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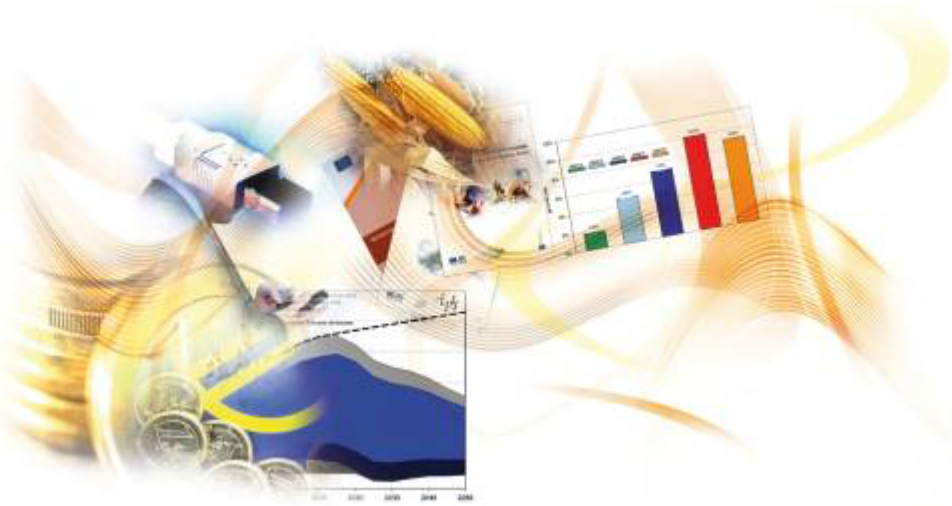
Tracking the Economic Value of Embedded Digital Technology: A Supply-side Methodology

Author: Geomina Turlea

Editor: Marc Bogdanowicz



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Contact information
Address: Edificio Expo. c/ Inca Garcilaso, 3. E-41092 Seville (Spain)
E-mail: jrc-ipts-secretariat@ec.europa.eu
Tel.: +34 954488318
Fax: +34 954488300

http://ipts.jrc.ec.europa.eu
http://www.jrc.ec.europa.eu

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Introduction

DG Information Society entrusted the Institute for Prospective Technological Studies (IPTS) of the European Commission's Joint Research Centre with the execution of a study called "Study on measuring the diffusion of Embedded Systems". The elaboration and testing of a comprehensive tailored statistical methodology were the main objectives of this research on Embedded Systems.

Information and Communication Technologies (ICT) are progressively penetrating all aspects of our everyday life and there is undoubtedly a growing need to understand and quantify the economic impact of the phenomenon. Indeed, for more than a decade, the scientific literature has become more and more concerned by the socio-economic impact of the ICT revolution. In particular, ICTs are recognised as factors of economic growth through their multi-channelled impact on productivity (as proxies for technological development) and their enabling capacities (both through easing new ways of business organisation and by facilitating innovation). This literature has become mainstream and offers many stabilised concepts, methodological frameworks and important results.[1]

Our current work attempts to shed light on a leap of faith on the boundaries of the definition of ICTs, which persists at the conceptual roots of the mainstream literature:. While the pervasiveness feature of ICTs, now embedded in an overwhelming number of goods and services, is widely recognised, only some ICT products and services (computers, telecom services, and commercial software) are considered when the ICTs are actually measured by official Information Society statistics, especially on the demand indicators.

Nevertheless, the diffusion of the Embedded Digital Technology (EDT) in everyday life is very significant. It is estimated that today about 98% of programmable digital devices are actually embedded[2] in other products. Current and future trends point to a dramatic potential for further growth: the number of microprocessors is growing far more than the number of PCs. This trend may even be accelerating,[3] as the diffusion of microprocessors becomes ever more significant and pervasive, due to both cost reduction and enhanced functionality. The former European Commissioner for the Directorate General Information Society & Media, Viviane Reding, remarked, "there are now more embedded devices than people on earth. As chips and wireless communications become universal and inexpensive, an enormous potential is created for new applications and novel ways to support our society and people's lives".[4] The author hopes this report will serve as initial step in better measurement of the economic impacts of the diffusion of the Digital Technology (DT) and a better informed policy-making process in Information Society-related issues.

The author is particularly grateful to Panos Tsarchopoulos, DG INFSO project officer, for his continuous and effective support during the development of this research.

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[1] The OECD and Eurostat Information Society Statistics Working groups have been core to those developments. They allowed the academics to develop their analysis, while offering a necessary feed-back to the further development of the measurement frameworks.

[2] World Semiconductor Trade statistics.

[3] Neuvo, Y., presentation at IST 2004.

[4] Reding, V. Embedded Systems at the heart of Europe's Industrial Growth, speech at the Artemis public event on 6 March 2006.

Executive Summary

From capturing ICT capital…

The dominant stream of macroeconomic literature on the contribution made by Information and Communication Technologies (ICT) to growth applies the neo-classical growth accounting framework developed originally by Solow (1957). The application of this framework to ICT started mainly with Jorgenson, Ho and Stiroh (2002) and Stiroh (2002). Despite being well-established and providing huge refinements in statistics and measurements, growth accounting literature has so far proposed few conceptual adjustments to the original setting (Kuppusamy et.al (2008)[i].

Basically, growth accounting exercises are based on the neo-classical production function, which is applied at macro, micro or sectoral level. Despite the criticisms made of growth accounting methodology on various grounds (see van Reenen (2009), or Felipe and Fisher (2003) a.o), it is still the more useful and powerful tools in explaining growth.

In ICT growth-accounting methodology, "ICT" comprises only general-purpose computers, software and telecommunications equipment. "Non-ICT" covers all the rest of the productive capital and intermediate inputs in use, irrespective of the underlying technology. The argument throughout this entire study is that this delimitation misses a lot of the ICT impact on the economy.

