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ICT and Cross-Country Comparisons: a Proposal of a New Composite Index

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Resumen

La idea de partida en este trabajo es que las tecnologías de la información y las comunicaciones (TIC), particularmente su uso y difusión, pueden resultar ser un mecanismo que contribuya a la disminución de la desigualdad existente entre países ricos y pobres en la era digital. Nuestra principal aportación está relacionada con la importancia que tiene la disponibilidad de información estadística para períodos extensos y mediciones más precisas de los distintos componentes que definen el nivel de acceso a las TIC de los países. Se recurre al uso de una técnica de imputación múltiple para estimar los datos ausentes de TIC y, a partir de esta estimación, se realiza la propuesta de un nuevo índice complejo de difusión de TIC que aporta una más adecuada cuantificación de las capacidades nacionales: el índice NaCap. Una de las características distintivas del NaCap es que intenta capturar el papel diferenciado de los distintos niveles de acceso a la educación en relación con la complejidad de las tecnologías y otros elementos estructurales de las economías, entendiéndolos como factores determinantes del impacto de las TIC en el desarrollo de los países. La estimación de los valores que adopta el índice NaCap en 170 países durante el período comprendido entre 1991 y 2003 permite la realización de análisis dinámicos así como acometer comparaciones internacionales más amplias y precisas que las que permite la información disponible en otras fuentes estadísticas internacionales.

Palabras clave: difusión tecnológica, adopción de tecnologías, brecha digital, indicadores compuestos, imputación de datos.

Abstract

This paper focuses on the use and diffusion of Information and Communication Technologies (ICT) as a mechanism that may reduce the *global divide* between rich and poor countries. Our main contribution deals with the importance of counting with accurate time-series data and a precise assessment of the components that define ICT indicators at a national level. Thus, a multiple imputation technique is carried out to estimate ICT missing data under the expectation maximization approach. The resulting dataset allows us to propose a more confident estimation of an ICT composite index based on the notion of *national capabilities*, the called *NaCap Index*. A distinctive feature of the NaCap is that it attempts to capture countries' differences on education and structural elements, both determinant factors to attain positive impacts from the use of ICT. The calculation of the *Nacap Index* for a broad sample of 170 countries and for a time spam from 1991 to 2003 enable us to do cross-country and time comparisons in a more robust manner.

Keywords: technology diffusion, technology adoption, digital divide, composite indicators, data imputation.

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Índice

1. Introduction

The Information and Communication Technologies (ICT) opens new windows of opportunities to improve the level of development in lagging economies. The new digital techniques might allow a greater and more dynamic insertion of the less developed countries into the world economy. Some of the factors that enable the reduction of the global divide are the greater access to information available at lower costs and the efficiency gains that these technologies may motivate. On the other hand, since national capabilities determine the degrees of excludability of the international communication network and its effects, the initial premise could be the need of the presence of some necessary conditions that countries should satisfy to be able to get the positive effects generated by ICT.

Several attempts of measuring ICT agree that their worldwide diffusion level strongly links to national income levels, educational aspects and the degree of technological advance. From this standing point, the existing indicators try to capture, in a synthetic way, the different components of technological development levels in a particular country and more specifically, the use of traditional and modern technologies. Most of the available indicators coming from different sources (UNDP, WEF, UNCTAD, UNIDO, ArCo, ITU) mainly reflect the issues emerging from the empirical evidence about the role that ICT has in welfare and economic growth. Although their values permit to rank the countries according to their access to information technologies, there are two pending issues for discussion. Firstly, the lack of data for extended temporal would enable us to understand the dynamics of the process and its interaction with the development level of countries. Secondly, the suitability of the selection of indicators which shape the available indexes and its measurement and to what extent these integrate some basic elements.

This paper focuses on the idea that ICT can enhance technology transfer among countries of different development levels. Therefore, the use and diffusion of ICT are mechanisms that may favour the reduction of world inequality, that is, it may reduce the gap between rich and poor countries. Accordingly, our main contribution deals with the importance of counting with accurate data and a precise assessment of the components that define ICT indexes at a national level: the more precise the measurement, the better our understanding of national ICT capabilities. The empirical approach of this paper integrates dynamics and a methodological effort to improve ICT indicators in order to approach the impact of ICT in inequality at the international level.

The structure of the paper is as follows: the next section presents the literature background and the main empirical findings on the relationship between ICT and development. The third section examines the available measurements of ICT diffusion in the international scenario in order to identify the main criteria used by researchers to build composite indexes and to distinguish their similarities and differences. The fourth section deals with the issue of data availability, which has been one of the main restrictions to evaluate the impact of ICT on economic development. We consider several methods to attain a broader sample of data, being the multiple imputation technique the most reliable procedure to conform a balanced data panel. In order to accomplish our empirical analysis, in the fifth section we propose the use of the multiple imputation method to get reliable cross-country and time series data of ICT variables. Accordingly, we conduct several tests to attain an efficient estimation model. In order to reach a more robust estimation of the absent data, our focus is not only in the imputation technique but also in the selection of the variables, which indicate the level of access to ICT and other national characteristics. Both the data estimation procedure and the choice of the variables will allow us to build a composite ICT index. Section sixth develops the NaCap Index and explain the construction of it main components. Firstly, it considers the role of national capabilities in order to build a distinctive index. Particularly, one of the key aspects underlined here is the differences on educational and structural factors across countries, which are determinant factors to achieve positive impacts from ICT diffusion. Finally, we present the results of the index estimation, which comprises 170 countries in the period from 1991 to 2003: The differentiated paths of the ICT evolution allow us to distinguish some countries profile, which permits to qualify and quantify more precisely the international digital divide.

2. The background

The role that ICT play in the development of countries is generally assumed positive. A first crucial international difference exists between the production of those technologies and its use, or more precisely between producers and users of ICT. For that reason, taking a broad sample of developed and developing countries, the research questions mainly deal with ICT diffusion. The search of the determinants explaining the access of countries to these technologies has occupied an important part of the related literature. Economic and social differences across countries also explain a different expansion of ICT: Income and infrastructure levels, as well as education and telecommunication costs are some of the most relevant common factors.

In the nineties global PC penetration took a huge leap forward, rising from 2.5% in 1990 to nearly 9% in 2001. The proportion of Internet users went from nearly zero to 8.1% in 2001 (Chin and Fairli, 2004). At the same time, the income gap between rich and poor countries widened further, while human development throughout the nineties stagnated and eroded more than even before, with the HDI (human development index) falling in more countries than in the previous decade[1] (UNDP, 2003). Available evidence bears out the important role of modern technologies as economic growth drivers in the vast computer and communications industries. The contribution of ICT to changing the behaviour of productivity between the first and second halves of the 1990s in the US it is estimated at 0.5% of the growth in total factor productivity (TFP), which has given rise to the concept of "the new economy" (Jorgenson & Stiroh, 2000; Oliner, Sichel, 2000; Temple, 2002). Recent estimates appear to confirm that the positive effects of ICT on productivity growth are spreading to other G-7 countries besides the US (Jorgenson, 2003). Furthermore, some authors argue that the European Union's lag in competitiveness and productivity is due to its later start in ICT investment. The impact could feed through incoming years (Temple, 2002).

There is a consensus regarding the positive impact of the production of digital technology related to goods and services on productivity, an effect accentuated by the fall of computer equipment prices. It is also important to point out the role of digital technologies in the newly industrialized SE Asian countries, led by Hong Kong, Singapore, Taiwan and South Korea. Despite their importance, however, there is not a full recognition of the factors explaining the international differences in the availability of information and communications equipment, even among industrialized countries. Results of international comparisons are not forceful enough, because empirical evaluations of the relationship between technology and a countries' advancement leads to varying conclusions according to the size of the samples and the time periods taken; i.e. the inclusion of developing countries and the study of long-term trends or potential cyclical changes.

The empirical findings are coincident on the high international inequality in the ICT diffusion. That inequality is twice the one related to the world income. This aspect has been conceptualised in the form of digital divide and in the extreme cases even as digital exclusion (UNCTAD, 2005). Ranking of countries is one of the most outstanding empirical findings, which use several criteria for its elaboration. First, taking into account geographical groupings the key characteristic is high dispersion. Secondly, regarding income levels, there is a high concentration and notable inequalities across regions (Alonso, Álvarez, Magaña, 2005).

While studying ICT, once should distinguish between production and use and, by extension, between producing countries and users, while also addressing supply and demand issues. This duality in the study of ICT becomes more important when we include in our analysis a broad set of countries. Accordingly, we must qualify the geographical uniformity of the "new economy" and its impact on inequality. After all, as indicated by literature on the technological divide, innovation or knowledge generation tends to widen international differences, while its dissemination would have an opposite effect (Fagerberg, 1987; 1994; Verspagen, 1993).

As Pojhola (2002) points out, few developing countries have invested heavily in ICT, let alo-

[1] The Human Development Index (HDI) considers three variables for development: life expectancy, access to education and income levels of a population. In the 1990s, the HDI fell in 21 countries. Of the 144 for which there are data since 1980, only four recorded increases in the 1980s and 15 in the 1990s. Some attribute this poor performance to the negative economic impact and the fall in life expectancy caused by the spread of HIV/AIDS (UNDP 2003).

ne seen a major impact from this type of technology[2]. Some factors shaping the real possibilities of countries that are far away from the technology frontier of the digital era are the lack of prior investment in physical and human capital, as well as the generation of complementary inputs, when defining the basic framework for ICT development. In fact, when looking at the impact of ICT on economies growing at different speeds we see that industrialization and the provision of advanced services are drivers of cumulative technological development.

Among the most feasible explanations for the growth of the ICT industry, the first is the recent evolution of international production networks, which have led to conceptions based on the gradual development of the productive sector. The first step is to begin with assembly processes, before actually producing components in later stages to supply large local producers, frequently owned by foreign capital. Costa Rica and Brazil are two countries where the strategy has been to encourage the development of the local computer industry via the establishment of foreign manufacturers. The second step is to leverage the virtual network, with businesses viewing it as a platform for exports and a means of creating niche markets, leaving them better placed to compete despite the geographical distance from the world's main markets. The role of foreign capital in developing countries is one of the keys to understanding the phenomenon; increasing their ability to attract foreign capital becomes crucial in their action plans. Similarly, ICT for development strategies are bearing in mind issues such as the role of qualified labour markets and human resources training.

Part of the empirical evidence is the one focused on the level of ICT access through a technology diffusion model –Gompertz model-. The inclusion of developed and developing countries reveals different results for each of these groups of countries. Kiiski & Pohjola (2001) show that for OECD countries GDP per capita and internet access cost explain the growth in computer hosts while competition and education are not so significant issues. On the other hand, education levels gain significance in the case of developing countries. Recent studies on ICT investment in the 1990s reveal an association between a country's human capital and, on the minus side, the specific weight of agriculture in the generation of aggregate value added[3] (Pojhola, 2003).

