COURSE

Telecomunicaciones y Sociedad de la Información para no expertos

SUBJECT

Techno-economic drivers

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Instituto de la Ingeniería de España

Claudio Feijóo
claudio@feijoo.net
http://upm-es.academia.edu/ClaudioFeijoo

Objectives

- Understand the techno-economic drivers of the ICT sector
- Analyse digitalization, its advantages and consequences.
- Analyse the evolution of electronics (hardware) and software.
- Analyse electronic communications network externalities
- Apply the above concepts in a case.

Index

DIGITAL BASICS

Digitalization of information is the base of the revolution of the ICTs and the process of convergence (Negroponte, 1995). Any type of information may be used in analogue or in digital format. An analogue information involves infinite values, while digital information only can take any two values clearly defined and separated ("0" or "1", "all" or "nothing", "true" or "false", or any other par). Each of these two values or digital states is called a **bit**. A bit is the minimum quantity of information possible.

Digitalization is the process of converting an analogue signal into a digital one. A **signal** is the physical representation of information.

Digital information processing offers several advantages, among them the economies of scale derived from its capacity to uniquely handle all kinds of sources of information and a greater flexibility and freedom to incorporate new solutions which are of interest to users. Moreover, it is more efficient to store, process and generally use and manage information in digital format. In the following, the main advantages of digitalization are summarized:

- **Independence of information source**. Digitalization allows to similarly managing diverse types of information (audio, video, data). The direct consequence is the creation of greater economies of scale for suppliers of hardware and software, operators of infrastructures, providers of services and applications, and content producers.
- **Flexibility**. Digital representation of information allows for an easier management of complex operations. Among a long list of possibilities, some examples are **compression** (suppression of redundant information), **encryption** (restrictions to usage and access, and security) or matching to the communication channel (improvement in efficiency of communications).
- **Adaptation of quality to user needs.** Digital quality is a parameter that can be adapted to the desired technical and business characteristics, usually related with an efficient solution to user demands. The success of a number of Internet-based solutions, like VoIP, is based in this feature.
- **Physical robustness.** Digital representation in the physical world makes it more immune to noise, interference and perturbations than its analogue counterpart. A practical advantage derived from this feature is the small rate of errors when using digital information. For example, compare a digital media (CD, DVD, …) with an analogue one (videotape, …).

However, digitalization is not the only technique required for the development of convergence; it should be complemented by economically efficient technological improvements in the elements of hardware, software, and communications which make up the supply of convergent solutions to users.

HARDWARE, ELECTRONICS AND MOORE'S LAW

Not every piece of hardware is made of (micro)electronic systems, but nowadays, it is the evolution of electronics what rules the advances in the field of hardware. To realize the evolution of electronics, it is necessary to consider Moore's Law.

It was 1965 when the director of Fairchild Semiconductor's R&D Laboratories Gordon Moore[1] wrote an article for the 35th anniversary of *Electronics Magazine* (Moore, 1965) where, based in the developments already achieved in the semiconductor industry, he ventured that the number of transistors in a chip of low cost will double in each year. This is the original conception of what today is known as "**Moore's law**".

The statement of Moore was based in data gathered from the creation of the first microchip in 1959, therefore, it was issued just with the trend in the very beginning of semiconductor industry. Following Moore's arguments, the cost per component was high if there were too few components on the chip or if there were too many. Alternatively, there was an optimum number of transistors when producing a new chip. Moore's prediction extrapolated the tendency, taking into consideration that the necessary technology was already at hand.

However, the exact expression of this empirical law has changed over time. Moore's original prediction expressed that the complexity of minimum cost semiconductor components will double every year, but subsequent (and more popular) versions talked about doubling the number of transistors on a chip every 18 months, two years or doubling of microprocessor power every 18 months. Finally, Moore's law acquired an economic nature and was formulated like "computing power at fixed cost is doubled each 18 months". Alternatively, a non-related formulation was that the cost of a constant computing power decreases by half each year and a half.

Nowadays, the most popular expression of **Moore's law** states that the number of transistors on a chip will double every 18 months, although lately is coming back to doubling every 24 months.

