Assessment of ICT Progress by Countries: A Segmentation Scheme Using Cluster Analysis

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Abstract. Although several indexes have been proposed to measure ICT progress at the country level, there is no a single such index universally recognized for this purpose. This situation poses problems for assessing ICT progress at the national level and for relating ICT progress with development.

We propose a methodology to group countries into ICT progress categories using cluster analysis considering several ICT indexes. Based on this methodology, an ordinal segmentation scheme is obtained.

Interesting relationships can be observed when this segmentation is related to the geographical distribution of the countries and to their socio-economical development. Therefore, the clustering obtained seems useful for exploring linkages between ICT and development.

Keywords: Information and communication technology, development, social and economical aspects, data mining

1 Introduction

Several indexes have been proposed to measure information and communication technology (ICT) progress at the national level, for example the Digital Opportunity Index [1], the ICT Diffusion Index [2], the ICT Opportunity Index [1], and the Networked Readiness Index [3]. They were developed with the aim of comparing ICT development among countries through ranking positions. However, since these indexes consider different, although related, ICT indicators, and also vary in the number of countries selected, it is difficult to assess the overall ICT progress of a country when more than one of such indexes is considered.

In this paper, we select four contemporaneous ICT indexes and develop an ICT progress segmentation scheme using cluster analysis for 124 countries around the world. Based on this analysis, we obtain a five-cluster structure on which countries can be segmented in terms of their ICT progress using a five-point ordinal scale, according to which countries can be grouped as very bad, bad, regular, good and very good ICT performers. Furthermore, we find a relationship between these clusters and the geographical distribution and socio-economical development of their corresponding countries.

This work is an exploratory research conducted by the Program on Information Technology and Development of the Universidad Nacional de Costa Rica to assess the ICT progress among countries and relate it to development.

The selection of the four ICT indexes used for clustering the countries is discussed in section 2. This section also shows the countries selected for the analysis. Two available data mining tools were used for clustering the data: SAS/STAT [4] and SQL Server 2008 Data Analysis Services [5]. These tools are presented in section 3 as well as the methodology employed for clustering the index data and the results obtained. Section 4 discusses the ICT progress results obtained from a geographical and socio-economical perspective. Finally, section 5 presents the conclusions and describes further research being conducted to study the linkages between ICT and development based on the analysis presented in this paper.

2 ICT Indexes and Countries Selected

A literature search indicates that at least nine indexes have been proposed to measure ICT progress at the national level. Most of these indexes were created by different international organizations, particularly United Nations (UN) organizations. They use different, although related, ICT indicators and have been published for diverse time periods and considering different sets of countries, as presented in Table 1.

For clustering countries based on their ICT progress, we selected the following four indexes: i) Digital Opportunity Index (DOI) 2005-2006, ii) the ICT Diffusion Index (ICTDI) 2005, iii) the ICT Opportunity Index (ICT-OI) 2005, and iv) the Networked Readiness Index (NRI) 2007-2008, based on the following criteria:

- Recency of the data used in the indexes, yet contemporariness of their data;
- Consideration of a large number of countries in the indexes (more than 100);
- Availability of data for the indexes on the Internet.

A brief description for each of the four selected indexes and the countries considered simultaneously by them is presented below.

Table 1. Proposed ICT indexes

Index	Creators	Years considered	Countries	Indicators used
Digital Access Index (DAI) [6]	International Telecommunications Union (ITU)	2002	178	8
Digital Opportunity Index (DOI) [1]	International Telecommunications Union (ITU), United Nations Conference on Trade and Development (UNCTAD), Korea Agency for Digital Opportunity and Promotion (KADO)	2004/2005	180	11
		2005/2006	180	11
E-Readiness Index (e-readiness) [7]	The Economist Intelligence Unit (EIU) and IBM Institute for Business Value	2006	68	31
		2007	69	
ICT Diffusion Index (ICTDI) [2]	United Nations Conference on Trade and Development (UNCTAD)	2005	180	8
ICT Opportunity Index (ICT-OI) [1]	International Telecommunications Union (ITU) and International Network of UNESCO Chairs in Communication (ORBICOM)	2003	139	17
		2005	183	10
Information Society Index (ISI) [8]	IDC Continuos Intelligence Service	2004	52	15
		2005	53	
Mobile/Internet Index [9]	International Telecommunications Union (ITU)	2001	171	26
Networked Readiness Index (NRI) [3]	World Economic Forum (WEF) and INSEAD	2005/2006	115	66
		2006/2007	122	67
		2007/2008	127	68
Technology Achievement Index (TAI) [10]	United Nations Development Programme (UNDP)	1998-2000	72	8