Studies on the factors underlying access and Internet use confirm this idea, highlighting those that explain the digital divide besides income levels, educational level, cost of telephone services and institutional factors such as the level of political freedom (Dasgupta et al., 2001; Kiiski and Pojhola, 2001). What's more important, taking broader samples, we see that the positive knowledge and economic growth relationship over the long term is greater for human capital and technological activity than for ICT (Chin and Fairli, 2004; Chen and Dahlman, 2004). This means that a broader conception of development strategies is required; it would include ICT as a basic, but not single, element. It is also clear that the digital divide differentiate by forms of technologies. Some technologies do not require users with high levels of literacy while others technologies, such as internet services are more associated with high educational levels. Apart from the consensus on the importance of income as a determinant of ICT diffusion, some findings reveal that urban population and competition policies are some of the significant elements that could explain the digital divide (Dasgupta et al.,2001).

In sum, differences in per capita income, physical and human capital levels, the degrees of freedom and the availability of infrastructure are all elements that clearly play a role explaining international differences in digital development. The threat to LDC is that they could leave out the wave of innovation and economic growth due to their low level of ICT investment and the lack of basic infrastructure and conditions to lead dynamic aggregation processes. This would appear to define a hypothetical vicious circle in which ICT can be understood as a source of development of countries (but not the only one), while the achievement of greater levels of development (via investment in human and physical capital, freedom,

[2] An example is South Africa, which by comparison has invested heavily in ICT in the region, but with a scant impact on economic well being (Pohjola, 2002). There are also other studies focused on ICT investment, such as Caselli and Coleman (2001), explain based on data for 89 countries between 1970 and 1990 the importance of computers per worker as a indicator of ICT investment through a set of economic, technological and institutional variables.

[3] This study takes a sample of 49 countries in the 1993-2000 period and a regression of ICT investment on per capita income, IT prices, human capital, the opening-up and weight of agriculture on the economy.

etc.) determine the advance of ICT and a country's access to the digital era.

Therefore, we would underscore that ICT can help to overcome problems common to both the 'old' and 'new' economies. Inherently intangible, access to new technologies can offer fewer barriers than traditional technologies, thereby slowing the increase of international inequalities. Well-aimed political measures by national governments and the international community are those that attempt to overcome the factors that increase such barriers, if not reduce them. But there is another reverse of the same issue. The literature has devoted scarce attention to the relationship between ICT development and the disparities existing inside the developing world. Particularly, the question would be to what extent the benefits of these networks (goods) may contribute to enhance equity worldwide.

3. Measuring countries technological capacity

There have been several attempts to measure the technological capacities of countries. Very often, the construction of indexes takes a set of reference' variables, which are related to both traditional and newest ICT. Those variables may classify into two differentiated groups. First, variables reflecting aspects directly associated to the ICT diffusion. Secondly, those that the empirical evidence shows closely related to the evolution of the sector or those that are the expression of necessary elements for the technological advance of countries. To quantify the role of ICT in a country there is a combination of both the more traditional elements, such as telephone use, and others that indicate a modern country or a greater degree of technological advancement such as mobile phones, PCs and Internet users and nodes.

The methodology of building a final index aggregating several variables or sub-indicators is rather similar in all of them. The premise is that an index for ICT is more robust than a single indicator in measuring qualitative and independent concepts, the challenge being on the definition of comprehensive indexes (Press, 1999). Thus, the method generally consists in taking simple or weighted means of the various components assuming an equal importance of them and the possibility to offset of one by another.

First, the UNDP *technological achievement index* (TAI) is integrated by a category called "diffusion of newest technologies", based on internet hosts and medium and high technological content exports, as well as another category called "diffusion of oldest technology" in which the telephone mainlines and the electricity consumption are considered. These two categories combine also with other two, one related to the creation of technology, based on patents, royalties and license fees, and the other related to human skills (UNDP, 2001). This index has been built for 84 countries. Second, "ICT diffusion" is also among the building categories of the WEF (World Economic Forum) technological indexes. This aspect is measured by internet access, telephones mainlines and PCs. The *WEF index* also includes some categories that represent the innovative capacities as well as technology transfer for countries (WEF, 2001; 2003). Third, the *ArCo index* includes internet, telephone mainlines and mobile phones as part of its "infrastructure" category, in which considers electricity consumption too. This index is also building upon innovative activity, measured by patents and publications, as well as some human capital indicators: tertiary science education, years of schooling and literacy rates (Archibugi & Coco, 2004: 2005). Fourth, UNIDO creates also some indexes for individual categories, among which telephone mainlines are included, but not a synthetic index in which the different categories combine in a more suitable measure of countries technological capabilities.

Other indexes more precise are also building to measure specifically ICT by countries. This is the case of the *Digital Access Index* (DAI), created under the auspices of the International Telecommunication Union (ITU). The DAI try to capture the ICT access and use capacities of the population of a country. It includes eight variables organised in five categories: infrastructure (telephones and cellular), accessibility (internet access costs), knowledge (adult literacy rate and a combination of primary, secondary and tertiary enrolment), quality (bits and broadband) and use (internet users). There are comparable data for a 4 years period, from 1998 to 2002.

UNDP and ArCo attribute the same importance to the elements composing the final index.

The WEF, on the other hand, weights the components differentiating between core and non-core countries. In the first group, the index is a simple mean of ICT and innovation sub-indexes. In the second group, although there is a third sub-index of technology transfer, ICT still contributes ½. The method to build the DAI is also rather similar. The index is a simple mean of the five categories, each of them built with weighted means of the integrating variables.

These indexes are provided for extended samples, which have the maximum values defined for the more developed countries. Some weak methodological aspects referred to the DAI (UNCTAD, 2004) can extend to others as well. Particularly, in the case of developing countries, beyond the lack of infrastructures and basic conditions, the costs of access to ICT are still considerable higher than in developed countries. Moreover, the indexes based on quantifiable elements do not reflect qualitative differences across-countries such as national regulation aspects. For these reasons, it is easy to find that the Government action partially support the success of some economies such as Slovenia and the creation of a Ministry in the field. On the other hand, we assume that the literacy rate and the education performance of countries crucial aspects for ICT diffusion. However, countries such as Korea, in which these two aspects are extremely considered, did not rank among the 10 first in international classification. The use of ICT therefore relate to socio-cultural aspects in countries.

Concluding, there is an agreement on the role of ICT elements as a factor enhancing the technological capabilities of countries. However, it is noticeable that there is not a uniform conception of ICT in all the existing measures. Most of them coincide on the role that these technologies have as a mechanism favouring *diffusion* aspects, while others consider them as part of the *infrastructure* level, together with other elements so different such as the energy supply. It is clear that all the mentioned indicators show a noticeable correlation among them and with the other precisely oriented to measure the digital accession of countries -see Table 1-.

Table 1
Correlation between Income and technological indicators

	TAI	ArCo	DAI	National per capita income ($ PPP)
TAI	1			
ArCo	0.971(**)	1		
DAI	0.951(**)	0.941(**)	1	
Per capita income	0.909(**)	0.851(**)	0.851(**)	1

Notes: (**) The correlation is significant at the 0.01 level (bilateral).
The correlation is based on the latest available data for each ICT indicator (the DAI is updated to 2002, and the ArCo and TAI indicators to 2000).

All these indexes have in common the combination of variables related to ICT and other that contributes to define the development context. It is possible to find a window of opportunity in the latter to explain technological change, specially taking into account that human capital is a basic condition for the assimilation and development of technological capabilities. Although the aspects of human capital are integrated in the available indexes, it is important to consider that some authors (Chin & Fairlie, 2004, Maker & McNamara, 2002) underline literacy rates while others (Kiiski, Pohjola, 2001; Satti, 2002) reference to the average years of schooling as an explicative factor of the new economy. Even more, other variables included are enrolment rates and students enrolled in science and engineering studies. Particularly important is therefore the idea that the development of different technologies also requires different inputs and abilities for its use and diffusion; i.e. the use of telephone does not require any distinctive skill.

In table 2, it is possible to see that the general enrolment rate and the number of students in science and engineering correlate more to the use of traditional technologies. In an analogue way, scientific publications and patens, as well as internet and computer users -that require greater levels of knowledge- are more associated to tertiary science enrolment and average schooling years. That is, the basic literacy abilities –reading, writing- are necessary but not sufficient conditions for a nation to develop its technological capabilities.

Table 2
Educational variables and ICT

	Literacy rate	Primary enrollment	Tertiary enrollment	Years of schooling
Patents in US	0.318	0.112	0.547	0.504
Patents by residents	0.126	0.004	0.235	0.233
Scientific articles	0.420	0.152	0.724	0.643
Internet users	0.432	0.128	0.689	0.641
Telephone mainlines	0.622	0.242	0.776	0.746
Mobile phones	0.493	0.209	0.693	0.647
Computers	0.508	0.173	0.730	0.686

SOURCE: World Development Indicators 2005.

For that reason, the inclusion of literacy rates in synthetic indexes may underestimate the importance of human capital in the use and diffusion of technological factors. The inclusion of differentiated human capital variables may improve the measurement of the education flow or stock even incorporating qualitative aspects. This would permit a more suitable combination of technological and contextual variables. Even more, in the latter the consideration of income levels as well as other structural elements such as the level of exports and urban population may have incidence in the demand of goods and services associated to ICT.

4. Estimation of absent data in ICT indicators

Several studies on the topic of ICT face the problem of carrying out dynamic analysis and cross-country comparisons due to the scarce availability of statistics, especially in the case of ICT databases. For instance, according to the World Development Indicators on ICT, figures on Internet users range from 28 countries with available information in 1990 to 188 countries in 2000. Although the collection of ICT figures for an increasing number of countries, it would take longer to have a balanced panel of reliable data to analyze the impact of ICT on international basis through time. Thus, the lack of data could hamper the realization of empirical research and it might constitute an important barrier to understand both the path and profile of the digital divide. The emerging character of some of the ICT indicators (computers, Internet users, secure nodes, broadband connections, etc.), and the existence of measurement errors related to data collection are the main factors explaining data deficiency.

The ITU states that statistics on Internet users, as well as other telecommunication indicators are collected indistinctly either through surveys conducted by public and private agencies or by compilation of national reports, which rely on registration and estimation techniques. However, surveys may differ in their methods and coverage, which could lead to misleading in the accountability process of ICT indicators, and many countries -particularly the less developed ones- face problems either to collect reliable data on novel activities as the aforementioned or in their estimation techniques. As some ITU reports state (ITU, 2003), the estimation figures often under-estimate data provided by sources that are more reliable -as the surveys-, when both kind of information are available.[4] Other international organizations such as UNCTAD also recognize that statistics differ according to their source. Thus, figures from ITU surveys are lower than others; i.e. the ones from Nua[5]. Besides, there lack of consistency in the applied methodology at a national level allows us to estimate the figures of Internet users in a more accurate manner.[6]

Moreover, according to the 2003 World Telecommunication Development Report, published by the ITU, which focused on the measuring issues of ICT indicators-, Internet users surveys systematically apply in the richest and developed countries (six of every ten) while not a single one has been conducted in near 60 countries and the available surveys are not coincident in their results. For instance, between the six surveys conducted in Spain to measure the population that have access to Internet in 2002, the results range from near 20 to 50 percent, being the figure of the National Institute of Statistics (INE) the more conservative and the highest the one reported by Nielsen agency. Disparities exist as well when comparing data estimated by national agencies and surveys figures. Internet users in Mexico also rise from 4.6 (estimate) to 9.8 percent (survey) in 2002, while in Jamaica a survey finds that in 2003 the population with Internet access was five times greater than the one previously estimated.