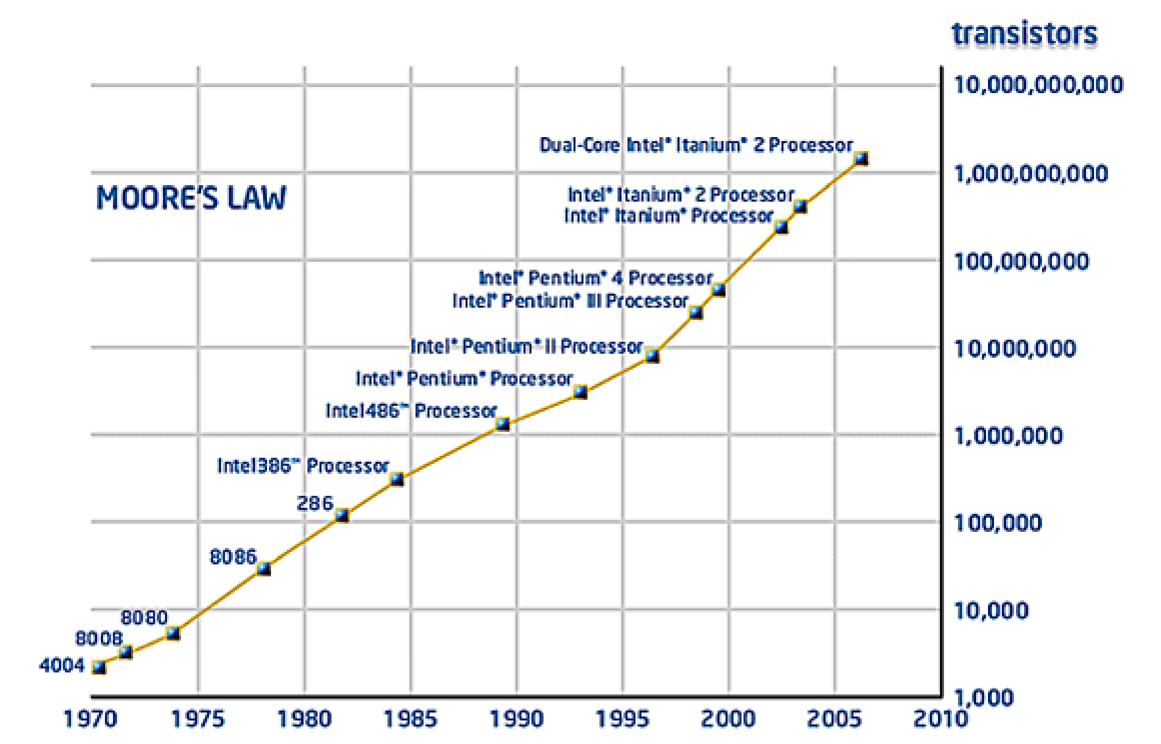

Figure 1. Evolution of Moore's law. ***Source: Intel***

[1] Gordon Moore was born in 1929. After studying Chemistry, he got a PhD in Physics and Chemistry. Moore was co-founder of Fairchild, a main semiconductor company. In 1968 he founded Intel, along with Robert Noyce, a colleague from Fairchild.

Supporters of Moore's arguments hold that his law has been met for the last four decades. However, the prediction has been subject to a number of critics, refer to the authoritative and very detailed essay of Tuomi (2002). The conclusion is that, in practice, it is only in a very approximate manner that it is valid and that its relationships with economy are good guesses at best. After Tuomi it can be said that "the claims that future developments in semiconductors, computer technology, or information processing would be determined by the continuation of Moore's Law are, therefore, obviously invalid". This simply means that there exists a rapid development, but that there are many more drivers of future development that just some blind internal determinism.

Another issue refers to the future limits of the law. Being a exponential law, it implies a continuous and increasing research effort to maintain the trend (even just in approximate terms). Most recent analysis shows that there is technology to maintain rapid increase in semiconductor industry capabilities around one more decade, but that further on it will be necessary to leap forward technologically or jump over economic difficulties derived from the increasing cost of manufacturing plants.

From the economic perspective, Gordon (2000) has argued that the rapid decrease in semiconductor and computer prices may reflect a rapidly decreasing marginal utility of computing technology. Its argument is that very rapid advances in semiconductor technology have been necessary because without the quality improvements customers would not have been interested in investing in computing technology. Manufacturers, in other words, have had to ship continuously more complex chips with better processing capabilities at the same time continuously decreasing prices. Without huge advances in processing capability, the market for computing would have become saturated. Economic appeal of semiconductor industry has derived in aggressive competition and it is another main reason behind the evolution of microchips capabilities.

To this regard, the sector dynamics play an important role. For example, computers require software. One of the important drivers for buying increasingly powerful computing equipment has been that new versions of operating system and application software have typically demanded more processing power.

