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Mapping the dimensions and characteristics of the world's technological communication capacity during the period of digitization (1986 - 2007/2010)

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Abstract— **This article analyzes the nature and characteristics of the world's technological capacity to communicate information in bits per second during the two decades that were characterized by the digitization of global information flows (1986 to 2007/2010). We distinguish between 12 broadcasting and 31 telecommunication technologies. Television still accounts for 95 % of the effective information flow in 2007. This also implies that most of the world's technologically mediated information (99 %) is carried through downstream channels, while upstream communication is still marginal (even though rapidly growing). We show that technological progress is the main driver behind the world's telecommunication capacity and that the contribution of the installation of new infrastructure is becoming less significant to the total growth of global communication. From an international perspective it is striking that the shape and form of the digital divide measured in kbps per capita turns out to be quite different from the evolutionary trajectory of the digital divide when measured in terms of technological devices per capita. While the average inhabitant of the developed world counted with some 40 kbps more than the average member of the information society in developing countries in 2001, this gap grew to over 3 Mbps per capita in 2010. It shows that telecommunication capacity (in kbps) is highly concentrated on the international level. Only eight countries host two-thirds of the installed global telecommunication capacity. All of this shows that it is pivotal to start measuring the world's communication capacity not merely in terms of the installed number of devices, but also in terms of the transmitted amount of information.**

November, 2012

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I. THE LACK OF INFORMATION ABOUT THE AMOUNT OF INFORMATION IN THE INFORMATION SOCIETY

MORE than a quarter of a century ago, Beniger (1986) already enlisted dozens of works that took a macro-outlook on the social transformations provoked by the massive introduction of computer-mediated communication. Since these early days, the resulting form of social organization has been given many names, including the "Computerized Society" (Martin and Norman, 1970), "Information Revolution" (Lamberton, 1974), "Electronics Revolution" (Evans, 1977), the "Information Economy" (Porat, 1977), the "Microelectronics Revolution" (Forester, 1980), "Information Technology Revolution" (Forester, 1985), "Network Society" (Castells, 2009), "age of Information and Communication Technology" (Freeman and Louça, 2002), "Information Age" (Jorgenson, 2005; Castells, 2009; Brynjolfsson and Saunders, 2010), and "Information Society" (Masuda, 1980; Martin and Butler, 1981, Miles, 1988, Webster, 2006; Mansell, 2009). This last term has stuck with many and even started to dominate the global political agenda. Between 2003 and 2005 the highest possible political level of the world gathered to discuss the social, political, economic and cultural implications of this revolution during the "World Summit on the Information Society"[1]. Despite all the attention that is being paid to the issue, there is ample disagreement on how to approach it conceptually and where to put the emphasis. Entire books have been written on methodological differences to analyze the information society (Lyon, 1991; Duff, Craig and McNeill, 1996; Duff, 2000).

One of the most fundamental decisions regards the quantification of the "information society". Finding the right indicator is one of the essential components of the scientific endeavor. In the words of Lord Kelvin: "when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the state of Science, whatever the matter may be" (quoted from Bartlett, 1968, p: 723a). Until now, researchers usually satisfy themselves with the use of proxies for the amount of information and communication in the so-called information society, which is approximated by measuring the number of technological devices (number of phones, computers, Internet subscriptions, etc.), or the related spending and investments. Rather surprisingly, few studies have yet attempted to quantify the amount of communicated information directly. Reminiscent of the famous drunk who is looking for the lost keys under a well-lit lamppost far away from the dark site where the keys were dropped, analysts have been content with these rough approximations for the informational capacity of a society simply because they were readily available (in the case of infrastructure indicators thanks to a sustained and unique effort by the members of ITU, who provide these statistics in a regular fashion, see ITU, 2011). In this article we will see that there is a decisive difference between the number of devices and the amount of communicated information in society.

A. *Context, background, and overview*

There are some pioneering studies that have used telecommunications traffic as their key variable. This has led to interesting new insights, but those projects usually only focus on one single technology, such as Internet traffic (George, Chon and Rosen, 2001) or fixed-line telephony traffic (Monge and Matei, 2004; Seungyoon, et al., 2007). Several government agencies, sometimes in collaboration with the private sector, have also started to measure Internet traffic and fixed broadband quality in particular (among others, MIC, 2007; Rep. of Korea, 2007; NZ Commerce, 2009; Ofcom, 2010; FCC, 2011). Only a handful of groundbreaking studies have started to directly quantify the overall amount of information communicated through different networks (Ito, 1981; Pool, 1983; Neuman, Park and Panek, 2009; Lyman and Varian,

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[1] A World Summit is a gathering of all acting Head of States or government. The World Summit on the Information Society (WSIS) was held in two phases. The first phase took place in Geneva, Switzerland, from 10 to 12 December 2003, and the second phase took place in Tunis, Tunisia, from 16 to 18 November 2005, both in collaboration with the International Telecommunication Union of the United Nations (ITU): http://www.itu.int/wsis

2000; 2003; Gantz, et al., 2008; Bohn and Short, 2009; Cisco Systems, 2011; Hilbert and López, 2011; for a discussion of these different approaches, see Hilbert and López, forthcoming a, b).

Based on the methodology presented in the most comprehensive of these exercises (Hilbert and López, 2011), we take a closer look at the informational capacity of the most prominent 10 analog and 33 digital kinds of communication technologies in this article. We track the effective capacity of the most common unidirectional (one-way) broadcast technologies (over-the-air terrestrial, cable, and satellite TV, as well as radio, each analog and digital; paper-based newspaper and advertising, and GPS personal navigation devices)[2]; and take inventory of the most prominent bidirectional (two-way) telecommunication devices (fixed-line and mobile telephony, both analog and digital; fixed-line Internet and mobile data services, and postal letters).

We start with presenting the applied methodology in Section (II). The time-limited reader is invited to skim this (rather technical, but fundamental) section during the first read of this article, and jump ahead to the later sections that present empirical results. In the first empirical section (III) we compare the effective capacities of unidirectional broadcasting versus bidirectional telecommunications. We analyze the evolution of the world's communication upstream and downstream capacities. In Section (IV) we exclusively focus on telecommunication. We measure the contributions of the different telecommunications technologies to the world's installed telecommunication capacity, identify the drivers behind the increase of this capacity, and have a fist look at the international distribution among countries. We measure the digital divide not merely in terms of the number of devices, but in terms of kbps per capita. The final Section (V) summarizes our findings and underlines that it does it leads to interesting and important insights to measure the world's communication capacity directly, in bits per second. It is proposed to start a coherent effort that will allow to register and to track the global evolution and distribution of the installed (and possibly effectively used) communication bandwidth.

II. METHODOLOGY: HOW TO MEASURE THE AMOUNT OF COMMUNICATION?

We work with two different measures of capacity:

- The **installed capacity** refers to the bandwidth installed from an end-user perspective (we also refer to this measure as "installed bandwidth potential"). We basically take the installed number of devices at a given point in time, multiply them with their communicational performance (the average bandwidth in bits per second), and sum up the result:

  $$\text{Communication Capacity} = \sum_{over\ all\ t_k} ([\text{number of devices } t_k] * [\text{performance per device } t_k])$$

  We sum the total broadcast capacity over 4 different groups of technologies *t* (TV, radio, GPS, and radio), for which we measure 12 different kinds of technologies *k* (e.g. terrestrial over-the-air TV and cable TV, etc.) (see Table 1). For the case of telecommunication we include 5 different groups of technologies *t* (fixed pone, mobile phone, fixed Internet, mobile data, postal), for which we distinguish among 31 distinct kinds of technologies *k* (e.g. dial-up and DSL Internet; GSM and WCDMA mobile, etc.) (see Table 1).
- The **effective capacity** tracks those bits that are effectively communicated through the installed capacity. This considers the fact that no all devices run all the time and only quantifies the number of bits effectively transmitted. In this case we multiply the installed capacity (which is usually measured in bits per second) by the number of minutes per year that each device is actually communicating information.

In both cases, we define the technological capacity to communicate as the amount of information that is transmitted over a considerable distance (outside the local area). This includes those transmissions whose main purpose consists in the overcoming of distances, not the local sharing of information (such as the

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[2] We make one exception in our distinction between one-way broadcasting and two-way telecommunications. Technically, digital television counts with an upstream link and could therefore be classified as a telecommunication device. However, this upstream link is very small in comparison to the downstream link (roughly the bandwidth of 2G short-messaging-service) and has only been used very sporadically by users until the year 2007 (mainly for some selected video-on-demand applications, which were very poorly developed until 2007). We therefore decided to count digital TV as part of the broadcasting capacity.

distribution of copies at a meeting, the carrying from a book from one room to another, or communication through private local area networks)[3].

A. Unit of measurement

Our variable of choice for communication performance is optimally compressed bits per second. This is not the only possible measurement unit to quantify information flows. During the 1980s researchers used the amount of words as the unifying variable to quantify communication (Ito, 1981; Pool, 1983; Pool, et al., 1984). Others use time-budget studies and quantify communication intensities in terms of minutes (Neuman, Park and Panek, 2009). For the larger public it turns out to be intuitive to quantify the amount of communication in terms of a commonly used information good, such as in terms of the informational equivalent of numbers of newspaper pages (see Hilbert, 2011a). One could even employ some measure of the amount of cognitive chunks or ideas if desired (e.g. Miller, 1956). The digital revolution suggested that the numbers of 0s and 1s that are transmitted by the communication hardware seem to be a natural measurement unit for information (Lyman and Varian, 2000; 2003; Gantz, et al., 2008; Bohn and Short, 2009; for a discussion of these different approaches, see Hilbert and López, forthcoming a, b).

The problem with those measures is that it is often not clear how to justifiably quantify different kinds of information content (e.g. when measuring the equivalent of "number of words", how to quantify a picture?), and that their magnitude is often quite arbitrarily defined. In order to illustrate the benefit of our indicator of choice in comparison of other alternative indicators, let us take a closer look at a concrete example.

B. An illustrative example: how much information does a phone communicate?

The amount of information that is communicated by a phone is often quantified by the number of 1s and 0s transmitted by the respective hardware (cable or wireless spectrum). We will refer to this measure as "binary digits", in order to distinguish it from our measure, which we refer to as "optimally compressed bits". A fixed line telephone subscription has a hardware performance of 64 kbps (measured in binary digits), while a mobile phone subscription transmits less than 10 kbps (some 8.5 kbps). These numbers imply that a fixed-line voice telephone has more than 7 times more capacity than a mobile voice telephone (e.g. see Bohn and Short, 2009, p. 32; also Hilbert, Lopez and Vasquez, 2010; both measure hardware capacity). But is this really the case? Does this actually provide a meaningful measure of communication capacity? Is the communication through a mobile phone merely 15 % of the capacity as a fixed-line phone? In terms of information quality, there is surely a difference between fixed and mobile phones, but does one fixed-line transmit as much information as 7 mobile phones? What are we measuring here?

In reality, voice content is much more compressed in mobile telephony than in fixed line telephony. The 8.5 kbps of voice transmission in a GSM-AMR 2G mobile phone is compressed from an original encoding of 128 uncompressed kbps. This rate of compression is what enables mobile transmission to begin with. Otherwise, it would have too many symbols for effective mobile communication. On the other hand, the 64 kbps carried by a digital fixed-line telephone is also compressed, down to only 57 % of its original content of 112 kbps (with Law-A, which is used in Europe for example, see recommendation G.711 of ITU-T). Compressing it to 64 kbps means to take part of the redundancy out. However, this level of compression is quite arbitrary and is rather dictated by what students of technology call "historical accidents" (David, 1985), "path dependence" (Arthur, 1994), "dominant design" (Utterback, 1996), or "lock-in" on a given standard (Shapiro and Varian, 1998). For example, using another (more efficient) compression algorithm like Speech Profile of MPEG-4 instead of using Law-A, the same information content of a fixed-line phone can be compressed down to some 12 kbps without loss of quality. According to the algorithms that are currently available, this is the optimal compression rate for voice with an adequate quality (mean opinion

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[3] This definition differs from the definition of Lyman and Varian (2000; 2003), who focus on the amount of uniquely created bits flowing through technological networks, and the one of Bohn and Short (2009), who focus on effective media consumption, independently if it is retrieved from a storage device or if the information has been communicated over some distance (for more on these distinctions, see Hilbert and López, forthcoming a, b).

score MOS quality between 3.6 and 4.1).

Normalized on the optimal compression rate, it turns out that a digital fixed-line telephone transmits an average of 12 kbps (not 64 kbps), while a mobile phone transmits around 8 kbps. These values represent the amount of information that is transmitted, independent on the (more or less redundant) amount of symbols (data) that is transmitted. We can now finally appreciate that in reality a digital fixed line phone transmits roughly 50 % more information than a 2G mobile phone (12/8), or the other way around, that a 2G GSM-AMR mobile phone reaches two-thirds of the information richness of a fixed-line phone (8/12). This also makes intuitively much more sense than the previous result.

C. From hardware with redundant data, to optimally compressed information

We achieved this much more intuitive result by normalizing on compression rates. More precisely: we normalized in the uttermost level of compression that maintains high quality (we call this measure “optimal compression”). The uttermost possible compression rate approaches the entropy of the source. To understand this logic, let us take a paragraph and return to the ideas of the intellectual father of the digital age, Claude Shannon.

Shannon (1948) proposed the entropic bit as the natural unit of measurement of information. Shannon started by defining information as the opposite of uncertainty, which makes intuitively sense: when we have uncertainty, we do not have information, and when we receive information, uncertainty is being resolved (per definition). In an information theoretic sense, communication is defined as the process of resolving uncertainty on the syntactic level, and the amount of uncertainty resolved, is measured in bits (this is the core idea of “information theory”, as commonly taught in Electrical Engineering Departments; see Pierce, 1980; Massey, 1998; Cover and Thomas, 2006)[4]. What compression does is that it “takes out” all those binary digit symbols that are “redundant”, and do not really reduce uncertainty, and therefore, do not transmit information. Those symbols often make part of a message, but they are not needed to communicate the information contained in the message. This is the reason why it is possible to reduce a phone conversation from 128 binary digits per second, to some 10 optimally compressed bits per second, without loss of information. Taking out all redundant symbols reduces a number of binary digits of 1s and 0s, into the (so-called) “entropy of the source”.

