Assessing the pattern between economic and digital development of countries

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ABSTRACT

This paper analyzes the digital development of 110 countries and its relationship with economic development. Using factor analysis, we combined seven ICT-related variables into a single measure of digital development. This measure was then used as the dependent variable in an OLS model that allows non-linear effects, with the GDP per capita of countries as the explanatory variable. Our findings are substantive in that the correlation between economic and digital development was found to be not linear, being much stronger in poorer countries, a finding not commonly seen in the literature. As a result, future studies that focus on the relationship between economic and digital developments may benefit from our findings, by postulating this type of relationship. In our model we were able to explain 83% of the variation in the digital development of countries, compared to just 72% if considering only a linear relationship.

Keywords: Digital Divide, Information society, E-inclusion, Diffusion, Developing countries, Technology adoption

1. INTRODUCTION

The importance of information and communications technologies (ICT) for the economic and social development of countries is now well supported by researchers and policy makers (Lee et al. 2005; World Bank 2006). International players often argue that greater adoption and use of ICT helps countries, communities, firms, and individuals to boost development and welfare, especially in times of economic crisis, such as the one currently facing the world (Ashraf et al. 2009). The United Nations (UN) (see, for example, WSIS 2005, 2003), the Organization for Economic Cooperation and Development (OECD) (see, for example, OECD 2011, 2004), the United States of America (USA) (see, for example, US Department of Commerce 2000, 2002), and the European Union (EU) (see, for example, European Commission 2010a, 2010b, 2013), have all deployed strategies to achieve digital development and thereby benefit from the use of ICT. Many other countries have also created their own public entities to engender economic growth through ICT supply and adoption (Ma and Huang 2014; Chang et al. 2012). However, their policies now appear to be contributing to a widening of the digital divide between developing and developed countries (Dwivedi and Irani 2009). Within the European Union there is evidence that the most digitally developed countries are increasing their adoption and use of ICT in certain areas, compared to those that are not as digitally developed, thus widening the digital divide even within Europe (Cruz-Jesus et al. 2012).

The literature is rich in studies in which the main findings, especially those offering empirical evidence, show how close the link is between disparities in ICT diffusion and economic development. Hence, as with past technological innovations, economic wealth is a prerequisite for ICT diffusion and the main determinant of the global digital divide. In fact, "*some authors consider digital divide to be a new expression of the traditional technological dualism between rich and poor countries*" (Billon et al. 2009b). However, although the importance of economic imbalances in defining digital gaps is well documented, there is a link missing in the literature with regard to analyzing the pattern of this important relationship. To the best of our knowledge, studies in which this link is assessed in detail are, to say the least, scarce. Thus, one may ask whether the impact of economic wealth in ICT diffusion is constant regardless of the different economic stages of countries. There are conflicting opinions expressed in the literature about this subject. For example, Zhao et al. (2014) report that, “surprisingly” GDP per capita was not a significant predictor of the digital divide in their investigation, whereas most studies present the opposite conclusion (Dewan and Riggins 2005). We therefore seek to answer the following research question:

RQ - Is the relationship between economic and digital developments of countries linear? Or is it that GDP has an effect to a certain level on ICT usage and then flattens out as adoption becomes more of an issue, making this relationship a nonlinear one?

This question is of special importance because, to the best of our knowledge, most of the empirical evidence from studies on this subject is grounded in statistical methodologies that assume a linear effect between these two important aspects of countries (e.g., OLS, PLS, etc.). Our intention is to shed some light on this issue by analyzing this relationship in detail. If, as we hypothesize, this relationship is not linear, then one might expect that from this point forward, future works in the literature may adjust their assumptions and hypotheses accordingly. Moreover, policy makers of regions/countries with relatively high economic levels may take into consideration that, in their cases, aspects other than those that are income-related may be more important in engendering ICT, whereas for developing countries, policies should focus first and with greater attention on this fact.

With these considerations in mind, we present an exploratory analysis of the important relationship between digital and economic development of 110 countries spread around the globe. In the context of this paper, digital development is the level of ICT diffusion within a country and is measured by a construct of seven ICT-related variables, while economic development is proxied using the gross domestic product per capita (GDP) as this is perhaps the most popular and accurate single indicator of the economic development of a country, measuring the overall output of the economy (Dewan et al. 2005). Hence, the most important priority of the data collection methodology was to include the greatest number of countries possible, even if some shortcomings had to be accepted in terms of data inclusion.

The remainder of the paper is organized as follows: In Section 2 we conduct a literature review of the digital divide; in Section 3 we present the framework and methodology for measuring the digital development of countries; Section 4 assesses the relationship between the economic and digital development of countries; Section 5 presents the implications and limitations of the paper; and Section 6 presents the conclusions.

2. SURVEYING THE LITERATURE

The development and use of ICT have undergone exponential growth in recent decades. It is only some 30 years ago that electronic calculators began to penetrate mass markets in developed countries. Today, most people in these countries are using or are familiar with devices that can store entire libraries of books, music, videos, and have thousands of times more processing ability than those calculators. Similarly, 30 years ago long-distance communications were mainly via postal services or telephone, but today much of the world is connected via digital networks that allow incredible volumes of text, images, sound, and video to be exchanged instantly. The pace of innovation and adoption of ICT has been astounding. Its impact reaches from science, engineering, and services, to manufacturing. ICT adoption has gone hand in hand with innovation, creating a snowball effect that individuals, firms, communities, and countries can benefit from.