As conclusion, it can be said that the belief in some version of Moore's law has often paid off. Instead of filling a market need, the semiconductor industry has actively and aggressively created markets. But, again in Toumi's words, "the rapid growth … has not been driven simply by technical advance in semiconductor industry. Although the aggressive pricing policy has facilitated the wide use of semiconductors, the high demand for semiconductor technology has fundamentally reflected a continuous stream of innovations that have occurred outside the semiconductor industry. In other words, the apparent explosive big bang in semiconductor technology is also an illusion. It has been produced in a rapidly expanding space where the boundaries of reality have escaped fast enough to create an effective vacuum that has suck up all emerging transistors". So, it was the vision from the supply side in the development of a, partially dreamed, information society made up of users' demands and expectative what has fuelled electronics evolution.

All in all, the evolution of electronics does not refer exclusively to transistors, not even to their future evolution. It also includes developments from nanoelectronics such as carbon nanotubes (able to behave as transistors, but not only) to new circuital elements like memristors (Williams, 2008) resembling the conductive properties of neurons.

(SOME WORDS ON) ECONOMICS OF SOFTWARE

As a matter of fact, we can find daily examples of the use of software in all kinds of environments, including developing countries. Other examples of devices strongly depending on software are industrial machinery, medical equipment, consumer electronics, and cash registers at any store. The list is endless, since software has taken a vital importance in modern society and it is present, without being aware of it, in the daily lives of an increasing number of citizens.

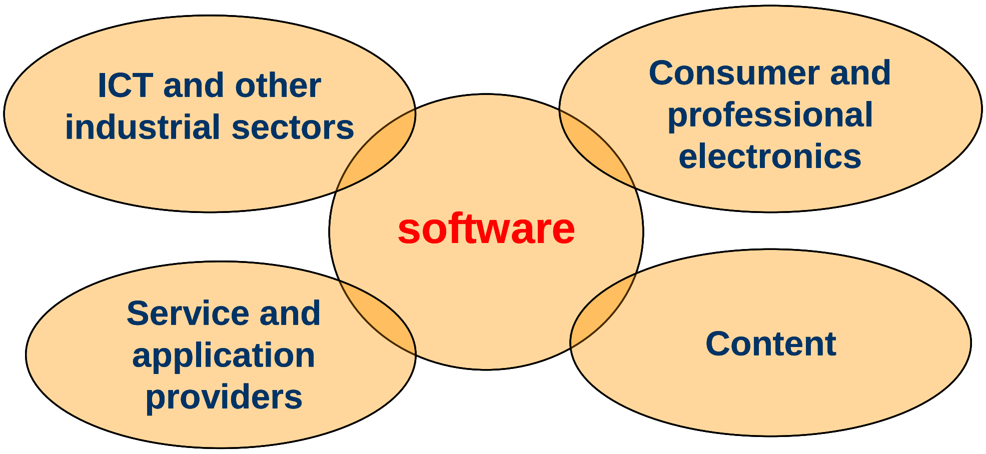

Figure 2. Some software-dependent industrial sectors.

This is why software is considered an enabler for many sectors, from communications to entertainment, making it increasingly pervasive. On one side, software is a technology enabler, since it is the base for technologies ranging from ICT to machinery, and it is the element that provides intelligence and flexibility to hardware. In this sense, software also has the capability to satisfy users' needs in terms of interoperability and standardization. On the other side, software is a real knowledge enabler, allowing the creation of user-friendly and environmentally-adapted technological solutions that drive citizens towards the Information Society.

Although hardware device innovation is the catalyst, it is software that embodies new value added functions (Barry & Kevin, 2000). Software—broadly construed as any representation of abstract information content of a computing machine, whether encoded in fixed circuits or in the state of a mutable device—thus takes on a critical level of economic and social importance. Yet, as the importance of software grows, its production and use remain among the most complex and problematical aspects of modern technology development.

Certainly, the development of valuable products, services, applications and contents, which are ultimately controlled by computer programs, explains the enabling capabilities of software and its growing importance, which is reflected by its ubiquity in the Information Society.

There are some characteristics of software that make it different from other industrial sectors from an economic perspective. First of all, entry barriers are smaller than those of most industrial sectors, due to software being less capital-intensive, more labour-intensive, with a lower rate of obsolescence and with fewer economies of scale.

