Information Societies or "ICT equipment societies"?

Measuring the digital information processing capacity of a society in bits and bytes

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ABSTRACT

The digital divide is conventionally measured in terms of ICT equipment diffusion, which comes down to counting the number of computers or phones, among others. This article fine-tunes these approximations by estimating the amount of digital information that is stored, communicated and computed by these equipments. The installed stock of ICT equipment in the consumer segment is multiplied with its respective technological performance, resulting in the “installed technological capacity” for storage (in bits), bandwidth (in bits per second) and computational power (in computations per second). This leads to new insights. Despite of the rapidly decreasing digital equipment divide, there is an increasing gap in terms of information processing capacity. It is shown that in 1996 the average inhabitant of the industrialized countries of the OECD had a capacity of 49 kibps more than its counterpart from Latin America and the Caribbean. Ten years later, this gap widened to 577 kibps per inhabitant. This innovative approach towards the quantification of the digital divide leads to numerous new challenges for the research agenda.

Key words: digital divide, ICT, measurement, development, international, inclusion, information, indicators
Word count: 6 876 (without Appendix), 9 727 (with methodological Appendix)

The far-reaching and profound impact of the digitization of information and communication processes has long been detected (e.g. Wiener, 1948; Machlup, 1962; Bell, 1973). It is widely recognized that the advancement of digital Information and Communication Technologies (ICT) has led to a new mode of development (e.g. Perez, 1983; Freeman and Louça, 2001). With the arrival of digital systems, the storage, communication and computation of information became the omnipresent core of social and political activity, and of economic and cultural production (e.g. Webster, 1995; Castells, 1996). This has put the question of how to track and measure the diffusion and eventual impacts of these new technologies at the centre of much attention.

This article is a contribution to this discussion. We propose to improve the measure of traditional ICT access indicators by adjusting existing ICT equipment statistics with the respective quality of their performance. The stock of available technologies is multiplied with their respective performances. The result are three new aggregate indicators which represent the "installed information processing capacity": (1) how much information can be stored (in bits), (2) communicated (in bits per second), and (3) computed (in computations per second). This improvement contributes not only to the sustainability of the traditional ICT indicators (new ICT equipments emerge faster than indicators ever can), but it also consolidates the array of currently available indicators, merging them into three straightforward measures.

Multiple dimensions of technology diffusion

As with previous innovations, the nature of the ICT diffusion process is characterized by a well-known S-curve from centre-periphery, whereas the centre can be depicted as being more developed and the periphery as underdeveloped (Rogers, 1962). As a result, technological revolutions create a divide between those that can first benefit from it and those that are embraced by it later on. In the case of ICT diffusion patterns, the term "digital divide" has been coined to describe the fact that some already rely on the facility to access and use digital tools, while others are still excluded from the ensuing opportunities (NTIA, 1995-2000; ITU, 1999; UNDP, 2001 ITU, 2009).

The increasing importance of ICT in the socio-economic development has lead to a broad variety of proposals on how to adequately measure this process of diffusion, and therefore, how to conceptualize the digital divide. The most straightforward notions select a specific technological solution as a representation of the bulk of digital technologies (such as Internet access or telephones) and compare the amount of equipment or services between societies (international digital divide) or within different social segments of one society (domestic digital divide). More complex measures distinguish between three consecutive steps during the adoption of the technology: ICT access, use and impact (OECD, 2002). Even though there might be a positive relation between the amount of ICT equipment, its usage and its impact, one of them does not automatically imply the next. The determinants of the divide can be assessed in each stage of the adoption process and with regards to all of the diverse existing technologies, or their combination.

For example, on the access level it has been shown that the same long established determinants of socio-economic inequality also define the digital divide, including income, education, geography, age, gender, and ethnicity, among others (e.g. Cullen, 2001; Norris, 2001; Hilbert and Katz, 2003). Moving on to the usage stage of technology embracement, the importance of computer skills and motivations has been emphasized (e.g. van Dijk and Hacker, 2003; Mossberger, et.al., 2003; Shelly, et.al., 2004). The final impact of the technology will ultimately be influenced by the purposeful application of the installed equipment, often requiring the readjustment of the general *modus-operandi* of the cultural and institutional setting, which leads to a complex dynamic of social change (e.g. Warschauer, 2003; van Dijk, 2006). Depending on the definition and the scope of the exercise, the results can be contradictory. Most typically, research that focuses on the access dimension (diffusion of technological equipment) argues in favour of a rapidly closing digital divide (e.g. Compaine, 2001; Howard, et.al, 2009), while research focusing on skill-related usage and impact indicators claims that the divide is still deepening (e.g. van Dijk, 2005; James, 2008).

In an attempt to create a coherent picture, various compound measures have been created, so-called e-Readiness indexes, such as the ICT Development Index (ITU, 2009). Those integrate a number of variables into a single index (access indicators and others, such as skills). The weight of each component of the index, as well as the chosen statistics, differs among indices (see Barzilai-Nahon, 2006; Vehovar, 2006; Hanafizadeh, 2009). Minges (2005), who has personally designed some of these indices at the leading United Nations agency ITU, has evaluated twelve of them[4] and reconfirmed the predictable conclusion that—besides problems of transparency, data reliability and subjectivity—the weight of each ingredient predetermines the result to a large extent. This leads to the well-known problem of subjectivity in the creation of any kind of index and therefore does not solve the problem of adequately measuring the divide, but rather passes the buck on to the methodological level.

In short, the digital divide is one of the rare breeds of a concept that flexibly adapts to the meaning that the analyst decides to give it. This can lead to much confusion, or, at least, to tedious semantic quarrels. Despite all differences, there is one feature that all of these studies and indexes have in common: the inclusion of the access dimension, such as the diffusion of telephony, computers and Internet, among others (mostly those harmonized by ITU, 2007). Access might not be sufficient, but it is a necessary first step. Without neglecting that the discussion of the digital divide can become much more complex, we will focus on improving the measurement of this indispensable dimension. At a later stage, the proposed measurement of ICT access could easily be integrated into more complex modular methodologies and indexes that—additionally to access measurements— might also include computer skills and cultural

[4] These include the twelve most widespread indices on a global level: Composite index of technological capabilities across countries (ArCo); Digital Access Index (DAI); Digital Opportunity Index (DOI); Economist Intelligence Unit (EIU) e-readiness; Index of Knowledge Societies (IKS); Knowledge Economy Index (KEI); Network Readiness Index (NRI); Orbicom Digital Divide Index; Technology Achievement Index (TAI); UNCTAD Index of ICT Diffusion; UN PAN E-Readiness Index; World Bank ICT Index.

considerations, among others. In the meantime, we will limit our focus to the improvement of ICT access measures.

The article starts by reviewing the traditional measure of ICT access, which is usually done by counting the number of existing equipments. We then propose an analytical framework for tackling the task of measuring the installed information processing capacity of a society, defined as the capacity to store, communicate and compute information with digital tools. This new framework is applied to one concrete example. We decided to compare the private consumer segment of the industrialized OECD (Organisation for Economic Co-operation and Development) with the one in Latin America and the Caribbean (LAC), as representatives for developed and developing countries on both sides of the international digital divide. While the scope of this article only allows for one concrete example, it is important to underline that the chosen example is just one case out of many that could have been chosen. It represents the international digital divide (neglecting domestic differences among population segments), and—in agreement with common literature on the digital divide—the analysis is restricted to the private consumer segment (this is mainly due to the lack of coherent statistics beyond households at the time of writing). The selection of this particular example should not prevent future research from applying the general framework of this article to analyse the domestic digital divide and to assess the "installed information processing capacity" of enterprises, public or private organizations or government agencies. The final section takes up the underlying methodological discussion, which is again independent from the concrete example that has been discussed before. The resulting differences between the traditional approach and the proposed approach are discussed, as well as the limitations and remaining challenges on the research agenda.

The closing digital equipment divide

After analyzing patterns of ICT equipment diffusion, some policy-related reports come to the delicate conclusion that the access dimension of the digital divide is closing rapidly and that underdeveloped segments are in an unprecedented process of catching-up (e.g. Compaine, 2001; ITU, 2006; UNCTAD, 2006; WEF-INSEAD, 2006; ITU and UNCTAD, 2007; Howard, et.al, 2009). In particular, it is argued that the difference diminishes rapidly to the extent to which developed country markets are increasingly saturated. Table 1 shows that ICT equipment penetration rates in the 30 industrialized countries of the OECD (1 184 million inhabitants in 2006[5]) are relatively advanced. The numbers in Table 1 also show that growth rates have been much higher in the 37 developing countries of Latin America and the Caribbean (LAC) (456 million inhabitants[6]). In agreement with this indicative evidence, the theory of the diffusion of innovation and the previously cited research, it can be expected that the typical S-shaped diffusion curve is starting to diminish in the more developed countries, while LAC just seem to be in the upward slope of the S-curve. There seems to be an upper limit on the amount of equipment an individual possesses, even if one person can posses several equipments of the same sort. The table shows that in 1996, OECD countries had 8.1 times more mobile phones per hundred inhabitants than LAC, while in 2006 the gap was reduced to a multiplication factor of 1.6. With regard to Internet users, the catching-up has even been more impressive, reducing the ratio between both groups of countries from 18.5 to 3.0 in ten years. Thus, analyses on the basis

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[5] Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary (starting 1996), Iceland, Ireland, Italy, Japan, Korea (Rep.) (1996), Luxemburg, Mexico (started to be a member of the OECD in 1994, and is therefore considered OECD for the ten year time frame considered in the graphs, and not as Latin America), Netherlands, New Zealand, Norway, Poland (1996), Portugal, Slovak Republic (2000), Spain, Sweden, Switzerland, Turkey, United Kingdom, United States.

[6] Antigua and Barbuda, Argentina, Aruba, Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Rep., Ecuador, El Salvador, French Guiana, Grenada, Guatemala, Guadeloupe, Guyana, Haiti, Honduras, Jamaica, Martinique, Neth. Antilles, Nicaragua, Panama, Paraguay, Peru, Saint Kitts and Nevis, Saint Lucia, St. Vincent and the Grenadines, Suriname, Trinidad y Tobago, Uruguay, Venezuela.

of these indicators seem to suggest convergence with a rapidly disappearing inequality in access to digital information.

Table 1: ICT equipment diffusion per 100 inhabitants in OECD and Latin America and the Caribbean, 1996-2006

Technology per 100 inhabitants		**1996**	**2006**
Fixed phones	OECD	46.5	46.8
	LAC	9.8	17.2
	ratio OECD/LAC	**4.7**	**2.7**
Mobile phones	OECD	11.0	86.6
	LAC	1.4	54.7
	ratio OECD/LAC	**8.1**	**1.6**
Personal Computers	OECD	18.5	56.6
	LAC	3.0	16.7
	ratio OECD/LAC	**6.2**	**3.4**
Internet users	OECD	3.7	23.4
	LAC	0.2	7.8
	ratio OECD/LAC	**18.5**	**3.0**
Broad band subscribers (2000-2006)	OECD	3.0	16.8
	LAC	0.1	2.3
	ratio OECD/LAC	**30.0**	**7.3**

Source: ITU, World Telecommunications Database, 2007.