This study refers to the limitations that growth-accounting methodology has in accounting for ICT embedded along the value chain.

… to estimating the economic value of the Embedded Systems…

The acknowledgement of the role of ICT outside the confined universe of general purpose computers (and associated services such as software and telecommunications) arose with the rapid development and spread of the use of the microprocessors in the last decades of the 20th century. The concept of *Embedded Systems* became the archetypal image of pervasive ICT. In accordance with the majority of definitions available until today, an Embedded System is a computer-controlled system; at its core is a microprocessor, programmed to perform one or a few tasks. This contrasts with general purpose computer systems like PCs which have general purpose hardware platforms and externally-loaded software.

The present study comprehensively reviewed available statistical data and measurement exercises in line with the above understanding. To the best of our knowledge, the existing estimations of the number of Embedded Systems and their value are almost exclusively based on the number or value of microprocessors as proxies. They quite often use other arbitrary and untested assumptions and miss out important elements, such as the embedded software, from the estimations. The formulation of policies for the Information Society can not internalise the use of this scarce and partial data for Embedded Systems and has to rely on data which therefore exclude an important share of ICT research, production and use.

Nevertheless, this type of measurement served its purpose during a certain stage of ICT technological development by providing an image of ICT embedded in other products which was, at that time, accurate enough. This explains the interest in perfecting it for use in policy-making. Yet,

our study concludes that it is increasingly difficult and unsuitable to use a measurement methodology based on the Embedded System concept because it is not longer operational enough,[5] and is in fact increasingly less suitable as an intuitive proxy for pervasive ICT.

The growing conceptual and, consequently, measurement problems that we face today when relying on a representation of Embedded Systems based on a microprocessor and dedicated functionality can be explained by the history of the technological development of embedded ICTs. The concept of Embedded Systems was proposed in an era of a high hardware/chip dependency, with little or no embedded software provided from system integrators. The programmable devices were proprietary and bought ready to be plugged in. Moreover, the software coding was highly optimised for individual functions, offering little flexibility for system reconfiguration. It seemed natural to see embedded ICT as a black-box, with some components clustered around one microprocessor.

Over the last decade, we have nevertheless witnessed a shift from **high hardware reliance** to **high software reliance** in ICT applications. This means that increasingly, embedded hardware platforms not only provide **multi-function capability**, but also build sufficient flexibility into the design so that various functionalities may be implemented through flexible hardware-software architectures.[6] This makes it nearly impossible to isolate conceptually one or more Embedded System running on a single or a multi-core chip. Moreover, there is substantial evidence that value added will concentrate in the software layers of networked, cross-systems and cross–equipment applications, for which the concept of Embedded Systems is particularly ill-defined. In an era of increasing software dependency, and of fast standardisation of both platforms and software application, we argue for the need to review and adjust the conceptual and measurement framework for pervasive ICT.

…to the measurement of the economic value of the Embedded Digital Technology (EDT)

The study advocates abandoning the measurement of Embedded Systems as a separate subject, and turns towards an integrated ICT-oriented approach at (mainly) product level. We call this approach: **the measurement of the economic value of Embedded Digital Technology (or, expressed alternatively, the measurement of EDT Intensity in output) at company, sector and/or national level.** Basically, it proposes singling out EDTs from overall productive inputs (intermediate consumption, capital and labour force) along the value chain of different goods and services.

The share of the cumulated value of these inputs along the value chain in the total value of the products or services will provide a measure of the **EDT intensity** of the final goods, or of the relative economic value of Embedded Digital Technology in the price of the final output. It approximates the value of EDT that intervene in the production of the final good at different stages of the value chain (from the electronic components onwards). This approach reduces the difference between the embedded and non-embedded DT (fading in reality, anyway) and facilitates a different, more suitable treatment of software. We also propose a related method of isolating the ICT R&D expenses from the overall R&D expenses.

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[5] Reasons of this failure are explained in detail in Section 2

[6] Juliussen E. , Robinson R. (2010)

This methodology has the advantage of being reproducible without major theoretical difficulties, and on the basis of acknowledged official statistical data. As with any fundamental methodology, the author is aware that it also shows numerous aspects which need substantial improvements, additions and refinement.

For the purpose of illustrating the benefits of applying and further developing the method, we implemented the approach with published German National Accounts data, corroborating the results with a substantial literature review and two dedicated studies on embedded electronics in the automotive sector. We relied on micro/sector approaches to complement the macro/national accounts approach. Their role was to substantiate and check the micro behavioural assumptions needed by the macroeconomic calculations, assumptions mostly related to the structure of the value chain and the process of value added creation along it.

The interlinked macro and micro approach supports the relevance of the proposed overall methodology. However, for its implementation as a policy support tool, we recommend using National Accounts data at a much higher level of granularity in order to refine the findings and run further sectoral/thematic studies in order to give more support to the results and to the approach itself.

Conclusions and policy implications

Looking at the economic value of Embedded Digital Technology is fundamental to support policy-making with robust economic evidence. This methodology, which accounts for EDT intensity of various groups of products and the ICT R&D efforts of their producing companies, provides additional, valuable and exact economic information, in support of policies related to general Information Society strategies. It takes fully into account the economic impact of DT at sector, national and European levels, for producing more flexible and timely indicators for research policy that aims to understand what future goods and services may develop, by the increasing presence of the EDT, etc.

Still, to be fully operational, further research is needed.

Firstly, the overall measurement would benefit from integrating the demand side into the picture. Changes in demand for products embedding digital technology and the welfare effects of these changes would allow us to take into account the demand effects on the price formation process, and facilitate a dynamic approach to technology diffusion. The ambition of this study is nevertheless limited to supply-side analysis. It proposes the sum of ICT-based factors' services and ICT-based innovation rent along the value chain as proxy for the economic value of the embedded digital technology.