The new positions that ICT-enabled products and services have acquired in modern economies have given birth to the concept of the “digital economy” (Ayres and Williams 2004). These technologies are playing a decisive role in improving almost every aspect of our societies (World Bank 2009; Gripenberg 2011), including education, business transactions, communications, economics, and politics (OECD 2004). Carlsson (2004) studied the effects of ICT in the economy, comparing the potential of these technologies to the so-called "*general-purpose technologies (GPTs) which in the past revolutionized the economy*”, such as the transportation and communications technologies in the 19th century, the Corliss steam engine, and the electric motor. He concluded that ICT appears to have an even greater impact on the economy since “*it affects the service industries (e.g., health care, government, and financial services) even more profoundly than the goods-producing industries, and these service sectors represent over 75% of GDP*”. Jalava and Pohjola (2008) showed that the contribution of ICT to Finland’s GDP between 1990 and 2004 was three times greater than the contribution of electricity between 1920 to 1938. Mo et al. (2013) report empirical evidence that ICT use in education, specifically in the context of the *One Laptop per Child* (OLPC) program, benefits children in developing their computer skills and math scores. Moreover, students' self-esteem is also improved by having access to a PC at home for as little as six months. Similar benefits regarding the availability and use of a PC for students were found by Hatakka et al. (2013), although these authors also drew attention to the possibility of the negative effects of PCs, such as distraction from school, isolation, or social media abuse, adding much needed criticism to the negative effects of ICT, a concern shared with Vishwanath (2014).

New types of ICT-enabled applications, or advanced services, are becoming more and more common. These include e-commerce, e-government, e-health, e-learning, e-banking, e-finance, social networks, and others (Çilan et al. 2009; Facer 2007; Vicente and Lopez 2010b; Vicente and Gil-de-Bernabé 2010; European Commission 2006; Fang Zhao et al. 2012; Krishnan and Lymm 2016). Actions and technologies, like Internet surfing, YouTube, social networking, on-line job seeking, email, wiki-sites, and access to online libraries, are gaining room in our daily routines, changing the way people interact with each other (A. Venkatesh 2008). As Gurstein (2003) argues, "*ICT provides the basic infrastructure for production, and dissemination in any area of activity which has a significant information, knowledge or learning component*". ICT positively affects the economy and welfare in several important aspects of life (Çilan et al. 2009; World Bank 2006), as it creates competitive advantages in enterprises, improves national health systems (Bakker 2002) through e-health, and improves educational systems (Hsieh et al. 2008; Cukusic et al. 2010) through e-learning, in turn creating new opportunities, all of which reduce distance constraints and create new industries that generate new employment opportunities (Castells and Himanen 2002; Castells 2007).

For these benefits to be realized certain obstacles need to be overcome, especially inequalities between and within countries regarding access to, and use of, these technologies. Thus, inequalities in access to and use of ICT draw marked distinctions between those who have access to privileged information and those who have not (Brooks et al. 2005), which is exactly what the digital divide is. This idea is even changing the notion of literacy in the sense that the inability to use these technologies is creating an entirely new group of disadvantaged people who were considered "literate" in the past (Unwin and de Bastion 2009).

The term digital divide became popular in the mid-1990s, when the former Assistant Secretary for Communications and Information of the United States Department of Commerce, Larry Irving, Jr., used it to describe a new inequality in the access to ICT (Dragulanescu 2002). According to the OECD "*the term digital divide refers to the gap between individuals, households, businesses and geographic areas at different socio-economic levels with regard both to their opportunities to access ICT and to their use of the Internet for a wide variety of activities*" (OECD 2001). Initially, in the early days of the digital revolution, the digital divide was understood in binary terms, meaning that the differences were simply "has" or "has not" access to ICT. Today, however, this binary difference is considered too narrow, since other factors need to be considered (Brandtzæg et al. 2011; Barzilai-Nahon et al. 2010). Digital divide is today understood to be a complex, multidimensional phenomenon (Hsieh et al. 2008; Okazaki 2006; Warschauer 2002; Bertot 2003). There are two types of digital divide, those that are analyzed across different countries – the global digital divide – and those within a single country – the domestic digital divide.

Regarding the domestic digital divide, i.e., ICT access and use disparities at an intra-national level, digital divide gaps often occur as a result of access to and use of ICT between regions or groups of individuals, when characteristics of a different nature exist (Ono and Zavodny 2007; Unesco 2003). One of the most common types of domestic digital divide, for both developing and developed countries, is between rural and urban areas, because setting up and maintaining ICT services in remote rural areas can be very costly. Some authors have demonstrated that the domestic digital divide is characterized by a higher risk of digital exclusion of the elderly, women, the population with a lower income and educational attainment, those with disabilities, those living in rural areas, and ethnic minorities (US Department of Commerce 1995, 1998, 1999, 2000, 2002; Vicente and Lopez 2010b; Vicente and Lopez 2006; Vicente and Lopez 2010c, 2008; Crenshaw and Robison 2006; Niehaves and Plattfaut 2013; Choi and Park 2013; Middleton and Chambers 2010; Richardson 2009). Hsieh and Rai (2008) showed that economically advantaged and disadvantaged people also demonstrate very different post-implementation behavior regarding the use of ICT. These authors concluded that economically advantaged people have a “*higher tendency to respond to network exposure*”, using these technologies with much more confidence than the disadvantaged. They named these inequalities about access and use of ICT as “*first order*” and “*second order*” digital divides, respectively, adding a greater complexity to the phenomenon and its study. Xiaojun Zhang and Maruping (2008) hypothesize that a household’s adoption of ICT may be influenced by the cultural aspects of individuals, adding Hofstede´s cultural dimensions as moderators to the Model of Adoption of Technology in Households (MATH). Moreover, according to Dewan and Riggins (2005), digital disparities may also be found at an organizational level, in which “*large organizations are more likely to adopt innovations and advanced ICT solutions than smaller organizations*”, an idea that seems to be in accord with Oni & Papazafeiropoulou´s study (2014). Hence, the digital divide is a complex issue that can represent a threat to all of the e-strategies around the world, including the Digital Agenda for Europe (Cruz-Jesus et al. 2012; OECD 2009; Cuervo and Menéndez 2006).