A resulting, but premature, policy conclusion of this analysis could be that public policies, such as market regulation and public access incentive programs, would be less and less necessary to close the access dimension of the gap. This seems to be emphasized by the success story of mobile telephony, which is the consumer technology with the fastest technological diffusion record in history. Competitive markets seem to take telecommunications networks and related hardware and software solutions to everybody around the globe, such as regularly pointed out by industry representatives (GSM Association, 2006; Frost and Sullivan, 2006).

Such conclusions are based in the simple accounting of equipment to assess the situation of access to the digital realm. One of the main limitations of the traditional equipment analysis is that technological progress is not considered. There are qualitative differences in access. These differences depend on the respective year and the respective user segment. The importance is easy to see. For example, Internet users with a 56 kbps modem connection are not able to access the multimedia content broadband users are benefiting from. However, in a simplistic count, both would be considered as one "Internet user" (see Table1). The same accounts for other ICT and also holds for difference inside one society. One hard disk from 1995 is not equal one hard disk from 2005. Older equipment is much less powerful. Besides technological progress in time, there are also differences in performance from equipments from the same year[7]. While most mobile phones that are bought by the poor enable short-message-services (SMS) through a 14 kbps data communication, third- and fourth generation mobile phones provide wealthy members of the Information Society with mobile videoconferencing of several hundred kbps. Even if both, rich and poor, would have the same number of equipments (by equipment headcount), their real "access to digital information" might be very unequal in reality. The currently available statistics (such as shown in Table 1) do not show this difference.

This problem is recognized by recent literature, for example through the emphasis in broadband connectivity (for example NTIA, 2002-2004). The current solution consists in simply adding additional indicators (such as broadband), which cannot easily be compared with the previous indicator of dial-up Internet. The resulting grab bag of indicators can be expected to become more confusing as ICT-convergence continues. The ongoing substitution between various services renders many traditional indicators quickly obsolete. Voice services can be

[7] The relevant statistics for this consideration are often more difficult to obtain than performance adjustment according to year-related technological progress.

transmitted with Voice-over-Internet-Protocol (VoIP) over the Internet and WebPages can be accessed through mobile phones. Actually, the traditional separation into the aforementioned technologies according to their hardware and functionality (and not according to capacity) is not really helpful for understanding and coping with the ongoing dynamics.

In order to obtain a deeper insight of current developments, it is proposed to measure the total sum of technological information processing capacity of diverse technological solutions. Considering the bits and bytes that can be processed by the different solutions brings two mayor benefits. First, it enables to consider technological progress in the performance of the different generations of equipment. It therefore recognizes the digital divide as a constantly moving target. Second, it permits to harmonize substituting technologies on a common unit of measurement (if two service substitute each other, per definition of substitution, they provide the same performance measure, for example bits per second, which are jointly aggregated to sum up to the installed capacity).

Three steps are necessary. First, ICT systems need to be classified according to their informational functionality. The following section identifies three distinct groups of basic information operations (communication, storage, computation). The next section discusses adequate measurement units for each of the three identified technological subsystems. As a third step, the evolving performance of each technology needs to be estimated for various years and respectively multiplied with the available technological equipment. This will result in the installed information processing capacity of a society.

The three subsystems of information processing

ICT systems do not represent a single technology, but are the result of a combination of symbiotic technological trajectories that converge into one larger technological system. As already mentioned, some of them might be potential substitutes (for example fixed and mobile voice-communication) and others serve different ends (for example hard disks and telephones). To avoid such confusion let us return to a basic definition of what technologies are. Technologies has been defined as patterns of solutions that are based on selected principles derived from the natural sciences and are applied to confront a specific question or promise (Dosi, 1988). Following this definition, ICT answers three different questions: (1) how to store information in some deposit for later usage; (2) how to convert and compute some kind of information in a meaningful manner into another kind of information; and (3) how to transmit and communicate information from one place to another. In order to adequately reflect existing technologies, we further subdivide this last function and differentiate between “transmission”, which we define as being unidirectional (only down-link, such as broadcast), and “communication”, which we define to be bidirectional (up-link and down-link, such as telecommunication)[8].

The scope of the technological system that is often loosely referred to as digital technologies is defined by the use of the “bit”. It is based on the idea of representing and manipulating information through its most basic code, the binary digit[9]. The binary codification and processing of information has not only improved and amplified the performance of each technological subsystem, it also meant that for the first time all three of them began to function according to a common logic: binary logic. This led to the integration of the three different technological subsystems into one system, a process colloquially referred to as ICT-convergence.

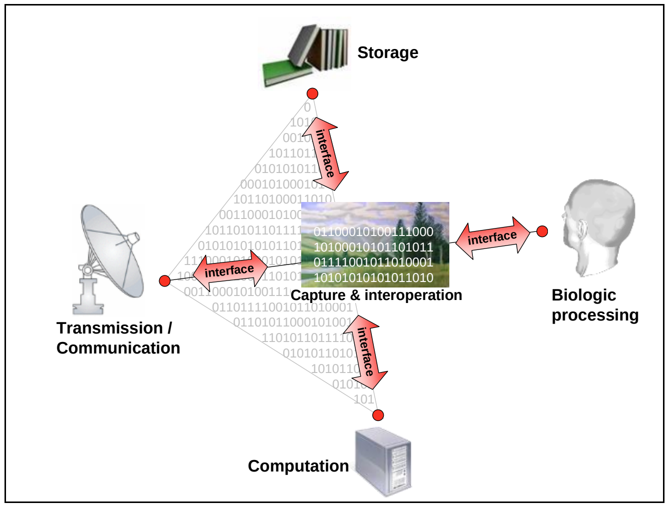
While the media-frictionless interconnection of storage-, communication- and computing devices has manifold advantages and leads to increased complementarities among the different tasks, the introduction of the bit has not changed the fact that each of the three operations has a distinct end. Figure 1 depicts the basic schematization on the basis of which the following analysis is structured. ICT dynamics are the result of the interplay of all three technological

[8] For conceptual reasons the separation is justified, because communication is expected to have different socio-economic potential than mere transmission. For practical reasons this separation is necessary because, in terms of bit-rates, broadcasting technologies transmit a much larger amount of data.

[9] A common unit of storage is the byte, equal to 8 bits, that is, eight consecutive yes-no decisions resulting in a decision tree with $2^8 = 256$ possible combinations.

subsystems, unified by the paradigm of the bit, which defines the scope of the technological system. Above and beyond the three technological information operations, the human brain is our indispensable recipient of, and contributor to, this dynamic process. We define the “information processing capacity” of an individual or a society as the construct of these three informational operations.

Figure 1: Schematization of the three basic information processes



Source: own elaboration.

All three subsystems have experienced extraordinary growth rates in their performance development during recent decades (see Table 2). The Table shows, for example, that it would be deceiving to compare a hard disk from 1980 with another one from 2005. Actually, one hard disk in 2005 would be equal to 792 hard disks from 1995 and 750 000 from 1980. Sustained annual growth rates of 56-76% over 25 years are outstanding, which can be seen when compared to more common socio-economic rates of change (annual economic growth rates are traditionally between 3-4%). In a field of such rapid change, it is essential to consider this constantly moving performance frontier in the measurement of the dynamics[10].

[10] A second look on Table 2 reveals that the technological frontier in each subsystem has advanced at a different pace. It is interesting to note that the advancement of telecommunications, which is often

Table 2: Price decline and performance increase in the technological frontier of all three ICT subsystems, 1980-2005

Basic function/ representative of the technological frontier (US$ 2006)	**1980**	**1995**	**2005**	**Compound annual growth rate between 1980-2005**
Transmission telecommunication (kilobits / sec / US$)	0.0007 (Modem Apple II)	0.06 (US Robotics v.34 modems)	48 (WiMax)	56%
Storage (MB / US$)	0.0032 (hard disk 5MD HD)	3.03 (hard disk MC191AV)	2400 (hard disk 320GB, 7,200 rpm, 8MB)	72%
Computation (millions of computations / sec / US$)	7×10^3 (IBM4341)	1×10^8 (Dell Dimension XPS P133c)	1×10^{10} (Precision Workstation690)	76%

Source: own elaboration.

The amount of digital information

The amount of digital information that can be processed by the available technologies is calculated by multiplying the amount of equipment with its respective performance, i.e. with the amount of bits that each equipment can store, the amount of kbps it can communicate and the amount of MCps is can compute. This approach is inspired by two groundbreaking studies done by the School of Information at the University of California, Berkeley in 2000 and 2003, that gauge the quantity of information that exists worldwide (Lyman, Varian and Swearingen, 2003). Working with proxies and assumption is unavoidable when working in this new field. Therefore we have taken great care to be transparent with our estimations, enabling replication and improvements in the future. Our methodological details are presented in the Appendix.

The decision of the unit of measurement of information transmission and storage is straightforward: the BI-nary digi-T. The encoded bits represent information, which can reduce

celebrated as the epitome of the networked revolution, shows the slowest technological progress, when measured in terms of its price/performance relation.

uncertainty with regard to a specified probability space[11]. From an engineering perspective, transmission and storage are conceptually similar: one transports information through space (bits per second through a transmission channel) and the other one transports information through time (bits on a storage device). Storage will be measured in bits and transmission in bits per second, or, to be more precise, in kbits and kibps (kibibit per second, equal to [2^10]=1024; while a kilobit per second remains be equal to [10^3]=1000).[12]

Computers also function according to binary logic (manipulating bits through Boolean logic gates). Unfortunately for us, the amount of bits [1s and 0s] that are manipulated per second do not provide any interesting performance indicator. A computer with the universal design of a Turing machine consists of different information operations, such as reading from and writing on different storage devices and the speed of computation depends on the chosen architecture of the system. The diverse functionality of computers leads to a large variety of quantitative approaches to performance measurement (Hennessy and Patterson, 2007). For pragmatic reasons, we refer to the historic data produced by Nordhaus (2006), which are mainly based on MacCallum (2003). The resulting index is called CPS (computations per second) and is oriented by the instructions per second a computer executes. In agreement with industry standards, it is calibrated on the computer Digital Equipment Corporation VAX 11/780 from the year 1978 and correlated to the millions of instructions per second that a computer can execute (MIPS) (see Appendix). The

[11] The binary code is a kind of alphabet with only two letters that can represent all other kinds of alphabets. In the best of cases (in which a bit represents information entropy), one bit of information can reduce uncertainty by half (Shannon, 1948). Every bit represents information and has the potential to reduce uncertainty. In this technical definition of information, uncertainty and information are seen as opposites and the reduction of a possibility space by half is the most efficient way to communicate information.

[12] To solve the longstanding ambiguity regarding the units of kilobit in storage (one kilo being traditionally equal to 1024 bits) and communication technologies (one kilo being traditionally equal to 1000 bits), the latter can be measured in kibibit per second [Kibps] and mebibit per second [Mibps], which correspond to 1024 bits and 1024^2 bits per second, respectively.

VAX 11/780 is considered to perform exactly 1 MIPS, which, as a rough guide, is 150 million times as powerful as manual computations[13].