Secondly, the methodology needs to solve two theoretical challenges:

- **Aggregation of microlevel results:** DT impacts induce extreme variations in companies' performance while it was shown that a well-behaved aggregate production function can be derived from micro production functions only when in compliance with very stringent conditions of homogeneity.

- **Identification of the determinants of profit margins for embedded digital components**: the methods used to allocate the total factor productivity on production factors are notoriously mechanical. Their relevance is particularly low when a given productive factor is a general purpose technology rather than a (fully) statistically identifiable production factor. The implications of seeing the ICT (or more general DT) as a general purpose technology for the calculations of the economic impact are recognised in mainstream economic theory (see DeLong (2002) and the literature on ICT as general purpose technology), but it is not yet dealt with in practical calculations. This is valid for both the DT embedded in the non-ICT capital goods and the ICT embedded in the non-ICT intermediate goods.

Thirdly, an adaptation of the statistical measurement tools at the level of their collection and processing is urgently needed.

This level of adaptation varies according to the statistical field of investigation:

- National account data only need to be provided at a higher level of disaggregation; **the major need for better data collection is for software**. The issue is stated as crucial at EUROSTAT, but the pilot exercises run so far have failed to meet the objective.
- **Labour data is instrumental in understanding the impact of DT**. Refinements are needed to take into account specific issues that escape today, like the DT-related content of non-ICT jobs matched by types of certifications additional to the main profession. A better measurement of the skilled labour force mobilised at national level by the various industrial sectors, within the constraints of the structure of that economy, would indicate much better the future needs for a trained ICT labour force. The process of improving the labour data is ongoing and involves both statistical institutes and academia.
- **R&D efforts and the participation of various actors from various levels of the value chain in the innovation networks is the area least covered**, yet it is the most interesting development from a policy-making point of view. Efforts are being made at EUROSTAT to investigate the field of research at company level, but these efforts are still in the early stages and have not borne any fruit as yet. The only sources of such data are still dedicated interviews and sector studies. Additional effort is needed to harmonise these results both at sector and national levels.

Notes in this section

[i] For a comprehensive literature survey on ICT and growth accounting see for example Reenen et al. (2009). The most important of the conceptual adjustments are related with accounting for the quality of human capital (Aghion and Howitt (2009), Sianesi and Van Reenen (2003) , Bart van Ark, Mary O'Mahony, and Marcel P. Timmer (2008) etc.

1. Scoping the field of research

1.1. In search of a definition

The initial purpose of this research was to propose a methodology for the measurement of the production and diffusion of Embedded Systems, in order to sketch a macroeconomic profile of the Embedded Systems domain. Early in the process, the study concluded by recommending a reconsideration of the entire perspective on Embedded Systems, starting with the definition itself, and going on step beyond the neo-classical growth accounting framework developed originally by Solow (1957) and of which application on ICT started mainly with Jorgenson, Ho and Stiroh (2002) and Stiroh (2002).

A large amount of literature is now available on the technological characteristics of various devices considered as Embedded Systems, while dozens of microeconomic analyses on sub-segments of this domain discuss markets and producers. A common definition is nevertheless, very difficult to find and agree.

Timmermann (2007) provides an extensive overview of the (mostly technological) literature available, and proposes as a *broad* definition of Embedded Systems the following:

> *"An Embedded system (EmS) is an electronic system with dedicated functionality build into its hardware and software. The hardware is microprocessor-based and uses some memory to keep the software and data, and provides an interface to the world or system it is part of"* (Timmermman, 2007).

According to Timmerman (2007), the functions performed by these different systems may vary a lot, but could be put in the following categories: (1) computation; (2) measurement; (3) control of the environment; (4) communication; and (5) human interface. They must, as minimum requirements, be (1) safe/secure; and (2) dependable/real time.

To the best of our knowledge, the essential step from such a broad definition towards an operational definition (i.e. a description of the subject which allows its direct statistical measurement) has not been taken yet in the existing literature.

Moreover, we argue that, for both theoretical and practical reasons, the concept of Embedded Systems as defined above cannot be operationalised today in a satisfactory manner.

Firstly, the existing scientific and empirical knowledge itself does not clearly define the criteria of what is (and what is not) an Embedded System, at least in terms of drawing boundaries around named physical structures or independent objects. Though a common understanding and common sense might exist at industrial level, we observe that this definition varies from one industry to another.

“Embedded Systems”, as a name for the domain, neither reflects nor covers the complexity of the field to be investigated (see Timmermann, 2007). In fact, both the concepts of “embedded” and of “system” are far too broad to give accurate interpretations. The combination of these concepts creates a ‘fuzzy’ definition that cannot easily be tied to specific objects (this is similar to the broadness of the term ‘communications’).

Quite often, Embedded Systems are defined, not by what they are, but by what they are not: General Purpose Computers. However, the frontier between what is an Embedded System and what is not is certainly not sharp enough to allow us to develop measurement methods (see Box 1; Annex 1 shows how the lack of sharp line around Embedded Systems is reflected in the lack of statistical information at the borderline between Embedded and General Purpose Computing).

Box 1: "Pitfall: Thinking there is a sharp line between Embedded and General-Purpose Computing

For the most part, it is easy to distinguish between systems used for the sole purpose of computing (e.g., a mainframe or a desktop computer) and systems that use computing as a means to achieve another primary task (e.g., a microwave oven, a camera, a car, or an airplane). Historically, computing power was a distinguishing factor, in that embedded electronics were mainly deployed to control the appliance in which they were embedded.

Such applications had small requirements for speed or generality. More recently, several trends have produced devices that are not clearly in one camp or the other. First, microprocessors became commodities. It is often possible to find a microprocessor with a performance/cost that outperforms a solution based on ad hoc electronics. VLSI technology, largely driven by desktop computers, has lowered the cost of silicon so much that microprocessors have become cost effective for most consumer priced products. [...]

