	**MI**	**EC**	**TC**
Advanced Economies	0.958	0.895	1.070	0.820	0.838	0.985	0.905	0.998	0.908
Central and Eastern Europe	1.078	0.972	1.110	0.898	0.916	0.984	0.990	1.012	0.978
Commonwealth of Independent States	**1.300**	1.182	1.098	**1.032**	0.954	1.082	**1.188**	1.144	1.048
Middle East and North Africa	1.103	0.993	1.115	**1.030**	1.035	1.003	1.015	1.053	0.965
Sub-Saharan Africa	1.056	0.980	1.076	0.952	0.970	0.980	0.978	1.054	0.930
Group/Model (MI)	**I3.O1Usage->Trade**			**I3.O2 Usage->Income**			**I3.O3 Usage->Labor**		
	MI	**EC**	**TC**	**MI**	**EC**	**TC**	**MI**	**EC**	**TC**
Advanced Economies	1.033	0.873	1.188	0.988	0.985	1.003	0.965	0.943	1.023
Central & Eastern Europe	**1.116**	0.966	1.154	**1.040**	1.060	0.982	1.020	0.982	1.038
Commonwealth of Independent States	1.100	0.960	1.144	0.978	0.962	1.016	1.006	0.958	1.048
Middle East and North Africa	1.095	0.958	1.145	1.003	0.993	1.015	**1.045**	1.033	1.013
Sub-Saharan Africa	1.120	0.990	1.130	0.970	0.994	0.980	1.022	0.972	1.052

Table 5 Change in Productivity and its Components

Analysis of the information in Table 5 allows us answering the following question:

What are the areas of strength and weakness in terms of the efficiency of the "ICT ->impact of ICT" links for each group?

Evaluation of the strengths and weaknesses is easily performed using two criteria: (1) whether a given economy exhibited growth in productivity for a given path? (e.g., is MI>0 or not?) And (2) what is the dominant source of growth in productivity (e.g., which component is greater in value, EC or TC?). Due to

a large number of models and groups in our study we can give a general answer to the stated above question, as follows:

For each group an area of strength is represented by those "ICT->impact of ICT" paths which exhibited growth in productivity (MI>1), the area of weakness is represented by the paths that did not exhibit growth in productivity (MI ≤ 1); within each path an area of strength is represented by the dominant component of growth in productivity (if EC > TC, then EC), and the area of weakness is represented by a less contributing component (if EC > TC, then TC).

5.2 Results from Phase 2 - Decision Tree (DT) based Analysis

We compile the results of DT in Table 6 below. In some cases, as with Middle East and North Africa, our analysis fail to produce a differentiating split, and in other case, as with Advanced Economies and Economies of Central and Eastern Europe for 2011, the top-split variable fail to differentiate two groups.

Year	Group	Differentiating Factors	Classification
2010	Advanced Economies(AE)	MarketEnv ≥ 4.355 & IndUse ≥ 3.5	100% of AE
	Central and Eastern Europe (CEE)	MarketEnv < 4.355 & IndUse ≥ 3.5	100% CEE
	Commonwealth of Ind. States (CIS)	MarketEnv < 3.925 & IndUse < 3.5	83% of CIS
	Middle East and North Africa(MENA)	N/A	N/A
	Sub-Saharan Africa (SSA)	MarketEnv ≥ 3.925 & IndUse < 3.5	63% of SSA
2011	Advanced Economies(AE)	InfraEnv > 3.65	100% of AE
	Central and Eastern Europe(CEE)	InfraEnv > 3.65	100% of CEE
	Commonwealth of Ind. States(CIS)	MarketEnv < 3.85 & InfraEnv < 3.65	83% of CIS
	Middle East and North Africa(MENA)	N/A	N/A
	Sub-Saharan Africa(SSA)	MarketEnv ≥ 3.85 & InfraEnv < 3.65	63% of SSA

Table 6 Differences between the Groups of Economies in Terms of ICT-related Factors

Overall, the information contained in Table 6 allows us to answer the following question:

What are the differences between the groups of economies in our sample in terms of ICT-related factors for each year?

The resulting answer to this question is as follows:

In 2010 the difference between the groups of economies in our sample could be expressed in terms of the difference in values of the scores of Market Environment and Individual Use; while in 2011 the difference could be expressed in terms of the difference in values of the scores of Market Environment and of Infrastructure Environment.

We could also answer the question regarding the differences between efficient and inefficient economies in our sample, namely:

What are some of the differentiating characteristics of the Relatively Efficient and Inefficient economies?

The information allowing answering this question is compiled in Table 7.

Model #	**Characteristics of Efficient Economies**	**Characteristics of Inefficient Economies**
Environment->Trade	N/A	N/A
Environment-> Income	BusRead ≥ 4.245	BusRead < 4.245
Environment-> Labor	Exports ≥ 43.4345	Exports < 43.4345
Readiness-> Trade	IndRead ≥ 4.51	IndRead < 4.51
Readiness-> Income	GovRead ≥ 4.345	GovRead < 4.345
Readiness-> Labor	IndRead ≥ 4.545 & BusRead < 4.005	IndRead < 4.545 & BusRead < 4.005
Usage->Trade	N/A	N/A
Usage-> Income	Tourism ≥ 0.01515 & BusRead ≥ 4.04	Tourism≥0.01515 & BusRead < 4.04
Usage-> Labor	BusRead < 4.245	BusRead ≥ 4.245

Table 7 DT Analysis: Characteristics of Efficient and Inefficient Economies, per Model

While DT analysis failed to produce splits differentiating two groups in the case of two models (*Environment ->Trade* and *Usage ->Trade*), we were still able to identify differentiating factors for seven models of the study.

6. CONCLUSION

In this paper we presented and applied a hybrid DEA/DT methodology to explore the impacts of three constructs of the ICT *Networked Readiness Index* (Dutta et al., 2010) on three precursors of GDP - *State of the Labor Market*, *International Trade*, and *Economic Well-Being*. Our methodology allowed us to answer four important research questions: 1) *What ICT inputs would benefit the most from innovative application of ICT?* 2) *What links between ICT inputs and ICT impacts would benefit the most from the changes to the Input-Output Transformation Process?* 3) *What are the differences between the Groups of economies in our sample in terms of ICT-related factors and outcomes for each year?* 4) *What are some of the differentiating characteristics of the Relatively Efficient and Relatively Inefficient economies?*

We conducted our exploration within the context of 9 separate DEA Input-Output models applied to five (5) groups of African, Asian and European economies for the years 2010 & 2011. For future research we intend to apply our methodology to additional countries for additional years depending on the availability of quality data.

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