For our purposes—in contrary to arbitrarily compressed binary digit of hardware capacity—the methodological benefit of Shannon’s measure is that it is a unique number that can unambiguously be assigned to some kind of message. Shannon (1948) proved that there is a unique optimal level of compression for a certain message, beyond which content cannot be compressed without loss of information (which he called “entropy”). He showed that—independent of its content or meaning—the amount of bits depends purely on the probabilistic nature of the source. Shannon defined that when the receiver receives one (binary) bit, uncertainty between the sender and receiver is reduced by half (with respect to an established probability space). It is important to reiterate that this does not depend on the number of symbols or signals received. In other words, one symbol can resolve different amounts of uncertainty, depending how crucial (or redundant) it is to the message. The sending of one symbol (such as a 0 or a 1) must not necessarily resolve any uncertainty (in this case the symbol is “redundant”), or it can reduce uncertainty, in which case it contains information (by Shannon’s definition).

In a nutshell, one optimally compressed bit (“entropy” in Shannon’s sense) differs from one binary hardware digit (in the sense of a symbol that represents a 0 or 1). Shannon’s measure refers to the amount of information (the amount of uncertainty resolved) and the other measure to the hardware capacity of the technology. Confusingly, both are sometime referred to as “bits” (Laplante, 2000). The hardware capacity of a technology accounts for the number of binary symbols that can be represented by this technology (for example the presence [1] or absence [0] of an electric current, an optical light, a magnetic field or a dot on a paper). The amount of uncertainty that can be resolved by one binary

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[4] Massey’s (1998) lecture notes are publicly available (see URL-link in references). They might be an easier read than the more complete work of Cover and Thomas (2006), which has become the standard textbook on Information Theory in Engineering Departments. For a light introduction and general overview of concepts, see Pierce (1980).

digit depends on the level of compression. Compression essentially eliminates the redundancy of the information and leaves us with plain information: the part of the messages that actually reduces uncertainty (i.e. uncertainty related to the syntactic level). As proven by Shannon in 1948, at its outermost level of maximal compression, the number of bits in a message approximates its entropy: the number of times uncertainty gets reduced by half (for more on information theory see Pierce, 1980; Massey, 1998; Cover and Thomas, 2006;[4] for more on the nature and role of information and entropy see Zurek, 1990). Let us have a look at another illustrative example to see how these theoretical arguments matter in practice and how to apply them to real-world statistics

D. Another illustrative example: how compression increases communication capacity

As shown in Figure 1, let us suppose the existence of one communication (or storage) device with a hardware capacity of two physical representations (e.g. two communication transmission "cables" or "wireless spectra") in year$_1$. Half of the information content consists of images and the other half of text. This matters because the achievable level of compression differs from source to source, but most notably among different kinds of content. Video is usually the most redundant form of content (containing both, redundancy in space and in time), which means that video can be compressed more than text, images or audio. For example, using the common compression algorithm ZIP, one can compress a text archive down to 20 % of its uncompressed size (compression factor of 1:5), while MPEG-4 can compress a video file to less than 2 % of its original size (compression factor of 1:60).

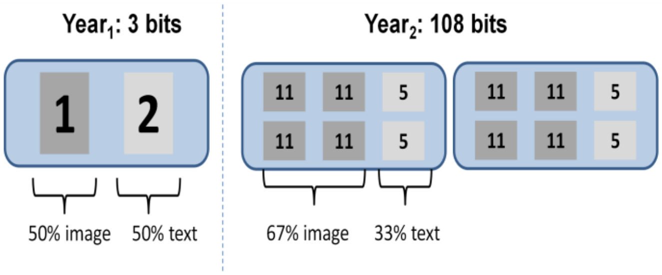

Fig. 1. Inside the black box of digital technological progress to communicate information.

In our example from Figure 1 we assume that images are not compressed (such as industrial x-rays or detailed maps) and that text is already compressed by a factor of 2:1 (for example with the Lempel–Ziv–Welch algorithm used in early UNIX systems in the 1980s). This implies a technological capacity to communicate 3 bits in year$_1$.

In year$_2$, investment in infrastructure leads to a duplication of the number of devices and technological progress in hardware leads to a triplication of communication units per device (e.g. through "more powerful cables" or "spectrum usage"). Additionally, we suppose that images are now compressed with JPEG (the norm in personal and industrial image handling nowadays), achieving a high-quality compression factor of 11:1, while text is compressed with ZIP or RAR, reaching a factor of 5:1. This enables to communicate (or store) a total of 108 bits in year$_2$.

The result is a multiplication of the initial amount of information by a factor of 36 (108/3, or a growth factor of 3600 %). This total of technological change can be traced back to a duplication of infrastructure (growth factor of 2), a triplication of hardware performance (growth factor of 3), and a sextuplication of the software performance for content compression (growth factor of 6), providing[5]: $2 * 3 * 6 = 36$ (overall growth factor from 3 to 108 bits). If we would not consider compression rates, we would neglect the fact that we can now send much more information through the same hardware infrastructure than in the past. Normalization on compression rates (measured in "optimally compressed bits") includes this driver of the growth of communication capacity. The example of Figure 1 visualizes that the growth of the installed communication capacity is the result of three factors: more technology, better hardware, and better software compression algorithms.

In practice, the contribution of ever more powerful compression algorithms for digital content (software performance) can either be calculated as a weighted average of the progress of compression of each kind of

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[5] In practice, the contribution of content compression is a combination of the advancement in compression algorithms (software performance) and the general shifts in the kind of content. If more compressible content gains importance, the average technological progress of content compression will increase.

content, or as a residuum[6]. The later alternative is more straightforward.

E. *The Evolution of Compression Rates*

Unfortunately, there are few sources that report the content of communication networks, and even less sources that allow us to estimate the most commonly used compression algorithms. Therefore we restrict our assessment of content and the applied compression rates to the years 1986, 1993, 2000, 2007 and 2010, and interpolate linearly between the content and respective compression rates of those years to obtain compression normalization rates for the intermediate years.

Figure 2 presents the resulting compression normalization factors for the content of the Internet, i.e. the number of binary digits that can be communicated through the installed hardware capacity (hardware "bandwidth"), divided by the optimally compressed number of bits communicated through this infrastructure. The higher the ratio, the larger the difference between the required hardware and the effective information communicated by this hardware capacity. A ratio of 1 implies that all information is optimally compressed.

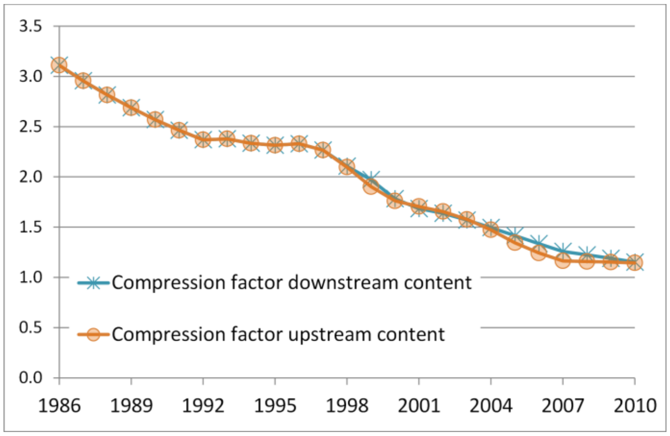

Fig. 2. Average compression factors for Internet content: ratio of [hardware capacity (binary digits)] / [optimally compressed capacity (entropic bits)], for upstream and downstream content.

Normalized on the most efficient compression algorithms currently known, Figure 2 shows that compression algorithms have become roughly three times more effective during the last two decades. For example, in 1986, the Lempel-Ziv-Welch LZW algorithm was the standard in UNIX systems. It was able to compress text by a factor of 1:2.2 (Welch, 1984). In 2007, a compression algorithm called DURILCA was able to achieve average compression rates of 1:6.6 (Mahoney, 2009). This implies an improvement by a factor of 3 (LZW:DURILCA = 6.6:2.2). In other words, thanks to compression algorithms, we communicate around three times more information through the same installed infrastructure as we did in 1986 . Since the type of content differs between upstream and downstream communication (Sandvine, 2008), the Figure 2 shows distinct compression factors for each kind of traffic[7].

Summing up, it would be deceiving if we would measure the amount of symbols (like the number of 1s and 0s) that are sent around the world. The power of the digital revolution has to be explained in terms of more symbols that are exchanged and by the fact that—normalized to the past—we each of them carries more and more information, which is extracted by encoding and decoding machines at both ends of the communication channel (note that there is no contribution of compression rates for analog information, since analog information cannot be compressed, reason why we consider analog content as "uncompressed"). In this sense, it is important to remember that the digital communication revolution would not be possible without the parallel development of a computational revolution, which enables us to en- and decode information, therefore enabling compression.

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[6] In the given example, the option of the residuum is straightforward: [108/3] / 2 / 3 = 6. More error-prone, but not less correct, is the calculation by way of expected value: Year_1: 1/2 of hardware contains image, 1/2 of hardware contains text; Year_2: 2/3 of hardware contains image, 1/3 of hardware contains text. This means that 1/2 of the hardware stays as image (equal to 1 hardware unit of Year_1), 1/6 of the hardware is converted from text to image (equal to 2/6 hardware units of Year_1) and 1/3 of the hardware stays text (equal to 2/3 hardware units of Year_1). Expressed in bits of Year_1, this is equal to 1 bit staying image (of 1/3 of the bits of Year_1), 4/6 bits being converted from text to image (or 2/9 of the bits of Year_1) and 4/3 bits staying images (or 4/9 of the bits of Year_1). These are the right weights to apply to calculate the weighted average of the contribution of compression: 1/3*(11/1) + 2/9*(11/2) + 4/9*(5/2) = 6.

[7] Content also differs between countries, most notably are distinct user profiles in developed and developing countries. We therefore distinguish between compression rates for the member countries of the OECD, and non-OECD.

F. Technological Performance of Communication Technologies

Table 1 shows the average performance transmission rates per device or subscription for the included 12 broadcasting technologies and 31 telecommunication technologies in (arbitrarily compressed) hardware capacities, and in optimally compressed information capacities (with normalized compression rates). The table shows clearly that the conventional hardware bandwidth rates, which are typically reported by equipment producers and network operators, are quite arbitrary. The amount of information transmitted through a given bandwidth depends on the applied level of compression of the message (compare our previous example for fixed- and mobile telephony with the bandwidths in Table 1). Therefore, we use the rightmost column of Table 1 for our purposes (of course, performances change every year, and Table 1 merely presents the rates for the year 2007).

TABLE I
AVERAGE PERFORMANCE RATES PER DEVICE OR SUBSCRIPTION RESULTING FROM OUR INVENTORY OF THE INSTALLED CAPACITY IN 2007 (KBPS) (*ITALICS: DIGITAL*).

Category	**Technology**	**Hardware bandwidth** (in kilo-binary-digits per second) **Downstream/ Upstream**	**Informational capacity** (in optimally compressed kilobits per second) **Downstream/ Upstream**
Telecommunications (bidirectional)			
Fixed-line telephony	Fixed-line phone analog	104 / 104	8.6 / 8.6
	Fixed-line phone digital	64 / 64	12 / 12
Fixed-line Internet (wireline and wireless)++	*Dial-up*	56 / 48	44 / 38
	ISDN BRI	128 / 128	102 / 102
	ISDN PRI	1,935 / 1,935	1,539 / 1,539
	Cable Modem	6,563 / 1,009	5,219 / 802
	DSL	2,286 / 654	1,817 / 519
	FTTH/B	18,696 / 4,917	14,873 / 3,912
	Other/unidentified	947 / 897	748 / 709
Voice mobile telephony	Analog (1G)	102 / 102	6.4 / 6.4
	GSM (2G)	8.5 / 8.5	8.0 / 8.0
	cdmaOne (2G)	13 / 13	4.0 / 4.0
	PDC (2G)	6.7 / 6.7	6.5 / 6.5
	TDMA (2G)	8.0 / 8.0	4.0 / 4.0
	iDEN (2G)	4.0 / 4.0	4.0 / 4.0
	GSM/GPRS (2.5 G)	8.5 / 8.5	8.0 / 8.0
	GSM/EDGE (2.5 G)	8.5 / 8.5	8.0 / 8.0
	CDMA2000 1x (3G)	8.6 / 8.6	5.6 / 5.6
	WCDMA / UMTS (3G)	15 / 15	11 / 11
	CDMA2000 1xEV-DO(3G)	13 / 13	12 / 12
Data mobile telephony	*GSM (2G)*	14 / 14	11 / 10
	cdmaOne (2G)	19 / 14	15 / 5
	PDC (2G)	29 / 29	22 / 20
	TDMA (2G)	10 / 10	7.4 / 6.7
	iDEN (2G)	19 / 19	15 / 13
	GSM/GPRS (2.5 G)	46 / 14	35 / 10
	GSM/EDGE (2.5 G)	100 / 42	77 / 29
	CDMA2000 1x (3G)	80 / 80	61 / 55
	WCDMA / UMTS (3G)	350 / 350	268 / 243
	CDMA2000 1xEV-DO (3G)	500 / 80	383 / 55
Postal	Postal letters^	0.000013 / 0.000013	0.000002 / 0.000002
Broadcasting (unidirectional)			
Postal	Paper Newspapers^	0.015 / 0	0.0016 / 0
	Paper advertisement^	0.00025 / 0	0.00003 / 0
Radio	Radio analog	706 / 0	35 / 0
	Radio digital	192 / 0	71 / 0
GPS	*Personal navigation device*	0.46 / 0	0.23 / 0
Television	TV-Terrestrial analog (black & white)	59,921 / 0	1,010 / 0
	TV-Terrestrial analog (color)*	87,849 / 0	1,487 / 0
	TV-Cable analog*	87,255 / 0	1,477 / 0
	TV-Satellite analog	90,560 / 0	1,533 / 0
	*TV-digital (x3):** Terrestrial / Cable / Satellite*	4,256 / 15	2,144 / 11

Notes: ^Paper based communication devices are presented in “weekday units”, which means that we assume that they are only delivered on the 261 weekdays of a year5. *The average performance of analog terrestrial TV is higher than the average performance of analog cable TV because there are proportionally more cable TV subscription in the U.S. and Japan (where NTSC is the standard), and NTSC has a lower performance than PAL/SECAM. ++The difference between fixed-line telecom (wireline or wireless, like WiFi) and mobile telecom is that the last one does not loose connectivity when the user is moving from one source of connectivity to another (with fixed-line connectivity the user has to reestablish connectivity once the source changes). ** See footnote 2.