Second, massive computing capability became pervasive. Telephones, consumer electronics, cars, and entertainment systems are just a few examples of areas that today run computer-intensive tasks that not long ago would have challenged a supercomputer. Third, mobile computing emerged as an important area. [...]

Although it is fair to classify laptops as "computers," how do we classify a general-purpose palm-sized device?

These three trends are not likely to stop, and it is already easy to find devices that defy our definitions. Such products are typically in the middle of an evolutionary change. For example, PDAs (personal digital assistants) evolved from being calculators with a phone book to full-blown computers powered by 32-bit high-clock-rate general-purpose microprocessors. Similarly, set-top-box devices transformed from simple descramblers of analog signals to Internet-enabled web browsers, following a very similar trajectory in terms of computing capabilities. In both cases, these systems are very close to the frontier between general-purpose and embedded and are likely to escape any classification attempt.

Game consoles are another confusing domain. For many generations, game consoles were clearly dedicated to one specific task, gaming, but the more recent generation of products often skirts the boundary of general-purpose computing, as they incorporate features such as networking, web browsing, and keyboards, and as they incorporate download support to programs that add functionality not planned at product design time. As an extreme example, in 2003 the National Center for Supercomputing Applications assembled an effective supercomputer out of $50,000 worth of Sony Playstation 2 components!

One might imagine that in these boundary areas only a few product concepts will survive to become the "standard" in mobile computing or the "standard" in home entertainment. Such a "narrowing of diversity" has happened in many marketplaces (e.g., desktop personal computers, videotape formats, and rail gauges). Economists are unresolved as to whether such narrowings reduce competition and innovation or provide standardization that fuels wider benefits."

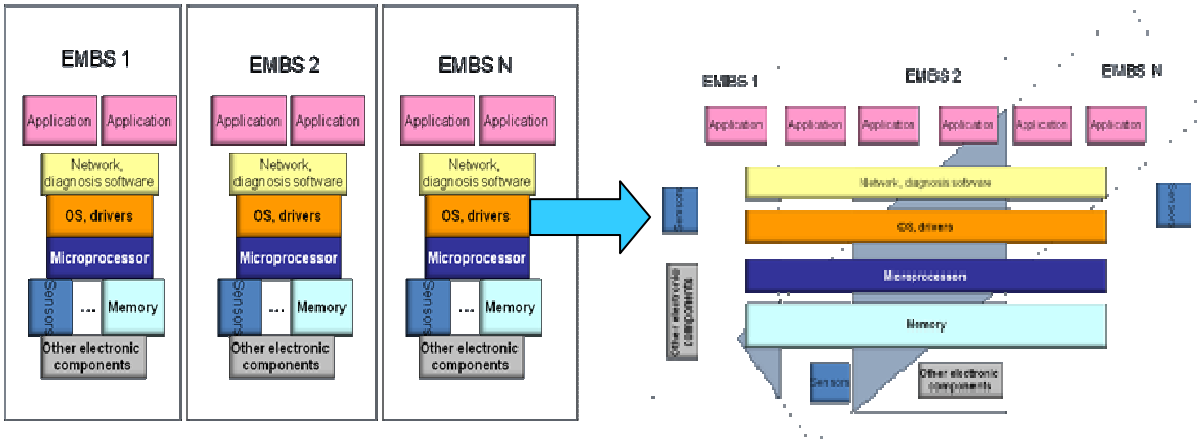
Quote from: J. A. Fisher et al. (2005), page 7

Secondly, fast technological change has important impacts on our capacity and methods for measuring Embedded Systems, or indeed, DT in general.

It is interesting to observe that technologically-driven developments increasingly allow systems to "form" as volatile architectures of hardware and software components that may be very loosely tied together, both in time and in physical structures. While the systemic behaviour above is bound to exist, the system itself increasingly loses its material definition. These technologically-driven developments are defined as a transition from high hardware (silicon) dependency to high software dependency (E. Juliussen and R. Robinson (2010)). A high software-dependent system is based on a smaller number of more powerful multi-core microprocessors (including newer approaches such as System-on-a Chip or System-in-a

Package), standardised low and middleware software and sophisticated embedded software applications.

Fig. 1: From high hardware dependency architecture to high software dependency architecture in the development of Embedded Systems



These hardware platforms running complex software functions are increasingly difficult to distinguish in technological terms from the general-purpose computers.

Moreover, the microprocessors involved in performing a certain function are increasingly networked, both between themselves and with other elements of the ICT infrastructure; the latter become an essential part of a dedicated function without being themselves dedicated systems. This has complex implications for the definition.

Let us take the following example: the eCall in the automotive domain. eCall is a European Commission project which aims to provide an automatic trigger for rapid assistance after a collision. The project aims to install hardware black boxes in vehicles that will, in the event of an accident, wirelessly send information on airbag deployment, from impact sensors, and GPS coordinates to local emergency agencies. Hence, the communication function of the eCall is assisted by hardware/software mounted in the car, data transmission services, and computers and software in the emergency agencies.

This trend of increasing computing power in microprocessors and higher interconnectivity between various devices is more than likely to continue in the future and in various domains or fields.

There is no doubt that, with the increased pervasiveness of DT, the economic output of any sector already is, and will increasingly be, dependent on some “embedded digital technology”. This digital technology defines parts and components but also feeds productive processes and creates productivity enhancing synergies (including through the use of General Purpose Computers). Hence, it cannot be uniformly and exhaustively identified as a separate "product" or "service" on technical grounds only - that is to say, one cannot draw physical boundaries around a formally named an "embedded system" with a view to its further quantification. Nevertheless, the technical background is still the backbone of the entire exercise and necessarily gravitates around the use of microprocessors.

1.2. An economic view of Embedded Digital Technology (EDT) - towards an operationalized definition

Translating technical observations into economic language, we can say that a definition of the "embedded digital component" operationalized for economic analysis, can nevertheless be proxied by using several standard concepts described in Box 2.