It is important to remember that the number of bits does not consider the meaning or value of the information content. As the father of information theory, Claude Shannon (1948), points out: "Frequently the messages have meaning […but…] these semantic aspects of communication are irrelevant to the engineering problem". From an engineering perspective, a bit only gives a measure of how much uncertainty can potentially be reduced with regard to a known possibility space (such as the selection of a letter from an alphabet to construct words or the selection of a color to fill an image). It does not reveal anything about the 'meaning' or 'value' of the information in the message (in a sense that some words might be more important to the receiver than others). Currently, there is no universally accepted scientific measure to classify the 'meaningful value' of information. This is not tragic for our purposes, as we estimate the installed information processing capacity to transmit and store information, independently of a specific purpose. Going one step further, some might want to trust in the common assumption that individual users are rational and self-interested actors, and would assume that they would utilize the provided technologies for ends that are useful and meaningful to their specific ends. This additional step, however, is independent from our basic exercise to estimate the available installed capacity in bits and bytes. Our estimations do not differentiate among the meanings of information contents (by the way, the same also counts also for estimations that are based on equipment headcounts).

Having defined the measurement units, the two required statistics are the amount of ICT equipments and their respective performance. The first statistic is mainly extracted form ITU's World ICT indicators Database (2007), which is the world's most complete historical administrative registry for ICT. It receives its inputs from national telecommunications and

[13] Nordhaus (2006) defines that manual computation would imply that "you can add two five-digit numbers in 7 seconds and multiply two five-digit numbers in 80 seconds".

industry authorities. We estimated missing years and complemented these data with information from mainly private sector sources, including the assessments of the distribution of the various generations of the particular technologies, such as the distinction between the share of existing mobile standards (such as analogue, GSM, GPRS, CDMA2000, etc), the different television standards, and the distribution of various existing hard disks according to their diameter, among others (see Appendix). The historical performance of the various technologies has been gathered by industry and academic sources, such as detailed in the Appendix.

The fact that we use national statistics as a basis for our calculations conceals the fact that the digital information infrastructure is global in nature. If a user from one country uses a hard disk in another country over an Internet connection, this international outsourcing of informational capacity cannot be covered by our estimations. This lack of coverage is not too damaging in the case of our specific example that estimates the installed information processing capacity of the consumer segment. The amount of international infrastructure sharing, such as cloud and grid computing, is minimum in the consumer segment. This would change, however, when applying the presented logic to the broader economy, including businesses, universities and research center. Super-computing facilities are often shared on the international level.

For reasons of simplicity and missing statistics, estimations focus on the installed capacity, not on its real usage. In other words, it is supposed that the installed technology would be running 24 hours for 365 days a year. As another general rule we have decided that estimations adopt an "optimistic bias" in favor of developing countries. This means that in case of missing statistical information, it was assumed that the newly introduced equipment performs at the technological frontier. This surely leads to an overestimation of the installed capacity in all countries, as consumers might purchase older technology from earlier years. Assuming that the technology consumed in developed countries is generally closer to the technological frontier, this bias rather overestimates the installed capacity in developing countries and is therefore "optimistic" from a development perspective.

The result is summarized in Table 3. It is to be understood as an optimistic estimation of the worldwide installed capacity to communicate, transmit[8], store and compute information through digital systems. It shows that the personal capacity to compute and store information has clearly experienced the largest progress. This is in agreement with what we have already observed in Table 2, and is rather surprising[10], as the advancement of telecommunications is often celebrated as the epitome of the network revolution. The plain numbers of Table 3 question this generally accepted notion of a telecommunication primer in the digital age. This conceptual concentration on communications –instead of computation or storage—is not only prevalent in academic writing, but also in the area of policy making. In most countries, for example, the telecom authority is in charge of shaping the road toward the digital age, and private and public authorities of computer engineering do often not even participate in policy agenda setting (for Latin Americ and the Caribbean see for example Guerra, et.al., 2008). The United Nations World Summit on the Information Society (2003-2005; e.g. Klein, 2004), as another example, has been organized by the International Telecommunications Union, and its audience and the discussed topics have been largely determined by this bias. Looking at Table 3, one can certainly no longer say that technological progress in communication technologies is the main characteristic of the digital age. The table rather suggests that the storage of information in vast memories and its meaningful computation are the principal character traits of the Information Society.

An interesting insight can be appreciated by comparing among the capacity of the different subsystems. For example, the table allows for the following thought experiment: if communication channels were running at full capacity and if every kind of communicated information were original and saved as soon as it was received, then every user could have filled the available per-capita storage capacity in roughly two weeks in 2006[14]. It shows, however, that

[14] (299 951 493 kbits/inhabitant storage) divided by (224 kibps/inhabitant communication) = 1 339 069 seconds, which are 15.5 days.

under the same assumptions[15] in 1990, the available storage capacity would have been filled up completely in less than one and a half hours[16]. This shows how the estimated global capacity to store information has increased much more remarkably than the global capacity to communicate.

Table 3: Worldwide installed capacity to compute, communicate and store digital information

	1980	1990	2000	2006	Compound annual growth rate between 1980 and 2006
Communication (telephony and Internet) **Kibps/inhabitant**	9	12	34	224	13.2%
Transmission (radio and TV) **Kibps/inhabitant**	2 653	4 403	7 230	8 143	4.4%
Computation (computers and mobile devices) **MCps/inhabitant**	0.0020	0.0958	63.15	957.74	65.4%
Storage (hard disks) **Kbits/inhabitant**	9 475	56 438	14 501 988	299 951 493	49.0%

Source: own elaboration, based on various sources, see specifications in Appendix.

The digital divide as a moving target

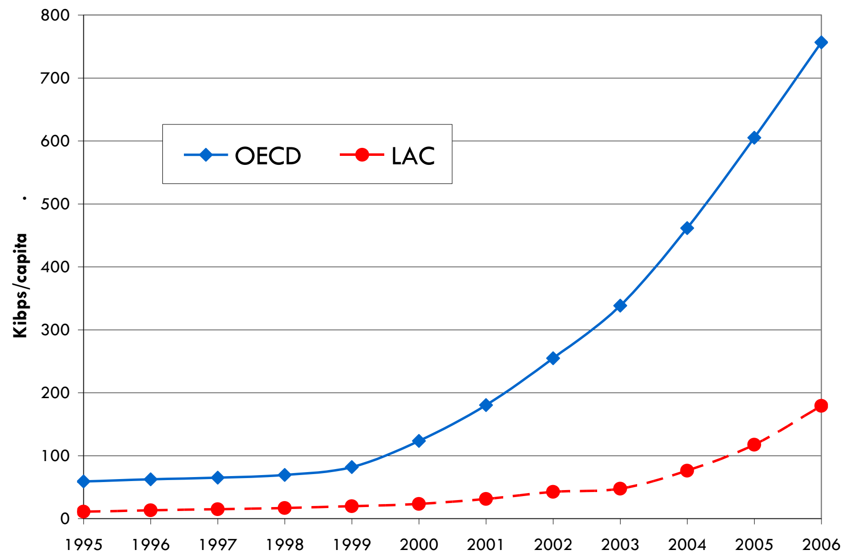
The result of comparing the countries of the OECD with the countries of Latin America and the Caribbean is shown in Figures 2 – 6. Figure 2 represents the digital divide of the capacity to communicate and exchange information through ICT, considering fixed lines and mobile telephony, as well as Internet (incl. broadband). It shows that in 1996 the average inhabitant of the OECD counted with a capacity of 49 kibps (equal to 49*1024 bits per second, see Appendix) more then its counterpart from LAC (62 kibps versus 13 kibps). Ten years later, this gap widened to 577 kibps (756 kibps as OECD average versus 179 kibps as LAC average). It is important to point out that this development also represents a slight reduction of the digital divide in relative terms, given that the ratio between OECD/LAC lowered from 4.7 to 4.3 (reduction to 91% of

[15] In reality, not all information is, of course, original, and neither is all received information saved on a hard disk right away. Therefore, the period between required erasures of memory are actually expected to be much longer.

[16] (56 438 kbits/inhabitant storage) divided by (12 kibps/inhabitant communication) = 4 703 seconds, which are 1.31 hours.

original). However, this relative reduction is significantly smaller than the ratios presented in Table 1 (which show ratio reductions between 16-57%). Furthermore, in contrast to the signs of saturation of the advanced OECD countries in ICT equipment diffusion (see Table 1), Figure 2 does not show any significant signs of saturation. The amount of information that is communicated by the average member of the developed region of OECD continues to grow explosively.

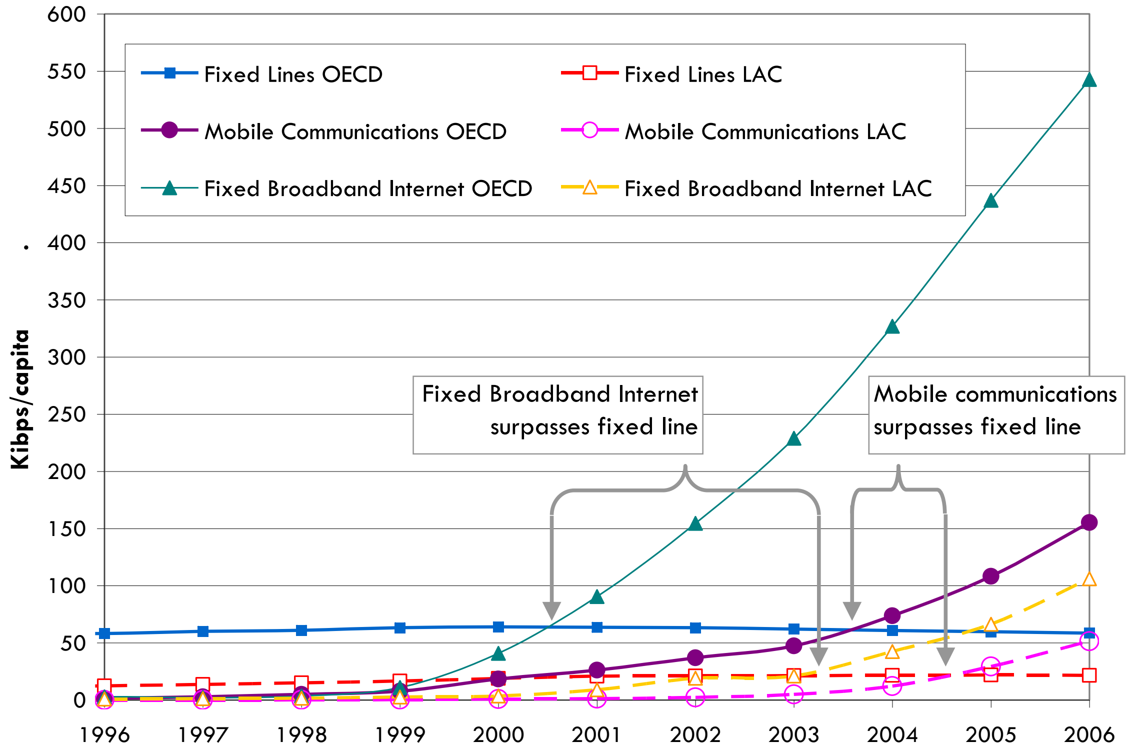
Figure 2: Capacity to communicate through fixed line, mobile telephony and Internet



Source: own elaboration, based on various sources, see specifications in Appendix.