III. BROADCASTING VERSUS TELECOM: HOW MUCH DOES EACH COMMUNICATE?

We start our empirical analysis with a general outlook on the magnitudes of the world's technological communication capacity for the period between 1986 and 2007. In this section we focus on the effective, not merely the installed communication capacity (only those bits that are effectively transmitted). We review four basic questions: how many broadcasting and how many telecommunication devices are installed in the world? How much information is effectively communicated by broadcasting and how much by telecommunication technologies? How much of technologically mediated communication takes place through analog and how much through digital networks? How much of the effective communication capacity consists of upstream and how much of downstream?

A. Communication Infrastructure

Our first step consists in the traditional presentation of the global stock of installed communication devices. Figure 3 presents the most prominent technological families and their contribution to the global communication technology stock for the years 1986, 1993, 2000 and 2007. The number of communication devices almost tripled during these two decades (from 4.3 million devices, to 12.8 million). The figures reveal that in 1986, 99 % of all installed communication devices were still processing information in analog format. This analog dominance was gradually replaced, especially around the year 2000. By 2007 the majority of communication devices are digital (51 %). In 1986 (Figure 2a), by far the dominating communication apparatus was the radio, presenting 40 % of the global stock (1.7 million devices), while paper-based communication was the second most widely used solution (1.5 million weekday units of newspaper, advertisement and postal letters, or 34 % of 1986). While the share of television sets and fixed-line telephony stayed pretty constant during the period (around 20 % and 10 % respectively), the share of radio and paper-based solution declined considerably (to 23% and 13 % respectively). In 2007, the largest share of the pie was captured by mobile phones (26 %), while Internet subscriptions represent less than 5 % of the worldwide stock of communication infrastructure.

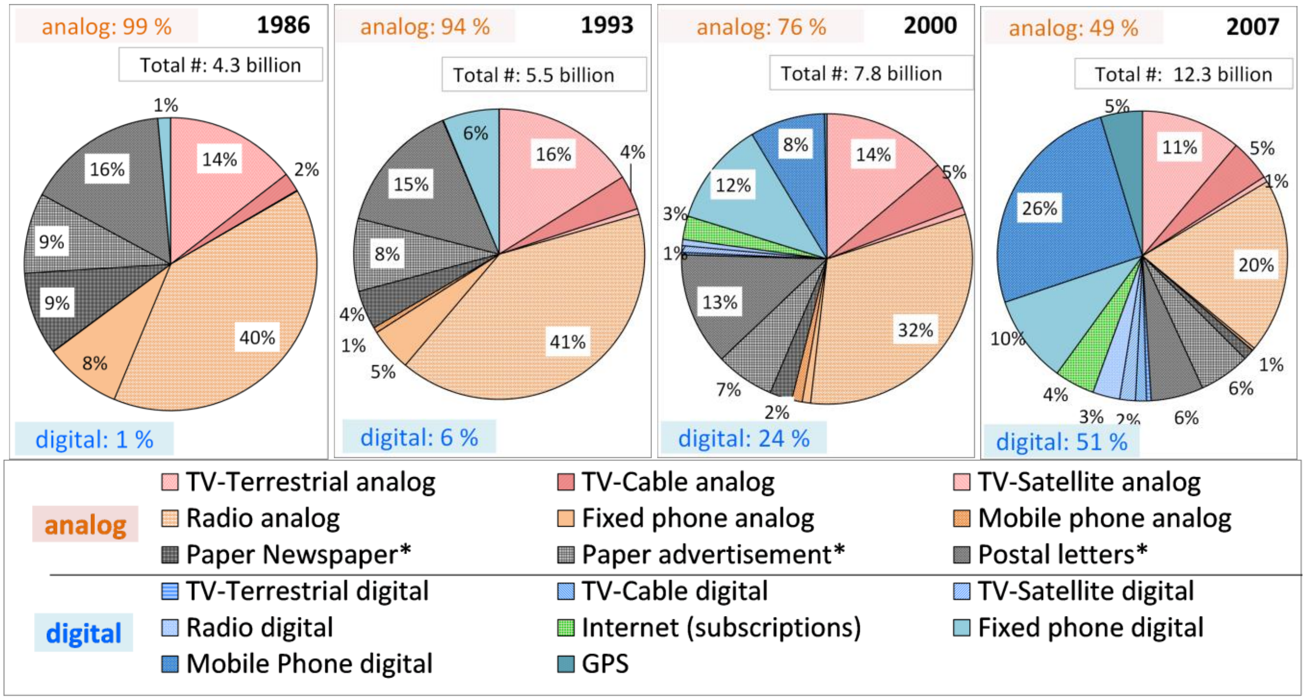

Fig. 3. Communication technology infrastructure, in numbers of devices for (a) 1986, (b) 1993, (c) 2000 and (d) 2007. Note: * Paper-based solutions are measured in "weekday units", which means that the annual total is divided by 261 weekdays, being equivalent to a "paper-based tablet which gets reloaded every weekday".

B. *Communication capacity*

We now proceed with the estimation of the effective communication capacity of this global stock of infrastructure. We obtain the effective usage times from time budget and media consumption studies for the years 1986, 1993, 2000, and 2007 and interpolate linearly between those years.

During the last two decades, the global communication capacity was multiplied by a factor of 4.5, growing from 432 exabytes (EB) to almost 2 zettabytes. This implies that the average person communicated 240 MB per day in 1986 (the informational equivalent of about 55 newspapers), 350 MB per day in 1993, 520 MB der day in 2000 and some 800 MB per day in 2007 (equal to roughly 180 newspapers per person per day) (compare Hilbert, 2011a).

Figure 4 shows that television has and still is dominating the global flow of information. Measured in optimally compressed bits of effective transmission, television constantly presents 93 % and 96 %. Analog over-the-air terrestrial TV still dominates (79 % in 1986 and 49 % in 2007), but is gradually being replaced by cable and satellite technology, as well as by digital TV.

In 1986, 7 % of all bits communicated were transmitted by radio and only 2 % in 2007. The communication capacity of paper-based communication is minuscular: letters, newspapers and paper-based advisement contribute less than 0.1 % in 1986 and less than 0.01 % in 2007. This is despite the fact that paper-based solutions are quite information intensive: we estimate an average newspaper of 60 pages to be equivalent to 4.5 MB of optimally compressed information. What counts here is the intensity of the information flow. Since newspapers are only delivered once per weekday, the average transmission rate (per second) is very low (see Table 1).

The omnipresent Internet contributes less than 3 % to the total amount of optimally compressed bits communicated in 2007. Mobile voice and data traffic represent less than 0.1 % of the total in 2007.[8] As a consequence of the dominance of TV, Figures 4 show that the global landscape of effective communication is still dominated by analog technologies. We estimate that only 27 % of the globally transmitted bits are digital in 2007. This is in contrast to information computation or storage, in which digital information already dominates

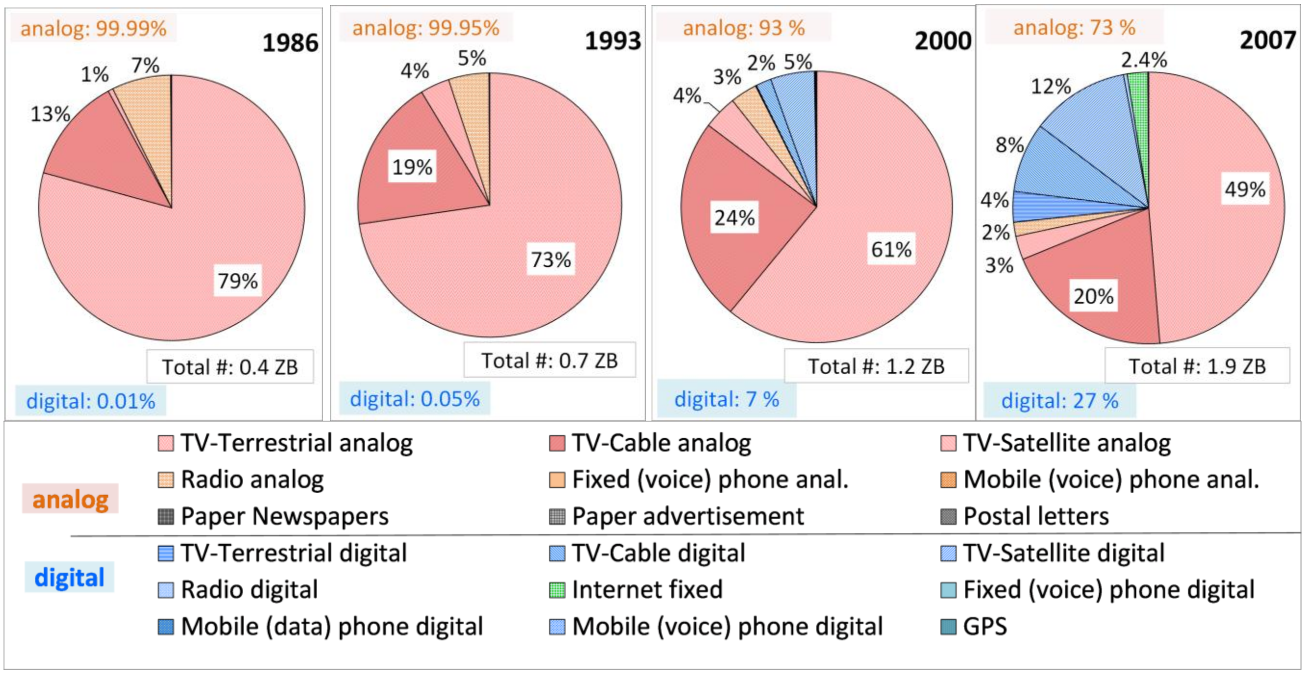

Fig. 4. Effective usage communication technology capacity, in optimally compressed petabytes , for (a) 1986, (b) 1993, (c) 2000 and (d) 2007.

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[8] Up to 2007, most mobile data traffic consisted of SMS (Short Message Service) and MMS (Multimedia Messaging Service), with some occasional Wireless Application Protocol (WAP) services, while the mobile surfing of traditional Webpages on the Internet was still incipient.

(see Hilbert and López, 2011). Digital satellite television leads broadcasting technologies into the digital age and represents 44 % of all digitally transmitted bits in 2007, while digital cable TV contributes with 31 % of all digital information flow. The Internet contributes with 9 % to the digital share.

The effective global telecommunications capacity has grown much more explosively than the global broadcasting capacity during the last two decades, reaching a compound annual growth rate of some 28 % (versus broadcasting 7 %). This growth is pushed by ever more potent digital telecommunications. While in 1986, only 20 % of the world's telecommunicated bits were delivered through digital networks (representing the incipient digitization of the fixed-line network), digital technology already dominated 69 % of telecom by 1993, 97.7 % in 2000, and 99.9 % in 2007 (see also Hilbert and López, 2011). We estimate that the year 1990 marked the turning point from analog to digital supremacy for telecommunications.

While telecommunication is growing rapidly in relative terms, Figure 4 shows clearly that in absolute terms the vast majority of the total of technologically communicated information is still carried through broadcasting networks. Telecom represented merely 0.07 % of the total effective communication capacity in 1986 and 1993, 0.2 % in 2000 and less than 3 % in 2007.

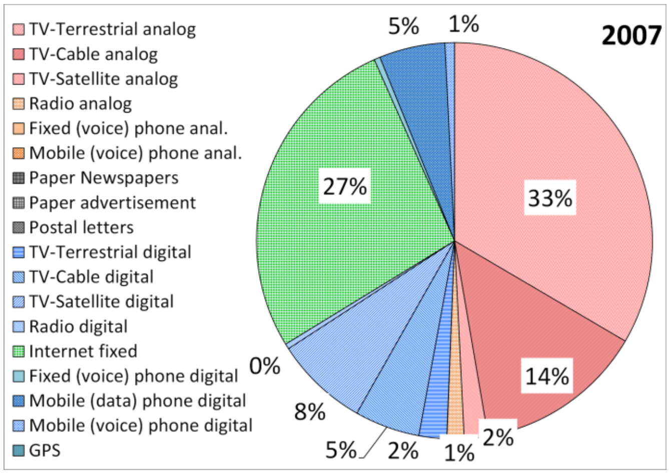

Fig. 5. Installed bandwidth potential of communication technologies in optimally compressed kbps in 2007. Note: Paper-based solutions are represented in effective usage, since we do not know the maximally possible performance of the postal system (how many letters could a postman potentially deliver at full capacity?).