Box 2. The techno-economic terminology used in this report

Digital technology (DT) is the set of techniques used to convert real-world information (analog) to binary numeric form, which leads to emergence of new ways of producing, storing and distributing this real world information.

Information and communication technology (ICT) is used here predominantly as summing up all technical means used for producing and handling digitized information.

There is a lot of overlap between the two concepts and they are used in this text as imperfect synonyms. We also tried to accommodate the established use of ICT within existing theories referred to in the text, even when the use of DT seemed more appropriate, in order to make those more recognizable to the reader

ICT/electronic components, hereafter called the *Hardware Component/Input (HC)*, necessarily consist of at least one microprocessor and could include various other parts or blocks, such as: memory, sensors, displays and networking equipment (bus). The level of complexity of the architecture of a HC varies considerably, from a single microprocessor to a fully-programmable computer. Most of the hardware will include some built-in **software**.

Software is contained in computer code that interacts with the HC in order to achieve one or more functions. These are called the *Software Component/Input (SC)*. Following iSuppli (2009), we split the analysis of the software block into the following layers: (1) operating systems, (2) drivers software, (3) application software and (4) diagnostic software. Following VDC (2005), we will also consider the design, development, and automation tools, especially when looking at R&D activities. We use the following taxonomy of software:

- **Enterprise/business software:** software which provides business logic support functionality for an enterprise, typically a commercial organization, which aims to improve the enterprise's productivity and efficiency (www.wikipedia.com)
- **Consumer software:** mostly off-the shelf software applications for the final consumer segment.
- **Embedded software:** computer software which plays an integral role in the electronics it is supplied with. Embedded software's principal role is to manage the interaction of various devices with the physical world (www.wikipedia.com).

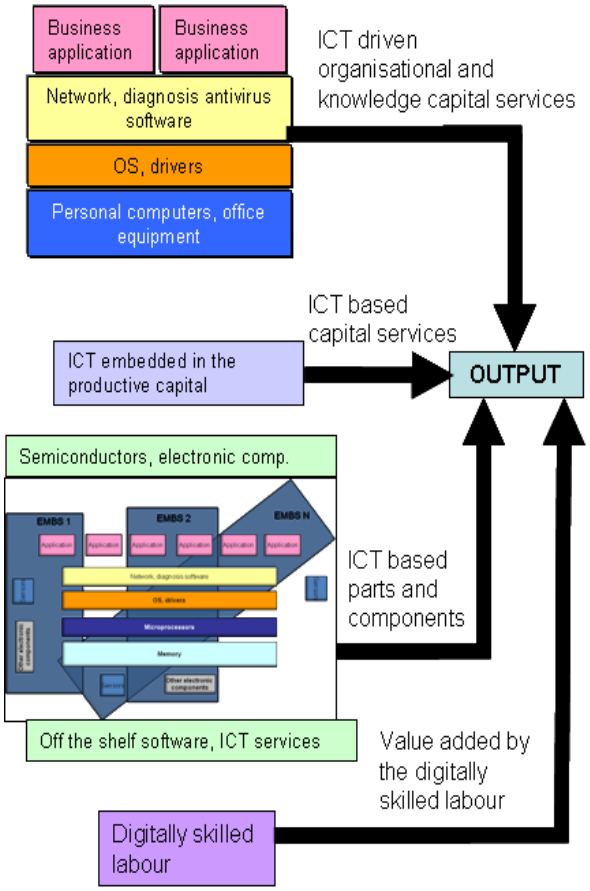
ICT Services are those concerned with electronic components and board mounting and assembly, maintenance and operation of ICT devices, IT design and development, networking, and data transmission, electronic communication etc.

A **general purpose computer** is an electronic device that receives input, stores and manipulates data, and provides output in a useful format. A general-purpose computer can perform a variety of functions according to the software implemented on it. This term refers to both personal computers and large data processing systems (mainframes). The previous section argues that it is increasingly difficult to distinguish, on a functional basis, between general-purpose computers and systems-on-a-chip, embedded in various other devices or networks (including automobiles, plains, robots and also devices such as PDAs, PSP, iPods and cellphones, etc.).

The concept of "**value chain**" used in this report is nothing more than a representation at sectoral/macroeconomic level of the supplier - customer relationships as implied by the technology rather than the market. The concept of "value" in the "value chain", is therefore straightforwardly accounted here as the value added from the economic statistics. Basically, this approach treats economic sectors as representative agents.

On the basis of the above definitions, a level of a productive unit, four ICT (DT) related inputs can be identified as in Figure 2:

Fig.2: ICT contribution to output in a generic firm



1. **ICT-based organisational and knowledge capital services** are mainly provided by general-purpose computers, enterprise/business software and office machines. ICT-based organisational and knowledge capital services (innovation rents) bring efficiency gains through improvement of business administration and information flows and through stimulating innovation when assisting design and research activities.

2. **ICT-based capital services** are mainly provided by the ICT equipment and software used as (or embedded in) the ICT and non-ICT productive capital.

3. **ICT (embedding ICT)-based parts and components** are mainly used as intermediate consumption**.** They are included as such in the final output.