As long as telecommunication activities have achieved an increasing role on the countries economies and on the people's welfare, more attention will be devoted to the proper measure of the information and telecommunication indicators that would improve our understanding of the determinant factors of that process. Statistics about older ICT indicators as the radio receptors, television sets or fixed lines, are more reliable now than they were in their beginnings, and the same is happening with the new ICT indicators. Several countries that in the early nineties did not conducted surveys to measure with a greater quality its telecommunication and information activities are doing so now. Nevertheless, it concludes that the contrasting results of the telecommunication figures -according to their source- calls for caution to conduct policy analysis and the problem of lack of data remains, particularly for the early years of the nineties. The key aspect to keep in mind is that nowadays researchers are not able to distinguish whether the missing figures or even cero values correspond to nonexistent activities or its absence relates more to errors in the sampling and estimation techniques.

4.1. MISSING DATA: AN OVERVIEW

The problem of having incomplete information is due to multiple reasons, which range from non-response data to sample error estimation or absent of proper registration and accountability systems. In order to face the absence of data for research purposes, it is necessary to deal with missing data techniques, especially when the data is going to be used for empirical analysis. In fact, this issue is a common problem in social sciences as well as in other science fields. In its ICT development indices report, UNCTAD recognizes that "treatment of data omissions is central in determining the results of an index" and it is a necessary step in the process of conducting empirical research.

Obviously, researchers are aware of the risk involving the enlargement of the sample and the potential biases introduced by missing data estimation. Nevertheless, their choice obeys to the integration of more comprehensive databases, which permit an extended time and cross-country comparisons. Frequently, this effort tries to extend the empirical research to the broad and larger group of developing countries instead on focusing only on the more developed ones whose overall indicators are more reliable and complete. Even if the rate of missing per case is low, the overall impact could be high enough to have a substantial effect on the analysis results. In a sample of 100 cases and 20 variables and a random missing rate of 2% for every case-variable combination (it is not an uncommon data set in economics), the pro-

[4] In the absence of national accountability systems or surveys, the estimation of Internet users -for example- is based on information provided by Internet service providers companies or in other unspecified sources.

[5] SangoNet surveys, available at http://www.clickz.com/stats/.

[6] UNCTAD (2003), «Information and communication technology development indices», UNCTAD/ITE/IPC/2003/1.

portion of cases with incomplete data could be as high as one third. Thus, the implications of the missing data are not trivial and could throw doubts about the conclusions of any empirical research, reason why researchers have become increasingly conscious about the consequences of missing data.

Moreover, because the usual statistical methods assume complete data in order to carry out with the analysis, the data shortage implies more than just the reduction of the sample observations. In regression analysis -for example- the entire case or observation has to be ignored, indistinctively regarding if the missing data is found in one or several variables. Whether the data is missing at random (MAR) or missing completely at random (MCAR), could be severe consequences on the parameters estimates. In the latter, the assumption is that the missing data is comparable to a random sample of the entire database and the outcome of the sample reduction is the loss of power and efficiency of the estimators. In the former, if the error term is correlated with the missing data, a more severe problem arises and the results of the analysis are biased estimators.

There are several methods to deal with missing data problems. The most commonly used is, by its simplicity, the case removal or listwise deletion, which discards the complete case whether the missing observation is present in one or more than one variables.[7] As we have said before, when data are MCAR the only consequence could be loss of power and efficiency, but in non MCAR data the deletion of the entire observation may imply an estimation bias due to the failure of the remaining data to properly represent the characteristics of the entire population. Another procedure for handling the missing data is the mean or median substitution, in which the missing observation is replaced with the average mean or median (to avoid outliers influence) of the remaining cases. This technique relies on strong assumptions about the comparability between the missing and the estimated data (something unusual in the economic data and particularly in the ICT indicators).

A further frequent approach to deal with missing data are regression methods, to treat the missing data vector as a dependent variable by using a set of regressors as predictors of the absent data. The predicted values are then used to fill in the missing data. Whether the replacement of the missing data is conducted by the average, median or by regression analysis, the weaknesses of the aforementioned methods is that all of them underestimate the true value of the variance and artificially forces the sample distribution toward its central values, thus shifting the real parameter values. Contrary to the abovementioned methods, the hot deck imputation substitutes the missing data with an alternative value borrowed from the same variable and selected based on the "similarity" of a certain observation to the case that record the missing data. Thus, the hot deck process relies on the subjective "beliefs" of experts about a single or multiple cases that resemble in an accurate manner the values of the variable that are being imputed, introducing a potential bias in the missing data estimation. Authors like Little and Rubin (1987), Wothke (1998) and Durrant (2005) explain in detail the advantages and shortcomings of the above missing data handling methods.

4.2. THE *MULTIPLE IMPUTATION* ALTERNATIVE

A technique of recent incorporation in the absent data estimation procedures that contributes to resolve some of the problems already referred is the multiple imputation (MI), proposed by Rubin (1987). The main idea behind the imputation process is that the existing information in any data set and the overall distribution of data provides insights for the estimation of the missing information and its variability, keeping at the same time the relative association between all the variables considered in the imputation process.

The MI draws on the expectation maximization (EM) approach, a likelihood method narrowly associated with bayesian methods. Firstly, through an iterative process -a kind of Monte Carlo chain- the EM algorithm generates maximum likelihood estimates of mean and variances as well as probabilities for the missing data. The second step is to run a data augmentation process that equally relies on an iterative process to estimate the distributional parameters, taking into account the posterior distribution of the data and the previous esti-

[7] The listwise and pairwise deletion are the default methods that most of the statistical software uses to deal with missing data problems.

mates of the EM algorithm.[8] The outcome is then *m* imputed datasets -with both the observed and predicted information- that resembles the overall distribution of the data maintaining as well its normal variability. The aggregation of the *m* imputed datasets allow for the punctual estimations of the data.

According to Rubin rules, it is possible to assess the level of efficiency of the imputed data. In the subsequent formula, the estimation efficiency level is approximated by Λ, while γ is the rate of missing data and *m* is the number of imputed data sets[9].

$$\Lambda = \left(1 + \frac{\gamma}{m}\right)^{-1}$$

4.3. GOODNESS OF FIT OF MI: A TEST

In order to run a test about the efficiency of the aforementioned methods and their suitability to estimate missing data in ICT indicators, the choice is a sample of 161 countries and a set of 11 variables for the year 2000. The Internet users is the predictive variable and a group of covariates, which commonly referred the literature, act as explanatory variables. They contribute to outline the digital path, i.e. the level of income per capita, human capital variables as secondary schooling years and adult literacy rate, structural variables as electric power consumption and fraction of urban population, and additional ICT indicators as fixed telephone lines, mobile telephone subscribers and computers. Categorical variables related to the country's geographic region and income level dummy's were constructed as well. In this exercise, one assumption to explore is that the posterior distribution (y_{t+1}) of the variable that is being imputed could be incorporated as a covariate, thus the observations of the Internet users in the year 2001 were included in the model.

In this sample, 35 out of the 161 cases (above 20% of the data) of Internet users were dropped in a random way that resembles the overall missing profile of the ICT indicators (the proportion of information and telecommunication missing data is higher in the less developed countries). For the rest of the variables, the observed rate of missing data ranges from 0% to 36%. The objective of the exercise is to test the efficiency of the estimation by imputing the missing data of Internet users through the MI method and compare the imputed data against the observed data.

Several different models were constructed and the efficiency of the estimation was fixed at 95%. To allow for a model selection, the criteria were to reduce the standard error ε between the real I_{obs} and the estimated I_{est} data. Hence, the common formula that minimises the error term comes from:

$$\bar{\varepsilon} = \frac{1}{n}\sum_{j=1}^{n}\left(I_{obs} - I_{est}\right)$$

Data on Internet users, GDP per capita (ppp), electric power consumption and the remaining ICT indicators were transformed -in natural logarithms- to assure univariate and multivariate normality. Both the country's region and income level variables were included –regardless of it strictly non normality- to test their contribution to the overall missing estimates procedure. One of the nice features of the MI method is that it allows for a flexible multivariate imputation, hence a set of covariates could be incorporated with the purpose not only to be imputed but also to draw information about the point estimates of the dataset, despite its rate of missing or its distribution properties, in accordance to Schafer.

The outcome of the tested models -Table 3- shows that the values from the error term range from 0.287 to 0.543 (equivalent to a 10.8% y 22.7% dispersion over the observed data, respectively). Neither the country region (first model) nor the income level (second model) were substantially meaning in signalling the true value of the imputed data. Likewise, there were no significant improvements with the incorporation of the overall set of ICT indicators. However, it might be the case that a more selective inclusion may improve their effect on the estimation process.

Remarkably, the inclusion of the posterior distribution of Internet users as a covariate contributed in a great manner to improve the goodness of fit of the model, as expected due

[8] Fortunately, several software support routines and stand-alone programs have been developed to execute the complex algorithms in which the EM approach relies.

[9] Details about the efficiency of MI procedure can be found in Annex I, in the Appendix.

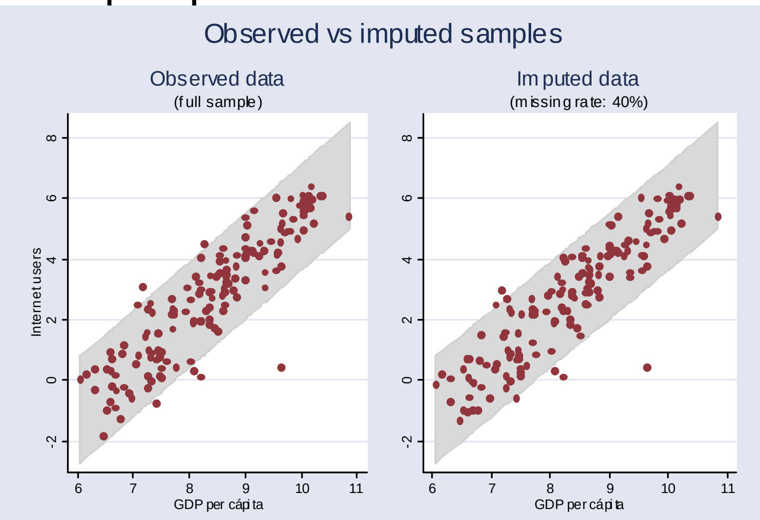
to its time and cross-country density function as well as its correlation with the imputed data (third model). Figure A1 in the Appendix shows the distributional pattern of the m imputed data sets and the overall punctual estimation, which constitutes the best approximation to the real parameters of the observed data.