C. Effective Communication versus Installed Bandwidth Potential

The dominance of TV and the comparatively marginal role of the Internet and mobile phones might be a little surprising at first sight, especially considering the omnipresent social role of digital telecommunications. It can be explained by the effective usage of each technology. The typical Internet subscription only transmits information during very short periods of time. According to our estimations, during an average daily gross Internet session of 1 hour and 36 minutes in 2007, the average user only makes 9 minutes of effective net usage of the maximum available bandwidth. In other words, the user only uses its full bandwidth for roughly 10 % of the session, while during the rest of the time, the information might be displayed at and consumed from the monitor, but no effective "tele"-communication takes place "over a considerable distance" (outside the local area) (see our definition from above; "tele" is Greek for "at a distance"). On contrary, the average TV runs an average of 2 hours and 51 minutes per day in 2007, constantly transmitting additional information to each consumer.

The sporadic demand for bandwidth in telecommunications allows for the sharing of the installed telecommunication backbone infrastructure among multiple users. The basic structure of the Internet and the investments made to maintain it follow this logic of infrastructure sharing (Odlyzko, 2003, 2008), whereas a large number of users is using the "same" backbone infrastructure at different moments in time. If all users would simultaneously try to use the total of their individually promised bandwidth, the network would actually collapse (an effect similar to what happens to the mobile phone network at New Year's Eve at midnight). This is contrary to how broadcast networks work. Television broadcast networks do not share infrastructure and all TVs could run in parallel all the time, without any competitive scarcity in the respective transmission channels.[9]

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[9] The technological reason behind this difference is that broadcasting networks transmit signals with one single content at the same time and broadcast receivers may, or may not pick it up; in the case of telecommunications, each user counts with an individualized user-defined channel, and may fill it with the same or different content, at the same, or a different moment in time. As a result of this, individualized telecom channels

In order to put things into perspective, Figure 5 presents the same distribution as Figure 4, but now supposing that all equipment would be running 24 hours per day with its potentially promised performance rate. This provides us what we call "installed bandwidth potential". It is important to realize that this form of presentation is equivalent to the traditional "kbps measure", which is commonly "promised" by telecommunications operators when offering bandwidth plans (simply normalized for compression)[10]. Obviously, when a telecom operator offers a bandwidth of (for example) 3 Mbps for a DSL connection, this is a promise given on the assumption that not all users would use their entire "installed bandwidth potential" at the same time (since then the network would collapse).

When measuring the "installed capacity" in this sense, television networks provide a little more than twice the capacity of fixed-line Internet, achieving 64 % (33 % + 14 % + 2 % + 2 % + 5 % + 8 %) and 27 % respectively (see Figure 5). This is the result of the fact that there are around 4.5 times more TV sets in the world than Internet subscriptions in 2007 (see Figure 3), but the average Internet subscription has around 1.9 times the promised communication performance of the average TV connection (in 2007 the average performing TV receiver can transmit 1.6 optimally compressed Mbps --weighted average between analogue and digital television, terrestrial, cable and satellite-- while the average fixed-line Internet subscription of 2007 can transmit 3 optimally compressed Mbps).

As already mentioned, Figure 5 does not represent the communication capacity that is effectively installed in reality, but rather the bandwidth that is promised on basis of the expectation that users will share the infrastructure. The figure is displayed purely for demonstrative purposes (to convince the skeptical reader that the previously presented effective capacity numbers in Figure 4 are correct).

D. Effective Downstream and Upstream Communication

The supremacy of broadcasting is also reflected in the amount of information effectively sent (upstream) and received (downstream) by the world's communication technology end-user devices.[11] Devices demand (downstream) much more information than they effectively send (upstream). This implies that the same information content is down-streamed multiple times, after only being up-streamed once. The driver of this logic goes back to the economic fact that information can be duplicated and distributed at a negligibly small variable cost per additional copy (Shapiro and Varian, 1998), which applies to broadcast information (one movie is sent simultaneously to many TV sets), as well as to information on the Internet (one user uploads a video once, while many users download it).

Figure 6 shows the same data as in Figure 4 (effective capacity), but separating between upstream and downstream capacities. Again, TV downstream represents some 95 % of the total, while the combined amount of information that was uploaded by the installed devices represents less than 1 % of the total in 2007. Nevertheless, the world's upstream capacity has grown much faster than its downstream capacity. While the

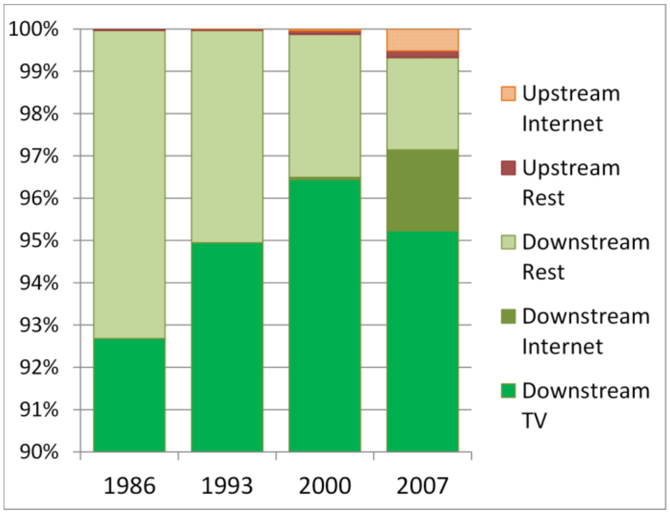

Fig. 6. Upstream and downstream capacity of effective usage capacity in optimally compressed kbps.

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compete for a shared infrastructure (bandwidth), which is not the case for broadcasting.

[10] 1 kilobit per second is equivalent to [1*60*60*24*365.2422] = 31,556,926 kilobits per year (of installed bandwidth potential). Since the presentation in Figure 5 is in percentage, multiplying each performance by this constant does not change the distribution. The effective usage capacity only accounts for a fraction of the total bits per year, or, equivalently, as a multiple of the promised bits per second.

[11] We use the terms "downstream" and "upstream" capacities of communication as a generic terms that includes "download" and "upload" capacity (which usually refers more specifically to bringing data from a remote source to local storage and storing it there, see Laplante, 1999), and "downlink" and "uplink" (which is mainly used to stress the wireless and mobile nature of the communication).

amount of information that was effectively downstreamed grew at a relative stable compound annual growth rate of 7 % between 1986 and 2007, communication upstreaming grew a compound annual growth rate of 8 % between 1986 and 1993, 30 % between 1993 and 2000, and 37 % between 2000 and 2007.

The Internet contributes ¾ of the global upstream capacity in 2007, while the rest originates from fixed-line and mobile telephony, as well as from (the yet small, but existent) uplink of digital TV subscriptions. Most of the downstream Internet traffic consists of content from the worldwide Web (around 60 %). This information originates on server hard-disks, which represent less than 8 % of the world's total storage capacity (see Hilbert and López, 2011). Most of the upstream Internet communication is generated by PC based peer-to-peer (P2P) user networking (also around 60 %), which originates from a broader source (PCs represent 42 % of world's installed storage capacity, see Hilbert and López, 2011).

IV. THE EVOLUTION OF TELECOMMUNICATION

In this section we take a closer look at the 30 telecommunication technologies presented in Table 1 (excluding postal letters). This basically includes fixed and mobile phone and Internet traffic.

The updated database of ITU (2011) enables us to extend the succeeding analysis of telecommunications until the year 2010. It also enables us to have a look at individual countries. However, as a trade-off, since detailed effective usage statistics for different telecommunications technologies in different countries are non-existent, we will mainly focus on the "installed capacity" (tracking the number of installed devices, multiplied with their performance in optimally compressed kbps[12]), and will neglect the measurement of effective usage for now. In a comparative analysis, this is equivalent with assuming that all telecommunication technologies are used with the same intensity in the different countries.[10] This assumption is not as unreasonable when analyzing telecommunication by itself (instead of mixing it with broadcasting, which—as discussed above—has quite distinct usage intensities).

A. *Infrastructure and Capacity*

We start with the same perspective as we did for the total of communication technologies in Figures 3 and 4. The upper graph in Figure 7 presents the distribution of subscriptions and the installed telecommunication capacity (in optimally compressed bits) between 1986 and 2010. In 1986, more than 99 % of two-way telecommunication devices were fixed-line phones. This did not change decisively until the mid-1990s (94 % in 1993). By 2000, 2G mobile phones already presented one third of devices (GSM, cdmaOne, PDC, TDMA, iDEN) and during the period 2007-2010, mobile phones occupied a stable ¾ of the installed telecom devices. 2.5 generation mobile telephony (transmitting data with GPRS and EDGE) was the most prominent mobile technology in 2007 (around half of all telecom devices). Between 2000 and 2010, Internet subscriptions

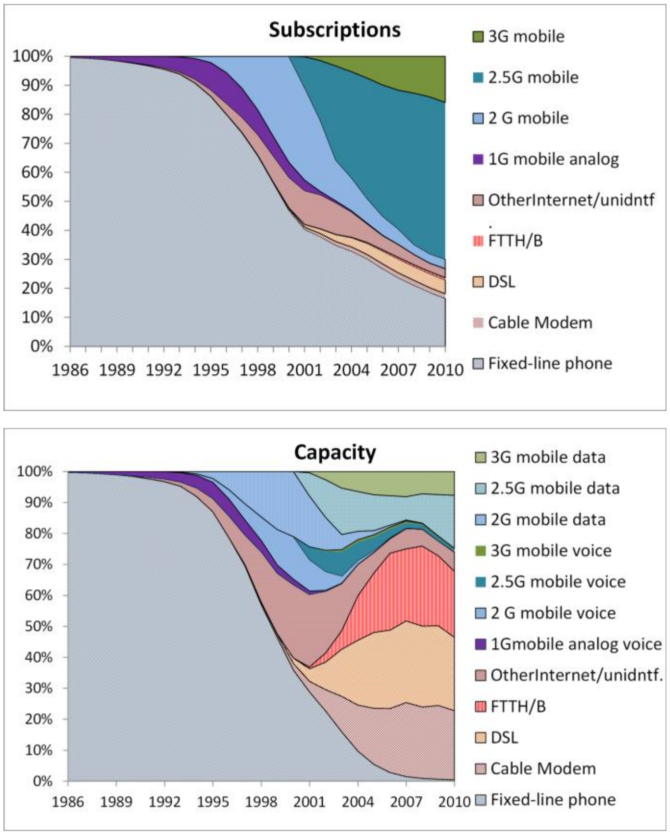

Fig. 7. Telecommunication technology infrastructure (upper Figure), and installed capacity in optimally compressed kbps (lower Figure), for 1986 – 2010.

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[12] To estimate compression rates, we use 1986, 1993, 2000, 2007, and 2010 as fundaments, and interpolate linearly, such as in Figure 2.

contributed a stable 10 % - 15 % to the global stock of telecom subscriptions. The total number of telecom subscriptions grew from 424 million in 1986, to 641 million in 1993, reaching 1.8 billion in 2000, 3.6 billion in 2005, and to 6.9 billion by 2010.

The lower graph in Figure 7 presents the respective communication capacity. In the figure it is considered that mobile phones provide two kinds of services: voice and data traffic. In 1986, fixed-line telephony represented 99.8 % of the world's telecommunication capacity, while the rest was contributed by analog mobile phones (1G) the incipient Internet (0.001 %). Around the years 2000/2001, fixed-line telephony, Internet and mobile telephony each contributed roughly one third to the global telecommunication capacity. Since then, data communication has taken over. In 2007, the installed capacity of fixed-line Internet reached its peak, representing some 80% of the capacity to telecommunicate optimally compressed bits, while since the mobile data services are catching up rapidly (capturing 25 % of the total installed capacity in 2010). DSL (Digital Subscriber Line), cable modem and FTTH/B (Fiber to the home/building[13]) contribute with roughly the same weight to the world's installed telecommunication capacity, according to our estimations.

Comparing both graphs of Figure 7, it becomes clear that the number of technological devices is a very unreliable statistic to draw conclusions about the installed telecommunication capacity. In 2007, fixed-line telephony presented 25 % of the devices, but only provided 1 % of the installed bandwidth. Mobile phones represent 2/3rd of the infrastructure stock, but less than 1/5th of the installed capacity. The share of fixed-line Internet capacity is more than 7 times larger than its share in terms of devices (80 % versus 11.5 %).

This was distinct at the time when telecommunications networks were dominated by voice communications (when most of the currently existing databases were set up). Since voice always requires roughly the same bandwidth, the number of telecom subscriptions was a very good proxy for the amount of information transmitted. This changed with the shift from voice to data transmission, which essentially took place during the decade between 1994 and 2004, as is shown in Figure 8. Since the network of network also starts to substitute previously distinct services (such as voice telephony through Voice-over-Internet-Protocol), it is to be expected that this trend continues.

B. *Drivers of Telecommunications Capacity*

In our hypothetical example of Figure 1 we placed emphasis on the fact that the growth of the world's telecommunication capacity is based on three distinct sources: more infrastructure, technological progress in hardware performance, and better compression algorithms (software performance). The first driver simply refers to the fact that the world hosts more devices. The second driver consists of the fact that telecommunications operator install better transmission channels ("cables" and use of "wireless spectra"). The third driver of technological change stems from the fact that ingenuous telecommunications engineers find ways to send ever more information over the same kind of channel, using better compression algorithms. How much does each of them contribute to the growth of the world's telecommunication capacity? Is it more, or better technology that accounts for the experienced explosion of available capacity?