As countries are the sum of individuals and firms, research on the global digital divide usually indicates that ICTs are a potential contributor for a nation’s socio-economic, technical, and cultural development. Developing countries have therefore rushed to implement ambitious ICT projects, with the direct/indirect supervision of institutions, such as the World Bank, the UN, and other donor/local agencies (Ashraf et al. 2007). In developing countries the digital divide occurs where there is a lack of infrastructure (such as electricity supply and telephone lines) or lack of access to modern technology (the Internet, computers, or mobile phones) (James 2007; Ashraf et al. 2009).

Across developed countries the digital divide is usually measured using different access patterns to ICT, especially those that focus on the extent to which individuals and firms make use, in terms of extent and intensity, of the wide possibilities that ICT provides (see, for example, Cruz-Jesus et al. 2012; Cuervo and Menéndez 2006). In any of these cases, there is consensus within this field of study that the digital divide is mainly a consequence of economic inequalities between countries (Xiaoqun Zhang 2013). For example, Dewan et al. (2005) analyzed the drivers of three generations of IT (mainframes, PC, and Internet) and found that all three were positively associated with national income. When examining the determinants of the global digital divide, these authors found evidence that although there are several factors that influence IT adoption, among the most significant is GDP. Chinn and Fairlie (2007) *"confirm the importance of per capita income in explaining the gap in computer and Internet use"*. In a later work (2010), these same authors confirmed that GDP *"remains the single largest factor"* in their regression analysis of the digital divide drivers. Billon et al. (2008) found that GDP per capita is a predictor of the likelihood of adoption and the extent of use of the Internet because, among other reasons, he argues that "*it is related to infrastructure communications*". Moreover, *"when specialized infrastructures for adopting innovations are required, it is expected that innovations will be located in those areas with higher level of infrastructure"*. As a result, it could be predicted that the higher the level of the GDP per capita, the higher the level of funding invested in ICT, and thus, the higher the diffusion rate of the Internet. Billon et al. (2009a) found that within the European Union *"the degree of Internet adoption is positively correlated with the level of GDP per capita"*. More recently, Doong and Ho (2012) used cluster analysis to classify countries with similar digital development levels and found, by using a probit model, that the national income had a significant positive impact on the digital development of each country. That is, "*countries with higher national income tended to enjoy a higher ICT development status*".

Another important feature of the global digital divide is whether it is narrowing or widening. Although there is no consensus in the literature, there appears to be evidence that the digital gap between countries is not likely to narrow in the near future, as empirical and qualitative studies on this subject show that "*the relatively low rate of investment in IT in developing countries appears to refute the hypothesis that diffusion patterns are somehow converging*", i.e., that the digital divide between developed and developing countries is narrowing (Indjikian and Siegel 2005). Xiaoqun Zhang (2013) found that even though the digital divide between high- and low-income OECD countries is narrowing, the gap between the developed and developing countries is widening. This fact was seen as natural considering "*the positive correlations between GDP per capita and the slope of diffusion curve*". A contributing cause for this situation may be related to the fact that developing countries cannot engender digital development with stand-alone policies focusing on increasing access to ICT, or by subsidizing these technologies, as these options would place a heavy burden on their limited financial resources. This constraint also affects countries with greater economic power, given that most of them are currently facing significant budget/expenditure cuts (e.g., European Union countries).

Another obstacle that developing countries face in pursuing digital development is a lack of knowledge about “best practice” in ICT investments, together with ICT-related skill deficiencies in the population (Indjikian and Siegel 2005). Zhao et al. (2014) used a multidimensional framework to analyze the digital divide and its effects on e-government adoption. Their findings suggest that ICT infrastructure and socio-demographic characteristics of countries are significant predictors of the global digital divide whereas, surprisingly, the GDP per capita is not. Indeed, this is one of the few studies that does not point to the economic development of countries, expressed by GDP per capita, as a significant driver of the global digital divide.

Despite the richness of the literature in analyzing the impact of economics in digital development, not much attention has been paid to the nature of this relationship. One exception is the study by Beilock and Dimitrova (2003), which is one of the first to hypothesize a possible non-linear relationship between income and Internet penetration. However, perhaps due to the fact that this was not the main focus of their paper and the unclear nature of their results (and particularly the fact that the overall explanatory value was not enhanced by including the non-linear relationship), their study did not receive the attention that it probably deserves. Nevertheless, to the best of our knowledge, almost every empirical study focusing on the digital divide assumes that theoretically and empirically, due to the statistical techniques used, economic effects on the global digital divide are linear, while there is nothing that suggests, or assures, that this is indeed so. For this reason, the main objective in this current paper is to focus on the digital/economic binomial, including as many countries as possible, in order to embrace the global spectrum to the greatest extent possible.

3. MEASURING THE DIGITAL DEVELOPMENT OF COUNTRIES

3.1 Framework

In order to measure the digital development of countries we needed to decide whether to do so by using one of the information society/digital divide indices that are already available, or to use ICT-related variables that need to be analyzed later. Each of these options presented pros and cons. With regard to using ICT variables, researchers are able to gain better control over the analysis by considering and choosing the technologies that they find suitable for the scope of the study, thereby achieving an improved awareness about how/why each country is classified in terms of digital development. However, the availability of consistent data for a large number of countries, which we seek to include in this study, is very limited. Thus, when using ICT-related variables, there is a trade-off between the *depth* and the *width* of the analysis (Cruz-Jesus et al. 2012). In other words, the more indicators that are used, the fewer the countries that can be included (Cuervo and Menéndez 2006). This constraint seriously affects accurate measures of the global digital divide, because ultimately the trade-off in terms of priority (*width* or *depth)* of the analysis' outcome must be considered. It is therefore necessary to be aware that if the data used are limited in terms of *width* (number of countries) the conclusions may be limited, as it is possible that they are not found in contexts other than the one being studied (e.g. within the European Union the relationship between digital and economic development may be linear, as all of the EU countries have a minimum level of wealth). On the other hand, if the data used are limited in terms of *depth* (number of variables), the conclusions may be misleading in the sense that digital development measures may have contradictory variables (e.g. unlike the general expectation, one country may have lower levels of Internet adoption by individuals than another country, but at the same time have a higher level of broadband penetration).