2.1 Digital Opportunity Index 2005-2006

The Digital Opportunity Index (DOI) [1] was designed by the International Telecommunications Union (ITU) and the United Nations Conference on Trade and Development (UNCTAD) with the collaboration of the Korea Agency for Digital Opportunity and Promotion (KADO). This index is a direct result of the first meeting of the World Summit on the Information Society, held in Geneva in 2003. It measures the digital opportunities for citizens and the existing ICT infrastructure and its use at the national level. The 2005-2006 version of this index used in the paper was evaluated for 180 countries using eleven indicators related to ICT opportunity, infrastructure and utilization.

2.2 ICT Difussion Index 2005

UNCTAD designed the ICT Diffusion Index (ICTDI) [2] to measure a country´s ICT achievement based on two main dimensions: connectivity and access. This index was created using eight indicators and has been applied to 180 countries.

2.3 ICT Opportunity Index 2005

The ICT Opportunity Index (ICT-OI) [1] is the result of two independent projects later joining efforts: the Digital Access Index (DAI) of the ITU [6] and the Digital Divide Index of the ORBICOM International Network of UNESCO Chairs in Communication [11]. The ICT-OI was designed to measure ICT access and use by citizens and households as well as to compare the digital gap among countries according to the ICT opportunities provided by their economies. The 2005 version of this index used in this paper was applied to 183 countries using ten indicators divided into two categories: info-density and info-use.

2.4 Networked Readiness Index 2007-2008

The Networked Readiness Index (NRI) [3] is perhaps the most widely used ICT index and the one relying on more indicators, as Table 1 shows. It is published periodically and was jointly designed by the World Economy Forum (WEF) and the INSEAD Business School, based in France. The edition for this index used in this paper, corresponding to the period 2007-2008, was the most recently available at the moment of preparing this paper and considers 127 countries around the world. It is based on 68 indicators divided into three components: ICT environment, readiness and usage

2.5 Countries Selected

One-hundred-and-twenty-four countries are considered simultaneously by the four ICT indexes selected and described before. These countries are presented by continents in Table 2.

3 Clustering of the Index Data

As previously mentioned, we used SAS/STAT [4] and the SQL Server 2008 Data Analysis Services [5] for cluster analysis. SAS/STAT was also used for principal component analysis.

Figure 1 shows the two-dimensional representation for the index values for the countries selected considering the two main components, obtained from a principal component analysis, which together account for 97% of the total variance. As shown in this figure, a group of mainly developed countries can be clearly observed at the right-hand side. The other countries are difficult to group visually requiring the use of cluster analysis methods

To cluster the data, we selected the expectation maximization (EM) clustering algorithm, instead of the traditional k-means. EM is an extension of the k-means algorithm that uses a probabilistic measure to assign objects to clusters, instead of a strict distance measure [5]. Furthermore, the EM algorithm is more capable to find elliptical cluster structures [12] and provided a more homogeneous distribution of countries among the clusters in comparison to k-means. Both SQL Server 2008 Data Analysis Services and SAS provide clustering procedures using the EM algorithm, yet the first system was preferred due to the facility it offers to identify cluster characteristics.

A critical issue in cluster analysis is determining the optimal number of clusters. This is defined as the number of clusters which minimizes the variance within clusters yet maximizes the variance among them [13,14]. Several heuristics have been proposed to address this problem. SQL Server 2008 Data Analysis Services, in particular, provides a heuristics aimed at this purpose, yet it is not very well documented. Furthermore, this heuristics produced a large number of clusters (7) for the data considered, which turned out to be not very meaningful. On the other hand, SAS provides the pseudo F and pseudo t^2 statistics, which are very well documented and commonly recommended to compute the optimal number of clusters. The results of these statistics are presented in Figure 2, and both suggested five as the optimal number of clusters.[1] Based on this information, SQL Server 2008 Data Analysis Services was then used to detect five clusters using the data for the four indexes and the 124 countries selected.