In order to answer these questions we decompose the total growth rate of the installed telecommunication capacity into its three contributors (see Figure 1, also footnote 6): [growth factor of subscriptions] * [growth factor of technological progress for hardware] * [growth

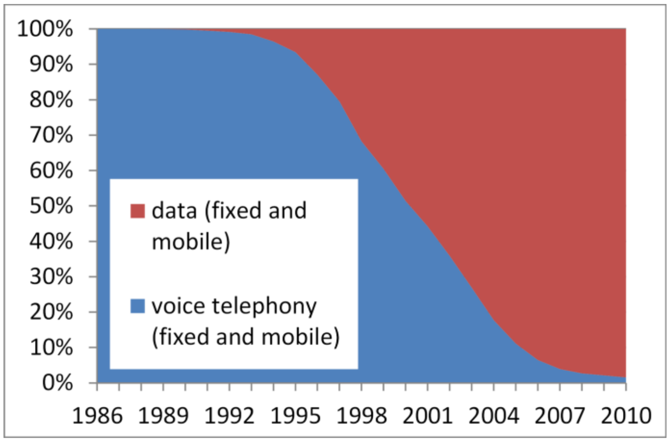

Fig. 8. Telecommunication technology capacity, percentage of data (fixed and mobile) and voice telephony capacity in optimally compressed bits, for

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[13] FTTH/B is a broadband network architecture that uses optical fiber to replace all or part of the usual metal local loop used for last mile telecommunications (FTTH Council, 2009).

factor of technological progress for compression algorithms] = growth factor of global capacity to telecommunicate. The upper graph in Figure 9 shows that, until the year 2001, the main driver of the world's telecommunication capacity has been the installation of more infrastructures. The world was flooded with additional devices (e.g. mobile telephony and Internet, see Figure 7). Starting in 2001, the broadband revolution changed this scenario and technological progress took over. During the years 2005-2007, the introduction of FFTH/B and 3G mobile telephony resulted in an outstanding technological shock: the average telecommunications device increased its bandwidth by more than 50 %. Since then the growth rate diminished somewhat, which does not mean that technological progress is not advancing anymore. What slowed down is the level of acceleration of the rhythm of change, which, with some 30% - 40% per year is still 3-4 times faster than the expansion of infrastructure.

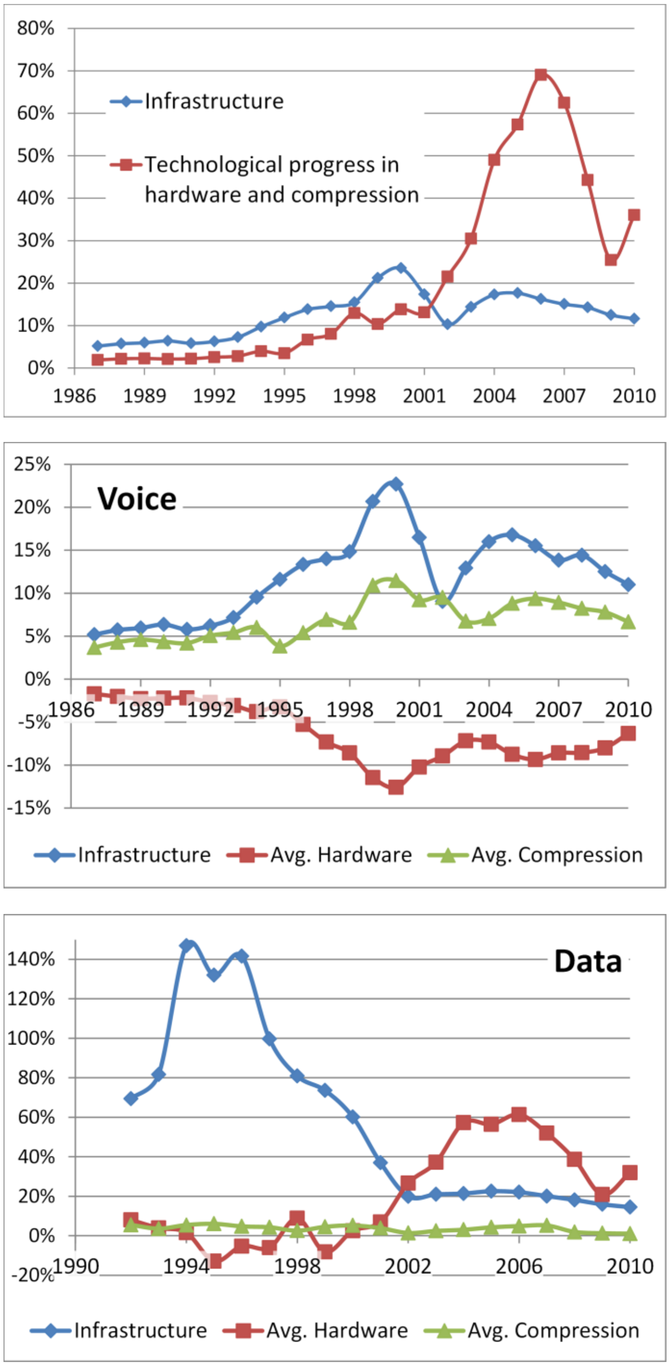

Fig. 9. Drivers of the globally installed telecommunication capacity (in optimally compressed kbps), growth rates of each driver for 1986 – 2007 (upper graph) contributions of additional infrastructure versus technological progress (incl. hardware and compression); (middle graph) drivers of voice capacity; (lower graph) drivers of data capacity.

The middle and lower graphs of Figure 9 distinguish between the drivers for the growth of voice- and data capacity. They provide empirical evidence that that the global capacity to communicate voice has been pushed by the installation of additional infrastructure, while data communication is rather driven by technological change. The average hardware capacity of a voice device actually diminished, since a mobile phone counts with less average performance than a higher quality fixed-line phone. Compression algorithms contributed its fair share to the total growth (some 6 % per year), which is mainly driven by the algorithms used in GSM or CDMA, without which mobile telephony would have hardly been possible on a massive scale. The scenario is totally different for the installed data capacity. The installation of more infrastructures pushed the global data capacity during the late 1990s (i.e. commercial Internet subscriptions and 2G SMS enabled mobile phones). During the 2000s, however, the global capacity started to be dominated by better, not by more devices. DSL, cable modem and fiber optics broadband Internet drove the expansion of the average hardware capacity per subscription.

C. *Downstream and Upstream Capacity*

Per definition, telecommunication technologies provide downstream and upstream capacity (see Table 1). When measuring installed capacity this measures how many bits a user could possibly receive and send per second. Figure 10a open up the previously presented logic of Figure 8 and shows that the dominance of data capacity implied an increasing imbalance between downstream and upstream. While downstream and upstream capacities were perfectly balanced while voice dominated the telecommunication landscape until the year 1997 (voice traffic is symmetric), in the mid-2000s, the global channels are built in such a way that the user can receive three times more information that can be sent.

The lower graph of Figure 10 (ratio between downstream and upstream capacities) reconfirms that it voice capacities stay symmetric, while data capacities became unbalanced. It is interesting to note that the introduction of fiber optics technology (FTTH/B) has led to a reversal of the trend since the year 2007. Fiber optic networks are more symmetric than other broadband solutions. Notwithstanding, this does not change the fact that the world's telecommunications networks provide more than twice as much downstream as upstream capacity.

Let us pause for a moment and reflect on what this means. From a communication theoretic perspective, Figure 10 might be a reason to worry. The digital revolution had been accredited with breaking the unidirectional one-way patterns of plain information diffusion, which is characteristic for one-way broadcasting (see also Table 1). The Internet was synonymous to interactivity, decentralization and peer power (Negroponte, 1995; Kelly, 1999). This promise seemed to be fulfilled by the user-driven Web 2.0 revolution (O'Reilly, 2005), during which users started to provide content through the video-sharing platform YouTube and social networks like Facebook. However, reality shows that over the years, downstream capacity has started to dominate the global telecommunication capacity. How to interpret this finding? Does this mean that digital telecommunication evolve toward becoming a unidirectional medium?

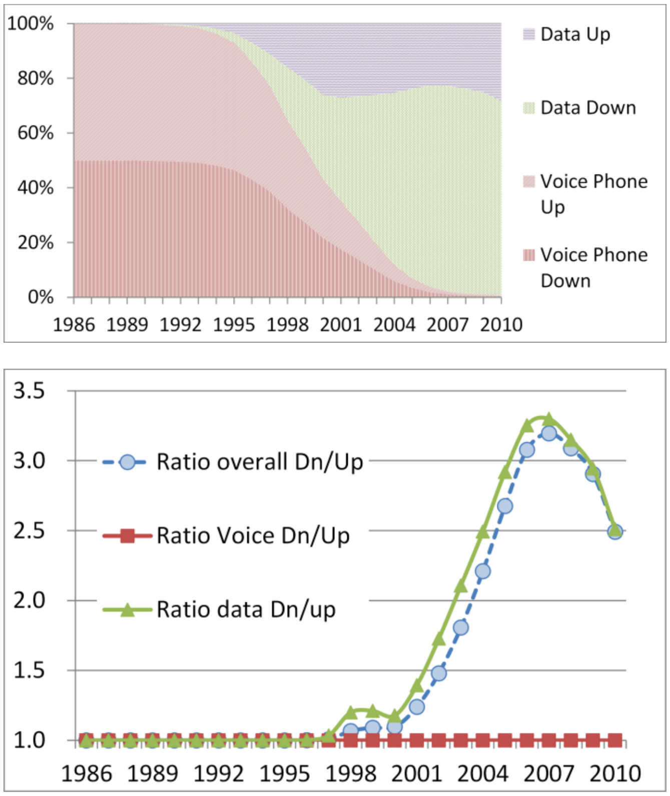

Fig. 10. Installed downstream and upstream capacity to telecommunicate (in optimally compressed kbps), (upper graph) distribution of voice and data (fixed and mobile) for 1986 – 2007, (lower graph) ratio downstream/upstream for voice and data Note: In contrary to Figure 6, Figure 10 does not refer to effective usage, but to installed bandwidth potential (in kbps).

Traditional information science and communication scholars might be quick to see parallels to the development trajectory of broadcasting. Historically, the Frankfurt school, with scholars like Bertold Brecht (1932) and Hans Magnus Enzensberger (1970), argued that there was no technological reason that the radio became a unidirectional medium of mere information diffusion during the mid-20th centrury. "On the contrary: electronic technology does not know a principle difference between sender and receiver… The development from a mere distribution- to a communication medium is not a technological problem" (Enzensberger, 1970, p. 92). Actually, during its initial days, the radio had been a truly bidirectional two-way medium of communication, and it is still used as such by thousands of hobby radio operators in regions were other telecommunications are not available (such as in the jungle or mountain region). It was not at all technological determinism, but rather the social construction of the media that has led to the fact that one side of the communication channel started to dominate the flow of information, crippling the return channel and turning an initially bidirectional technology in a de-facto unidirectional medium of information distribution. According to Brecht and Enzensberger, the commercial logic of communication industry in a capitalistic society makes it almost inevitable to avoid such scenario: fostered by capital accumulation and economies of scale, one side of the two-way channel will eventually prevail and the return channel will inevitably be crippled.

Might it be that the same dynamic determines the destiny of the Internet? During its initial days, dial-up connectivity provided equal upload and download channels. Bidirectional email dominated the communication landscape. Over time, the Internet industry matured and some professional content providers learned quicker than amateur users and started to attract more resources, providing high quality content, and attracting most of the views. As a result, it could be expected that the group of content providers starts to concentrate, which would lead to a scenario in which most content is drawn from some selected content provider.

While this theory cannot be refuted at this point, one has to remember the architecture of the Internet and the nature of digital information when interpreting the findings of Figure 10. In contrary to traditional media networks, the internet does not require equally powerful bidirectional channels to assure the participation of everybody in equal terms. Digital information can easily be duplicated (copy-paste) and instead of sending one message to one user at a time (such as necessary through analog fixed-line telephony), a user can upload an archive one time at a virtual despository, and multiple users can download it thereafter. In other words, in traditional media networks, the user requires the equal amount of upstream and downstream to get a message equally diffused. In digital networks, an imbalance between upstream and downstream does not necessarily mean that the message does not get equally diffused.

In order to gain a better understanding of this dynamic, it is important to consult statistics about content provision. One the one hand, content provision seems ever more concentrated on fewer sites, which would reconfirm the Frankfurt School hypothesis of an increasing dominance of some powerful content provider. In 2001, the most popular webpages provided commercially created content. Portals like msn.com (Microsoft's Portal) and yahoo.com each captured 11 % of the views (Barabasi, 2001; Freiert, 2007). In 2010, the media landscape was much more concentrated in terms of portals: the two most powerful portals each captured one third of the views of the worldwide web (Google, 2010). However, both of them count with millions of contributors, one being a social network (Facebook) and the other one a video-sharing platform (YouTube). The content of those webpages is created by peers and consists of personal news stories, postings, photos or home-made videos. These webpages do not require much upstream capacity, but need a substantial download channel to satisfy the demand of millions of users. The fact that downstream capacity has started to dominate the global telecommunication landscape, does not necessarily imply that the content is not created by peers. More fine-tuned indicators will need to be used to have a closer look at this dynamic in the future.

D. A Different Look at the Digital Divide

Another way of looking at the world's telecommunication capacity is in terms of its international distribution. The unequal access and usage of ICT among countries is usually referred to as the international "digital divide" and is traditionally measured in terms of number of devices and telecom subscriptions (e.g. Compaine, 2001; OECD, 2001; Howard, et al., 2009; ITU, 2010).

We replicate this approach in Figure 11, in which we track the divide in terms of telecom subscriptions per capita in the (developed) member countries of the OECD (Organisation for Economic Co-operation and Development) and the rest of the world for fixed-line telecommunication (upper graph) and for mobile telecom (lower graph). The graphs show very clearly that the divide between developed and developing countries has been diminishing when measured in terms of subscriptions per capita. In 2001, fixed-line telecommunication penetration reached 70 % of society in developed OECD countries and 10 % of the developing world. This resulted in a ratio of 7 to 1 (divide in relative terms) or a difference of 60 % (divide in measured in absolute terms). During the next decade, fixed-line penetration stayed almost constant in OECD countries (at 70 %), while the rest of the world started a catch-up, closing the divide to a ratio of 3.5 to 1. The divide is also diminishing in absolute terms. In 2001 the OECD had 60 % more fixed-line penetration than the rest of the world, 55 % more in 2006, and 50 % more in 2010.