Table 3
Comparisons of MI models
Internet users (ln), 2000

	Obs	Mean	Std dev.	ε
Observed data	161	2.829	2.045	- -
Missing sample	126	2.890	2.049	- -
Imputed model 1	161	2.783	2.056	0.543
Imputed model 2	161	2.780	2.048	0.524
Imputed model 3	161	2.836	2.042	0.287

A sensitivity analysis conducts the test of estimation efficiency when introducting changes in the missing rate of the covariate and predicted variables. In both cases, iterative univariate imputation of the missed data may compensate the loss of efficiency related to a higher rate of missing information in the entire dataset. Even when registering a higher rate of missing data in the predicted variable, accurate modelling through effective covariate selection and correct assumptions about the distributional properties of the data could improve the estimation. As seen in Figure 1, it was possible to obtain a good fit of data with a dispersion error of near 10% compared to the observed one, with a rate of missing of almost 40% in the predicted variable (63 missing observations).

Figure 1
Goodness of fit of multiple imputation data



Source: authors calculations.

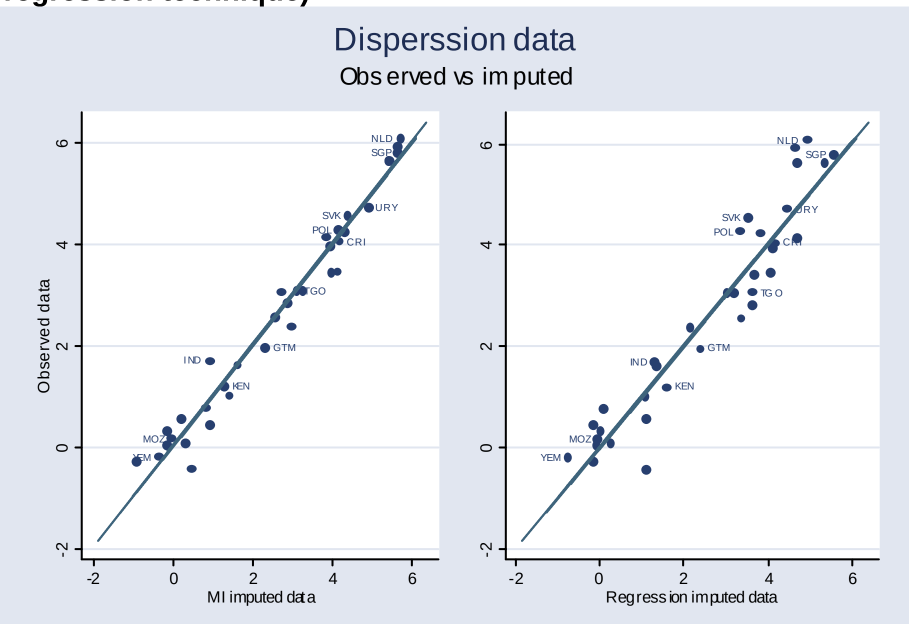
Lastly, there is an exercise to test the effect of the number of imputations rising according to Rubin's rule. In all the cases that increase the number of imputations, improves the efficiency estimation in a meaningful manner, diminishing the imputed data dispersion below 10%. Once done the choice of a final model, the comparison was the results of the mean and regression missing data procedures, which are the most common techniques in data missing estimation –Table 4.

The error term from the mean estimation is highly enough to throw doubts about the convenience of its use as a prediction technique, while the regression overall error is twice the one of the multiple imputation procedure. As seen in the displayed Figure 2, the MI method outperforms significantly the aforementioned methods and allows us for a more confidence data estimation.

Table 4
Comparisons of missing data techniques
Internet users (ln), 2000

	Obs	Mean	Std dev.	ε
Model: MI	161	2.836	2.042	0.287
Model: mean	161	2.890	1.811	1.751
Model: regress	161	2.815	2.018	0.490

Figure 2
Efficiency of imputation procedure
(MI versus regression technique)



Source: authors calculations.

5. Missing data estimation of ICT indicators

Following the technique previously explained, we conducted an exercise to impute missing data for a set of information and telecommunication indicators that stands in the ICT literature as some of the core variables that contributes to explain the technological profile at a national level. There are four key choice variables: telephone mainlines, mobile phones, personal computers and Internet users.

The selected variables are common in the theoretical and empirical literature on ICT and technology development: Pohjola (2002) describes the aforementioned variables as the main components of the new economy, devised as an engine for growth and development. Eggleston *et al* (2002) focus the importance of ICT indicators -mobile phones and telephone mainlines- as factors improving market coordination and efficiency; particularly, in poor countries. In a study more focused on the components of the technological gap, Chinn and Fairlie (2004) estimated the factors explaining the digital divide looking at disparities in the population use of computers and Internet.

Special attention deserves these variables for the construction of synthetic indices, a recurring technique nowadays to sum up information about the countries technological profile. However, the challenge of integrating into a single indicator such an intricate concept as the technological development of a country has to be taken with caution; nevertheless, it could draw meaningful information and allows for an easier and more direct way to rank and compare the countries overall progress. Therefore, it is crucial to count with complete datasets that aims to carry on widely and timely analysis. Nevertheless, the fact is that some of the existing ICT indicators fail to provide complete and reliable information, particularly for the earlier years of the nineties. In order to conduct the MI missing data procedure, it was selected a broad sample that comprises 170 countries and a period from 1991 to 2003. The source of information is the World Bank (World Development Indicators 2005). According to the procedure previously tested, the first step was to define the best set of covariates for each one of the ICT selected indicators, in line with the theoretical and empirical literature: A set of common variables were defined to play as a structural covariates in all the models. All of the selected variables are common in the ICT literature to explain the ability of countries to acquire and develop its technological capabilities. Moreover, these provide relevant information about the distribution pattern of the ICT indicators and its low rate of missing data improves the efficiency of the imputation process.

The selected covariate is GDP per capita, measured in purchasing power parity, which relates the general ICT development to the income level. Infrastructure variables, such as the proportion of urban population as a fraction of the entire population and the energy consumption per capita in kw, contribute to explain the affordability access to ICT technologies. Human capital variables, such as literate and secondary school enrollment rates and the posterior distribution of the dependent variable (its value in the $_{t+1}$ time) that it is being imputed was also included.

Another assumption is that every ICT variable could correlate with other information and telecommunication indicators. Thus, we estimate correlations among the core ICT variables to measure the bivariate associations in order to include the correspondent indicator in each one of the imputation models. Instead doing a selective testing and inclusion of *n* variables, another alternative is to run a regression or multivariate model to identify the best signal indicators. The key point is to build the best predictive model of the imputed variable. Core ICT variables were transformed to logarithms to comply the assumption of univariate normality. As result of the aforesaid assumptions, four models were defined an a matrix of missing and observed data was integrated. The overall pattern of the data follows a random sample with observed (1) and missing (0) data.

$$M = \left\{ \begin{array}{|c|c|c|c|c|} \hline 1 & 0 & 1 & 0 & 1 \\ \hline 0 & 1 & 1 & 1 & 1 \\ \hline 1 & 1 & 1 & 0 & 0 \\ \hline 1 & 1 & 1 & 0 & 1 \\ \hline 0 & 0 & 0 & 1 & 1 \\ \hline 1 & 1 & 1 & 1 & 1 \\ \hline \end{array} \right\}$$

The rate of missing information for each one of the imputed variables ranges from the lowest value of 1.18 percent to the highest record of 78.24 percent – Table 5. The new technology indicators (Internet users, computers and mobile phones) concentrate the maximum proportion of absent data. As result of the missing data, the sample size is equal to 6,897 observations.

Table 5
ICT selected variables
(missing data, %)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Internet users	78.24	71.76	63.53	50.00	27.06	9.41	4.12	1.76	0.00	0.00	16.47	18.24
Computers	62.35	60.00	54.71	47.65	38.24	33.53	25.88	16.47	12.94	11.18	11.18	12.35
Telephone	1.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.76
Mobile phones	58.24	48.24	40.00	32.94	25.29	12.94	9.41	5.88	4.12	2.35	2.35	2.94

To improve the fit and quality of the estimation, a rate of efficiency of 95% was assigned in the imputation process of the ICT core indicators. Therefore, near 250 *m* data sets were generated (3 to 15 *m* imputations for every indicator-year combination) in order to count with an accurate estimation. Due to rates of missing data above 50% for the beginning years of the nineties, in some cases as much as 2500 iterations were needed to allow for the convergence of the EM algorithm.

The usual parameters were estimated for the *m* imputation data sets. The variance for selected years of the sample showed in the Table 6. In all cases most of the variation is explained by the *within-imputation* variance while the variance corresponding to the point estimate imputation is in many cases indistinguishable. As it was expected, the total variance and its components reduced their values in the last years of the sample according to changes in the density function that reflects the relative reduction of the cross-country technological gap.

Once the punctual imputation data is averaged for each ICT indicator, it is possible to compare the original sample and the imputed information. The first and obvious gain from the MI procedure is an increase in the sample size, which is substantial. As can be seen in the Appendix, Table A3, sample data on computers increased in 30.0% and Internet users raised their observations in 8.6%, whereas mobile phones and telephone mainlines data were completed. Particularly for the beginning years of the nineties information on computers doubled its data availability and Internet users sample augmented its observations in more than 45%.

Table 6
Imputation summary statistics
(selected years)

	Mean θ	Within var. ω	Between var. β	Total var. α	Std dev.
Internet users$_{1991}$	-7.3713	30.5185	0.7258	31.2928	5.5940
Internet users$_{2002}$	3.6674	3.1406	0.0003	3.1410	1.7723
Computers$_{1991}$	0.8400	5.8677	0.0013	5.8691	2.4226
Computers$_{2002}$	3.5956	2.9618	0.0002	2.9621	1.7211
Telephone$_{1991}$	3.7270	3.4717	0.0000	3.4717	1.8633
Telephone$_{2002}$	4.3793	2.9596	0.0000	2.9596	1.7203
Mobile phones$_{1991}$	-2.5680	14.2056	0.0079	14.2141	3.7702
Mobile phones $_{2002}$	4.4709	3.4170	0.0001	3.4171	1.8485

Note: Data in Log.

Finally, if assumptions about the validity of the cero values are relaxed (in some cases records filled with 0 are more related to sampling errors or not available data), the usefulness of the imputation procedure turns more evident. Mobile phones indicator increases its data in 13.8% (more than 50% for selected years), Internet users likewise augment its sample in 12.2% and computers doubled its observations for the early years of the sample. Nevertheless, in some cases the imputation technique throw cero values, thus reflecting that some of the records must be considered truly like cero according to the pattern distribution of the imputed variables as well as the covariates indicators.