The cluster structure found with SQL Server 2008 Data Analysis Services showed a very good separation, as depicted by the two-dimensional representation of the data using principal component analysis (see Figure 3). Table 3 presents the profiles for the five clusters obtained based on their characteristic values for the indexes. Based on these profiles, and considering that the greater the value for

[1] The number of clusters corresponding to the maximum pseudo F value and the prior number of clusters to this maximum indicate candidates for the optimal number of clusters. In the case of the pseudo t^2 statistic, the knee point indicates the optimal number of clusters [13,14].

each index is then the better is the ICT progress, the five clusters obtained were labeled using an ordinal scale as follows:

- Cluster 1: **Very bad ICT performers** with the lowest characteristic values for the four indexes
- Cluster 2: **Bad ICT performers** with higher characteristics values for the four indexes than cluster 1
- Cluster 3: **Regular ICT performers** with higher DOI characteristic values and equal values for the other indexes, as compared to cluster 2
- Cluster 4: **Good ICT performers** with higher characteristic values for the four indexes than cluster 3
- Cluster 5: **Very good ICT performers** with higher ICT-OI and NRI characteristic values and equal values for the other indexes, as compared to cluster 4.

Table 2. Countries considered by continent

Africa	Americas	Asia and Pacific	Europe
Algeria (DZ)	Argentina (AR)	Australia (AU)	Albania (AL)
Benin (BJ)	Barbados (BB)	Azerbaijan (AZ)	Armenia (AM)
Botswana (BW)	Bolivia (BO)	Bahrain (BH)	Austria (AT)
Burkina Faso (BF)	Brazil (BR)	Bangladesh (BD)	Belgium (BE)
Burundi (BI)	Canada (CA)	Cambodia (KH)	Bosnia and Herzegovina (BA)
Cameroon (CM)	Chile (CL)	China (CN)	Bulgaria (BG)
Chad (TD)	Colombia (CO)	Hong Kong (HK)	Croatia (HR)
Egypt (EG)	Costa Rica (CR)	India (IN)	Cyprus (CY)
Ethiopia (ET)	Dominican Republic (DR)	Indonesia (ID)	Czech Republic (CZ)
Gambia (GM)	Ecuador (EC)	Israel (IL)	Denmark (DK)
Kenya (KE)	El Salvador (SV)	Japan (JP)	Estonia (EE)
Lesotho (LA)	Guatemala (GT)	Jordan (JO)	Finland (FI)
Libya (LY)	Guyana (GY)	Kazakhstan (KZ)	France (FR)
Madagascar (MG)	Honduras (HN)	Korea (KR)	Georgia (GE)
Mali (ML)	Jamaica (JM)	Kuwait (KW)	Germany (DE)
Mauritania (MU)	Mexico (MX)	Malaysia (MY)	Greece (GR)
Mauritius (MR)	Nicaragua (NI)	Mongolia (MN)	Hungary (HU)
Morocco (MA)	Panama (PA)	Nepal (NP)	Iceland (IS)
Mozambique (MZ)	Paraguay (PY)	New Zealand (NZ)	Ireland (IE)
Namibia (NA)	Peru (PE)	Oman (OM)	Italy (IT)
Nigeria (NG)	Suriname (SR)	Pakistan (PK)	Latvia (LS)
Senegal (SN)	Trinidad and Tobago (TT)	Philippines (PH)	Lithuania (LT)
South Africa (ZA)	United States (US)	Qatar (QA)	Luxembourg (LU)
Tanzania (TZ)	Uruguay (UY)	Saudi Arabia (SA)	Macedonia (MK)
Tunisia (TN)	Venezuela (VE)	Singapore (SG)	Malta (MT)
Uganda (UG)		Sri Lanka (LK)	Moldova (MD)
Zambia (ZM)		Syria (SY)	Netherlands (NL)
Zimbabwe (ZW)		Tajikistan (TJ)	Norway (NO)
		Thailand (TH)	Poland (PL)
		Turkey (TR)	Portugal (PT)
		United Arab Emirates (AR)	Romania (RO)
		Vietnam (VN)	Russia (RU)
			Slovak Republic (SK)
			Slovenia (SI)
			Spain (ES)
			Sweden (SE)
			Switzerland (CH)
			Ukraine (UA)
			United Kingdom (UK)