Even more dramatic has been the catch-up in terms of mobile devices. The OECD had 8 times more mobile penetration than the rest of the world in 2001, 3 times more in 2005, and merely 1.5 times more by 2010. These results show a clearly diminishing digital divide in relative terms, which is the general main-stream conclusion of studies that analyze the digital divide (e.g. Compaine, 2001; ITU, 2006; ITU and UNCTAD, 2007; Dutta, Lopez-Claros and Mia, 2006; Howard, et.al, 2009).

Figure 12 takes a different look at the digital divide by measuring it in terms of telecommunication capacity. The lower graph of Figure 12 shows that the divide in terms of mobile telecommunication has also been reduced in relative terms. In 2001, the average inhabitant of the OECD counted with an installed capacity of 20 kbps, while the average inhabitant of the rest of the world counted with 2.5 kbps (ratio of 8 to 1). Five years later the average member of the OECD information societies counted with 5 times more bandwidth, and ten years later with merely twice as much 525 kbps vs. 225 kbps). Despite this improvement in relative terms, the mobile divide increased in absolute terms. The average inhabitant of the OECD counted with some 8 kbps more than the average inhabitant of the rest of the world in 2001, and with some 300 kbps more in 2010.

Even more ambiguous is the result for fixed-line capacity (upper graph in Figure 12)/ Here the divide has widened in both, relative and absolute terms during the decade from 2001 to 2010. While the average member of the information societies in OECD countries counted with 29 kbps more than a person in developing countries in 2001, this difference got multiplied by a factor of one thousand (to a difference of 2900 kbps). However, in relative terms, the fixed-line capacity divide was even worse during the introduction of broadband Internet at the middle of the first decade of the 2000s, when the OECD counted with 20 times more capacity per capita than the rest of the world. This leaves us with an

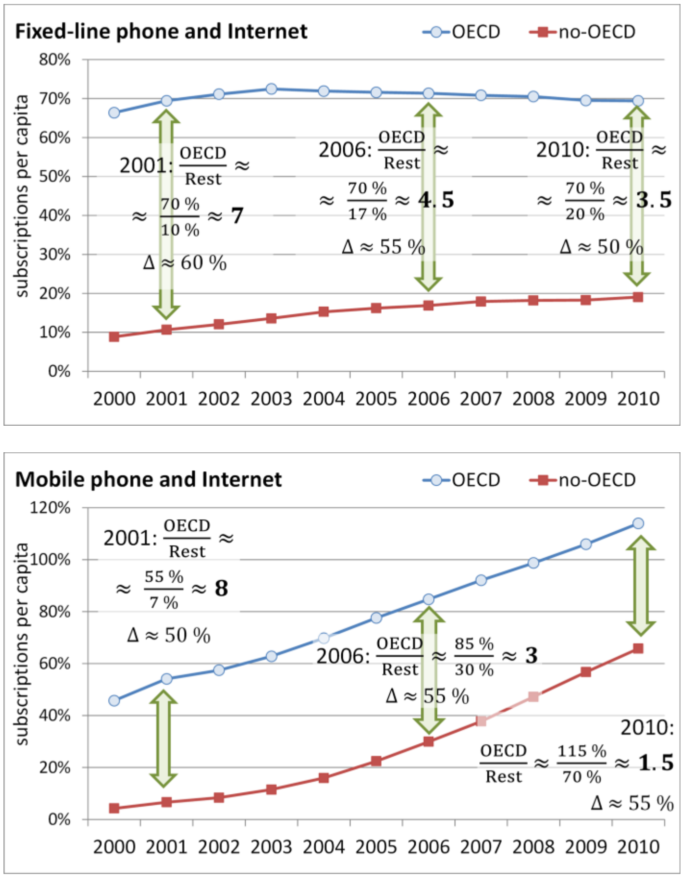

Fig. 11. International digital divide in terms of number of telecom subscriptions per capita. Upper graph: Fixed-line phone and fixed-line Internet per inhabitant; Lower graph: Mobile phone and mobile Internet per inhabitant. Member countries of the OECD vs. rest of world

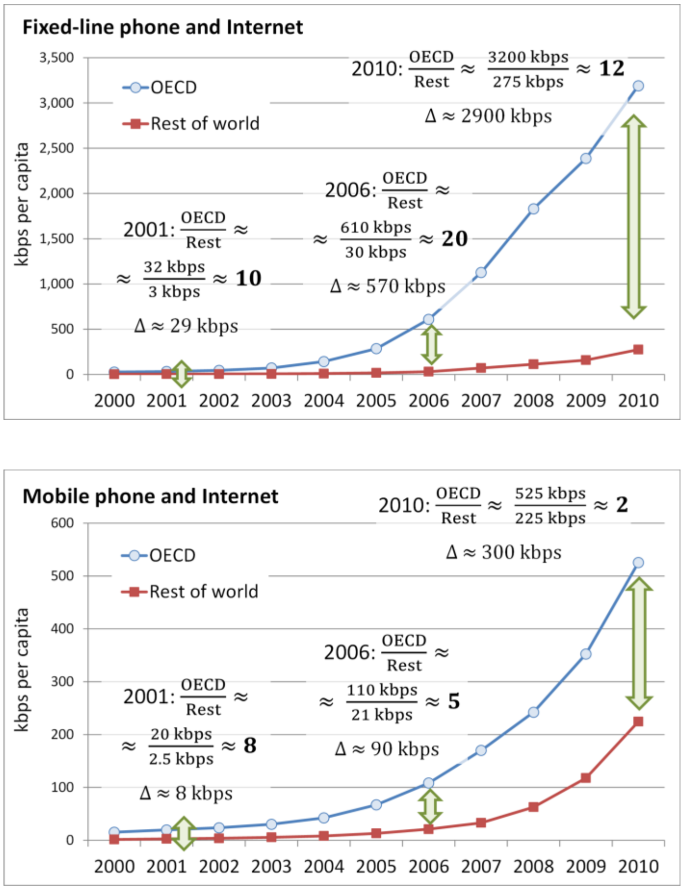

Fig. 12. International digital divide in terms of optimally compressed kbps of telecom capacity per capita. Upper graph: Fixed-line phone and fixed-line Internet per inhabitant; Lower graph: Mobile phone and mobile Internet per inhabitant. Member countries of the OECD vs. rest of world.

ambiguous picture about the evolution of the digital divide in terms of telecommunication capacity.

It is also interesting to note that in the developing world, the installed mobile capacity is almost as large as the installed fixed-line capacity (275 kbps per capita vs. 225 kbps).

Summing up, the digital divide is clearly closing when measured in terms of the number of subscriptions. There seems to be a natural limit to the number of subscriptions and devices a person can handle. As the markets in the developed world seem to reach this level of saturation, the number of devices grows faster in developing countries, allowing them to catch up and close the divide. On the contrary, it is not clear if there is a limit in the number of bits a person can handle. The emergence of broadband during the first half of the last decade opened up the telecommunications capacity divide, at the same time as the divide diminished in terms of infrastructure.

This result calls for a much more refined analysis of the digital divide, one that does not focus on the number of devices and subscriptions, but on the core variable of the information society: the information and communication capacity of its members.

E. International Distribution

With this in mind, let us now take a closer look at the international distribution in the year 2010. Figure 13 focuses on 8 selected countries and contrasts the global distribution of world population with the global distribution of telecommunication subscriptions. Figure 14 compares the global distribution of Gross National Product with the installed telecommunication capacity in optimally compressed kbps. As a first insight we can see that the number of subscriptions seems to roughly follow the structure of world population, while the telecommunication capacity seems to be a more accurate reproduction of the patterns of economic power. We can also notice that the distribution of telecommunication capacity is more skewed than the distribution of telecom subscriptions, and even more concentrated than income distribution: eight countries (USA, Japan, China, Russia, South Korea, Germany, France, and India) represent roughly half of the world's population and telecommunication subscriptions, 58 % of the world's income, and 67 % of the world's telecommunication capacity. These eight countries have the installed capacity to telecommunicate two out of three bits in the world.

Let us take a closer look at the differences in each case. Several of the selected countries perform better than others. When comparing population with subscription, the United States, for example, represents 5 % of the world population, but some 8 % of the world's subscriptions. In this sense, the U.S. is over-represented in the global information society, when measured in terms of devices. On the contrary, India represents 18 % of the world population, but only 10 % of the world's telecommunication subscriptions. India is under-represented when measured with this yardstick. In contrary, the United States in under-represented in the global information society when comparing its telecommunication capacity with its economic capacity. The U.S. manages 24 % of global income, but only 14 % of the global telecommunication capacity. India, however, is over-represented form this perspective, managing only 2 % of the world's income, but 3 % of the world's installed telecommunication capacity.

Some countries, such as Russia and South Korea (Rep. of) are highly overrepresented when we consider telecommunication capacity. Their share of the world's telecommunication capacity is four times larger than their share of the world's economy.

We continue with this logic and track the level of representativeness and participation of different world regions in the global information society over time. The upper graph of Figure 15 shows the share of global subscriptions of the different world regions, divided by the share of the world population (i.e. the equivalent of dividing the lower graph in Figure 13, with the upper graph in Figure 13). If this ratio is 1, the region's participation in the global information society in terms of subscriptions is equal to the region's representation in terms of world population. The graph shows a clear convergence toward a ratio of 1, which implies a stable tendency toward a decreasing digital divide, confirming our previous finding for a more fine-grained grouping of countries. In the "analog age" of the 1980s, the global share of telecommunication infrastructure of regions like North America and Europe was 3-6 times larger than their share in terms of world population. In the digital age of 2010, the telecom infrastructure share has almost approached “real world” proportions.

The lower graph in Figure 15 shows the ratio of the global telecom capacity with the global share of Gross National Income (GNI) (i.e. dividing the lower graph of Figure 14, with the upper graph of Figure 14). It shows a quite different picture. During the “analog age” of the 1980s, the share of telecommunication capacity was much more aligned with the global economic reality.

During the reign of fixed-line telephony, the ratio was closely clustered around a ratio of 1. Once broadband started to dominate the global landscape, some world regions started to make much more efficient use of their economic possibilities than others. Asia clearly stands out in this regard. The telecommunications performance of large Asian countries, like China, India and Russia, was way above what could economically expected from these countries during the period between 1995 and 2005, while Japan and South Korea increased their global share of bandwidth during the fiber-optics revolution at the end of the decade.

South Korea has long been seen as a best practice in broadband adoption (Rhee and Kim, 2004) and, according to our statistics, the country obtains the world’s highest bandwidth per capita: some 11.5 optimally compressed Mbps per capita (comparing with a global average: 1 optimally compressed Mbps per

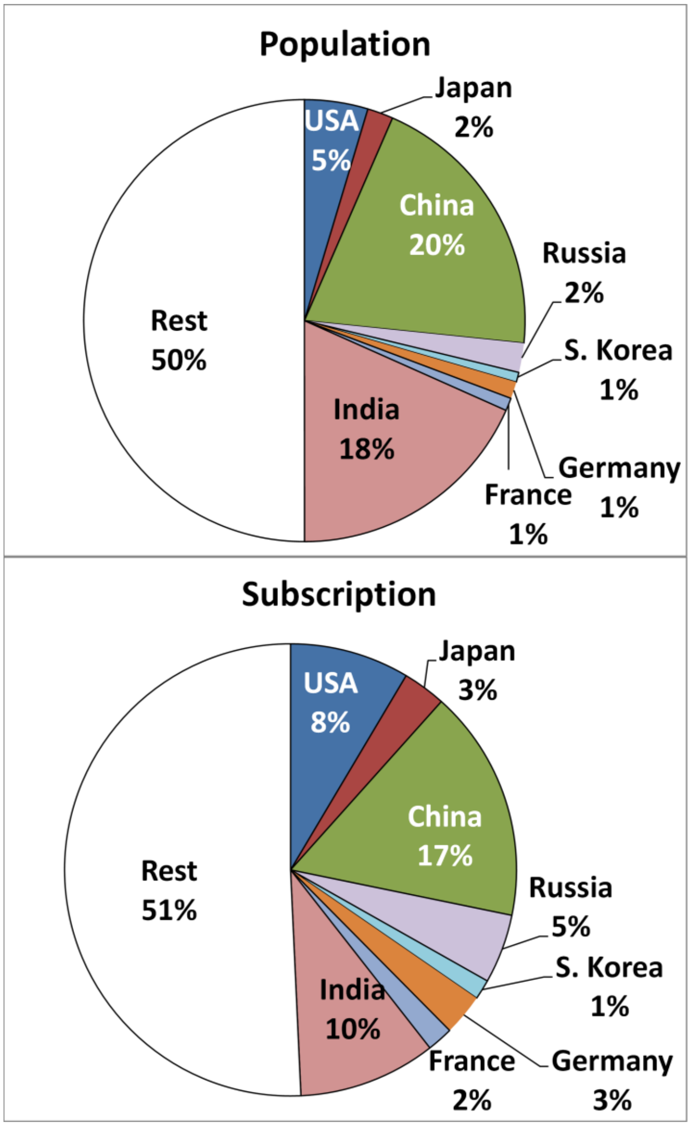

Fig. 13. International distribution of world population (upper Figure), and telecommunication subscriptions (in optimally compressed kbps) (lower Figure) for 2010.