The alternative to using ICT-related indicators is to use society/digital divide indices. Using these indices counters the limitations of the ICT-related indicators mentioned above. Among the most popular of these are the IDC´s Information Society Index; the United Nations Development

Program´s Technology Achievement Index; the International Telecommunications Union´s (ITU) Digital Access Index and Digital Opportunity Index; and the Infostate Index (Sciadas et al. 2005). However, along with the widespread use of these indices, the problem arises that there are no standardized guidelines or consensus about using one index over another. Moreover, different indices may lead to different results (Vicente and Lopez 2010a), which may lead to partial choices about which index to use. This choice can also be made purely on an "easier to obtain" basis. In answering this issue some authors have even proposed using second-order indices (Emrouznejad et al. 2010), which can comprise other indices - not variables, as theory would suggest. The main advantages of using indices instead of ICT variables resides in the fact that they have the ability to summarize what is a complex and multidimensional phenomenon, provide easily interpretable results and comparisons, and also allow for quite simple analysis across different time series. On the other hand, the indices also entail several limitations. They may oversimplify complex interrelationships, i.e. reduce the information regarding society/digital divide to a single value, which may be misleading (Vehovar et al. 2006), and the composition of the indices (in terms of contributing variables) is always a subjective choice (OECD 2008; Unesco 2003). Thus, besides technologies that are already in widespread use, it is important to be aware of new types of ICT.

Finally, there is the issue that the weight of each variable (or index in the case of second-order ones) *"could be the subject of political dispute"* (Bruno et al. 2010; OECD 2008), and as such be unreliable for a specific subset of countries' ICT dimensions. These limitations are mitigated when using ICT-related indicators. Being well aware of the advantages and disadvantages of indices, we consider that using ICT-related indicators is, wherever possible, the most reliable option. Some researchers have followed the same methodology in earlier studies of the global digital divide (see, for example, Cuervo and Menéndez 2006; Vicente and Lopez 2010a; Çilan et al. 2009; Cruz-Jesus et al. 2012; Dewan et al. 2005).

In order to reduce possible negative implications associated with the use of original ICT variables, we turn to the literature for guidance in choosing which to include in our analysis. Moreover, although it is a relatively common practice due to data limitations, we did not want to proxy the digital development with only one ICT indicator. As for some other studies focusing on the digital divide, we sought to include indicators that measure the ICT infrastructure of each country along with their pervasiveness. For each indicator included there is a *rationale* associated with it, which is as follows: as one major feature of the digital development of a country is its ICT infrastructure, this feature should be measured (Billon et al. 2009b). Accordingly, we included the fixed-telephone subscriptions per 100 inhabitants (**FixTel**) (Cuervo and Menéndez 2006) and mobile cellular telephone subscriptions per 100 inhabitants (**MobTel**) (Okazaki 2006; Billon et al. 2009b; Doong and Ho 2012; Kim and Hwang 2012); along with the percentage of households with a computer (**HsPC**) (Cuervo and Menéndez 2006; M. Chinn and Fairlie 2007; Nishida et al. 2014), and connected to the Internet (**HsInt**) (Cruz-Jesus et al. 2012; Çilan et al. 2009). Regarding the first two variables (FixTel and MobTel), although developed countries have seen stagnation in telephone density in recent years, this density continues to grow in developing countries. As for the last two variables, HsPC and HsInt are often used in the literature to measure the digital development, by measuring the countries' connectivity level in terms of ICT infrastructure and general adoption. These four variables therefore provide an important basis upon which to assess the level of first and second generation ICT diffusion.

As the Internet is constantly evolving and becoming more and more demanding in terms of resources, to make the best use of it a broadband connection is often necessary, as the majority of websites contain bandwidth-intensive applications, such as audio and video streaming, animated content, or interactive applications. We therefore chose to include the fixed (wired) broadband subscriptions per 100 inhabitants (**BroRt**) (Brandtzæg et al. 2011; Vicente and Lopez 2010a), which are a prerequisite for full participation in cyberspace. Like the fixed (wired) broadband, a mobile (wireless) broadband connection (**MobRt**) (Brandtzæg et al. 2011; Vicente and Lopez 2010a; Kim and Hwang 2012) is becoming an important and increasingly popular way to access the Internet in places other than the household or workplace, making it a further important measure of ICT adoption.

Finally, as Internet browsing is perhaps the most popular action that individuals can perform through the use of ICT, we have also included the percentage of the population regularly using the

Internet (**IntPop**) (Brandtzæg et al. 2011; Vicente and Lopez 2010a; Nishida et al. 2014) as an effective way to assess the intensity of use of ICT of individuals. It is important to keep in mind that we do not claim that this set of variables is exhaustive in terms of expressing the digital development, but we do believe that by considering the limitations of data availability, these variables can efficiently measure each of the 110 countries' digital development to a considerable and meaningful extent. Moreover, for the skills dimension of digital development, frequency of use can be a reasonable proxy. All of the variables are sourced from the ITU's World Telecommunication ICT Indicators and were available, as was our objective, for an elevated number of countries – 110. These countries include both developed and developing ones (including the BRICS – Brazil, Russia, India, China, and South Africa), and are also geographically representative, including 42 countries from Europe (all of the EU-28 and others); 25 from Africa; 22 from Asia; 11 from North America, 8 from South America; and 2 from Oceania. The descriptive statistics are in Table 1.