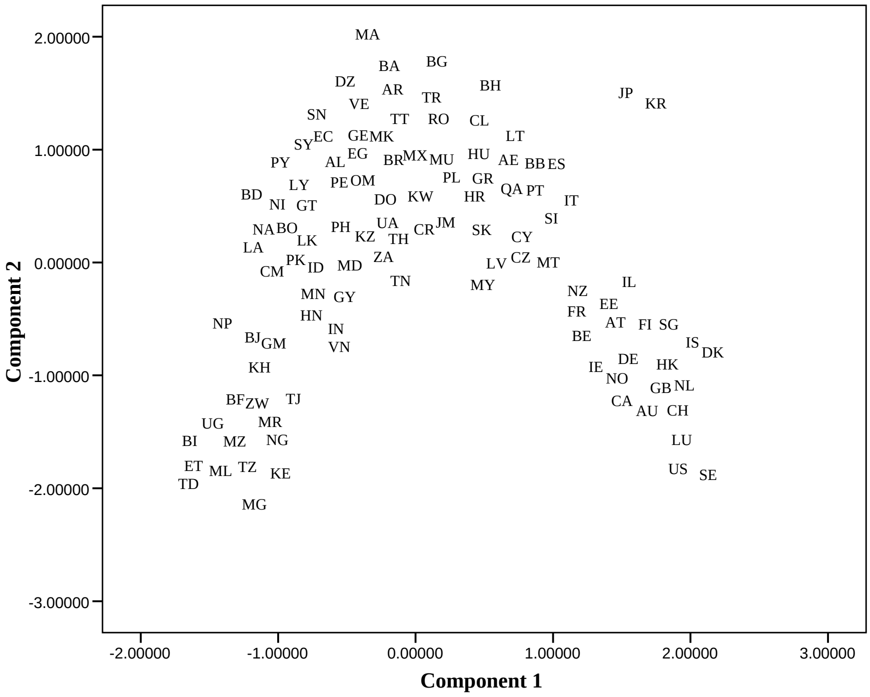

Figure 1. Graphical representation of countries using the first two components of the values for the indexes