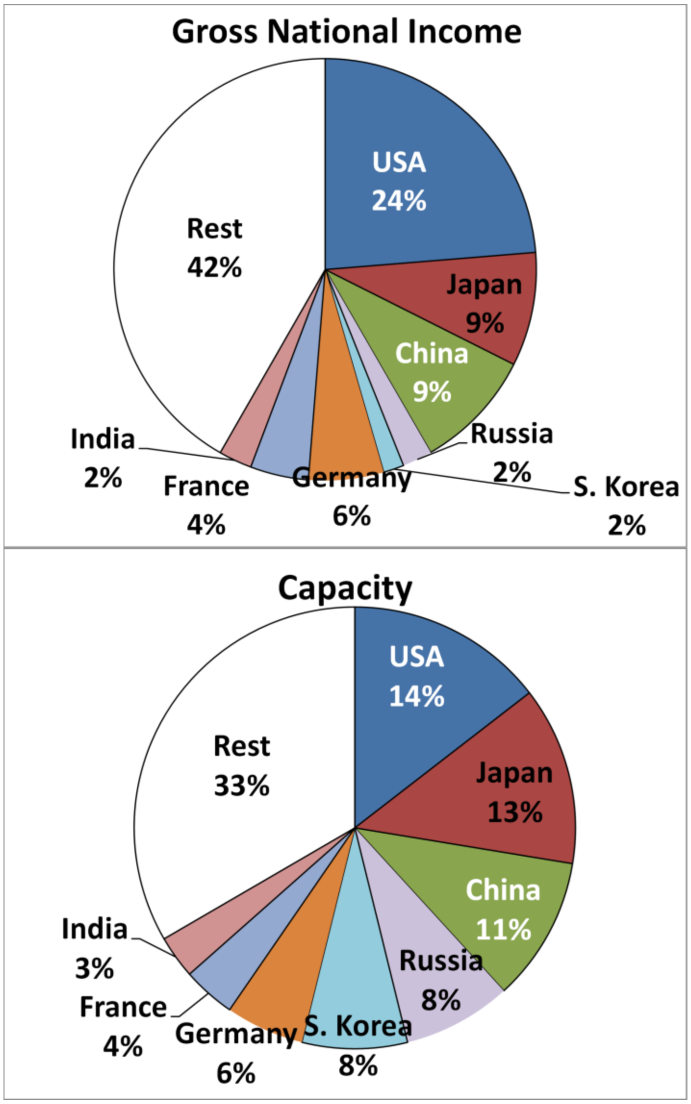

Fig. 14. International distribution of Gross National Income (upper Figure), and installed capacity (in optimally compressed kbps) (lower Figure) for 2010.

capita; and an OECD average of 3.7 Mbps per capita). Europe's evolution of telecommunication capacity is a quite faithful reflection of its economic development, while the ratio of telecommunication capacity and economic power has continuously decreased for North America.

Naturally, one could have cut the cake differently as well. For example, we can as well compare the two lower graphs in Figures 13 and 14, which results in a measure of a country's telecommunication capacity per installed subscription. For example, India's telecommunication capacity is a clear result of many devices (counting with 10 % of the world's telecommunication subscriptions, but only with 3 % of the world's telecommunication capacity), while Japan's capacity is based on high bandwidth per device (counting with 3 % of the world's devices, and 13 % of global capacity).

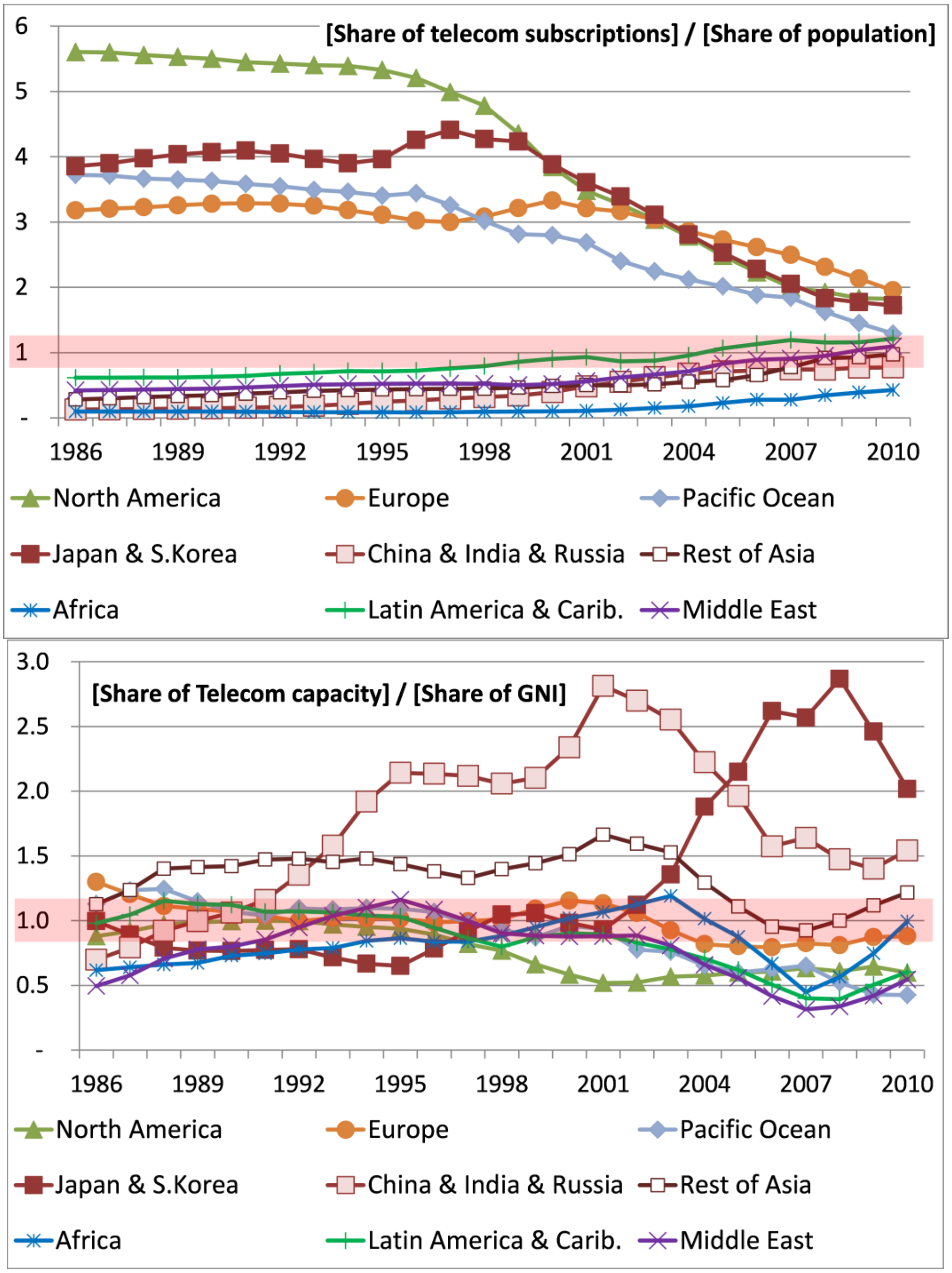

Fig. 15. Evolution of regional shares. Ratio of global share of telecom subscriptions divided by global share of world population (upper graph); Ratio of global share of telecom capacity divided by global share of world Gross National Income (lower graph); for 1986 - 2010.

F. *Yet another illustrative example: The case of Japan*

Let us take a closer look at the case of Japan. Figure 16 reports the impressive transformation of the telecommunications sector in Japan. In the late 1980s, the Internet in Japan was almost exclusively accessed by organizations (universities, companies, etc.), which used ISDN BRI (Integrated Services Digital Network Basic Rate Interface, which is known as INS64 in Japan). During the 1990s, dial-up access popularized the Internet with Japanese homes. In the year 2000, dial-up technology provided Internet access to still 62 % of the Japanese subscribers, representing 37 % of the countries Internet capacity. This changed drastically in the next few years. In contrary to the majority of countries (compare with Figure 7), Japan leapfrogged the stage of DSL and cable modem broadband access and went almost directly from dial-up Internet to fiber optics FFTH/B. This is no coincidence, nor is it the result of a lucky or accidental kind of market driven interplay between supply and demand, but well calculated public communication policy: the e-Japan strategy and policy program from the year 2001 (Kantei, 2001a, 2001b). Literally inexistent in 2000, FTTH/B technology represents 30 % of Japan’s Internet subscriptions in 2007, and more than 80 % of the countries installed Internet capacity. It is interesting to note that the total amount of Internet subscriptions has stabilized around 39 million between 2002 and 2010 (or 31 subscriptions per 100 inhabitants) and does not seem to grow further, while bandwidth grew from an average of 175 kbps per subscriptions to an impressive 21 Mbps per subscription during the same period. This explains the relatively close relationship between Japan’s population and the number of its telecommunication subscription, and its over-performing bandwidth per capita (see Figures 12 and 13).

Summing up, a saturated telecommunication infrastructure does not mean that the digital divide is not at work. Measuring the case of Japan in terms of subscriptions would lead to a quite misleading picture of stagnation, while in reality a far-reaching revolution was taking place. When measured in terms of communication capacity, the digital divide chases after an ever moving frontier, which is technological progress. The number of devices a person can possess might be limited, but this does not give us insight into how much information a person can process with them. Since it is not clear if there is a limit to how much information a person can handle, there is no end in sight for this race for now.

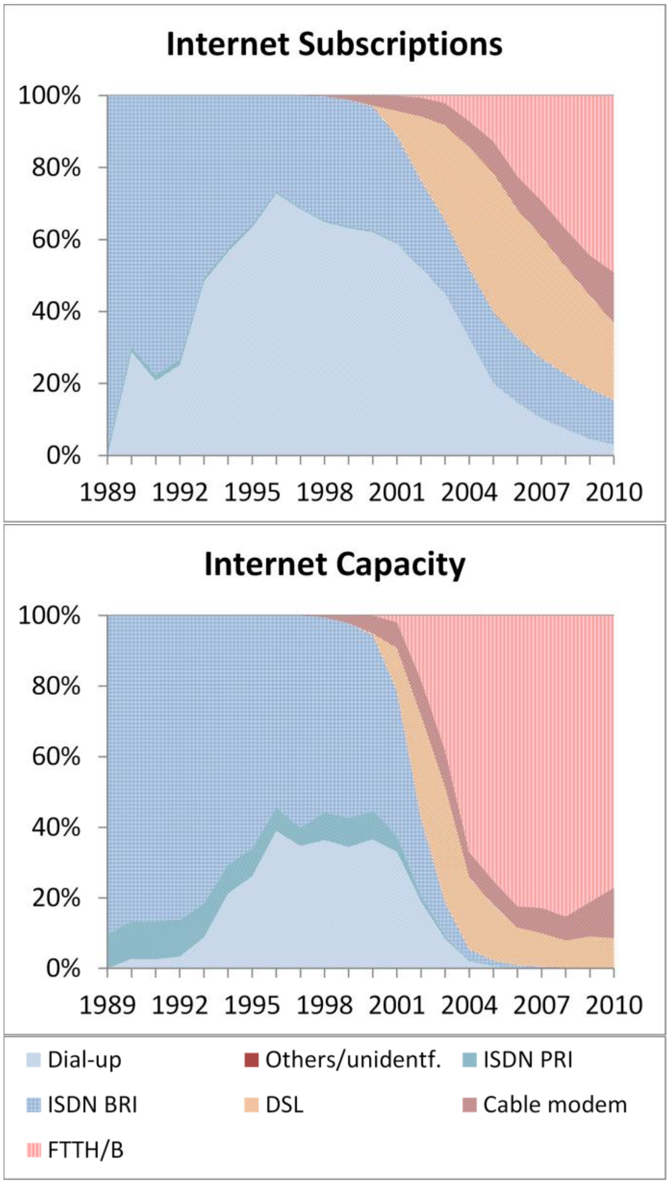

Fig. 16: Case of Japan. Upper graph: fixed-line Internet subscriptions; Lower graph: fixed-line Internet capacity (in optimally compressed kbps).

G. *Approximating Effective Usage: ICT purchasing parity (ICTpp)*

In our more detailed analysis of telecommunication in Section IV we have measured the “installed capacity” (or “installed bandwidth potential”), not “effective usage” (as we did in our global analysis in the previous Section III)[14]. The reason of opting for this was the lack of national statistics for effective usage patterns. In this section we will try to approximate effective usage with the help of a trick a trick. We will suppose that the effective usage of telecommunications services exclusively depended on the economic resources that an individual has available to purchase them. While there are surely other factors that influence ICT usage, there is ample empirical evidence that costs and available income are among the main determinants of effective usage (e.g. Barrantes and Galperin, 2008; Hilbert, 2010; 2011b; 2011c).

This assumption suggests weighing the amount of installed telecommunication infrastructure with the available economic resources for ICT usage. Naturally, the available economic resources to purchase telecommunication services depend on the available income, and on the prices of the services. For the years 2008 and 2010, ITU (2009, 2011) and its members prepared an ICT Price basket which can be used for this purpose. The index tracks three different tariff sets, referred to as price sub-baskets: the fixed-telephone sub-basket; the mobile-cellular sub-basket; and the fixed-broadband sub-basket. Tariffs are collected for several selected services for these three groups and expressed as a percentage of the available Gross National Income per capita (capped at a maximum of 100% of the income).

The three price baskets provide us with a relative measure of how much the average inhabitant of a certain country can spend on telecommunication services, and therefore provide us with a proxy for the likely intensity of effective usage. Naturally we assume that cheap telecommunication services (relative to the available income) lead to more intensive telecommunication usage than the other way around.

For example, if two countries count with the same installed telecommunication capacity (let’s say 1 Mbps per capita), but in one country the average citizen would have to spend 20 % of its income to purchase them, while in the other country the same services cost only 10 % of the income, we can conclude that the latter country counts with twice the economic possibilities to effectively use the respective services. This logic suggests normalizing the available telecom capacity on the available economic resources to purchase them. The result could be called “ICTpp” (“ICT capacity purchasing parity”), since, similar to the logic of traditional “purchasing power parity” (PPP), this measure normalizes the available capacity (in this case communicational capacity) in terms of the respective economic possibilities. In practical terms this means that we simply divide our capacity per capita variable by the respective ITU price basket.

Figure 17 presents the results when applying this logic to the cases of fixed-line telephony (upper graph), mobile telephony (middle graph), and Internet (lower graph), and compares our previous measure of capacity per capita in plain kbps, with kbps normalized on ICTpp). Similar to the analysis that we did with Figure 12, we can now track the development of the digital divide between the average inhabitant of the OECD and the rest of the world.