This is one of the greatest appeals of software as an element representing the backbone of ICT, since it is relatively easy to carry out local projects in developing countries. Software programming is a technique that requires reduced investments and capabilities that can be taught with limited resources, as opposed to other ICT sectors such as hardware or communications equipment manufacturing. When creating new technology companies, the main advantage of software as opposed to other sectors lies in this factor. Countries or regions with qualified workers and minimum capital are prepared for the creation of companies, and can foster enterprising initiatives through the promotion of software technology parks (like the ones, for example, in India).

Additionally, see, for example, Blind et al (2001), software is strongly incremental and code re-use is a common practice both by proprietary and Free/Open Source developers. This feature allows sparing unnecessary efforts on the development of state-of-the-art methods and algorithms, hence focusing on personalization or innovative steps.

Software developments are fundamental to new disruptive innovations such as context-awareness (Cook, Augusto, & Jakkula, 2007; Coronato & De Pietro, 2010; Yndurain, Feijóo, Ramos, & Campo, 2010) and artificial intelligence.

Network Externalities

The economic concept of externality shows that the demand of a certain product or service depends, additionally to prices, income, and preferences, in the presence of external factors. Network externalities refer to the fact that the demand of a particular individual influences the demand of the rest of consumers. Telecommunications has always been a typical example of a network industry and, therefore, of externalities influence (Shapiro, 1999).

Communication networks feature typically a significant positive network externality; this is to say that as the number of users connected to a network increases, more valuable it is for an additional user to be connected to the network. How is this increment and the reasons behind it is another factor ruling the development of ICT sector and the convergence process.

Network externalities--the requirement that there be a group of subscribers if communications are to occur--play a central role in the demand for new networks. And as telecommunications evolve, new networks have increasingly taken attention and in particular the need for a critical mass of users (Allen, 1988).

Based in the idea of externality in communication networks, a number of empirical "laws" have been proposed to quantify the increase in network value as a function of the n-user connected, ceteris paribus. The most interesting proposals are (being n the number of users in the network):

- Lineal growth (also known as Sarnoff's law[2]): value is proportional to n
- Logarithmic growth: value is proportional to $n \log(n)$
- Quadratic growth (also known as Metcalfe's law[3]): network value is proportional to n^2
- Exponential growth (also known as Reed's law[4]): value is proportional to 2^n

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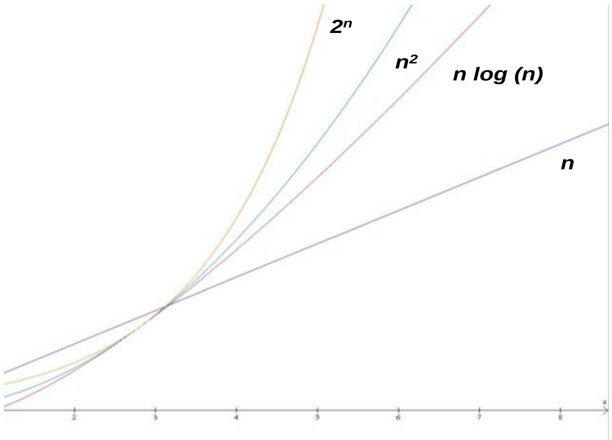
[2] After David Sarnoff, pioneering RCA television executive and entrepreneur

[3] After Robert Metcalfe, inventor of the Ethernet, and proposed circa 1980.

[4] In honor of David Reed, computer networking and software pioneer.



Depiction of network value growth "laws"

The first proposal (linear growth) was directed to broadcasting networks, where does not seem to be any direct relationship among users (note that some relationships does exist through the forecast of consumption of a certain tv programme).

Anyway, interactivity of communications networks brings about growth beyond the linear model with each new user connected to the network. The reason behind is that there exists more value for each user derived from the possibility of reaching every other user in the network.

One model to express this externality is Metcalfe's law. So, if n is the number of users in a network, each one could be connected with the rest, this is, with (n-1) users. If all those connections are equally valuable (and this is the critical point) the total value of the network is proportional to n(n-1), that is, roughly, n^2.

Its implications are formidable for the ICT industries if it is taken in consideration that networks deployment costs are directly proportional to the number of users, this is, to n. For this reason, Metcalfe's law (and the others laws beyond linear models) implies the existence of a threshold in the number of users of a network (some critical mass) from which the value of the network begins to increase well above its costs. This is the reason that explains that sometimes communication operators look for critical mass of users, not for maximization of profits.