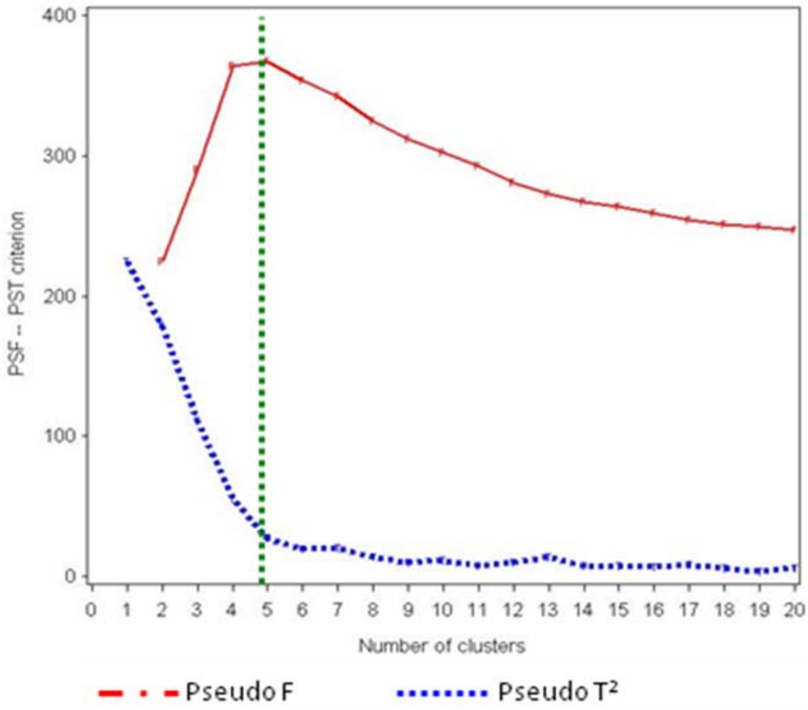

Figure 2. Pseudo F and pseudo t^2 statistics computed by SAS/STAT

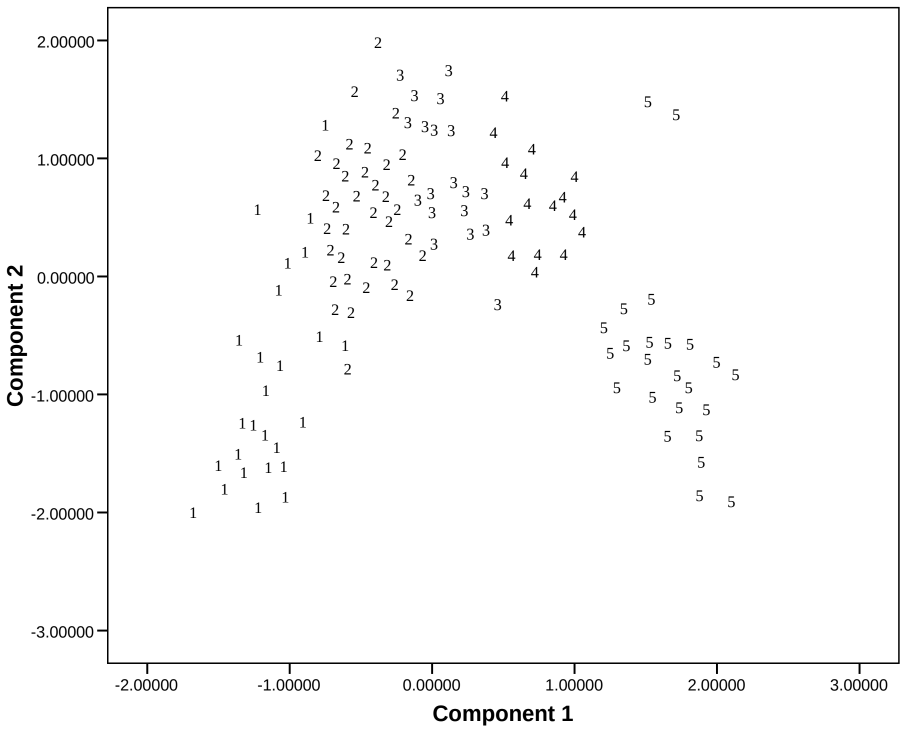

Figure 3. Clusters for countries presented on the two first components

Table 4 presents the ICT progress segmentation for the selected countries considering the five clusters obtained. As presented in this table, the largest cluster corresponds to bad ICT performers (37), followed by the very bad ICT performers (27), the very good ICT performers (24), the regular ICT performers (20) and the good ICT performers (16).[2]

Table 3. Cluster profiles

Cluster	Index	Charactheristic value	Label
1	DOI	0.0-0.3	Very bad ICT performers
	ICT-OI	13.8-76.7	
	ICTDI	0.1-0.3	
	NRI	2.4-3-4	
2	DOI	0.3-0.4	Bad ICT performers
	ICT-OI	76.7-146.4	
	ICTDI	0.3-0.4	
	NRI	3.4-3.9	
3	DOI	0.4-0.6	Regular ICT performers
	ICT-OI	76.7-146.4	
	ICTDI	0.3-0.4	
	NRI	3.4-3.9	
4	DOI	0.6-0.8	Good ICT performers
	ICT-OI	146.4-216.1	
	ICTDI	0.5-0.8	
	NRI	3.9-4.5	
5	DOI	0.6-0.8	Very good ICT performers
	ICT-OI	216.1-377.7	
	ICTDI	0.5-0.8	
	NRI	4.5-4.8	

[2] In contrast the k-means algorithm grouped 27 countries as very bad ICT performers, 18 as bad ICT performers, 40 as regular ICT performers, 11 as good ICT performers and 28 as very good ICT performers. Furthermore, the cluster profiles obtained with k-means were very similar to the ones produced by the EM algorithm.