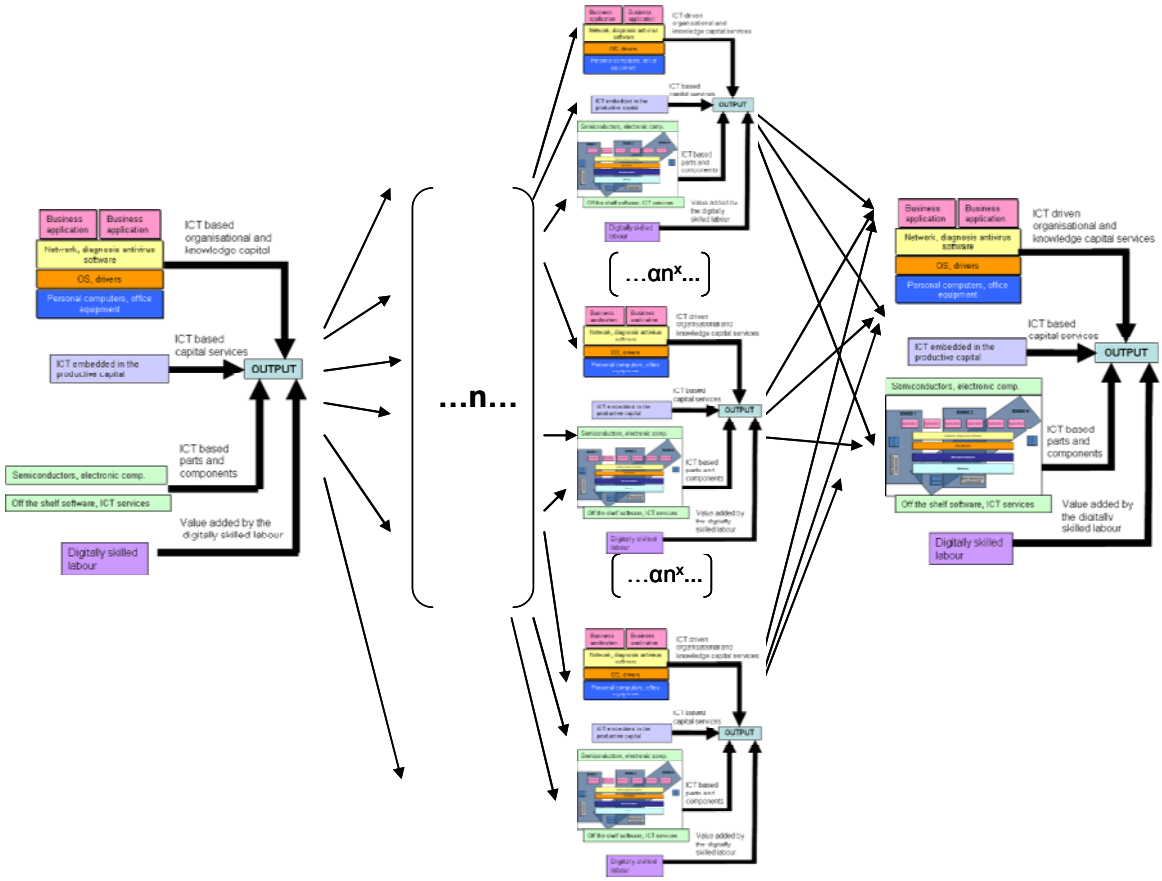
4. **Value added by digitally-skilled labour**. The contribution of ICT-skilled labour can be found at all stages of the production activity. Conceptually, the contribution of ICT labour is at the very core of value added due to ICT adoption, yet, it remains the most elusive and difficult-to-measure element of the process. The use of the ICT inputs by ICT skilled labour consists of in-house software creation and/or provision of a wide range of production and business services related with the adoption of the DT.

The combination of intermediate ICT inputs (Hardware Components (HCs - including general-purpose computers), Software Components (SCs) and ICT services), ICT labour services, ICT capital services and ICT-driven innovation rents (product, process or organisational) form the ICT component of the output value.

To define the Embedded Digital Component, or the DT intensity of the output, measurable in economic terms, one step further needs to be taken by considering the cumulative value of these ICT component along the value chain.

Along the value chain,[ii] intermediate inputs (classified as ICT products or not) are normally output from the previous productive node, and have their own ICT component defined as above (see Figure 3).

Fig. 3: ICT use along the value chain



Our all-ICT-encompassing approach broadens our understanding of Timmermann's definition (2007) in the sense that the direct systemic behaviour of a specific tandem HC+SC is broadened to the assembly of HC+SC used along that value chain. Various EDT-based equipment and components may not interact directly in the production process, but they jointly contribute to the overall production. The result of this approach is an image of the value of the total Embedded Digital Technology, rather than that of rather hypothetically isolated Embedded Systems**.**

1.3. Embedded Digital Technology (EDT) and the production function

So far the macroeconomic literature did not approach directly the issue of EDT. The dominant stream of macroeconomic literature on ICT contribution to growth applies the neo-classical growth accounting framework developed originally by Solow (1957) and of which application on ICT started mainly with Jorgenson, Ho and Stiroh (2002) and Stiroh (2002). Despite of being well-established and engaging huge refinements in statistics and measurements, the growth accounting literature proposed so far little conceptual adjustments from the original setting (Kuppusamy et.al (2008); for a comprehensive literature survey on ICT and growth accounting see for example Reenen et al. (2009), a.o)[iii].

Basically, growth accounting exercises are based on the neo-classical production function, which is applied at macro, micro or sectoral level:

(eq.1a) $Y = A * L^{\alpha} * K^{\beta} * M^{\gamma}$ (or $Y = A * L^{\alpha} * K^{\beta}$)

or in logarithms:

(eq.1b) $y = a + \alpha l + \beta k + \gamma m$ (or $y = a + \alpha l + \beta k$),

where Y is the total output (or value added), L is the labour, K is the capital and M the intermediate consumption. A, the Total Factor Productivity (TFP) or the Solow residual, is simply covering the growth emerging from synergies between factors of simply from factors unaccounted explicitly in (eq.1).

The application of this approach for accounting the growth due to the ICT starts from distinguishing between ICT and non-ICT capital mainly on a value added function:

(eq.2) $y = a + \alpha l + \beta_1 k^{nonICT} + \beta_2 k^{ICT}$

In order to account growth (eq.2) is rewritten in first differences and usually takes the form of labour productivity:

(eq.3) $\Delta(y - l) = s_1 + s_2 \Delta(k - l)^{nonICT} + s_3 \Delta(k - l)^{ICT}$

The impact of ICT on growth is mainly accounted as the capital deepening estimated by the coefficient s_2. The impact of ICT on TFP is usually estimated on industry-level databases and it is proxied by the contribution of TFP in ICT producing industries (Jorgensen, Ho and Stiroh (2008) is summarising the relevant recent literature).