Figure 3 takes a closer look at the reasons for this result. The bulk of installed communication capacity of a country is explained by fixed broadband Internet connections, especially DSL, cable modem and fixed-wireless, such as WiFi (representing 73% of the installed communication capacity in OECD and 61% in LAC in 2006). The capacity of the broadband Internet has surpassed the installed fixed line capacity (incl. fixe-line telephony or alternatively dial-up Internet) in the OECD in 2000 and in LAC in 2003. An interesting insight refers to the importance of mobile telephony. In terms of equipment diffusion, the number of mobile phones equaled the number of fixed lines in 2001 in the OECD and in 2002 in LAC (ITU, 2007). This does however not directly lead to a conclusion about the installed communication capacity through fixed or mobile networks. It has to be considered that 2G mobile communications (such as GSM and cdmaOne) provide a bandwidth of roughly 14 kibps, which only allows very limited data services, such as SMS messaging. A fixed line opens up a communication channel of up to 125 kibps, which can for example be used for Internet dial-up. Therefore, in terms of communication capacity, a 2G mobile phone channel is only a partial substitute for a fixed line in terms of data transmission rates. On the other hand, 2.5G or 3G mobile communications allow up to 350 kibps (such as WCDMA). As a result, the bulked communication capacity of mobile technology only surpassed fixed line communication with the introduction of advanced mobile data services, such as EDGE and CDMA2000. The breakeven point between fixed line and mobile communication is delayed for two years in both regions (2003 in OECD and 2004 in LAC). On the one hand, these cost-effective solutions also lead to the fact that mobile communication is increasingly becoming important in developing countries: in 2006, mobile channels represented 28% of the communication capacity in LAC and only 19% in the OECD (partly due to lacking fixed lines in developing countries). On the other hand, while the number of mobile phones has started to slow down in the OECD during recent years (with 86.6% of the population having a mobile phone in 2006), the amount of information communicated through mobile networks in the OECD does not show any sign of deceleration. The introduction of multimedia 3G and 4G communication continues to push the capacity of communicating on the go, even though the number of equipments might not grow as fast anymore. These findings demonstrate that the analysis of communication capacity can lead to different results and insights than the analysis of the number of equipments.

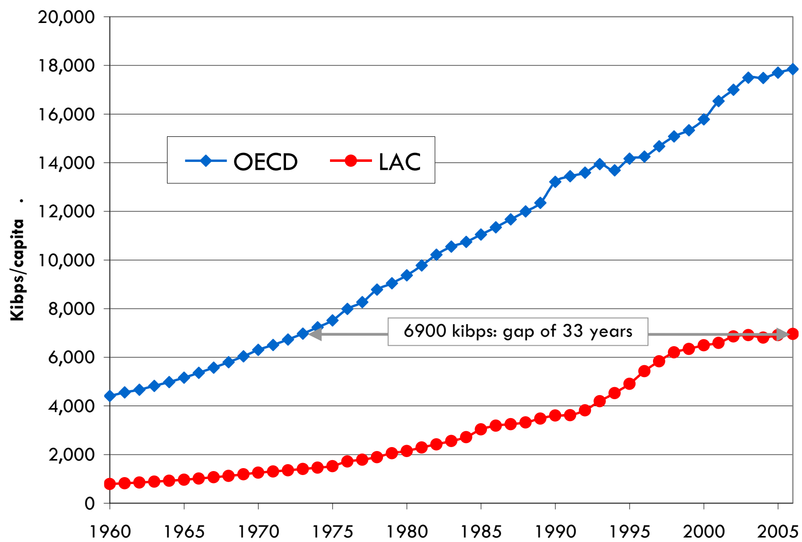
Figure 3: Capacity to communicate according to technology



Source: own elaboration, based on various sources, see specifications in Appendix.

Figure 4 shows the capacity to transmit and disseminate information through one-way broadcasting channels, such as TV and radio. In 1996, the OECD had 8800 kibps more than LAC (14 200 kibps versus 5 400 kibps). In 2006, this gap widened to 10900 kibps (every OECD inhabitant on average had 17 800 kibps, versus 6900 kibps for every LAC inhabitant). The massive diffusion of satellite and cable-TV in developed countries is contributing to this widening of the gap. Actually, the data reveal that in 2006 around 62% of the OECD's broadcast capacity was installed in high-quality cable and satellite technology, while in LAC 71% was still transmitted through unreliable analogue terrestrial TV systems. While the data show a relatively stable OECD/LAC ratio in relative terms (around 2.6 throughout the decade), the absolute numbers disclose that the 6900 kibps/capita broadcast capacity of LAC in 2006 corresponds to the installed OECD capacity of the year 1973. In other words, in terms of installed broadcast capacity per-capita, LAC is 33 years behind the OECD. It can be expected that the introduction of digital TV will very soon introduce a new dynamic in both regions.

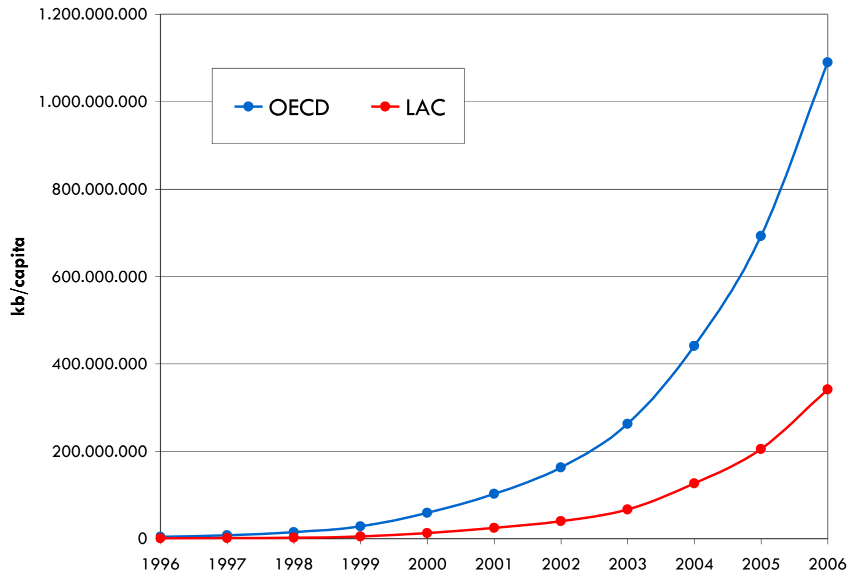
Figure 4: Capacity to transmit information through radio and TV (terrestrial, satellite, cable)



Source: own elaboration, based on various sources, see specifications in Appendix.

A similar situation accounts for the storage of information in computer hard disk drives (Figure 5). In 1996, an inhabitant of the OECD had on average 3 780 000 kilobits more storage capacity in hard drives of PCs and laptops than its LAC counterparts (4 552 000 vs. 772 000). Ten years later, the advantage of the OECD increased to almost 750 000 000 kilobits per capita (1 090 000 000 vs. 341 160 000).

Figure 5: Capacity to store information in hard disks of PCs and laptops



Source: own elaboration, based on various sources, see specifications in Appendix.

We have repeated this –and other—exercises with different methodological assumptions. For example, in agreement with Jorgenson and Vu (2005) we have estimated an economic utility lifetime of seven years for a computer and its respective hard disk (this estimate is based on economic depreciation rates) (see Appendix). Changing this assumption to five or three years (which might be close to the actual usage period of usage, not its complete economic depreciation), the results do not significantly affect the ratio between both regions[17]. It does, however, affect absolute storage capacity in both regions. In the case of reducing lifetime, the installed equipment is updated to the technological frontier more frequently, increasing the final storage capacity in 15-17 or 45-47 per cent with the five- and three years assumptions, respectively. Methodological considerations surely can make a difference in the absolute

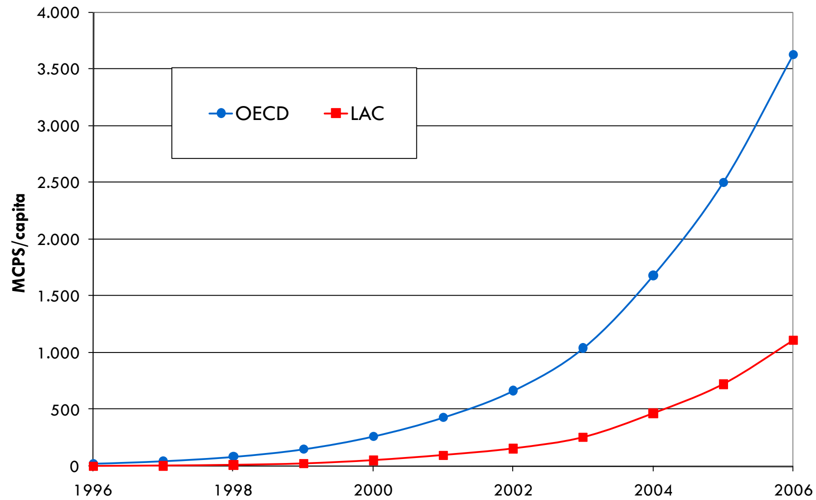
[17] The gap increases roughly 200-fold regardless of the seven years assumption ([750000000]/[3780000]=198); five years assumption ([878000000]/[4345500]=202) or three years assumption of computer life-time ([1091000000]/[5560000]=196). We can conclude that changing the lifetime of hard disk drives does not significantly affect the final results in terms of the ratio between the differences of the storage capacity in OECD and Latin America, as those methodological changes affect both regions in a similar manner.

numbers, but our tests and re-tests have shown that they do not change the general tendency and therefore the validity of the arguments that are presented here.

Figure 6 shows the capacity to compute information. For computers (PCs and notebooks) we apply the same performance indicators to both regions. We include computers (including Mac and PC), laptops and mobile phones (which have started to possess considerable computing power). Regarding mobile phones, we use the available statistics of 2G, 2.5G and 3G communication services to estimate the computational power of mobile devices. As a result, we can see that in 1996 the OECD counted with 19 million computations per second per capita more than LAC, while in 2006 this gap widened to 2 520 MCPS/capita[18]. It is interesting to observe the increasing importance of computing capacity of mobile phones, which rely on a little processor. We estimate that the individual processing power of a computer or notebook in 2006 is 22 times larger than the computational power of a multi-service mobile phone (see Appendix). As a result, in 2006, mobile devices represent 3.5% of the installed computational power in the OECD and in LAC 2.3%. It is expected that the rapid diffusion of multimedia phones will decisively increase the computational importance of mobile devices in the short-term future.

[18] Retesting these results with varying utility lifetime of computers, we observe something similar as already observed with storage. The total installed computing capacity increases in both regions between 10-20 when changing lifetime from seven to five years, and 20-40% with three years. Notwithstanding, the ratio between both region does not change too much: with the seven years supposition the gap increases over 130-fold [2520]/[19]=132.6, with five years [2920]/[22]=132.7 and with three years, it reduces to 115-fold [3456]/[30]=115.2.

Figure 6: Capacity to compute information with PCs, notebooks and mobile phones



Source: own elaboration, based on various sources, see specifications in Appendix.