6. Proposal of a combined ICT Index: The *NaCap ICT Index*

According to the available empirical evidence, indexes are widely used as a helpful tool to measure the access of countries to ICT. The key idea is that the definition of the ICT techno-economic paradigm responds in countries to the evolution of both traditional and more modern techniques; for that reason, the existing indexes integrate those technologies in a weighted scheme. Overall, the access to ICT also responds to a kind of cumulative learning process and the evolution of a set of structural factors. An important fact is that the abilities required to adopt some of the ICT related technologies are less exigent in terms of human qualification than others. However, we believe that most of the available indexes -which we review in previous sections of this paper- do not consider extensively this last feature of ICT access.

From our perspective, it is plausible to conceive an index which would be a combination of three different main components and which could explain the access of countries to ICT in a more comprehensive way. The main assumption is that both the use of technologies and the level of human capital are aspects that go always hand in hand. Their joint consideration, together with some structural factors which determine the role of the aggregated demand, contributes to achieve a more precise definition of an index about the level of *national capabilities* for ICT development that we call "The NaCap ICT Index". Three different components integrate the NaCap Index as it follows:

A first component, called I_T relates the more traditional information and communication technologies. Although this is as a determinant factor for the development of societies, they do not require a high level of qualification for its use. Secondly, the component I_M refers to the use of modern ICT, which are associated with a higher level of human capital. For this component, the role of education and the level of qualification in the national labour markets seem to be crucial aspects. The third component I_S is devoted to understand the potential for the development and speed of ICT in countries. Several structural factors integrate this component, all of them closely related to the differentiated development phases of countries.

Overall, I_T and I_S can be seen as a less qualified elements and they can be understood as basic conditions for access to ICT while I_M is a factor qualifying that access. All of them together integrate a measurement that allows us to detect and better understand the differences existing not only between developed and developing countries but those inside the latter group. The economic literature traditionally tends to take developing countries as a homogeneous set of countries and just a marginal part of the literature tries to discern and to explain the differences existing among them. This is a crucial aspect, which is gaining more and more ground in the international debate and in the definition of policies to enhance development processes. The NaCap Index also responds to this controversial issue.

The methodology to build the NaCap Index is common to both the method used by UNDP for the HDI as well as the method used by Archibugi and Coco in the construction of the ArCo Index. Therefore, the proposed Index is the addition of the three aforementioned components, which combine as follows[10].

[10] Each I component is constructed according to the following formula:
(observed value - minimum value) / (theoretical maximum value - minimum value).
To allow for a cross-country and time-series comparisons, both the theoretical maximum value and the minimum value corresponds to the highest and lowest values (observations near 0 are rounded to 0) that can be achieved by any country in each one of the variables for the time series data. The observed value corresponds to the variable value for each moment of time. Each one of the components of the index is multiplied by a factor of 1/3 to get the simple average. In order to avoid that any country

NaCap Index = $I_T + I_M + I_S$, where:

I_T Traditional ICT component: Telephones lines, Mobiles phones, Secondary school enrolment[11].

I_M Modern ICT component: Number of computers, Internet users, Tertiary school enrolment[12].

I_S Structural component: Real GDP per equivalent adult, Export of goods and services, Urban population.

The results of the NaCap Index and their components provide an international classification, which is very similar to the ranking obtained accordingly to the other available indicators. Moreover, as it was expected, the level of partial correlation between the Index and the three components is higher than 0.9 –Table 7-. It is also high and positive the relation existing between the behaviour of the three components; it is more notable between the traditional and the modern ICT integrants while the lowest value corresponds to the correlation between modern ICT and the structural component.

The NaCap Index provides values for a sample of 170 countries and for a time spam of 13 years, from 1991 to 2003[13]. This is a strength aspect for comparisons across countries and for capturing the dynamics in the evolution of ICT too. Table 8 summarises the scores of the top ten countries and the countries in the last positions –the complete set of data for 170 countries are in Table A4 in the Appendix.

There is a notable concentration of the countries that have obtained the highest NaCap values among the European countries: 7 out of the top 10 with values going from 0.71 to 0.63. These countries share some common features: they are mainly small economies with a high degree of openness –the three members of the historical BENELUX, some Nordic economies and the dynamic Irish economy. Three Asian economies, in which ICT have been at the core of their recent development, complete the leading group: Singapore, Hong-Kong and Macao. On the other hand, the worst positions in the rank classification of countries according to the NaCap Index correspond entirely to the African economies.

Considering the dynamic behaviour of the ICT national capabilities, we report here the main changes that have occurred in the NaCap Index between 1991 and 2003. Particularly, Graph 1 illustrates the main winners and losers in that period. There are variations of the national position accordingly to the countries values of the NaCap in 2003 in relation to 1991. A first aspect to recall is that there is any high-income country among them; that is, the evolution of ICT is more than noticeable inside the developing world. Thailand has improved near 50 times its position in 1991 while Uzbekistan has gone back more than 40 times its ICT capabilities in the period considered. It has been also notable the advance achieved by some American middle income economies, such as Brazil, the Dominican Republic and Grenada, together with some Asian economies, such as Vietnam and Singapore. Among other countries which have also improved more than 20 times their relative position in ICT, it is noticeable the advance of Hungary, Turkey and Poland and even the advance of Cape Verde. Among the losers, there is a notable concentration among the ex-soviet territories, being Georgia, Armenia, Azerbaijan, Turkmenistan, Tajikistan, Kazakhstan and Kyrgyzstan whose have notably worsened their relative positions. St. Lucia, Bahamas have also experienced a very negative behaviour.

get an index value outside the expected range of 0.00 - 1.00, values are adjusted to fit between the goalposts. Thus, for observations below the theoretical maximum value (i.e. secondary schooling rate) the maximum allowed registry is fixed to 100.

[11] Telephone lines: Telephone lines connecting the customer terminal equipments to the public telephone network; Mobile phones: Users of portable telephones who subscribe to a public mobile telephone service using cellular technology; School enrolment, secondary (gross): Ratio of total enrolment, regardless of age, to the population of the age group that corresponds to the selected level of education. Accordingly, it is possible to observe countries with percentages above the theoretical objective of 100% of population attendance to the correspondent scholar grade. Source: World Development Indicators 2005 and International Telecommunication Union.

[12] Computers: Personal computers installed in a country. Statistics includes PCs, laptops, notebooks, etc. and excludes terminals connected to a mainframe and mini-computers intended for shared use; Internet users: Internet subscribers with access to public Internet, regardless of the type of connection; School enrollment, tertiary (gross): Ratio of total enrollment, regardless of age, to the population of the age group that corresponds to the selected level of education. Source: World Development Indicators 2005 and International Telecommunication Union.

[13]Although full comparisons with other available indexes are not possible due to method issues, as a matter of fact, the rank correlation between the obtained values of NaCap and other similar indexes such as the TAI, ArCo and ICT in available years is higher than 0.95. Complete series data can be provided by authors upon request.

Table 7
NaCap partial correlations
(I_T, I_M, I_S components, 2003)

	NaCap	I_T	I_M	I_S
NaCap Index	1.000			
I_T component	0.9752	1.000		
I_M component	0.9407	0.9065	1.000	
I_S component	0.9023	0.8192	0.7505	1.000

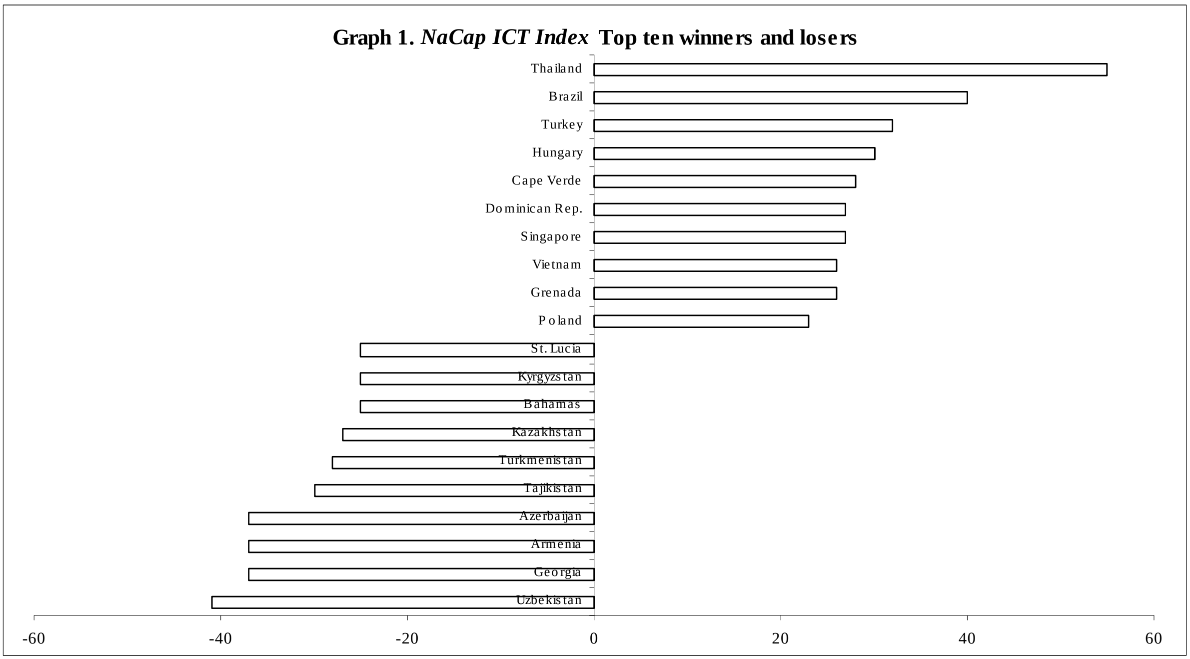
Table 8
NaCap Composite Index
(I_T, I_M, I_S components, 2003)

Ranking	Country	NaCap	I_T	I_M	I_S
1	Luxembourg	0.719	0.919	0.291	0.948
2	Iceland	0.687	0.875	0.597	0.589
3	Singapore	0.684	0.768	0.605	0.679
4	Sweden	0.668	0.957	0.473	0.572
5	Denmark	0.663	0.851	0.544	0.595
6	Macao	0.659	0.703	0.446	0.827
7	Netherlands	0.658	0.794	0.515	0.664
8	Hong Kong	0.656	0.778	0.348	0.841
9	Belgium	0.648	0.761	0.433	0.749
10	Ireland	0.633	0.79	0.392	0.717
160	Chad	0.066	0.053	0.013	0.133
161	Eritrea	0.064	0.098	0.008	0.087
162	Madagascar	0.063	0.024	0.01	0.155
163	Tanzania	0.058	0.01	0.007	0.156
164	Ethiopia	0.053	0.063	0.009	0.087
165	Uganda	0.049	0.064	0.014	0.069
166	Niger	0.045	0.023	0.007	0.105
167	Congo, D.R.	0.042	0.016	0.005	0.106
168	Burkina Faso	0.038	0.043	0.007	0.064
169	Rwanda	0.032	0.06	0.012	0.024
170	Burundi	0.024	0.038	0.008	0.027