Table 4. Segmentation of countries into ICT progress clusters

Very bad ICT perfomers	Bad ICT perfomers	Regular ICT perfomers	Good ICT performers	Very good ICT performers
Bangladesh	Albania	Argentina	Bahrain	Australia
Benin	Algeria	Bosnia and Herzegovina	Barbados	Austria
Burkina Faso	Armenia	Brazil	Chile	Belgium
Burundi	Azerbaijan	Bulgaria	Cyprus	Canada
Cambodia	Bolivia	Costa Rica	Czech Republic	Denmark
Cameroon	Botswana	Croatia	Hungary	Estonia
Chad	China	Greece	Italy	Finland
Ethiopia	Colombia	Jamaica	Latvia	France
Gambia	Dominican Republic	Kuwait	Lithuania	Germany
Honduras	Ecuador	Macedonia	Malta	Hong Kong
India	Egypt	Malaysia	Portugal	Iceland
Kenya	El Salvador	Mauritius	Qatar	Ireland
Lesotho	Georgia	Mexico	Slovak Republic	Israel
Madagascar	Guatemala	Poland	Slovenia	Japan
Mali	Guyana	Romania	Spain	Korea
Mauritania	Indonesia	Russia	United Arab Emirates	Luxembourg
Mozambique	Jordan	Saudi Arabia		Netherlands
Nepal	Kazakhstan	Trinidad and Tobago		New Zealand
Nicaragua	Libya	Turkey		Norway
Nigeria	Moldova	Uruguay		Singapore
Pakistan	Mongolia			Sweden
Senegal	Morocco			Switzerland
Tajikistan	Namibia			United Kingdom
Tanzania	Oman			United States
Uganda	Panama			
Zambia	Paraguay			
Zimbabwe	Peru			
	Philippines			
	South Africa			
	Sri Lanka			
	Suriname			
	Syria			
	Thailand			
	Tunisia			
	Ukraine			
	Venezuela			
	Vietnam			

4 ICT Progress Clustering from a Geographical and Socio-Economical Perspective

Table 5 presents the geographical distribution of countries by clusters. As this table shows, the majority of the African countries belong to the very bad ICT performing cluster (68%), and the second largest group of countries in this continent is composed of bad ICT performers (29%). A notable country in this continent is Mauritius, which appears as a regular ICT performing country. No other African countries are either in the good or very good ICT performing clusters.

With regards to the Americas, most of the countries are in the bad ICT performing cluster (46%), e.g. Bolivia, Colombia, the Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Panama, Paraguay, Peru, Suriname and Venezuela, followed by regular ICT performers (29%), e.g., Argentina, Brazil, Costa Rica, Jamaica, Mexico, Trinidad and Tobago and Uruguay. Exceptional countries in this continent are Honduras and Nicaragua which are grouped as very bad ICT performers, below the majority of the countries. On the other hand, above the majority of the countries are Barbados and Chile, cluster as good ICT performers and Canada and the United States which belong to the very good ICT performing cluster.

In the case of Asia-Pacific, we observe an interesting dichotomy. Although the majority of the countries are grouped as bad ICT performers (38%), e.g., Azerbaijan, China, Indonesia, Jordan, Kazakhstan, Mongolia, Oman, Philippines, Sri Lanka, Syria, Thailand and Vietnam, the following major cluster in this continent is the one corresponding to very good ICT performers (22%), e.g. Australia, Hong Kong, Israel, Japan, Korea, New Zealand and Singapore. Exceptional countries to this pattern are Bangladesh, India, Nepal, and Pakistan, in the Southern Asian sub-continent, and Cambodia and Tajikistan, all of them grouped as very bad ICT performers. On the other hand, Kuwait, Malaysia, and Saudi Arabia appear as regular and Qatar and the United Arab Emirates as good ICT performers in this continent.

Finally in Europe, the majority of the countries are very good performers (39%), e.g., Austria, Belgium, Denmark, Estonia, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Sweden, Switzerland and United Kingdom, followed by good performers (28%), e.g., Cyprus, Czech Republic, Hungary, Italy, Latvia, Lithuania, Malta, Portugal, Slovak Republic, Slovenia and Spain. This is the continent with the highest proportion of good and very good ICT performing countries (67%). Below the majority of European countries are Albania, Armenia, Georgia, Moldova, and Ukraine considered as bad, and Bosnia and Herzegovina, Bulgaria, Croatia, Greece, Macedonia, Poland, Romania and Russia, grouped as regular ICT performers. No European country is clustered as a very bad ICT performer.