Summing up, measuring the digital divide in terms of information processing capacity leads to different conclusions than comparing ICT equipment diffusions. Contrary to the superficial conclusion of a rapidly closing digital divide in terms of plain access to the technology, the change in perspective presented here shows that the digital divide is a moving target. Increasing saturation of ICT equipments diffusion in developed markets does not imply a stagnation of increases in information processing capacity, due to the incessant creative destruction of technological innovation. The amount of equipments a person can possess might be limited, but this does not give us insight to how much information a person can process with them.

Limitations and resulting research challenges

This article proposes to measure digital development in terms of information processing capacity, not in term of the mere number of installed equipments. The headcount of equipments has long served as a rough proxy to show the development of the digital age. While it is a fact of socio-economic research that measurement efforts have to work with proxies most of the time, we need to take care that the usage of proxies does not disguise the nature of the analyzed phenomena, which can result in misleading policy conclusions. The quite simple exercise presented here shows that a refinement of indicators can tell a quite different story about the same observed phenomena. There is a difference in measuring the amount of equipments in a society, we might call the result “ICT-equipment-societies”, and measuring the amount of information that a society processes: “Information Societies”.

Starting from the presented exercise, a series of research questions arise. The first set of questions focuses on the limitations of the presented exercise and on potential refinements:

Access and real usage: in our estimations, we have supposed that ICT run 24 hours for 365 days a year. An important refinement would be to estimate the “actual usage” of these technologies in hours, not simply the installed and potentially usable capacity. Available statistics are the limiting factor, but can be found in local or national samples, such as time-budget studies.

Analogue ICT: coherent with the common definition of the digital divide, we only consider digital ICT as access tools. In the Information Society, however, analogue technologies, such as books, newspapers, radio and analogue TV, VHS and music cassettes, among others, also play an important role. Presenting all of those technologies in approximated bit rates would allow for the first time to quantitatively compare the capacity of “analogue” and “digital” solutions. Is most of the world’s information already in digital format? If yes, when did it happen? What is the current ratio? Right now, nobody knows the answer to these questions. Nevertheless, this translation from analogue to digital is not straightforward. Analogue technologies do not work with bits and any translation would require a set of reasonable assumptions.

Aggregate measures disguise their underlying distribution: one of the main benefits of the presented approach is that it reduces an array of traditional indicators to only three indicators, expressed in: bits, bits per second and computations per second. In the presented exercise we have not focused on the nature of the distribution that leads to these aggregate values. For example, four 14 kbps 2G mobile phones reach the same amount of kbps as one 56 kbps modem connection (4*14 = 56). However, in the former case, lower capacity is distributed among four tools (and most probably four distinct users), and in the latter case it is concentrated in one tool. This leads to questions of equality and is well known to socio-economic literature: is there a trade-off between having few with much resources (capacity) and having many with little? The total amount of bits per inhabitant does not tell us anything about its concentration. The inclusion of this aspect could lead to interesting insights into the effects of the concentration of information processing capacities. The installed information processing capacity of one particular Information Society might be build on high-quality broadband connections for a few, while another Information Society with the same aggregate information processing capacity (*ceteris paribus*), might be constructed on the basis of low-quality mobile phones for everybody. What difference does it make? This leads to the analysis of the domestic digital divide. As already mentioned in the introduction, even though the presented example focuses on the international scenario, the presented logic can easily be applied to the domestic setting.

ICT Functionality: a similar logic of aggregate disguise applies to the consideration of other determinants of functionality. Mobile solutions are different to fixed solutions, and storage devices come with all kinds of different storage latency and throughput (reading and writing speed). A multi-dimensional definition of ICT functionality would certainly make any analysis more complex, but could enable deeper insights.

Type of content: The present analysis does not differentiate between the type of content, such as voice, text, images, videos, etc. The main restriction to this refinement is the availability of statistics about the nature of digital content. Considering the type of content would not only allow to analyse its relevance, but also to estimate the ultimate information entropy of installed systems (in Shannon’s sense), since compression algorithms heavily depend on the type of content.

The second set of resulting research questions is rather conceptual and policy oriented in nature.

Moving target: If the Information Society is defined by its capacity to work with information, the digital access divide becomes an extremely rapidly moving target. From this perspective, it becomes clear that the incessant force of technological change will make it impossible to "close" the digital access divide in a uniform sense. Some will always have more access than others and the presented approach points out to these qualitative differences. While qualitative difference will remain, the divide could be bridged nevertheless. This implies that every member of an Information Society could have sufficient resources to continuously maintain minimum connectivity to the public on a basis of equal entitlement. This is a constant challenge, and much depends on how the terms "sufficient" and "minimum" are defined for the time being.

Sustainable policies: Given that the digital access divide is a constantly moving target that re-opens an informational abyss inside and between societies with every digital innovation, and given the importance of digital ICT for today's socio-economic organization, related policies will not cease to be part of the policy agenda. During the past decades, the private sector has led the deployment of infrastructure, in most cases under vigilant observation by regulators, such as the FCC, the European Commission and other national authorities in countries all over the world. The regulation of ICT infrastructure has become a complex subject by itself and even the fiercest market competition is often closely regulated. This task will continue as technological progress continues. The figures in article have shown no sign of an innovation downturn. Users continue to strive for more and more information processing power all over the world. One of the resulting research questions is how to design policies that consider the fast innovation cycles, but are independently of a specific –and rapidly outdated—technological solution.

Is there an end? Even though there might be a limit to the amount of ICT equipment a person can possess, is not evident that there is a limit to the number of bits an individual or a society can process. The human brain seems to have an upper limit of conscious information processing, but when is it reached? And even once it would be reached, the theory of biological evolution suggests that human intelligence is a flexible and expandable variable. While our grandparents could hardly imagine the amount of information we consume today on a daily basis, there seems to be no reason why our grandchildren would not shake their heads in amazement when looking back at our informational snail-systems.

From a methodological perspective, the conclusion is that it is necessary to go beyond simplistic approximations of ICT equipment penetration rates. This will also deepen our comprehension about the digital paradigm and its Information Societies. This article has presented an alternative perspective and intends to contribute to the elaboration of new approaches for this challenging undertaking.

References

Barzilai-Nahon, Karine. "Gaps and Bits: Conceptualizing Measurements for Digital Divide/s." *The Information Society* 22, no. 5 (2006): 269.

Bell, Daniel. *The Coming of Post-Industrial Society : A Venture in Social Forecasting*. New York: Basic Books, 1973.

Castells, Manuel. *The Rise of the Network Society*. The Information Age, Economy, Society, and Culture. Vol. 1. Cambridge, Mass.: Blackwell Publishers, 1996.

Compaine, Benjamin M. 2001. *The Digital Divide: Facing a Crisis or Creating a Myth?* illustrated edition. The MIT Press, June 18.

Cullen, R. "Addressing the Digital Divide." *Online Information Review* 25, no. 5 (2001): 311-320(10).

Dosi, G. "Sources, Procedures and Microeconomic Effects of Innovation." *Journal of Economic Literature* (1988).

Dutta, Soumitra, Augusto López-Claros, Irene Mia, Insead, and World Economic Forum. *The Global Information Technology Report, 2005-2006 : Leveraging ICT for Development*. Basingstoke England ; New York: Palgrave Macmillan, 2006.

Freeman, Christopher and Francisco Louçã. *As Time Goes by : From the Industrial Revolutions to the Information Revolution*. Oxford ; New York: Oxford University Press, 2001.

Frost and Sullivan Research Group. *Social Impact of Mobile Telephony in Latin America*GSM Association in Latin America and AHCIET (Ibero-American Association of Research Centers and Telecommunication Enterprises), 2006.

GSM Association. *Universal Access- how Mobile can Bring Communications to all*GSM Association, 2006.

Guerra, Massiel, Martin Hilbert, Valeria Jordán, and Christian Nicolai. 2008. *Digital Review 2007 of Latin America and the Caribbean:Progress and Challenges Policies for Development with ICT-Abridged document* . SocInfo 37. ECLAC United Nations, November. http://www.cepal.org/SocInfo .

Hanafizadeh, Payam, Mohammad Reza Hanafizadeh, and Mohsen Khodabakhshi. 2009. Extracting Core ICT - Indicators Using Entropy Method. *The Information Society: An International Journal* 25, no. 4: 236. doi:10.1080/01972240903028490.

Hennessy, John L., David A. Patterson, and Andrea C. Arpaci-Dusseau. *Computer Architecture : A Quantitative Approach*. 4th ed. Amsterdam ; Boston: Morgan Kaufmann, 2007.

Hilbert, Martin and Jorge Katz. *Building an Information Society : A Latin American and Caribbean Perspective*. LC/L.1845 ed. Santiago, Chile: Economic Commission for Latin America and the Caribbean, United Nations, 2003.

Howard, Philip N., Ken Anderson, Laura Busch, and Dawn Nafus. 2009. Sizing Up Information Societies: Toward a Better Metric for the Cultures of ICT - Adoption. *The Information Society: An International Journal* 25, no. 3: 208. doi:10.1080/01972240902848948.

ITU (International Telecommunication Union). *Measuring ICT for Social and Economic Development*. Geneva: ITU Secretariat, United Nations, 2006.

ITU (International Telecommunication Union) and UNCTAD (United Nations Conference on Trade and Development). *World Information Society Report 2007: Beyond WSIS* . Geneva: United Nations, 2007.

ITU (International Telecommunications Union). *World Telecommunication/ICT Indicators Database*. Geneva: ITU Secretariat, United Nations, 2007.

———. *Challenges to the Network: Internet for Development*. Geneva: ITU Secretariat, United Nations, 1999.

———. 2009. *Measuring the Information Society - The ICT Development Index 2009*. Geneva. http://www.itu.int/ITU-D/ict/publications/idi/2009/index.html.

James, Jeffrey. "Digital Divide Complacency: Misconceptions and Dangers." *The Information Society* 24, no. 1 (2008): 54.

Jorgenson, Dale W., and Khuong Vu. 2005. Information Technology and the World Economy. *Scandinavian Journal of Economics* 107, no. 4: 631-650.

Klein , Hans. 2004. Understanding WSIS: An Institutional Analysis of the UN World Summit on the Information Society. *Information Technologies and International Development* 1, no. 3-4: 3-13.

Kvasny, Lynette. "Virtual Inequality: Beyond the Digital Divide, by Karen Mossberger, Caroline J. Tolbert, and Mary Stansbury. Washington, DC: Georgetown University Press, 2003. Xvi + 192 Pp. $19.95/£14.25 (Paper). ISBN: 0-87840-999-8." *The Information Society* 20, no. 5 (2004): 409.

Lyman, Peter, Hal R. Varian, Kirsten Swearingen, Peter Charles, and University of California, Berkeley. School of Information Management and Systems. *How Much Information? 2003*. Berkeley, Calif.: School of Information Management and Systems, University of California at Berkeley, 2003.

M Shelley, L Thrane, S Shulman, E Lang, S Beisser,. "Digital Citizenship: Parameters of the Digital Divide." *Social Science Computer Review* (2004).

MacCallum, John. "CPU Price Performance 1944-2003." .