-----------------------------------Insert Table 1 here -----------------------------------

3.2 Methodology

In order to compare the digital and economic development of countries it was necessary to obtain a single measure for their digital development. As there is no suitable way to choose one from among the seven variables already mentioned – the choice would always be subjective – a new measure of digital development that includes information from all of the seven variables described was required. For this we used factor analysis. Factor analysis is a multivariate technique that examines the latent (unobservable) patterns of complex and multidimensional phenomena, summarizing them in a smaller set of new measures, the factors, and thus making interpretation easier (Hair 2014). This technique is especially suitable for the analysis of the digital divide, considering the pervasiveness of ICT (Cruz-Jesus et al. 2012) and its wide set of applications, which require considering multiple dimensions.

In order to use this technique correctly, we followed certain steps. As factor analysis depends on the correlation structure within the input data, the first step was to confirm that this correlation exists, otherwise the factor analysis could provide meaningless results (Hair et al. 1995). We therefore calculated the correlation matrix of our data (see Table 2). The second step was to confirm the suitability of the data, which is generally done by using the Kaiser–Mayer–Olkin (KMO) measure (Sharma 1996). Finally, as a third step, we extracted the new factor and performed a reliability analysis of the original variables.

-----------------------------------Insert Table 2 here -----------------------------------

The correlation matrix (see Table 2) showed that every correlation was statistically significant at the 0.01 level ($p < 0.01$), thereby assuring that all of the variables share an underlying common phenomenon – the digital development of countries. To confirm the suitability of the data for factor analysis we calculated the KMO, obtaining a value of 0.86, which expresses a very good suitability. The number of factors to extract depends on the data and context of analysis. From a statistical point of view, there are three criteria, Pearson’s, Kaiser’s, and the Scree Plot, for deciding how many factors should be retained in this analysis. All of these pointed to a one-factor solution. Accordingly, the context of the analysis, in which we wished to transform our seven ICT-related variables into a single new measure of the digital development of countries, also encourages the one-factor solution. Thus, the statistical criterion coincided with the analysis framework. As shown in Table 3, the factor loadings, i.e., the correlations between the original variables with the extracted factor, range from 0.69 up to 0.97. HsInt (0.97), HsPC (0.97), and IntPop (0.96) are the original variables with highest correlations, whereas MobTel (0.69) is the variable with the lowest correlation. The percentage of variance retained in this factor was 78%. We thereby reduced the seven ICT-related variables into a single new measure of digital development with a minimal loss of information. In order to measure the scale reliability of this new measure, Cronbach’s alpha was calculated. This evaluates the internal consistency of the factor within itself, and a value over 0.7 is generally considered to be good (Nunnaly 1978). The value returned was 0.92, confirming the extremely high reliability of our solution, without contradictory values.

----------------------------------Insert Table 3 here -----------------------------------

With this methodology we obtained the digital development score (**DigDev**) for the 110 countries (see Table 6, in the Appendix). With the DigDev measure we were then in a position to analyze the relationship between economic and digital development for a large number of countries.

4. ASSESSING THE PATTERN BETWEEN ECONOMIC AND DIGITAL DEVELOPMENT

4.1 Theoretical background and hypothesis testing

The link between economic development, particularly GDP, with access and use of ICT is well supported in academic literature (Kauffman and Techatassanasoontorn 2005). The explanation is rather simple: in order for an individual to access and use ICT, some type of financial capability to do so is usually required. Simultaneously, given that newer technologies tend to be more expensive, their adoption naturally presents higher risks, especially for those who have limited resources. The diffusion of innovations (DOI) theory (Rogers 2005), which is one of the most prominent in IS research, especially in the digital divide field, focuses on explaining how technological innovations are communicated through channels, over a period of time and among the members of social systems (Ashraf et al. 2007; Sey 2008). The DOI theory claims that wealthier individuals and firms – and thus, wealthier countries in the aggregate – are more likely to adopt technological innovations (as is the case with ICT). Moreover, the digital revolution took place within the Western (developed) world and, as a result, the developed countries rapidly adopted and increased their use of ICT for a wide variety of activities (e.g. individuals started using PCs for personal purposes and firms for business use). The developing countries (most of Africa, South America, and Asia), on the other hand, did not possess the same resources to effectively acquire ICT, nor did they benefit from its use on the same scale as did the wealthier countries. During the early years of the ICT revolution the adoption rate was unquestionably several times higher in richer and more developed countries. However, the question as to whether this fact still holds true today is not yet clear. Nevertheless, countries with stronger economies are more likely to have the possibility of using ICT. Additionally, as these countries tend to have more developed economies in terms of information-, financial-, and innovation-based economic activities, the likelihood of presenting higher levels of ICT adoption is also greater.

Moreover, higher ICT adoption and use is likely to lead to higher levels of economic growth, generating a snowball (bi-dimensional) effect that leads to an increasing digital divide between developing and developed countries. On the other hand, it seems plausible that continued increases in GDP result in ever smaller increases in ICT adoption, as there is a finite limit to its level, and its financial constraints lose importance. As this takes place factors other than economic ones gain importance, such as educational, demographic, or geographic ones. Education may affect a country's digital development because of ICT complexity, a major obstacle for adoption (Rogers 2005). Hence, as the ease of use of a technology is important to its adoption rate (Katz and Aspden 1997), when facing a technical challenge the more educated individuals are more prone to flexibly and effectively overcome the constraints of ICT complexity (H. Zhao et al. 2007). There is evidence in the literature that in the context of ICT adoption, user friendliness, or effort expectancy, is an important factor (Wang and Shih 2009). Thus, countries with relatively higher educational attainment should present greater digital development. Accordingly, as Peng et al. (2011) demonstrate, those who use a PC at work or school are more likely to adopt ICT, and as Tengtrakul and Peha (2013) found, "the higher the educational level of students, the stronger the increase in likelihood of a household adopting ICT".