Note that an approach even more optimistic than Metcalfe's is Reed's law, that considers that the value of closely tighten group networks (like chats, mailing lists, or instant messaging) growths proportionally to 2^n.

Indiscriminate application of both laws sure led to disproportionate valuations and expectations during the bubble dot.com.

Following the detailed article of Briscoe et al (2006), "there are common-sense arguments that suggest Metcalfe's and Reed's laws are incorrect. For example, Reed's Law says that every new person on a network doubles its value. Adding 10 people, by this reasoning, increases its value a thousand fold. But that does not even remotely fit our general expectations of network values—a network with 50 010 people can't possibly be worth a thousand times as much as a network with 50 000 people". Again Metcalfe's law are similar (but more subtle) arguments: if it were true, it would create overwhelming incentives to mergers and interconnection of networks, isolated networks would be hard to explain and interconnection would happen regardless of comparative size of the networks. Counterexamples are frequently encountered in practice.

The fundamental flaw underlying these two laws is in the assignment of equal value to all connections. On the contrary, all network connections are not used with the same frequency, take for example Internet, where the immense majority of possible connections with other users are seldom used.

Logarithmic growth takes into consideration this effect. Roughly speaking (see paper of Briscoe et al for details) if there are a million connections, the most popular 100 contribute a third of the total value, the next 10.000 another third, and the remaining 989.900 the final third. This logarithmic approach, that lies above the linear growth and below quadratic growth, is an oversimplification of what creates value in a network (and also what subtracts value), but it is without doubt a more cogent model.

Concluding Remarks

Digitization triggered the process which has made ICTs part of our everyday lives. However, the information and communications revolution is still in its middle age. The building blocks of it: microelectronics –or maybe we should say nanoelectronics-, software and networks permeate each and every of the solutions we enjoy for our quality of life. To understand these drivers is to understand the basics of the ICT future.

Summary of Concepts

- At the base of ICTs developments is digitization, that represented a true revolution in the usage and treatment of information. Digital information processing offers several advantages, among them the economies of scale derived from its capacity to uniquely handle all kinds of sources of information and a greater flexibility and freedom to incorporate new solutions which are of interest to users. Moreover, it is more efficient to store, process and generally use and manage information in digital format.
- The rapid growth in electronics has not been driven simply by technical advance in semiconductor industry. Although the aggressive pricing policy has facilitated the wide use of semiconductors, the high demand for semiconductor technology has fundamentally reflected a continuous stream of innovations that have occurred outside the semiconductor industry.
- Software is a technology enabler, since it is the base for technologies ranging from ICT to machinery, and it is the element that provides intelligence and flexibility to hardware. Also, software is a knowledge enabler, allowing the creation of user-friendly and environmentally-adapted technological solutions.
- Communication networks feature a significant positive network externality; this is to say that as the number of users connected to a network increases, more valuable it is for an additional user to be connected to the network.

Open Questions, Applications and Case Study

1. Find and explain a case where digitalization has been used to decrease quality of the solution provided to users in order to make it practical.
2. Suppose that a rapid development of electronics (like Moore’s Law) is met until the end of the next decade and find a practical detailed consequence.
3. Find which the technological limits in the fabrication of transistors are currently and which new developments are foreseen in the middle to long term.

4. Find some new developments in micro/nanoelectronics not mentioned in the text and evaluate their potential impact.
5. Explain in a simple way the economics of operating systems and the applications that run over them. Explain the effects of software piracy in this model.
6. Research on the role of software on context-awareness. Which is the relationship between context-awareness, smart environments and artificial intelligence?
7. Calculate the increase in value for each player if two mobile communications interconnect, having the first 10 million users and the second just 1 million. Compare logarithmic growth and Metcalfe's law.
8. Which is the type of externalities in a web 2.0 social network? Discuss the options.
9. Which are the relationships between the concepts of network externality, natural monopolies and public intervention? Illustrate them with examples from the telecommunications sector or any other ICT market.
10. Study case. Apply the concepts explained to the deployment of digital terrestrial television (DTT) in a specific country or region. In particular, a) identify the advantages and opportunities of digitalization of tv broadcasting, b) identify the advantages of network externality and quantify (a first approach) the possible growth in value of the network, c) identify problems and barriers for its deployment from the point of view of private players in analogue broadcasting that have to migrate to DTT, d) explain why (if any) should be a public intervention for the migration to DTT (also called digital switch over or analogue switch off).

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