Mossberger, Karen, Caroline J. Tolbert, and Mary Stansbury. *Virtual Inequality : Beyond the Digital Divide*. American Governance and Public Policy. Washington, D.C.: Georgetown University Press, 2003.

Nordhaus, William D. "An Economic History of Computing." *Yale University and the NBER* (2006).

Norris, Pippa. 2001. *Digital Divide: Civic Engagement, Information Poverty, and the Internet Worldwide*. Cambridge University Press, September 24.

OECD (Organization for Economic Co-operation and Development). 2002. *Measuring the Information Economy 2002*. Paris, France: OECD (Organization for Economic Co-operation and Development). http://www.oecd.org/document/5/0,2340,en_2649_34449_2765701_1_1_1_1,00.html.Perez, Carlota. "Structural Change and Assimilation of New Technologies in the Economic and Social Systems." *Futures,* 15, no. 5 (10, 1983): 357-375.

Rogers, Everett M. *Diffusion of Innovations*. New York: Free Press of Glencoe, 1962.

Shannon, Claude. "A Mathematical Theory of Communication." *Bell System Technical Journal* 27, (July and October 1948, 1948): 379–423 and 623–656.

UNDP (United Nations Development Programme). *Human Development Report 2001: Making New Technologies Work for Human Development*. New York: Oxford University Press for UNDP, 2001.

United States. Economics and Statistics Administration and United States. National Telecommunications and Information Administration. *Falling through the Net : Toward Digital Inclusion : A Report on Americans' Access to Technology Tools*. Washington, D.C.: U.S. Dept. of Commerce, Economic and Statistics Administration : National Telecommunications and Information Administration, 2000.

United States. National Telecommunications and Information Administration. *Falling through the Net : Defining the Digital Divide : A Report on the Telecommunications and Information Technology Gap in America*. Washington, D.C.: U.S. Department of Commerce, National Telecommunications and Information Administration, 1999.

———. *Falling through the Net II : New Data on the Digital Divide*. Washington, D.C.: U.S. Dept. of Commerce, National Telecommunications and Information Administration, 1998.

———. *Falling through the Net : A Survey of the "have Nots" in Rural and Urban America*. Washington, D.C.: U.S. Dept. of Commerce, National Telecommunications and Information Administration, 1995.

van Dijk, Jan and Kenneth Hacker. "The Digital Divide as a Complex and Dynamic Phenomenon." *The Information Society* 19, no. 4 (2003): 315.

Vehovar, Vasja, Pavle Sicherl, Tobias Hüsing, and Vesna Dolnicar. "Methodological Challenges of Digital Divide Measurements." *The Information Society* 22, no. 5 (2006): 279.

Warschauer, Mark. 2003. *Technology and Social Inclusion: Rethinking the Digital Divide*. The MIT Press, January 24.

Webster, Frank. *Theories of the Information Society*. The International Library of Sociology. London ; New York: Routledge, 1995.

Wiener, Norbert. *Cybernetics : Or Control and Communication in the Animal and the Machine*. New York ; Cambridge ; Paris: Wiley ; Technology Press, Massachusetts Institute of Technology ; Hermann, 1948.

Appendix

Transmission/ Communication

Regarding the adequate measuring unit for communication, the recently defined agreement between IEC, IEEE, EU and NITS, and some governments has been considered. To solve the longstanding ambiguity regarding the units of kilobit and megabit in storage and communication technologies, the latter are measured in kibibit per second [Kibps] and mebibit per second [Mibps], which correspond to 1024 bits and 1024^2 bits per second, respectively. Using this definition, the Kbps and Mbps used in storage technologies become comparable with the units used in communication technologies.

Fixed line

The amount of fixed main lines (digital and analogue, including public and residential) is taken from (ITU, 2007). Furthermore, (ITU, 1988) specifies a transmission rate of 64 [kbps] per line and a normal voice-communication relies on one line in both communication directions. Therefore, each fixed line equals two times 64 [kbps] or 125 [Kibps][19]. It is important to remember that a fixed line can be used for either voice-communication or dial-up Internet access in an exclusive manner. However, for our purposes of calculating the installed capacity to transmit bits/s (and given the lack of statistics about the distribution of each usage during the day), we estimate the maximum value of a fixed line, equal to 125 [Kibps], independently of its specific usage.

Mobile telephony

The division in different generations of mobile telephone systems is considered according to the classification IMT-2000 (ITU, 2008). The commonly used “average user data rates” are presented in Table 1. First generation (analogue) mobile telephony only enabled voice communication. Second generation technologies (2G) allow the mutually exclusive transmission of voice or data. Once again, given missing statistics about how much of the 2G channel is used for voice and how much for data, we consider the maximum transmission rate of the installed capacity. With the implementation of 2.5 generation networks, the transition from circuit-switched (2G) to packet-switched networks enables the simultaneous transmission of voice and data, so the presented transmission rates for data downlink and uplink are added to the voice channel. It has to be pointed out that additional mobile telephony technologies exist. For reasons of simplicity we only considered the GSM and CDMA families (presented in Table A1) and PDC (Digital Personnel Cellular) in Japan, which is a special case with a transmission rate of 28,13 [Kibps] (Mobile-technology.com, 2007). Together these three represent more than 95% of the universe of digital telephony subscribers (GSM World, 2008; CGD, 2008).

Table A1
Performance of mobile telephony systems

Technology	Generation	Average user data rates		Finally used transmission rates	
		Uplink [kbps]	Downlink [kbps]	Downlink [Kibps]	Uplink [Kibps]
Voice (only)	1G	13	13	12.70	12.70
GSM (voice or data)	2G	14	14	13.67	13.67
cdmaOne (voice or data)	2G	14	19	13.67	18.55
PDC (voice or data)	2G	28.8	28.8	28.13	28.13
GPRS (voice&data)	2.5G	13 + 14	13 + (28 to 64)	12.70 + 13.67	12.70 + 44.92
EDGE (voice&data)	2.5G	13 + 40	13+100	12.70 + *41.02*	12.70 + 97.66

[19] Calculated as follows: 2 [lines] x 8000 [samples/s] x 8 [bits/simple] = 128000 [bps] or 125 [Kibps]

WCDMA (3GSM) (voice&data)	3G	13 + 350	13+350	12.70 + 341.80	12.70 + 341.80
CDMA2000 1x (voice&data)	3G	13 + (70 to 90)	13 + (60 to 100)	12.70 + 78.13	12.70 + 97.66
CDMA2000 1xEV-DO (voice&data)	3G	13+ (70 to 90)	13 + (300 to 700)	12.70 + 78.13	12.70 + 488.28

Sources: Steele, Lee & Gould; 2001; GSM World, 2008; CDG; 2008a; 3G Americas, 2006

The total amount of mobile telephones is taken from (ITU, 2007). The distribution of the various technologies and generations is shown in Table A2. Given that this information is not publicly available on the country level (except PDC in Japan), the distribution of mobile technology in each country has been estimated according to the distribution in the region in which each country can be found.

Table A2

Percentage of technologies GSM/GPRS/EDGE 2G/2.5G

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Europe	*0,025*	*0,118*	*0,259*	0,425	0,639	0,818	0,901	0,940	0,977	0,966	0,979	0,985	0,979
Latin America	*0,000*	*0,000*	*0,000*	0,000	0,000	0,000	0,009	0,017	0,027	0,042	0,069	0,167	0,304
USA/Canada	*0,000*	*0,000*	*0,001*	0,001	0,005	0,023	0,042	0,063	0,081	0,097	0,122	0,191	0,289
Total World	0,009	0,041	0,090	0,143	0,226	0,331	0,435	0,525	0,616	0,650	0,681	0,697	0,717

Percentage of technologies GSM 3G y 2G/2.5G

	% WCDMA						% GSM/GPRS/EDGE	
	2001	2002	2003	2004	2005	2006	2005	2006
Latin America	0,000000	0,000000	0,000000	0,000000	0,000000	0,000000	0,5664	0,6974
Asia Pacific	0,000066	0,000338	0,003534	0,013541	0,028397	0,041805	0,8278	0,8083
East Europe	0,000000	0,000000	0,000000	0,000033	0,000624	0,005401	0,8621	0,8796
West Europe	0,000028	0,000172	0,002152	0,021604	0,064353	0,108733	0,9781	0,9242
USA/Canada	0,000000	0,000000	0,000000	0,000015	0,000235	0,004238	0,3266	0,3611
Total World	0,000031	0,000172	0,001899	0,009758	0,022555	0,035217	0,7543	0,7676

Percentage of technologies cdmaOne 2G

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Asia Pacific	0,083	0,136	0,172	0,149	0,111	0,076	0,056	0,042	0,023	0,019
USA/Canada	0,025	0,091	0,177	0,243	0,348	0,331	0,228	0,143	0,086	0,056
Latin America	0,000	0,057	0,126	0,234	0,234	0,263	0,234	0,189	0,142	0,039
Europe, Africa & ME	0,000	0,005	0,018	0,021	0,020	0,020	0,014	0,009	0,006	0,002
Total World	0,036	0,072	0,102	0,109	0,112	0,098	0,073	0,053	0,035	0,018

Percentage of technologies CDMA 3G

	% CDMA2000 1x						% CDMA2000 1xEV-DO				
	2001	2002	2003	2004	2005	2006	2002	2003	2004	2005	2006
Asia Pacific	0,011	0,048	0,075	0,088	0,106	0,109	0,000	0,008	0,017	0,023	0,025
USA/Canada	0,000	0,075	0,205	0,316	0,362	0,336	0,000	0,000	0,003	0,019	0,097
Latin America	0,000	0,002	0,017	0,049	0,096	0,185	0,000	0,000	0,000	0,002	0,006
Europe, Africa & ME	0,000	0,001	0,005	0,006	0,007	0,013	0,000	0,000	0,000	0,001	0,002
Total World	0,004	0,028	0,057	0,076	0,090	0,098	0,000	0,003	0,007	0,011	0,020

Source: (GSM World, 2007a); (GSM World, 2007b), (CDG, 2008b)

Given that the available statistics do not distinguish between GSM/GPRS/EDGE, estimations have to be made for this transition from 2G to 2.5G. The introduction of the first GPRS networks in the OECD was in the year 2000 and in Latin America and the Caribbean in 2002 (ZDNed.co.uk, 2007; CITEL, 2007). Starting from this date, we optimistically estimate that each new mobile phone will run on a GPRS network. For this, we estimate a maximum durability of 3 years for a mobile phone (Helsingin Sanomat, 2000). This implies a complete transition from GSM to GPRS in three years starting on the indicated years. For the introduction of EDGE networks, 3G Americas (2008) provides country specific data.

Broadband Internet

The penetration rates for ISDN, cable modem and DSL are taken from (ITU, 2007). In many cases data had to be completed for early years. For ISDN, cable modem and DSL, a simple exploration has been made since their first year of commercialization [ISDN in 1989 (FHTE, 2001), cable modem in 1996 (Motorola Inc., 2002) and DSL in 1998 (Cable News Network, 2000)]. The respective average communication rates for these three technologies are shown in Table A3.