Taking into account the evolution of the different aspects related to the national capabilities in ICT, the top-ten winners and losers in each of the integrating components are in Annex II. There are at least 20 countries rank on the top or bottom ten ranks in more than one indicator. Sixteen of them are either winner or losers according to the NaCap scores that the Graph 2 shows in combination to their behaviour in the components. This allows us to distinguish several profiles of countries:

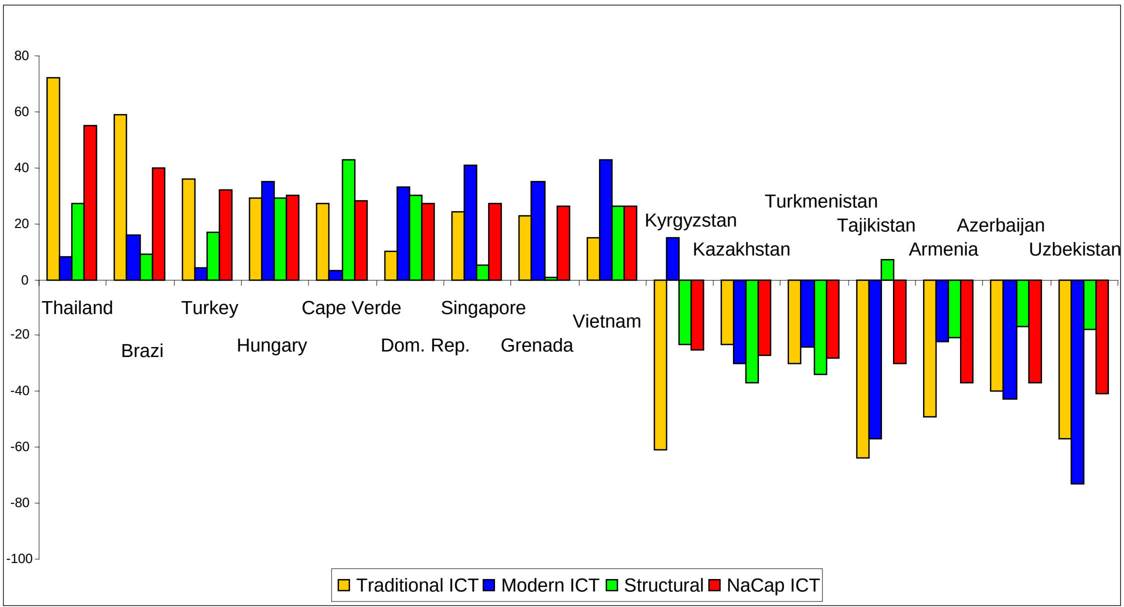
Among the winners, those that have improved their national capabilities in ICT, there is a first conglomerate composed by those economies with an important development of the traditional technologies. Brazil, Turkey and Thailand integrate this; the latest has also experienced an important advance in the structural elements. The improvement of the national capabilities in Singapore and Grenada relates more to the positive behaviour of the modern component. Hungary and Vietnam present a combined profile in which both the development of modern technologies and structural transformations coincide. Finally, the shift of the NaCap positions in Cape Verde and Dominican Republic is mainly associated to the behaviour of the structural elements.

Graph 1
NaCap ICT Index. Top tenwinners and losers



Finally, the main losers in ICT national capabilities present a clear geographical concentration. There is a high level of coincidence in the aspects that given them a loser position. Particularly, the lost of national capabilities in Uzbekistan y Azerbaijan is associated with their positions in both traditional and modern ICT, aspect which is also noticeable in Tajikistan. Structural factors matter in Kazakhstan and Turkmenistan while Armenia and Kyrgyzstan are losers due to their traditional ICT positions.

Graph 2
Profile of ICT winners and losers



7. Concluding remarks

The availability of information in the construction of indicators to measure the technological capabilities of countries is a very relevant topic that still deserves more attention among researchers. International technological differences are characterised for the existence of the global digital divide but the provision of accurate data and worldwide indexes may be helpful to understand the dynamics of ICT and review the overall progress of countries, particularly in the developing world. The advantages of the composite indicators are not only from a statistical point of view but also because its function to deliver synthetic and qualitative information to both, the general public and the policy-makers.

Assessing the technological progress of countries -either or not trough a composite indicator- requires time-series and cross-country data, which would be comparable. Nevertheless, it is common to face problems of unreliable information or missing data for several years and countries. For these reasons, in this paper the use of multiple imputation technique provides reliable ICT data from 1991 to 2003 and for 170 countries. With the imputed information, we propose a new indicator that intends to summarize the national capabilities of ICT, called the NaCap Index. This buils over the idea that the countries structural elements determine their access to ICT and the use and diffusion of technological factors requires differentiated human qualifications.

The scores for the sample of countries reveal that although the digital divide defines a gap between the more industrialised countries and the developing economies, there are substantive differences among the latter. The evolution of the different aspects related to the national capabilities in ICT shows distinctive profiles of countries -at national and regional level-. Countries may achieve improvements in the NaCap Index either trough their efforts in setting up some basic traditional technologies such as telephone mainlines and raising the population basic skills, or making further advances in their modern technologies sector, which goes hand in hand with the enhancement of more qualitative human capital skills. In all cases, the structural factors are a key role of their ICT advances. Finally, dynamics matters in the development of ICT: the improvement achieved over the last decade is more than notable in developing countries.

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Appendix

ANNEX I

As can be shown in the Table A1, something between 3 and 10 imputations are needed in most of the cases to achieve an efficiency of 95% in the MI procedure when the missingness proportion is lower than 50%, which is a frequent case in economic and social indicators. Even with a greater rate of absent data it is possible to reach an accurate prediction of missing values raising the number of *m* imputed data sets, once the prediction model is correctly specified.

Table A1
Efficiency of MI procedure

	γ				
M	0.1	0.3	0.5	0.7	0.9
3	96.7	90.9	85.7	81.1	76.9
5	98.0	94.3	90.9	87.7	84.7
10	99.0	97.1	95.2	93.4	91.7
20	99.5	98.5	97.5	96.6	95.7
50	99.8	99.4	99.0	98.6	98.2

Once the imputed datasets are created, it is possible to apply the usual statistics procedures to each one of the *m* imputed data. In accordance with Rubin (1987), the point estimates of any vector θj are the average of the complete individual estimates $j = 1,2,\ldots..m$.

$$\bar{\theta} = \frac{1}{m}\sum_{j=1}^{m}\hat{\theta}_j$$

The variance estimate of the data vector is calculated in two steps. The first thing is to summarize the *within-imputation* variance ω, which measures the overall variance.

$$\bar{\omega} = \frac{1}{m}\sum_{j=1}^{m}\hat{\omega}_j$$

The *between-imputation* variance β, the one related to the point estimate imputation, is computed with the following equation.

$$\hat{\beta} = \frac{1}{m-1}\sum_{j=1}^{m}\left(\hat{\theta}_j - \bar{\theta}\right)^2$$

Hence, the total variance α is the result of summarizes both variances estimates adjusted by the availability of *m* datasets.

$$\alpha = \bar{\omega} + \left(1 + \frac{1}{m}\right)\beta$$

Once more, it is important to state that the assumptions about the sample distribution -normal, chi-square, etc.- are crucial to draw efficient estimations of the missing data and its approximation to the population parameters will depend on the covariates selection. Several researchers as Schafer and Olsen (1998), Wayman (2003) and Durrant (2005), have stated this method as an extremely efficient missing data procedure.

Table A2
Variables definition

Indicator	Description
Telephone mainlines	Telephone lines (per 1,000 people) connecting a customer's equipment to the public telephone network. *Source:* WDI 2005 / International Telecommunication Union.
Mobile phones	Users of portable telephones (per 1,000 people) subscribing to an automatic public mobile telephone service using cellular technology that provides access to the public switched telephone network. *Source:* WDI 2005 / International Telecommunication Union.
Personal computers	Self-contained computers designed to be used by a single individual (per 1,000 people). *Source:* WDI 2005 / International Telecommunication Union.
Internet users	People with access to the worldwide network (per 1,000 people). *Source:* WDI 2005 / International Telecommunication Union.
Gdp per capital	Gross domestic product per capita in purchasing power parity. Data are in constant 2000 international dollars. *Source:* WDI 2005 / World Bank, International Comparison Programme database.
Real Gdp per capita per equivalent adult	Real GDP per capita per equivalent adult. The equivalent measure assigns a weight of 1.0 to all persons over 15 years old and 0.5 for those under age 15. *Source:* Penn World Table version 6.1.
Urban population	Share of the total population living in areas defined as urban in each country. *Source:* WDI 2005 / United Nations, World Urbanization Prospects.
Energy consumption	Electric power consumption (kwh per capita). *Source:* WDI 2005 / International Energy Agency, energy statistics and balances of non-OECD countries and energy statistics of OECD countries.
Literacy rate	Literacy rate, adult total (% of people ages 15 and above). *Source:* WDI 2005 / United Nations Educational, Scientific, and Cultural Organization (UNESCO) Institute for Statistics.
Secondary school enrollment	Ratio of children of official school age enrolled in secondary school level. *Source:* WDI 2005 / United Nations Educational, Scientific, and Cultural Organization (UNESCO) Institute for Statistics.
Exports of goods and services	Exports of goods and services as percentage of GDP. *Source:* WDI 2005 / World Bank national accounts data and OECD national accounts data files.