Despite the criticisms brought to growth accounting methodology on various grounds (see van Reenen (2009), or Felipe and Fisher (2003) a.o) it stands as one of the more useful and powerfull tools in explaining growth. We will further refer to the limitations of the methodology to account for the ICT embedded along the value chain.

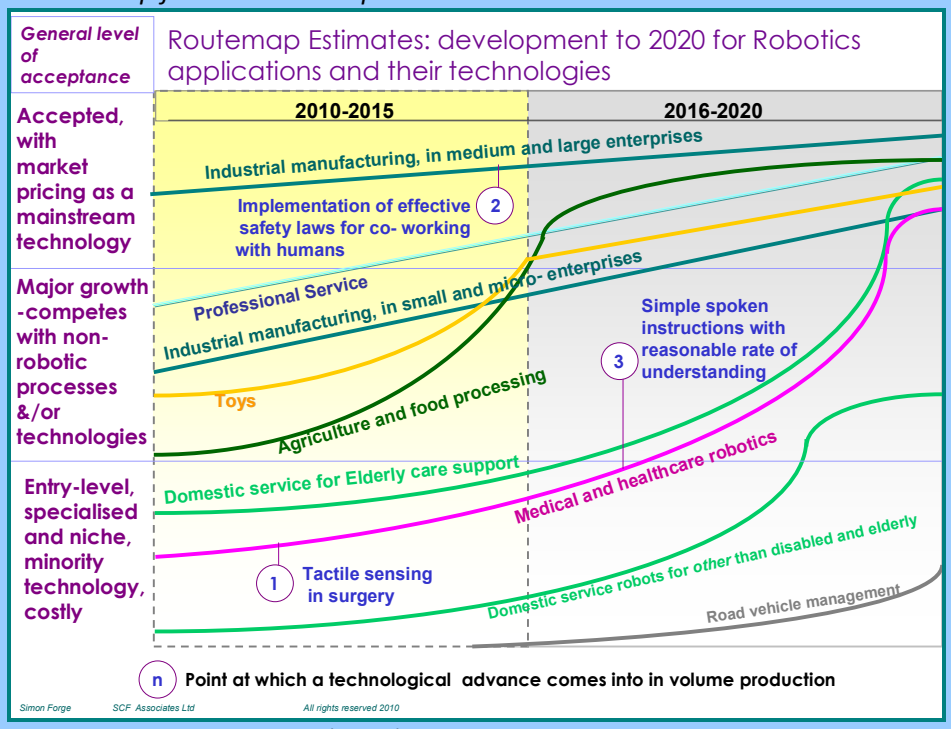
ICT embedded in the non-ICT capital and intermediate inputs

In the ICT growth accounting methodology, "ICT" stands only for general-purpose computers, software and telecommunications equipment. "Non-ICT" is all the rest of the productive capital and intermediate inputs in use irrespective of the underlying technology (see Box 3). The argument of this entire study is that this misses a lot of the ICT impact on the economy.

Box 3: Pitfall: Thinking there is a sharp line between an ICT and a non-ICT good (or service)

Industrial robots, for instance, are probably the best image of productive capital embedding ICT. The International Organization for Standardization even defines "a robot" based on its ICT content as "an automatically controlled, reprogrammable, multipurpose manipulator, programmable in three or more axes." Robots include ICT-based technologies vital for their functioning among which: Sensor fusion, Human interaction, System integration, Cognitive and learning systems, Vision comprehension systems, Positioning systems, Mobility & motion, Bio-mimetic movement, Gripping/placing, Power supplies, Swarms and co-operating robot teams, Nanorobotics (Forge and Blackman (2010)). Forge and Blackman also provide scenarios of robots take-up which are illustrative for the ICT diffusion through embedding it in capital goods in the future, which will accentuate the need for an adjusted methodology for accounting it, especially after the point at which the ICT-based technologies enter into the mass volume production.

A route map for robots take-up



Source: Forge & Blackman (2010)

Our methodology implicitly solves this problem. Except for the very first node of the value chain, we will no longer distinguish between ICT and non-ICT capital, but take into account the fact that a certain share of capital services are provided by the Digital Technology embedded into it.

To illustrate the proposed method, we start with by distinguishing between the ICT capital k^{ICT} and the non-ICT capital k^{nonICT} (standard taxonomy in the growth theory). We further distinguish at theoretical level between the ICT component of the non-ICT capital k^{embICT} and the rest of the non-ICT capital $k^{nonICT*}$, so that $k^{nonICT} = k^{embICT} + k^{nonICT*}$.

Rewriting a standard output function leads to:

(eq.4) $y = a + \alpha l + \beta_1 k^{nonICT*} + \beta_2 k^{ICT} + \beta_3 k^{embICT} + \gamma m$

Assuming that all the companies in the economy, including those that produce capital embedding ICT, have the same production function, we can replace:

(eq.5) $y = a + \alpha l + \beta_1 k^{nonICT*} + \beta_2 k^{ICT} + \beta_3 \left(a + \alpha l + \beta_1 k^{nonICT*} + \beta_2 k^{ICT} + \beta_3 k^{embICT} + \gamma m\right) + \gamma m$

Continuing the process until the first node of the value chain (where there the capital consists only in ICT capital and non ICT capital), leads to:

(eq.6) $y = \frac{1-\beta_3^{n+1}}{1-\beta_3}\left(a + \alpha l + \beta_1 k^{nonICT*} + \beta_2 k^{ICT} + \gamma m\right)$

or, under the assumption that the value chains are sufficiently long (n→∞), and knowing that the coefficients in the production function are lower than 1,

(eq.7) $y = \frac{1}{1-\beta_3}\left(a + \alpha l + \beta_1 k^{nonICT*} + \beta_2 k^{ICT} + \gamma m\right)$

The coefficient β_3 represents the contribution of ICT embedded in productive capital to the total output and affects the contribution of all the other factors.