Table A3
Internet transmission rates

Technology	Bit Rates		Bit Rates	
	Uplink [kbps]	**Downlink [kbps]**	**Uplink [Kibps]**	**Downlink [Kibps]**
B-ISDN	128	128	125	125
Cable Modem (average)	300	1000	208.33	976.56
DSL (average)	1133	3464	1106.45	3382.81
Others	256	256	250	250

Source: (Moulton, 2001; Freeman, 2005).

The difference between the users of these technologies and the total number of Internet users is assumed to consist of other kinds of Internet access, such as wireless technology (e.g. WiFi), microwave or satellite, electric cable (PLC), etc (ITU, 2007). For them, an average transmission rate of 250 [Kibps] is considered in both directions.

Television

Two groups of analogue television standards exist around the world: NTSC (since 1954, later also PAL-M and PAL-N, all three working with a channel of 6 [MHz]); and PAL and SECAM (since 1967, working with a channel of 7 or 8 [MHz]) (Ibrahim, 2007). In the second case, the 8 [MHz] channel has been chosen, since we estimate the maximum installed capacity. It is important to point out that it is not straightforward to translate MHz into bits. We have opted to consider digital transmission rates of DVB (the most commonly used digital-TV standard) and to register how many bits DVB can transmit through a 6 or 8 [MHz] channel. Once again, even this is not straightforward, as the bits rate depends on network configurations and channel conditions. For DVB-T (terrestrial) and DVB-C (cable) we have finally opted to consider the most utilized configurations in Europe (the home region of DVB) and for DVB-S (satellite) the average rate for typical broadcasting has been calculated (Benoit, 2008) (ETSI, 1997). The transmission rates for analogue television that we have estimated this way are shown in Table A4.

Table A4
Transmission rates used to estimate bit rates of analogue television

Standard	Transmission rate 6 [MHz] = NTSC, PAL-M, PAL-N	Transmission rate 8 [MHz] = PAL/SECAM	Transmission rate 6 [MHz] = NTSC, PAL-M, PAL-N	Transmission rate 8 [MHz] = PAL/SECAM
DVB-T	18,09 [Mbps]	24,13 [Mbps]	17.25 [Mibps]	23.01 [Mibps]
DVB-C	28,85 [Mbps]	38,47 [Mbps]	27.51 [Mibps]	36.69 [Mibps]
DVB-S	30.25 [Mbps]		28.85 [Mibps]	

Sources: (ETSI, 2004; ETSI, 1997)

Considering which standard is used in which country (TigerDirect, 2007), (R.C.O., 2007), these rates are then been multiplied with the statistics for TV penetration from (ITU, 2007). Unfortunately, this source only provides data about total TV equipment and the number of cable and satellite subscriptions. In order to be able to harmonize the number of subscriptions with the number of equipments, we multiply the cable and satellite subscriptions with estimations for the number of TV-equipments per household for the OECD and for the rest of the world (based on the same source) (see Table A5).

Table A5
Average number of TV-equipment per household

Year	1960-1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Average OECD	1,23	1,25	1,25	1,28	1,31	1,28	1,34	1,31	1,34	1,34	1,34	1,37	1,38	1,37	1,40	1,44
Average Rest of World	1,10	1,15	1,16	1,16	1,27	1,18	1,21	1,22	1,26	1,22	1,22	1,24	1,26	1,23	1,20	1,23
Year	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Average OECD	1,45	1,43	1,44	1,49	1,52	1,51	1,53	1,55	1,51	1,53	1,64	1,69	1,72	1,72	1,72	1,72
Average Rest of World	1,23	1,19	1,23	1,29	1,30	1,31	1,34	1,36	1,34	1,36	1,37	1,37	1,37	1,37	1,37	1,37

Source: (ITU, 2007)

Radio

In order to obtain an estimation of the amounts of bits in radio transmission, we consider the digital standard MPEG Layer II, which uses MUSICAM (*Masking pattern adapted Universal Sub-band Integrated Coding and Multiplexing*) and was designed for the broadcasting of digital audio (DAB, Digital Audio Broadcasting). The transmission rates are 128 kbps for AM (125 Kibps) and 256 kbps for FM (250 Kibps) (Ibrahim, 2007). To understand the difference, consider that AM transmits only one channel (mono) and FM in two (stereo). Given that most radios are able to receive both signals in an exclusive manner, and given that we estimate the maximum installed capacity, we calculate FM transmission rates for all existing radio equipment. Their penetration rates are taken from (ITU, 2007).

Storage

Hard Disk Drives (HDD)

The historic capacities of HDD according to disk’s diameter are registered according to Hitachi (2007), Seagate-Quantum (Schmidt, 2005), IBM (Grochowski, 2007) and Disk/Trend Report (Porter, 2005), see Table A6.

Table A6
Historic capacities of Hard Disk Drives, according to diameter

Year / Diameter	< 1,8"	2,5"	3,5"	5,25"	6.5"-9.5"	10"-14"
1976	0	0	0	0,2188****	0,568****	317,5****
1977	0	0	0	0	0	*386*
1978	0	0	0	0	0	*469*
1979	0	0	0	0	60**	571,4****
1980	0	0	0	10**	90**	*516*
1981	0	0	0,4375****	15**	135**	466****
1982	0	0	*2*	22**	300**	*616*
1983	0	0	10****	50**	680**	*815*
1984	0	0	*10*	115**	460**	*1078*
1985	0	0	10,5****	170**	*654*	*1426*
1986	0	0	40****	*234*	*931*	1890***
1987	0	0	*28*	*323*	*1325*	*2092*
1988	0	20****	21****	*446*	1890***	*2316*
1989	0	*35*	*76*	*616*	*2061*	*2564*
1990	0	*62*	*275*	857****	*2248*	2840***
1991	21,4****	*111*	1004****	*1212*	*2452*	*4092*
1992	42,5****	*199*	*1465*	*1714*	*2674*	*5897*
1993	*60*	*357*	2139****	*2425*	2920****	8500***
1994	*84*	*640*	*3071*	*3431*	*4131*	*12026*
1995	*118*	1200*	*4410*	*4854*	0	0
1996	*166*	*2473*	*6333*	*6868*	0	0

1997	234	5100*	9100****	9717	0	0
1998	340*	9200****	18200****	13748	0	0
1999	340****	8100*	36200***	19452	0	0
2000	1000*	18350****	73000***	27523	0	0
2001	1414	25702	103289	38943	0	0
2002	1999	36000*	146146	55101	0	0
2003	2827	60000*	206785	0	0	0
2004	4000*	80000*	292585	0	0	0
2005	5659	113194	413986	0	0	0
2006	8007	160161	585760	0	0	0
* Hitachi, 2007	http://www.hitachigst.com/hdd/hddpdf/tech/chart01.pdf					
** Seagate-Quantum Glen M. Schmidt, 2005	http://ite.pubs.informs.org/Vol5No2/SchmidtVanMieghem/index.php					
**** Disk/Trend Report	http://www.disktrend.com/5decades2.htm, 2005					
*** IBM	http://www.pcguide.com/ref/hdd/hist-c.html					
Italic numbers	Own estimations. Growth rates of neighbouring disk diameters have been adopted to fill gaps, as it is assumed that the rate of innovation is homogeneous throughout the hard disk industry.					

We assume that every PC/notebook has one hard disk drive (HDD). The computer penetration rates (PC/notebooks aggregated) are taken from (ITU, 2007). The kinds of hard disks used by the available computers are estimated with the market shares of the worldwide hard disk exports according to Disk/Trend Report (Porter, 1998), see Table A7. The table shows for example that 2.5" hard disks, which are usually used for notebooks, reach a market share of more than 20% in recent years. This is in agreement with other sources about the market shares of notebooks.

Table A7
Export market share of hard disk drives with different diameters

Year	% 10"-14"	% 6.5"-9.5"	% 5.25"	% 3.5"	% 2.5"	% < 1.8"	100%
1976	1,0000	0,0000	0,0000	0,0000	0,0000	0,0000	1
1977	1,0000	0,0000	0,0000	0,0000	0,0000	0,0000	1
1978	1,0000	0,0000	0,0000	0,0000	0,0000	0,0000	1
1979	0,9599	0,0401	0,0000	0,0000	0,0000	0,0000	1
1980	0,8368	0,1608	0,0024	0,0000	0,0000	0,0000	1
1981	0,6612	0,2653	0,0735	0,0000	0,0000	0,0000	1
1982	0,4605	0,2843	0,2552	0,0000	0,0000	0,0000	1
1983	0,2214	0,1577	0,6184	0,0025	0,0000	0,0000	1
1984	0,1325	0,0936	0,7462	0,0278	0,0000	0,0000	1
1985	0,0959	0,0665	0,7493	0,0883	0,0000	0,0000	1
1986	0,0491	0,0421	0,7309	0,1779	0,0000	0,0000	1
1987	0,0273	0,0259	0,6187	0,3281	0,0000	0,0000	1
1988	0,0203	0,0237	0,4927	0,4633	0,0000	0,0000	1
1989	0,0114	0,0175	0,3745	0,5956	0,0011	0,0000	1
1990	0,0078	0,0120	0,2409	0,7090	0,0304	0,0000	1
1991	0,0049	0,0082	0,0933	0,7989	0,0947	0,0000	1
1992	0,0022	0,0035	0,0502	0,8271	0,1165	0,0005	1
1993	0,0015	0,0019	0,0246	0,84760	0,1213	0,0030	1
1994	0,0007	0,0011	0,0113	0,8621	0,1215	0,0034	1
1995	0,0001	0,0001	0,0079	0,8685	0,1188	0,0047	1
1996	0,0000	0,0001	0,0443	0,8413	0,1121	0,0022	1
1997	0,0000	0,0000	0,0431	0,8402	0,1151	0,0016	1
1998	0,0000	0,0000	0,0281	0,8488	0,1223	0,0008	1
1999	0,0000	0,0000	0,0129	0,8174	0,1687*	0,0010	1
2000	0,0000	0,0000	0,0056	0.8010	0.1921*	0,0013	1
2001	0,0000	0,0000	0,0018	0.7842	0.2118*	0,0021	1
2002	0,0000	0,0000	0,0000	0.7680	0.2290*	0,0030	1
2003	0,0000	0,0000	0,0000	0.7352	0.2618*	0,0030	1
2004	0,0000	0,0000	0,0000	0.7133	0.2837*	0,0030	1
2005	0,0000	0,0000	0,0000	0.6782	0,3188*	0,0030	1
2006	0,0000	0,0000	0,0000	0.6518	0,3452*	0,0030	1

Porter Jim 1976-2002 (From 1998 are estimates of Porter)
* Morgan Stanley
Italic numbers: Own estimations

We assume a durability of 7 years for a computer (Jorgenson and Vu, 2005). We have done the same exercise for 3 and 5 years of durability and the result favor developing countries, but do not change the general tendency of the argument. We have not found a trustworthy source that would favor a three or five years assumption, reason why we stay with the economic depreciation rates presented in (Jorgenson and Vu, 2005). Finally we calculate the amount of bits to be stored in hard disk drives by multiplying the number of “new” computers of a given year, with the average performance of hard disks, weighted by the market share of the various hard disk diameters (see Table A8).