Table 5. Geographical distribution of countries by cluster

Continent	Cluster					Total
	Very bad ICT performers	**Bad ICT performers**	**Regular ICT performers**	**Good ICT performers**	**Very good ICT performers**	
Africa	67.9%	28.6%	3.6%	0.0%	0.0%	100%
America	8.0%	45.8%	29.2%	8.0%	8.0%	100%
Asia and Pacific	18.8%	37.5%	12.5%	9.4%	21.9%	100%
Europe	0.0%	12.8%	20.5%	28.2%	38.5%	100%

The previous analysis shows a relationship between continent and ICT progress which can be represented in another way in the next table, which illustrates the relative contribution of each continent to the five clusters obtained. As shown in Table 6, the majority of the countries in the very bad ICT performing cluster are African countries (70%). Together the Americas and Asia-Pacific account for the majority of the bad ICT performers (59%) and the Americas and Europe for most of the regular performers (70%). Finally, Europe alone contributes the majority of both the good and very good ICT performing countries (63 and 58%, respectively).

Table 6. Relative contribution of continents to clusters

Continent	Cluster				
	Very bad ICT performers	Bad ICT performers	Regular ICT performers	Good ICT performers	Very good ICT performers
Africa	70.4%	21.6%	5.0%	0.0%	0.0%
America	7.4%	29.7%	35.0%	12.5%	8.3%
Asia and Pacific	22.2%	29.7%	25.0%	25.0%	33.3%
Europe	0.0%	18.9%	35.0%	62.5%	58.3%
Total	100%	100%	100%	100%	100%

Furthermore, there is also a relationship between ICT progress and the socio-economical situation of the countries, as evidenced by the Human Development Index (HDI)[3]. This index is commonly used to measure the socio-economical development of a country and has been proposed to relate ICT progress with development [16,17]. Table 7 presents the mean and standard deviation of the HDI for the countries in each of the ICT clusters. As this table shows, the better the cluster is in terns of ICT progress, the higher is the mean and the lowest is the standard deviation for the HDI of its countries.

Table 7. Human development index statistics for ICT clusters

Cluster	Mean	Standard deviation
Very bad ICT performers	0.511	0.095
Bad ICT performers	0.748	0.047
Regular ICT performers	0.826	0.042
Good ICT performers	0.887	0.028
Very good ICT performers	0.945	0.022

Source: Computed using data from [15]

5 Conclusions and Further Research

The ICT progress clustering obtained using from the four ICT indexes obtained allows to group the 124 countries into five ordinal categories: very bad, bad, regular, good, and very good ICT performers. Through this segmentation scheme is possible to assess the ICT progress of countries combining the strengths of each of the indexes selected. This is important for assessing ICT progress at the national level due to the proliferation of ICT indexes.

Furthermore, the clustering scheme obtained reveals relationships between ICT progress and geographical distributions of the countries as well as with the socio-economical development of the countries. According to Avgerou [18], the digital divide is the main articulation in the development field to explain the linkages between ICT and development. Based on this notion, the more socio-economically successful countries have more ICT available, and therefore are better prepared for using these technologies in their advantage, particularly in competitive terms.

However, having or using more ICT *per se* may not necessarily result in a better economic performance since technology might not serve the same to all nations as an enabler for development. While it is been argued in the literature that ICT is critical for economic growth and development, a strong link has not yet been found supporting this empirically, particularly in developing countries [19]. These contradictory results could be explained due to the fact that economic action cannot be isolated from social structures [20] or that they might be complementary investments needed, for example in human skills and upskilling, to take advantage of ICT [21,22].

The country clustering presented in this paper is being used to explore the relationship between ICT progress and socio-economical development. Previous work in this area, see for example Gholami et al. [16] and Ngwenyama et al. [17], tend to use ICT investments, which are difficult to measure, and to relate

[3] This is a composite index measuring average achievement in three basic dimensions of human development: a long and healthy life (life expectancy at birth), access to knowledge (adult literacy index and gross enrolment ratio) and a decent standard of living (GDP per capita). Data for this index was obtained from the last published Human Development Report 2007-2008 [15], which considers data from 2005.

to socio-economical indicators through regression models, which most likely are not appropriate due to violations of the normality and linear independence assumptions in the data.

Due to the lack of parametric assumptions, data mining techniques such as cluster analysis, used in this work, and decision trees and neural networks, employed in an extension of this research underway, have proved to be very useful for studying the linkages between ICT and development.

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