Figure A1
Distribution pattern of imputed data

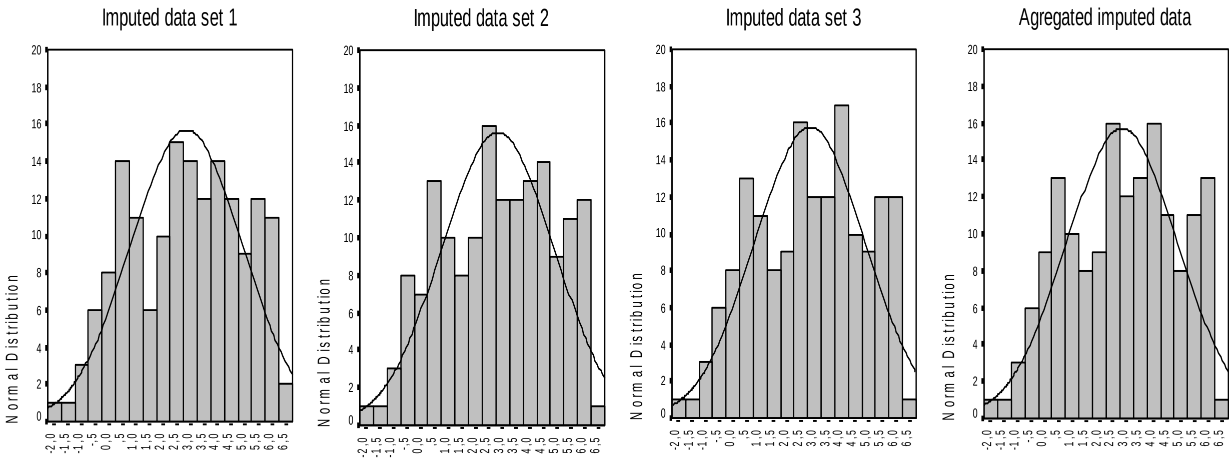
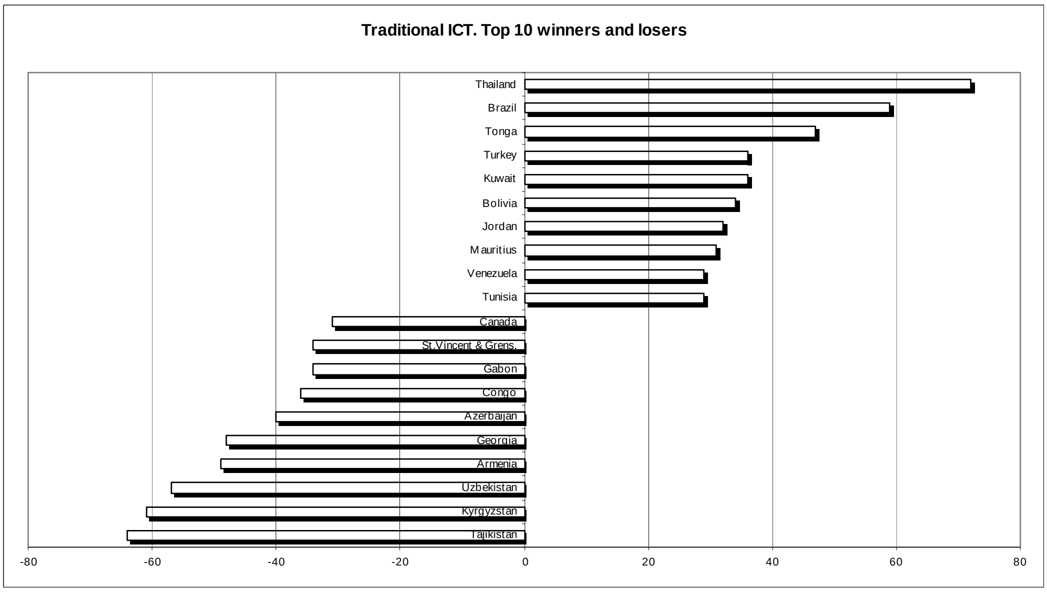


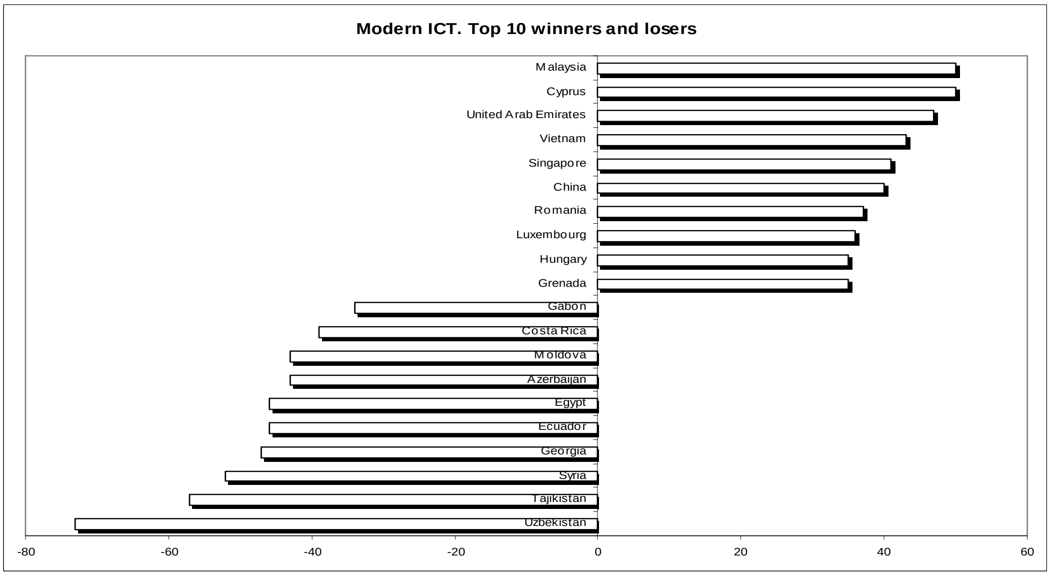
Table A3
Sample gain from imputation (increase in data availability, %)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Internet users	48.6%	43.8%	50.0%	34.1%	7.3%	1.9%	2.5%	1.2%	0.0%	0.0%	19.7%	22.3%
Computers	134.4%	136.8%	113.0%	84.3%	59.0%	50.4%	34.9%	19.7%	14.9%	12.6%	12.6%	14.1%
Telephone	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.8%
Mobile phone	3.0%	2.4%	2.4%	2.4%	1.2%	0.0%	0.6%	0.0%	0.0%	0.0%	0.0%	1.2%

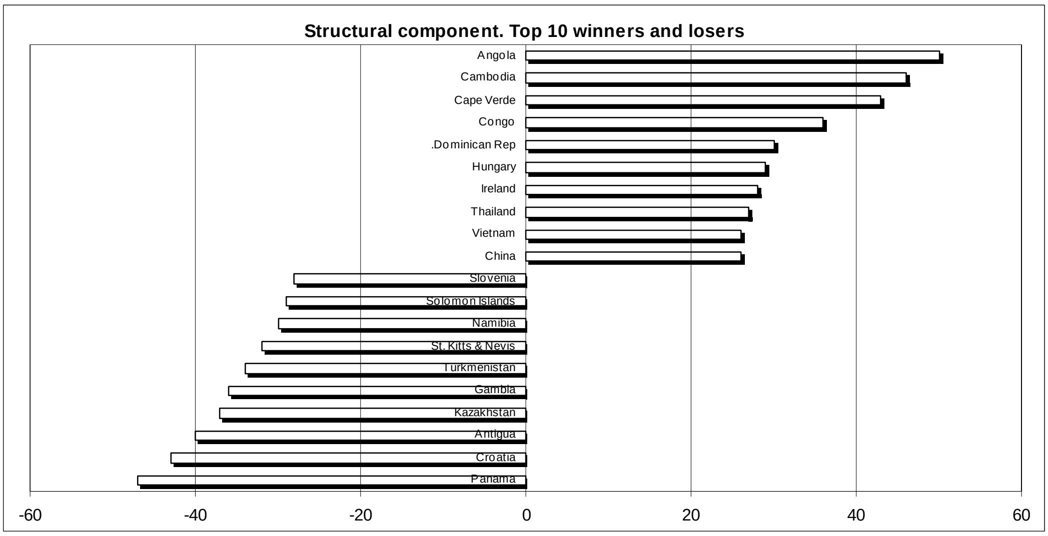
ANNEX II



Traditional ICT. Top 10 winners and losers
Thailand
Brazil
Tonga
Turkey
Kuwait
Bolivia
Jordan
Mauritius
Venezuela
Tunisia
Canada
St.Vincent & Grens.
Gabon
Congo
Azerbaijan
Georgia
Armenia
Uzbekistan
Kyrgyzstan
Tajikistan
-80
-60
-40
-20
0
20
40
60
80



Modern ICT. Top 10 winners and losers
Malaysia
Cyprus
United Arab Emirates
Vietnam
Singapore
China
Romania
Luxembourg
Hungary
Grenada
Gabon
Costa Rica
Moldova
Azerbaijan
Egypt
Ecuador
Georgia
Syria
Tajikistan
Uzbekistan
-80
-60
-40
-20
0
20
40
60



Structural component. Top 10 winners and losers
Angola
Cambodia
Cape Verde
Congo
.Dominican Rep
Hungary
Ireland
Thailand
Vietnam
China
Slovenia
Solomon Islands
Namibia
St. Kitts & Nevis
Turkmenistan
Gambia
Kazakhstan
Antigua
Croatia
Panama
-60
-40
-20
0
20
40
60