Table A8
Summary of weighted hard disk drive capacities

Year	**1970**	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**
Capacity [MB]	73	91	113	141	177	221	318	386	469	551	446	345	375
Year	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**
Capacity [MB]	319	272	309	310	300	321	341	452	966	1343	1935	2777	4011
Year	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**		
Capacity [MB]	5910	8652	16960	31207	62154	86519	120491	167754	231415	316878	437130		

Computation

At the beginning of mechanical computation benchmarks registered the time a computer required to carry out additions. Thereafter, during the period 1940-1980, commonly used variable to measure of a computer’s processor speed in was MIPS (million instructions per second). However, this measure does not consider the content and importance of the different possible instructions. Realistic workloads consist of a mix of instructions and even applications, some of which take longer to execute than others. The performance of the memory hierarchy also greatly affects processor performance, an issue barely considered in MIPS calculations. That is the reason why most of today’s standardized tests, such as SPECint, which present computers with a set of common benchmarking tasks and evaluate the speed of execution of this standardized set.

Nordhaus (2002, 2006) has revised and harmonized several computer performance indicators on a standardized index called CPS (computations per second). Given that 81% of the gathered performance measures of the 242 different computers registered by Nordhaus between 1850 and 2006 used MIPS and come from a single source (McCallum, 2007), Nordhaus equaled his CPS index to MIPS and normalized the other benchmark measures according to it. To normalize the other benchmarks with MIPS he naturally used the computer VAX 11/780, which the industry has adopted as the reference 1 MIP machine[20].

[20] In other words, in reality, the VAX 11/780 does not execute 1000 instructions per seconds. For example, when using the common Dhrystone method to measure MIPS, the VAX 11/780 achieves 1757 Dhrystones per second. Therefore, the commonly used Dhrystone figure is actually calculated by measuring the number of Dhrystones per second for the system, and dividing that by 1757. So "10 MIPS" (such as the MSM2 Intel 80186 mobile phone from the year 1996) means "10 Dhrystone VAX MIPS", which means that this mobile phone from 1996 was 10 times faster than a VAX 11/780 from 1978. A manual calculation,

Computers and notebooks

The ITU (2007) statistics are utilized to obtain the number of personal computers and notebooks. Average processing power levels for each year are based on the performance indication (in million computations per second) of the 143 computer equipments observed for the period 1971-2006 by W.D. Nordhaus (2002). We erased the 25 super computers included in the data, leaving 118 observations. We created a fourth degree polynomial function to estimate the average performance for the period 1971-1995 (which covers the S-shaped curve of performance rise of the technological paradigm of the microprocessor, which was invented in 1971) and another fourth degree polynomial function for the period 1995-2006. For a good fit of the estimated polynomial, it was necessary to separate these two periods, because computer performance productivity experienced a sharp slowdown in 1995.

Table A9
Average home computer processing levels (PC and notebook) in millions of computations per second

Year	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**
MCps	0,561	0,492	0,446	0,417	0,403	0,402	0,415	0,441	0,485	0,55
Year	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**
MCps	0,644	0,778	0,9712	1,252	1,666	2,288	3,243	4,746	7,168	11,174
Year	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
MCps	17,978	29,852	51,157	90,468	154,07	272,17	463,653	761,719	1206,881	1844,259
Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**				
MCps	2718,227	3864,337	5299,18	7009,802	8945,099	11011,989				

It is assumed that the durability of a computer/notebook is 7 years (Jorgenson and Vu, 2005). We have done the same exercise for 3 and 5 years of durability and the result favor developing countries, but do not change the general tendency of the argument. We have not found a trustworthy source that would favor a three or five years assumption, reason why we stay with the economic depreciation rates presented in (Jorgenson and Vu, 2005). In this sense it is supposed that each additional computer remains 7 years at the performance of its first year and will then disappear from the count, being replaced with an up-to-date model.

Mobile phones for computation

Mobile phones penetration rates are taken from (ITU, 2007). The MIPS for the processors of mobile phones (Dhrystone method) are extracted from CDG (CDMA Development Group), and are presented in Table A10. According to Nordhaus (2002, 2006), Dhrystone MIPS, which are harmonized on the VAX 11/780, are equal to his own unit of measure MCps (millions computations per second). A durability of 3 years per mobile phone is considered for GSM and GRPS, EDGE (Helsingin Sanomat, 2000).

Tabla A10
Mobile phone processors performance

Technology	Generation	MCPS = MIPS
GSM	2G	15

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for example, that is if you can add two five-digit numbers in 7 seconds and multiply two five-digit numbers in 80 seconds, is identified by Nordhaus to be 150,000,000 times slower than the VAX 11/780.

cdmaOne	2G	15
PDC	2G	15
GPRS	2.5G	23
EDGE	2.5G	160
CDMA2000 1x	3G	160
WCDMA (3GSM)	3G	495
CDMA2000 1xEV-DO	3G	495

Sources: own elaboration, based on Belk, Jeffrey, 2007.

References Appendix

3G Americas (2006). *Mobile* Broadband: EDGE, *HSPA & LTE.* http://www.3gamericas.org/PDFs/white_papers/Rysavy_EDGE_HSPA_LTE_2006.pdf

3G Americas (2008). *Global UMTS and HSPA Operator Status.* http://www.3gamericas.org/pdfs/Global_3G_Status_Update.pdf

Benoit, Hervé (2008). *Digital Television: Satellite, Cable, Terrestrial, IPTV, Mobile TV in the DVB Framework.* Focal Press, 3rd Ed.

Belk, Jeffrey K. (2007). *CDMA2000: Insight into the Future of 3G Devices and Services*. CDG Webcast. http://www.cdg.org/news/events/webcast/070228_webcast/Qualcomm.pdf

Cable News Networks (1998), “Europe's first ADSL service launches”. http://www.cnn.com/TECH/computing/9812/10/euradsl.idg/

CDG (2008a). *CDMA2000: Market Facts.* http://www.cdg.org/technology/3g/resource/CDMA2000%20Market%20Facts.pdf

CDG (2008b). *4Q 2007 Subscribers Statistics.* CDMA Development Group, http://www.cdg.org/worldwide/cdma_world_subscriber.asp

CITEL (Comisión Interamericana de Telecomunicaciones, Organización de los Estados Americanos) (2007), “Boletín electrónico, Número 31”, Enero 2007. http://www.citel.oas.org/newsletter/2007/enero/gsm_e.asp

DVB (Digital Video Broadcasting, 2008), DVB Worldwide: http://www.dvb.org/about_dvb/dvb_worldwide/index.xml

ETSI (European Standard Telecommunications Series, 1997). *ETSI EN 300 748 V1.1:2 Digital Video Broadcasting (DVB); Multipoint Video Distribution System (MVDS) at 10 GHz and Above.* Based on ETS 300 421 DVB-S. EBU-UER. http://broadcasting.ru/pdf-standard-specifications/transmission/dvb-ms/en300748-v1-1-2.pdf

ETSI (European Standard Telecommunications Series, 2004). *ETSI EN 300 744 V1.5.1: Digital Video Broadcasting (DVB); Framing Structure, Channel Coding and Modulation for Digital Terrestrial Television.* EBU-UER. http://broadcasting.ru/pdf-standard-specifications/transmission/dvb-t/den300744.v1.5.1.oap20041029_040630-041029.pdf

FHTE (Fachhochschule für Technik Esslingen) (2001), The FHTE Web History of Telecommunications“, http://www2.hs-esslingen.de/telehistory/1975-.html

Freeman, Roger L. (2005). *Fundamentals of Telecommunications.* Wiley-Interscience (IEEE), 2nd Ed., p. 327.GSM World (2007a). *Growth of the Global Digital Mobile Market (1992 – 2004),* http://www.gsmworld.com/news/statistics/pdf/gsma_stats_q4_04.pdf

Grochowski Ed, 2007, "IBM HDD Evolution", http://www.pcguide.com/ref/hdd/hist-c.html

GSM World (2007b). *GSM Subscriber Statistics (2002 – 2004).* http://www.gsmworld.com/news/statistics/pdf/gsma_stats_q4_05.pdf

GSM World (2008). *GPRS Class Type.* http://www.gsmworld.com/technology/gprs/class.shtml

Helsingin Sanomat (2000). "*Continued Growth in Mobile Phone Sales",* Business & Finance – International Edition, 2000. http://www2.hs.fi/english/archive/news.asp?id=20000710xx5

Hitachi Global Storage Technologies, 2007, http://www.hitachigst.com/hdd/hddpdf/tech/chart01.pdf

Ibrahim, K. (2007). *Newnes Guide to Television & Video Technology*. Elsevier, 4th Ed.

ITU (International Telecommunications Union, 1988). *G.711: Pulse Code Modulation (PCM) of Voice Frequencies.* http://www.itu.int/rec/T-REC-G.711-198811-I/en

ITU (2007), "Internationals Telecommunication Union World Telecommunications database, including definitions", http://www.itu.int/ITU-D/ict/material/IndDef_s_v2007.pdf

ITU (International Telecommunications Union, 2008). *About Mobile Technology and IMT-2000.* http://www.itu.int/osg/spu/imt-2000/technology.html#Cellular%20Standards%20for%201G%20and%202G

Jorgenson, Dale and Khuong Vu, 2005, "Information Technology and the World Economy", http://www.frbsf.org/economics/conferences/0511/6_ITAndWorldEconomy.pdf

MacCallum, John (2007), "CPU Price Performance 1944-2003 - John McCallum", http://www.jcmit.com/cpu-performance.htm

Mobile-technology.com (2007). *PDC (Personal Digital Cellular) Telephone Technology*. http://www.mobilecomms-technology.com/projects/pdc/

Morgan Stanley (2006). *Q1 2006 Global Technology Data Book*. http://www.morganstanley.com/institutional/techresearch/pdfs/global_techdatabook0306.pdf

Motorola Media Center (2002), "Motorola Sets Another Broadband-Industry Milestone with Landmark 10 Millionth Cable Modem Shipment", http://www.motorola.com/mediacenter/news/

Moulton, Pete (2001). *Telecommunication Survival Guide.* Prentice Hall, p. 367, 377, 593, 603, 608.

Porter Jim, 1998, "Disk Drives´ Evolution Five decades of disk drive industry firsts, 1998", http://www.disktrend.com

Nordhaus , William D. 2002, "The Progess of Computing", Yale University, http://nordhaus.econ.yale.edu/

Nordhaus , William D. 2002, "An Economic History of Computing", Yale University, http://nordhaus.econ.yale.edu/ .

R.C.O. Componentes electrónicos (2007), "Sistemas de Televisión en el Mundo", http://www.rco.es/utilidades/sistemas%20de%20television.htm

Schmidt, Glen M. (2005), Seagate - Quantum: Encroachment Strategies Case Article, http://ite.pubs.informs.org/Vol5No2/SchmidtVanMieghem/index.php

Steele, Raymond; Lee, Chin-Chun & Gould, Meter (2001). *GSM, cdmaOne and 3G Systems.* John Wiley & Sons.

TigerDirect.com (2007), "PAL, NTSC or SECAM", http://www.tigerdirect.com/static/html/pal-ntsc-secam.html

ZDNet.co.uk (2007), "GPRS: A timeline", http://news.zdnet.co.uk/hardware/0,1000000091,2080038,00.htm