The upper graph of Figure 17 (fixed-line telephony) shows that the divide in terms of installed fixed-line phone capacity has been closing between the average inhabitant of the OECD and the average inhabitant of the rest of the world between 2008 and 2010. In 2008, the average inhabitant of the OECD counted with an installed 8 kbps more than the average inhabitant of the rest of the world, while this difference was reduced to 7 kbps per capita in 2010. However, when normalizing in terms of purchasing power (divided by the ITU fixed-line price basket), it turns out that the divide has been widening: from a difference of 15 to a difference of 17. In other words, while the developing world has been catching up in terms of installed fixed-line telephony capacity (the difference decreased in absolute terms), it has been falling behind in terms of the economically

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[14] For the analysis of the global flows of information in Section III we used global traffic studies in order to approximate an effective usage profile for the member countries of the OECD, and another one for non-OECD countries. This allows us to determine which percentage of the installed capacity is effectively used on a global scale. However, since effective traffic flow statistics do not exist for the national level, we neglected effective usage in Section IV, and measured the installed capacity (see Section II for the respective definitions).

viable usage of this capacity when compared with the developed world. This is because the relation of fixed-line telephony prices and the available income have been worsening for the average inhabitant of the developing world between 2008 and 2010

Analyzing the case of mobile capacity (middle graph in Figure 17), we can see that developing countries are doing worse in both measures when measured in absolute terms: plain installed mobile capacity and mobile capacity normalized on ICTpp. However, it is interesting to note that economic factors worsened the gap. While the difference in average kbps per capita increased by a factor of 1.64 between 2008 and 2010 (pushed by the diffusion of 3G in OECD countries), when normalized on purchasing party, the divide between developing and developed countries even increased by a factor or 2.13. This implies that the divide in terms of kbps has grown between the developed and developing world, and that the divide in terms of the economic possibilities to use this capacity has even grown more.

Interestingly, we get the opposite result for fixed-line Internet (lower graph in Figure 17). Here the divide in terms of installed capacity is increasing more rapidly than the divide when normalized on purchasing parity. This provides us with the interesting insight that developing countries have been falling behind more rapidly in terms of the potential effective usage of their installed mobile capacity, than in terms of the economic possibilities of effectively use fixed-line Internet.

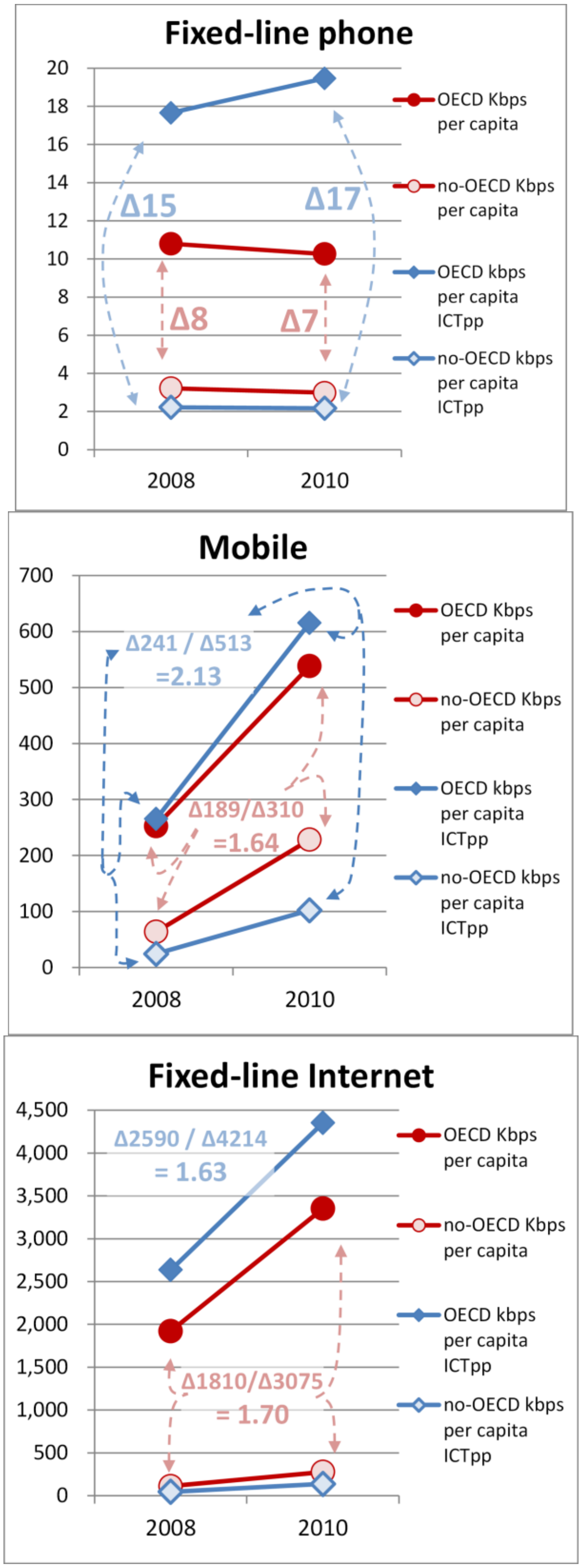

Fig. 17: Absolute differences between the communication capacity per capita in optimally compressed kbps, and in optimally compressed kbps per capita normalized in purchasing parity (divided ITU price baskets = ICTpp), for OECD and rest of world, 2008 and 2010.

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V. CONCLUSIONS AND OUTLOOK

We reviewed a methodology that allows us create an unambiguous measure to estimate a society's technological capacity to communicate and stressed the importance of compression algorithms when measuring information. Most studies in the field of ICT for development merely measure the number of devices, or account for the investment in infrastructure. Our approach provides a new outlook on the issue. We quantify the main variable of interest directly: the communicated information. We analyzed the effective communication capacity of 31 telecommunication and 12 broadcasting technologies, and had a closer look at the installed capacity of 30 telecommunication technologies. We reached several conclusions, which have important consequences for research and policies in the field of ICT for development, among them:

- Unidirectional broadcasting still dominates the global flow of technologically mediated information, representing more than 97 % of the effectively communicated bits in 2007. Almost every second bit that is transmitted in the world in 2007, was transmitted through analog terrestrial TV. However, the world's effective capacity to telecommunicate has grown much faster than the world's capacity to broadcast information. It is important to keep these general orders of magnitude in mind when designing policies that aim at fostering information and communication processes around the world, especially during the transition toward digital television.
- Almost 99 % of the world's technologically information is received by users through broadcasting and telecommunication networks (downstream), while only around 1 % is sent through telecommunication networks (upstream). However, it is important to better understand the content of those up- and downstream channels. While the digital revolution turned formerly symmetric telecommunication networks into asymmetric channels with much more downstream than upstream capacity, it is to be seen if this affects the decentralized and user-produced nature of online content. If the Internet is to hold the promise of online participation, we will have to obtain more insight of who uploads and who downloads how much information and if this asymmetry makes a difference or not.
- The most widely diffused communication device is the mobile phone (26 % of all communication devices in 2007, and 56 % of all bidirectional telecom devices). In terms of telecommunication capacity, mobile telephony represents a much smaller, but nevertheless rapidly growing share: in 2007 mobile data channels represented 16 % of the installed telecom capacity, while it already captured 25 % by 2010. Fixed-line Internet still represents the lion share of telecommunication bandwidth (74 % in 2010).
- We have shown that the digital divide in terms of kbps per capita takes a different trajectory than the divide in terms of the number of subscriptions and devices. In terms of device headcount, the world's telecommunication devices are increasingly distributed in the same fashion as the world's population; however, in terms of telecommunication capacity, the divide replicates quite well the unequal distribution of the world's income. More so, the world's telecommunication capacity is even more concentrated than the world's income. Eight countries (USA, Japan, China, Russia, South Korea, Germany, France, and India) capture two thirds of the world's telecommunication capacity.
- The case of Japan shows that it is in the hand of public and private policies to take advantage of the ever increasing performance of telecommunications and to design policies that allow to foster the telecommunication capacity of a society. The case also showed that a mere headcount of devices does not provide the necessary insights: between 2002 and 2010, Japan's fixed-line Internet penetration stayed constant at between 30 and 33 subscriptions per 100 inhabitants. However, during the same time, Japan's fixed-line Internet capacity grew from 54 kbps per capita, to 6.7 Mbps per capita. Informed telecommunications policies have to consider this development.
- More general, we have seen that while the first stage of the digital revolution was driven by the diffusion

of technological devices, in recent years the world's telecommunication capacity has been driven by technological progress. As telecom penetration reaches a certain level of saturation around the world, the amount of newly installed infrastructure increasingly plays a secondary role. This does not mean that the telecom revolution has come to a halt. On the contrary, it is accelerating at a neck breaking speed: while telecommunication capacity has grown some 8 % per year between 1986 and 1993, it grew with 25 % per year between 1993 and 2000, and with 55 % per year between 2000 and 2007.

- Additionally to measuring capacities, it is important to observe the development the available economic resources to effectively use the installed capacity. We proposed one possible measure that we called "ICT capacity purchasing parity" (ICTpp). The measure normalizes the installed communication capacity on the economic possibilities of individuals to effectively use this capacity. We have seen that both do not automatically develop in the same direction.
- This leaves us with three distinct indicators for the quantification of the information society:
    - The most basic indicator is the number of **subscriptions and devices**. This is the traditional indicator and it is increasingly becoming irrelevant. In 2010, 4 out of 5 people around the world count with a minimum connection to the information society through a mobile phone that communicates some 10 kbps (see Table 1). Based on this minimum of potential connectivity, the divide becomes a continuum which has to be measured in communication capacity.
    - Therefore, a second indicator measures the **installed capacity**, which focuses on the "installed bandwidth potential". This is a continuum that spans from 10 kbps (mobile telephony) to an open ended frontier that is constantly pushed by incessant technological progress. Installed capacity is a condition sine qua none, but does not automatically lead to flourishing communication processes.
    - Therefore, a third indicator aims at measuring aspects of the **effective usage** of the installed capacity. During the first part of this study in Section III we have estimated effective usage directly, derived from statistics of time-budget studies and direct measurements of traffic[14]. In the later Section 0 we have approximated the economic potential to effectively use bandwidth by normalizing the installed capacity on the available economic resources. This focus led to different results and different insights.

These findings are extremely important for developing countries. Until now, most developing countries emphasize ICT diffusion, independent of their performance. The overwhelming majority of official and academic statistics and research measures the advancement toward the digital age in terms of the numbers of installed ICT devices. As we have seen, this can be very deceptive. An ICT device is not equal an ICT device, and differences in performance become ever more pronounced and decisive. This implies a major shift in the general focus of ICT for development studies: measuring technological capacity is quite distinct from counting devices.

Since we are not accustomed to measure information and communication flows, our knowledge of the information society is still of "a meagre and unsatisfactory kind" (returning to our quote of Lord Kelvin, from the beginning of this article). What is not measured does not exist for policy makers. This leads to the most fundamental policy recommendation that results from this study:

- In order to be able to design and evaluate meaningful policies in the field of information society development, authorities have to start measuring telecommunication capacities. The statistical effort has to go beyond the mere accounting of subscriptions. The numbers and statistics in this article, based on our academic exercise, are merely a first approximation of the future work that remains to be done. The main purpose of this exercise is demonstrative and aims at exploring several of potential questions to ask, and the kind of insights to obtain. The presented numbers could be greatly refined (i.e. on the national level), and extended, which will lead to much more solid insights.

- Several alternatives are available to undertake such effort. Two straightforward alternatives include the direct measurement of telecommunication traffic at selected points of the network, or (less expensive, but also less reliable) the systematic use of bandwidth speed checks of private consumers as proxies for the installed up- and download capacities (such as done in this article[15]). Other ways remain to be explored to regularly obtain reliable traffic statistics.
- Such effort also has to include statistics on the kind of content that flows through the networks. This is important in order to be able to calculate the applicable compression rates, which are necessary to "deflate" and "normalize" traffic flows (similar to the readily usable normalization rates provided in Figure 2). Without normalization on compression rates it is possible to measure more or less arbitrarily compressed hardware capacities, but not the flows of information. This is similar to what economists are accustomed to do when they normalize economic progress on inflation rates. In the case of economic inflation, such conversion rates are officially produced by central authorities. If we are to advance the measurement of the "information society" "to the state of Science" (continuing to quote Lord Kelvin), such technical issues have to be considered as well.

APPENDIX

Given its demonstrative purpose, this exercise places large emphasis on transparency in outlining the methodological assumptions and sources on basis of which we elaborated the presented estimates. The necessary statistics that we use in our analysis are based on more than 500 sources. These are listed and explained in some 150 pages of methodological notes that are available online.

See http://www.martinhilbert.net/WorldInfoCapacity.html

Also Section B and Section D in López and Hilbert (2011)
http://www.sciencemag.org/content/early/2011/02/09/science.1200970/suppl/DC1

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[15] We estimated DLS, cable modem and FTTH/B upload and download speeds of countries with help of the speed test results reported by NetIndex (Ookla, 2011). NetIndex compiles the results of two bandwidth velocity meters (Speedtest.net and Pingtest.net) and in this way estimates the average upstream and downstream speed for countries worldwide since 01/01/2008 (for 2008, a daily average of 84,671 tests per country day for 128 countries; for 2009 and average of 129,852 tests per country per day for 150 countries; for 2010 an average of 179,822 tests per country per day for 160 countries). A recent independent analysis by a group of academic researchers arrived at the conclusion that Ookla's methodology gives a "realistic estimation" of the bandwidth speed for the most common uses of the web (Bauer et al., 2010). For more see Supporting Appendix at http://www.martinhilbert.net/WorldInfoCapacity.html

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