Besides education, at the country level other factors may affect the digital development, including the country's demographic and geographic distributions (Billon et al. 2009b). Although the impact of these effects is ambiguous (Dewan et al. 2005), one might argue that denser and smaller areas are easier to connect than those that are more dispersed or larger. In denser areas it is more likely that innovations spread faster (Rogers 2005), as innovations are more observable by other potential adopters. Some authors argue that larger areas are more likely to adopt ICT because of the advantage of these technologies in replacing other ways of traditional communication, which usually grow more expensive as the distance increases (Forman 2005). Contrarily, other authors believe that as larger areas tend to be more heterogeneous, they are harder to connect (Cruz-Jesus et al. 2012; Emrouznejad et al. 2010). Moreover, greater surfaces tend to need greater amounts of resources to be connected, in terms of the infrastructure coverage of all of its territories. The literature also theorizes other aspects of countries as drivers or inhibitors of digital development. However, as mentioned above, the scope of this paper is the specific role of economic development, and we therefore focus on that issue.

In regard to other studies explaining digital development/divide, previous researchers have often employed multiple regression analysis, explaining one, or several single dependent variables using separate models. Some examples include Hargittai (1999) (Internet connectivity); Kiiski and Pohjola (2002) (Internet hosts and telephone main lines); Guillén and Suárez (2005) (Internet users); Kauffman and Techatassanasoontorn (Kauffman and Techatassanasoontorn 2005) (digital mobile phones); Dewan et al. (2005) (mainframes, PCs, and Internet users); and Chinn and Fairlie (2007) (PCs and Internet users). However, all of these authors examined the digital development of countries with a single technology separately, which does not provide much information about the real level of digital development, a limitation that we believe the present study avoids as we combine seven ICT-related variables into one measure. As Wolcott et al. (2001) have pointed out, a single dependent variable is not enough to study the Internet, for example, because it is the result of the combination of a group of interrelated and clustered innovations. From another perspective, most studies of this type have used the economic development of countries as the explanatory factor of the digital development/divide (see Table 4).

------------------------------------Insert Table 4 here ------------------------------------

As mentioned above, the economic development level of a country is proxied by the GDP. The correlation between the DigDev (coming from the factor analysis with the seven ICT-related variables) with the GDP was positive (0.78) and statistically significant at a level of 0.01 ($p < 0.01$). The pattern in the relationship between economic and digital development can be assessed more easily by visualizing the 110 countries in this bi-dimensional relationship (see Figure 1). The horizontal axis represents the GDP of countries, while the DigDev is projected on the vertical one. Each axis represents the respective average values of the countries.

-----------------------------------Insert Figure 1 here -----------------------------------

Macau, one of the two Special Administrative Regions of China, is the most digitally developed “country”. This fact comes as no surprise considering that this region has a very high GDP, stemming mainly from the gaming industry. In addition, its administrative system and laws were developed based on Western culture (Macau was administered by Portugal until the end of 1999, which was responsible for developing the present laws), and it is a very small territory with an astonishing diffusion of ICT. Moreover, in the last few years Macau´s government has deployed important measures to provide the territory with ICT. For example, local communications are free; Internet access is very affordable; the territory is completely covered by a 3G network; the price of equipment (e.g. cell phones, PCs, and tablets) is modest; and there are almost no restrictions on access to Internet content. All of this stands in marked contrast to the situation in the rest of mainland China. At the other end of the spectrum, Eritrea is the least digitally developed country. This is because the country is one of the poorest on the globe and, as a result, its citizens and firms are unable to adopt ICT, and its infrastructure remains insufficiently developed. The values of DigDev for the 110 countries are given in Table 6 in the Appendix.

Figure 1 helps us to see some interesting aspects about the behavior of countries in regard to economic and digital developments, some of which show atypical patterns. Qatar, Norway, Switzerland, and Luxembourg are four examples. Their GDP is extremely high and for this reason they were rescaled to fit within the plot area, which explains the dashed line separating them from the other countries (they were originally more horizontally distant from the other countries). Given the strong relationship between GDP and DigDev, one might say that these four countries are doing worse in DigDev than their GDP would suggest. However, this can be easily understood by looking at their economic context. The economies of Qatar and Norway are strongly supported by natural resources where, in both cases, high natural reserves of oil makes their GDP so high, i.e., inflated. On the other hand, Switzerland and Luxembourg (although at a different scale) have unusual financial and tax systems and operate as hosts for many international companies and institutions, thereby also inflating their GDP to off-the-scale levels. The GDP of these countries can thus be considered inflated with regard to the real output of their national economies and, naturally, to their economic ability to adopt ICT for their citizens and firms. South Korea presents the opposite condition, i.e., it is a case in which digital development is higher than its economic development would suggest. The pattern in this country is explained by the emphasis that the South Korean government and policy-makers have placed on ICT adoption, making it a priority.

In answer to our research question, the slope of the pattern between economic and digital development appears to behave differently in countries with below average GDP, in comparison to those with above average, i.e., between the countries located to the left and right of the vertical axis, respectively. In fact, for the first group the correlation is 0.89, contrasting with the 0.47 of the second group, although the two correlations are statistically significant at the 0.01 level ($p < 0.01$). Note that the overall correlation is 0.78. Thus, the correlation between the two developments does not appear to be linear, depending on the level of GDP.

In order to test the non-linear relationship between GDP and DigDev, we calculated two ordinary least squares (OLS) models, both with DigDev as the dependent variable. The difference between the two resides in the fact that the first had only GDP as an independent variable, while the second had GDP and GDP-squared to allow for a non-linear effect (Klasen et al. 2014). If the second model were statistically better than the first, then our hypothesis of a non-linear pattern would be confirmed. The models were mathematically expressed as follows:

$$DigDev_i = \beta_0 + \beta_1 * GDP_i + \varepsilon_i \qquad (1)$$

$$DigDev_i = \beta_0 + \beta_1 * GDP_i + \beta_2 * GDP^2_i + \varepsilon_i \qquad (2)$$

where β_0 is the constant term and β_1 and β_2 are the coefficients to be estimated by the OLS, and ε_i is the error term of the i_{th} country.