Table A4
The *NaCap* Index

Ranking	Country	NaCap (1991)	NaCap (2000)	NaCap (2003)	I_T (2003)	I_M (2003)	I_S (2003)
1	Luxembourg	0.419	0.664	0.719	0.919	0.291	0.948
2	Iceland	0.397	0.630	0.687	0.875	0.597	0.589
3	Singapore	0.327	0.603	0.684	0.768	0.605	0.679
4	Sweden	0.401	0.652	0.668	0.957	0.473	0.572
5	Denmark	0.416	0.624	0.663	0.851	0.544	0.595
6	Macao	0.395	0.526	0.659	0.703	0.446	0.827
7	Netherlands	0.424	0.634	0.658	0.794	0.515	0.664
8	Hong Kong	0.447	0.621	0.656	0.778	0.348	0.841
9	Belgium	0.443	0.605	0.648	0.761	0.433	0.749
10	Ireland	0.349	0.580	0.633	0.790	0.392	0.717
11	Korea	0.318	0.567	0.632	0.712	0.671	0.512
12	Norway	0.409	0.647	0.630	0.874	0.458	0.559
13	Finland	0.379	0.593	0.623	0.801	0.603	0.465
14	Australia	0.362	0.560	0.621	0.754	0.568	0.540
15	United Kingdom	0.362	0.565	0.612	0.842	0.473	0.521
16	Germany	0.373	0.546	0.608	0.813	0.464	0.546
17	Switzerland	0.380	0.593	0.600	0.836	0.431	0.533
18	New Zealand	0.371	0.547	0.597	0.699	0.573	0.520
19	Israel	0.345	0.526	0.589	0.787	0.453	0.528
20	Austria	0.369	0.557	0.585	0.784	0.429	0.543
21	Estonia	0.328	0.495	0.584	0.692	0.509	0.550
22	Canada	0.459	0.568	0.579	0.682	0.481	0.574
23	USA	0.433	0.579	0.579	0.698	0.532	0.507
24	Malta	0.375	0.503	0.562	0.719	0.271	0.695
25	Italy	0.314	0.489	0.552	0.822	0.400	0.435
26	France	0.370	0.499	0.551	0.754	0.421	0.476
27	Japan	0.341	0.502	0.540	0.717	0.457	0.448
28	Cyprus	0.299	0.451	0.536	0.762	0.296	0.549
29	Slovenia	0.332	0.484	0.533	0.759	0.380	0.459
30	Czech	0.297	0.432	0.532	0.761	0.289	0.546
31	Spain	0.325	0.474	0.531	0.781	0.349	0.462
32	Barbados	0.293	0.376	0.521	0.672	0.453	0.438
33	Bahrein	0.374	0.465	0.520	0.621	0.257	0.683
34	Hungary	0.237	0.423	0.496	0.706	0.284	0.498
35	United A.Emirates	0.330	0.472	0.493	0.601	0.270	0.608
36	Portugal	0.256	0.463	0.489	0.770	0.285	0.413
37	Greece	0.297	0.435	0.488	0.785	0.322	0.358
38	Lithuania	0.281	0.379	0.474	0.623	0.343	0.457
39	Kuwait	0.270	0.406	0.474	0.556	0.237	0.630
40	Latvia	0.286	0.378	0.472	0.585	0.426	0.405
41	Slovakia	0.261	0.378	0.468	0.606	0.271	0.528
42	Bahamas	0.371	0.409	0.450	0.565	0.265	0.520
43	Argentina	0.251	0.354	0.445	0.551	0.350	0.435
44	Chile	0.253	0.361	0.433	0.540	0.294	0.466
45	Puerto Rico	0.332	0.394	0.432	0.458	0.250	0.588
46	Malaysia	0.240	0.384	0.431	0.439	0.259	0.595
47	Bulgaria	0.276	0.352	0.428	0.596	0.255	0.432
48	Belarus	0.298	0.365	0.414	0.444	0.288	0.509
49	Poland	0.227	0.353	0.413	0.590	0.323	0.325
50	Croatia	0.286	0.353	0.410	0.563	0.266	0.403
51	Uruguay	0.278	0.358	0.402	0.542	0.226	0.437
52	Russia	0.284	0.352	0.389	0.441	0.331	0.395
53	Cuba	0.229	0.232	0.379	0.541	0.189	0.408
54	Trinidad & Tob.	0.255	0.324	0.372	0.490	0.136	0.490
55	Ukraine	0.283	0.345	0.357	0.401	0.243	0.427
56	Oman	0.231	0.308	0.357	0.389	0.108	0.575
57	Antigua	0.288	0.392	0.350	0.453	0.171	0.427
58	Saudi Arabia	0.234	0.304	0.349	0.381	0.135	0.531
59	Kazakhstan	0.319	0.291	0.343	0.430	0.192	0.408
60	Dominica	0.234	0.335	0.337	0.396	0.162	0.452
61	Thailand	0.124	0.260	0.335	0.496	0.190	0.320
62	Mauritius	0.205	0.302	0.335	0.454	0.123	0.429
63	Brazil	0.166	0.286	0.334	0.495	0.142	0.365
64	Jordan	0.230	0.297	0.327	0.407	0.145	0.427
65	Lebanon	0.245	0.313	0.324	0.383	0.214	0.376
66	Panama	0.284	0.312	0.321	0.364	0.182	0.416
67	Romania	0.201	0.261	0.320	0.455	0.195	0.309
68	Turkey	0.176	0.283	0.319	0.473	0.138	0.346
69	Venezuela	0.221	0.291	0.316	0.360	0.172	0.417
70	St. Kitts & Nevis	0.214	0.298	0.313	0.457	0.166	0.318
71	Mexico	0.193	0.276	0.312	0.401	0.146	0.389

72	South Africa	0.204	0.265	0.311	0.485	0.121	0.327
73	Grenada	0.177	0.281	0.308	0.461	0.149	0.314
74	Mongolia	0.239	0.264	0.307	0.340	0.168	0.411
75	Dominican Rep.	0.170	0.262	0.302	0.323	0.162	0.421
76	Tunisia	0.182	0.260	0.294	0.366	0.112	0.404
77	Turkmenistan	0.271	0.213	0.294	0.418	0.128	0.336
78	Philippines	0.202	0.268	0.293	0.376	0.130	0.373
79	Fiji	0.205	0.282	0.290	0.353	0.077	0.441
80	Guyana	0.248	0.279	0.283	0.360	0.040	0.447
81	Gabon	0.243	0.228	0.281	0.252	0.049	0.542
82	Peru	0.205	0.255	0.279	0.354	0.164	0.320
83	Macedonia	0.192	0.288	0.276	0.359	0.138	0.330
84	Costa Rica	0.194	0.267	0.274	0.312	0.125	0.386
85	Bosnia-Herzeg.	0.174	0.179	0.272	0.463	0.103	0.251
86	Moldova	0.229	0.231	0.272	0.361	0.140	0.315
87	Colombia	0.186	0.249	0.270	0.342	0.118	0.351
88	Georgia	0.263	0.232	0.270	0.346	0.146	0.318
89	Iran	0.165	0.239	0.270	0.349	0.125	0.336
90	Armenia	0.259	0.241	0.269	0.347	0.119	0.340
91	Bolivia	0.154	0.236	0.268	0.362	0.150	0.292
92	St.Vincent & G.	0.208	0.272	0.264	0.316	0.084	0.391
93	Botswana	0.181	0.252	0.264	0.365	0.064	0.364
94	Belize	0.187	0.247	0.263	0.364	0.049	0.377
95	Azerbaijan	0.249	0.229	0.257	0.356	0.091	0.322
96	Algeria	0.179	0.230	0.249	0.304	0.099	0.345
97	Jamaica	0.203	0.270	0.249	0.329	0.082	0.337
98	Serbia & Mont.	0.200	0.278	0.249	0.396	0.091	0.259
99	Kyrgyzstan	0.219	0.239	0.247	0.340	0.161	0.241
100	St. Lucia	0.215	0.265	0.242	0.350	0.038	0.339
101	El Salvador	0.125	0.208	0.239	0.293	0.110	0.313
102	Paraguay	0.140	0.199	0.239	0.325	0.077	0.314
103	Cape Verde	0.096	0.207	0.235	0.322	0.046	0.338
104	China	0.109	0.175	0.231	0.364	0.080	0.251
105	Ecuador	0.193	0.203	0.219	0.300	0.060	0.298
106	Uzbekistan	0.235	0.200	0.218	0.344	0.063	0.248
107	Tajikistan	0.211	0.225	0.213	0.301	0.056	0.284
108	Congo	0.179	0.210	0.213	0.136	0.017	0.485
109	Albania	0.129	0.179	0.212	0.370	0.053	0.214
110	Egypt	0.184	0.218	0.212	0.364	0.049	0.222
111	Tonga	0.113	0.188	0.210	0.406	0.054	0.169
112	Swaziland	0.180	0.191	0.207	0.192	0.034	0.395
113	Vietnam	0.087	0.176	0.204	0.270	0.063	0.280
114	Morocco	0.136	0.171	0.201	0.243	0.054	0.307
115	Honduras	0.130	0.204	0.199	0.232	0.063	0.302
116	Sri Lanka	0.139	0.180	0.197	0.327	0.064	0.198
117	Namibia	0.156	0.182	0.195	0.268	0.069	0.247
118	Nicaragua	0.144	0.175	0.194	0.242	0.077	0.263
119	Syria	0.161	0.172	0.190	0.200	0.049	0.321
120	Equatorial Guinea	0.157	0.208	0.187	0.218	0.062	0.282
121	Indonesia	0.121	0.181	0.187	0.234	0.073	0.255
122	Samoa	0.098	0.160	0.178	0.291	0.053	0.190
123	Ivory Coast	0.105	0.129	0.169	0.180	0.029	0.298
124	Sao Tomé & P.	0.112	0.142	0.163	0.154	0.058	0.278
125	Nigeria	0.110	0.139	0.159	0.137	0.031	0.309
126	Djibouti	0.141	0.167	0.157	0.079	0.015	0.377
127	Mauritania	0.114	0.136	0.148	0.120	0.015	0.309
128	Guatemala	0.100	0.135	0.146	0.189	0.056	0.191
129	Angola	0.077	0.159	0.146	0.074	0.012	0.354
130	Haiti	0.080	0.110	0.137	0.212	0.041	0.157
131	Ghana	0.092	0.136	0.137	0.145	0.020	0.246
132	Cameroon	0.101	0.130	0.135	0.128	0.028	0.250
133	Zimbabwe	0.123	0.129	0.130	0.151	0.042	0.197
134	Lesotho	0.063	0.100	0.130	0.135	0.026	0.229
135	India	0.089	0.113	0.125	0.190	0.050	0.134
136	Gambia	0.119	0.130	0.124	0.127	0.017	0.230
137	Cambodia	0.056	0.094	0.122	0.094	0.013	0.258
138	Yemen	0.089	0.135	0.122	0.170	0.025	0.170
139	Senegal	0.092	0.113	0.119	0.088	0.019	0.251
140	Vanuatu	0.092	0.120	0.110	0.116	0.034	0.181
141	Sudan	0.082	0.096	0.109	0.131	0.028	0.168
142	Central Afr. R.	0.063	0.088	0.109	0.113	0.008	0.207
143	Kenya	0.086	0.100	0.109	0.128	0.013	0.188
144	Togo	0.093	0.116	0.108	0.079	0.033	0.212
145	Laos	0.050	0.096	0.105	0.154	0.021	0.139
146	Nepal	0.060	0.084	0.103	0.210	0.020	0.079

147	Bangladesh	0.048	0.097	0.102	0.162	0.024	0.121
148	Zambia	0.108	0.091	0.100	0.100	0.014	0.184
149	Benin	0.066	0.090	0.100	0.104	0.016	0.180
150	Solomon Islands	0.088	0.106	0.099	0.124	0.012	0.160
151	Papua New Guinea	0.081	0.105	0.096	0.111	0.018	0.158
152	Pakistan	0.081	0.083	0.091	0.087	0.017	0.170
153	Mali	0.049	0.081	0.088	0.073	0.011	0.178
154	Sierra Leone	0.073	0.084	0.087	0.067	0.010	0.184
155	Comoros	0.069	0.081	0.087	0.107	0.012	0.143
156	Guinea	0.062	0.086	0.087	0.084	0.013	0.164
157	Malawi	0.041	0.075	0.086	0.115	0.020	0.122
158	Mozambique	0.037	0.057	0.084	0.061	0.015	0.177
159	Guinea Bissau	0.042	0.085	0.081	0.038	0.014	0.191
160	Chad	0.040	0.051	0.066	0.053	0.013	0.133
161	Eritrea	0.040	0.061	0.064	0.098	0.008	0.087
162	Madagascar	0.061	0.079	0.063	0.024	0.010	0.155
163	Tanzania	0.033	0.051	0.058	0.010	0.007	0.156
164	Ethiopia	0.025	0.046	0.053	0.063	0.009	0.087
165	Uganda	0.026	0.034	0.049	0.064	0.014	0.069
166	Niger	0.033	0.043	0.045	0.023	0.007	0.105
167	Congo, Dem. Rep.	0.070	0.047	0.042	0.016	0.005	0.106
168	Burkina Faso	0.027	0.033	0.038	0.043	0.007	0.064
169	Rwanda	0.017	0.025	0.032	0.060	0.012	0.024
170	Burundi	0.016	0.023	0.024	0.038	0.008	0.027

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