As there were severe outliers in our data, particularly the four countries with off-the-scale GDP, these were excluded from the analysis, leaving a remainder of 106 countries. Also, as recommended by Neter and Wasserman (1974), we conducted a series of tests to confirm the suitability of the models. We analyzed the residuals' distribution and in order to demonstrate their normality we used the Shapiro-Wilk (1965) test. For a 5% significance level the assumption of the residuals' normality was not violated ($p > 0.10$). With respect to a possible heteroscedasticity problem in our model we used White's test (White 1980), which indicated no presence of heteroscedasticity ($p > 0.10$) (see Figure A in the Appendix). At a 1% significance level the two models were significant ($p < 0.01$); the second model, however, explained more than 10 p.p. of DigDev´s variation, achieving the remarkable value of 83%, and is statistically significant at the 1% significance level ($p < 0.01$). We therefore confirmed that there is a non-linear relationship between the economic and digital development of countries. The results can be seen in Table 5.

-----------------------------------Insert Table 5 here -----------------------------------

Although the OLS did not establish any direction of causality between explanatory and dependent variables – these were hypothesized *a priori* in Subsection 4.1 – these results are strong evidence that the economic level of a country is indeed decisive in ICT adoption, especially in its initial stages. Thus, economic power is a prerequisite for countries to have the capacity to acquire ICT. However, our analysis appears to reveal that for those countries that already have the (financial) ability to adopt ICT, GDP is not as important as it is for poorer countries. One might therefore argue that for richer countries digital development is influenced by other factors that are not purely economically based.

4.2 Classification of countries

In order to classify the 110 countries in terms of their joint economic and digital developments together, we made use of cluster analysis. Using the DigDev and the GDP together in this analysis allows us to obtain a classification for each country based on these two types of developments, grouping the countries according to a similarity criterion regarding their performance in these two dimensions. This multivariate technique allowed us to optimally group the countries into clusters in such a way as to maximize the information retained on each individual country. The aim of using it was to classify each country and then geo-reference its profile cartographically on a map of the world. It is then possible to recognize important insights about the geographical distribution of the pattern between economic and digital development of countries across the globe.

In cluster analysis we used several hierarchical clustering algorithms to determine the number of digital profiles present in the dataset and also the initial seeds to perform a non-hierarchical algorithm (k-means), an approach that, according to Sharma (1996), tends to yield better results. Among the four hierarchical clustering algorithms that we used (Complete, Centroid, Ward, and Single), the Ward method achieved the best results, pointing to a five-cluster solution, according to the dendogram and R-Squared criteria (see Figure B in the Appendix). The averages of each cluster provided by this algorithm were used as initial seeds in k-means.

The first group of countries included 34 homogeneous nations and presented the lowest level of economic and digital developments. These countries are labeled "*economically-digitally underdeveloped*". The second group included 30 countries with the second lowest level of these two developments. These countries are labeled as "*economically-digitally developing*". The third cluster comprised 23 countries that together rank as third in the averages of the two developments. These countries are labeled "*economically-digitally developed*". The fourth group comprised 18 countries with the highest level of digital development and the second highest level of economic development, and is thus named "*economically-digitally highly developed".* The last group included the five bi-dimensional *outliers*, i.e. the countries with the second highest level of digital development and extremely high levels of GDP. We named these "*economically-focused*". The descriptive statistics of each cluster are given in Figure 2. The complete list of countries is given in Table 6 in the Appendix.

-----------------------------------Insert Figure 2 here -----------------------------------

As the geographical distribution of the countries in terms of economic and digital development profiles is also interesting (illustrating how countries are scattered across the globe), we geo-referenced the countries on a World map (Figure 3). Some interesting considerations emerged from the examination of this Figure:

- The geographic location of each country appears to have something to say regarding the link between economic and digital developments. Of the 34 "*economically-digitally underdeveloped*" countries, 22 (65%) are African, followed by 8 (24%) from Asia; The 31 "*economically-digitally developing"* countries are more evenly spread around the globe, although 14 (45%) are from the extreme East of Europe; and the 23 "developed" countries include 15 (65%) from the EU-28.
- From another point of view, 88% of African countries are classified as "*economically-digitally underdeveloped"*; Asian countries are relatively well spread across all profiles, although the relative majority (36%) is classified as "*economically-digitally underdeveloped*"; South American countries are mainly classified as "*economically-digitally developing*" (63%); there are no European countries classified as "*economically-digitally underdeveloped*".
- It did not come as a surprise that the economic/digital leaders of the world are located in North America (Canada and USA), Europe (particularly countries in the North and Center), Oceania (Australia and New Zealand), and East Asia (Macau, Hong Kong, Japan, and South Korea).
- The least *"economically-digitally developed*" countries in the world are mainly located in Africa and South Asia.
- Russia is the only one of the BRICS countries that achieved a good classification ("*economically-digitally developed*").

------------------------------------Insert Figure 3 here ------------------------------------

5. IMPLICATIONS AND LIMITATIONS

5.1 Implications

Implications for researchers and policy-makers can be drawn from the present study. One of the main implications comes from the close relationship between digital and economic development. As with technological innovations in the past, economic wealth is a critical prerequisite for ICT diffusion and is a main antecedent of the digital divide. As ICT depends upon specific infrastructures, more often found in richer areas, it is reasonable to expect that those having higher levels of infrastructures will be the ones with greater digital development. This result is not considered to be surprising. As the empirical results have demonstrated, this link between infrastructures and digital development is even stronger in countries with lower levels of economic development, where (even before other aspects come into play) the first thing needed in order to use ICT is the financial ability to do so.

As in the context of the digital divide, linear effects are usually assumed from the outset of the research, and misleading conclusions may have been drawn in the past regarding the role of economic development in the digital divide, with obvious implications in the policy-making definition. As such, those seeking to narrow the digital gaps, whether in developing or developed countries, should keep in mind that it is only when the ability to effectively acquire ICT is achieved, that other factors come (increasingly) into play to explain variations in its use. We therefore separate the implications for developing countries from developed ones, as the main conclusion of this study shows that in promoting digital equality, these different types of country need to have different strategies.

For developing countries, and from a supply perspective, some actions might promote digital development, especially in the case of simpler technologies, such as the Internet and PCs. It is often suggested in the literature, and eventually followed in practice, that liberalization and deregulation, with the aim of lowering prices or subsidizing purchase, may effectively nurture ICT. Some authors argue that doing this could in fact drive the interest of private organizations of developed economies to invest in developing economies, thereby increasing digital development.

Another implication for developing countries has to do with trying to explain the reasons behind the failure of one of the most common initiatives policy-makers and private organizations have developed in order to foster ICT adoption and use in developing countries, the telecenters or information kiosks (Gomez et al. 2009). These telecenters and information kiosks should enable "*poor people to receive information about their governments, market prices, health and education*" (Ashraf et al. 2007). Moreover, these "kiosks" could and should, theoretically, be used by members of any income group, especially those who cannot afford to own a computer but who need access to these services (Kuriyan et al. 2008). However, there is evidence that this is not what actually occurs in practice, as most of these "kiosks" are underutilized, especially by those considered most disadvantaged or those who could benefit the most (Sey 2008). We posit that the reason behind this is that the same effect found at the country level holds true at the individual level, i.e., it is imperative to first provide the financial conditions to adopt ICT to those with lower incomes, something that the "kiosks" are unable to do, as they treat users as consumers and do not provide regular and free access to ICT. Moreover, as individuals' financial capabilities grow, so does their ability to acquire additional and more advanced ICT goods and services, increasing the overall digital development level. In Internet kiosks this does not happen, as individuals are simply given access to the Internet, which is almost the same as remitting them to the initial conception of digital divide (has/has not).

As for developed countries, policy-makers should encourage digital diffusion of more advanced technologies. In particular, economic development associated with an increase in the role of services (in terms of GDP) might boost Internet use, broadband use, and e-commerce development by firms and the public sector. As our results appear to demonstrate, improving quality in public services, such as education and infrastructure, is likely to boost digital development, thereby promoting ICT-based educational resources and highlighting the opportunities and uses associated with ICT adoption. From this approach, new digital services, new e-learning content, e-business, e-health, and e-government could help to promote advanced ICT diffusion. Additionally, instead of providing hidden subsidies to technology, resources could and should be directed at developing useful and usable applications for those for whom such applications might be of immediate benefit, and who likely already have access to ICT. What is especially needed is the means to use ICT in an effective way to respond to real crises in health care, education, economic development, and resource degradation, which could be achieved through education and IT formation (Gurstein 2003).

In summary, developing countries should facilitate general ICT adoption, such as the Internet, whereas developed countries should give more attention to actions devoted to promoting the use of the more advanced applications allowed by ICT, by means of improving education and infrastructure, as these gain importance after the acquiring conditions have been met.

5.2 **Limitations and future work**

In spite of our efforts to offer a complete and updated analysis of the pattern between digital and economic development of countries, some limitations must be acknowledged. Although we included 110 countries in our analysis, our empirical application for measuring the digital development of countries comprised just seven variables and, therefore, some features of the information society may not be captured, and also there are other countries that could not be included due to data availability constraints. The analysis was conducted at country level, meaning that all indicators used are concerned with aggregated national realities, so domestic/intra-national digital divides are therefore not covered. Note that these potential domestic divides are more likely to be present in larger, and therefore more heterogeneous, countries, as well as in those presenting lower economic development. Such countries are perhaps more likely to reveal domestic digital disparities, because smaller and richer societies are easier to connect than those that are larger and poorer (Emrouznejad et al. 2010; Dewan et al. 2005). Hence, for future work, it would be of interest to extend the study of the digital divide to the intra-national level. Using prominent IS theories, such as UTAUT2 (V. Venkatesh et al. 2012), a better understanding of general-ICT adoption decisions by individuals might be achieved. Finally, this analysis refers to a specific point in time, the year 2011. Although this limitation was derived from the goal of this paper to include the greatest number of countries possible (no data are available for other years without reducing the number of variables or countries), changes in this context are likely to occur rapidly and our findings may soon become outdated.

We intend to broaden our analysis of the digital divide in future work, especially through the inclusion of other features of countries that, as our analysis seems to reveal, may be especially important in explaining the digital gaps among the wealthier countries.

6. CONCLUSIONS

We measured the digital development of 110 countries from all over the world. As our aim was to explore the link between economic and digital developments, we assessed the pattern between the score of a factor analysis based on seven ICT-related indicators of countries, with their gross domestic product per capita. The link between the two types of developments was analyzed using an OLS with the GDP and GDP^2, which revealed a nonlinear relationship between economic and digital development of countries. This methodology allowed us to explain 83% of the variation in the digital development of countries (the global digital divide) with our model, a result that exceeds the explanatory power of most similar studies reported in the literature. Finally, with the use of cluster analysis we profiled each country's economic and digital development and geo-referenced them on a world map, where some interesting insights were revealed. There are five groups of homogeneous countries regarding the digital and economic development. The less "economically-digital" groups are located in Africa and Southeast Asia. Progressively, countries with higher "economically-digital" development are located in South America, Europe, and North America and Oceania.

The main conclusion of our study is that, although the correlation between economic and digital development of countries is very high, it appears to be even stronger in developing countries. Thus, one might assume that for those countries with the conditions to acquire ICT, other factors emerge regarding the actual use of these technologies.

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APPENDIX

------------------------------------Insert Table 6 here ------------------------------------

------------------------------------Insert Figure A here ------------------------------------

------------------------------------Insert Figure B here ------------------------------------