The same can apply further to the intermediate consumption if we distinguish between ICT, non ICT and intermediate consumption embedding ICT:

(eq.8) $y = \frac{1-\beta_3^{n+1}}{1-\beta_3}\left(a + \alpha l + \beta_1 k^{nonICT*} + \beta_2 k^{ICT} + \gamma_1 m^{nonICT*} + \gamma_2 m^{ICT} + \gamma_3 m^{embICT}\right)$

and applying the same procedure as for capital:

(eq.9) $y = \left(\frac{1-\beta_3^{n+1}}{1-\beta_3}\right)\left(\frac{1-\gamma_3^{n+1}}{1-\gamma_3}\right)\left(a + \alpha l + \beta_1 k^{nonICT*} + \beta_2 k^{ICT} + \gamma_1 m^{nonICT*} + \gamma_2 m^{ICT}\right)$

if value chains are sufficiently long (n→∞) and knowing that the coefficients in the production function are lower than 1:

(eq.10) $y = \frac{1}{(1-\beta_3)(1-\gamma_3)}(a + \alpha l + \beta_1 k^{nonICT*} + \beta_2 k^{ICT} + \gamma_1 m^{nonICT*} + \gamma_2 m^{ICT})$

ICT skilled labour vs non-ICT skilled labour

The statistical definition of DT skills is discussed in detail in section 3, here is enough to specify that, for the purposes of this methodology, the ICT skilled labour (the ICT specialists (ICTs) and ICT users (ICTp)) needs to be defined on the basis of skills themselves (and the hourly input) and on not the basis of the occupation, as it is customary used as proxy in the growth accounting theory.

(eq.11)

$$y = \frac{1}{(1-\beta_3)(1-\gamma_3)}\left(a + \alpha_1 l^{ICTs} + \alpha_2 l^{ICTp} + \beta_1 k^{nonICT*} + \beta_2 k^{ICT} + \gamma_1 m^{nonICT*} + \gamma_2 m^{ICT}\right)$$

ICT and the Total Factor Productivity

The assumption of the growth accounting theory is that the TFP cumulates effects of the technology and organisational change. "Technology" here means the synergy between labour and capital, while the coefficients α and β capture all the ceteris-paribus effects of the capital and labour.

There is not much work available on the impact of ICT on the total factor productivity (as proxied by coefficient s_1) in a macroeconomic or sectoral framework[iv]. Yet, there is a lot of evidence that in the recent years the TFP in non-ICT producing sectors have increased including more than the TFP in ICT producing ones, which is attributed to the diffusion of ICT, mostly as a proxy for innovation and efficiency-enhancing organisational change.

Despite abundant microeconomic literature (for an account of the seminal papers and major contribution to this stream of literature see (Draca et al (2006)), the impact of ICT on the total factor productivity of using companies is an issue not entirely solved.

The extremely wide literature on ICT impacts on the companies´ performance explains how the emergence of information as economic good entails specific price formation process on new e-markets, generates new business models, networks and online communities, and ultimately provides two perspectives on how ICT as (information-processing technology) impacts on the productivity of a (non-ICT) company.

The first perspective simply correlates the ICT/IT capital (in sense of computers, software and telecommunication equipment in various combinations) to the labour productivity (y-l in the eq.3 notation). These works carefully account for other factors with impact on productivity as the company sector or size and came to the conclusion that typically these effects are associated with the organisational and the knowledge capital of the firm generated by the use of ICT (first of our identified effects of ICT in figure 5). Business practices as opening the access to information, empowering of the employees, using performance based incentives and investing in human capital and corporate culture, were pinpointed as factors for increasing the benefits from adopting ICT (Brynjolfsson (2005)) and can explain the huge differences between companies with respect to the ability to do so. The literature that started with Milgrom and Roberts (1990) added issues of complementarity between business practices and technologies and between various technologies as additional factor for maximising the impact of ICT on productivity.

The second perspective uses the production function in (eq. 2) $y = a + \alpha l + \beta_1 k^{nonICT} + \beta_2 k^{ICT}$ and assumes that there are two types of effect of ICT. The first simply results from treating the ICT as a form of productive capital. The second introduces various additional impacts of ICT on the TFP. We will further refer several of these approaches (that we see as potentially relevant for scaling at the macro-level) following the overview in the relevant literature made by Reenen (2009).

The total factor productivity is often regressed on sectoral or regional ICT capital to account for network effects (for a recent overview of this literature, see for example Reenen et al. (2009)). This approach also means an important point for the micro-to macro bridging: at

micro-level, it is recognised that the endowment of the firm´s environment with ICT is a source of firm-level growth additional to the ICT capital inside the firm – this possibility is lost at sectoral and macro level. This is a situation when the aggregated function describes a different behaviour of the representative agent: at microeconomic level, the representative agent would see efficiency gains from the ICT environment in the TFP (coefficient *a*), while macro-level productivity function will absorb this effect into the ICT capital coefficient (β_2).

Reenen (2009) proves empirically the existence of productivity enhancing complementarities between the company ***organisational structure*** and the ICT capital, when introducing the corresponding interaction factor in the productivity function. This effect underpins the distribution of various firms´ performance within the same market segment. Similarly with the network effects case, however, at the level of the sector (or the representative agent) the capital coefficient (β_2) should encompass this organisational structure effect as well.

ICT impacts on total factor productivity also through its role in supporting ***innovation***. This is merely possible either by enhancing the R&D activity of the firm or by acting as vehicle for adoption of product and process innovation. At the microeconomic level, Reenen (2009) accounts for the first type of effect employing a procedure similar with the one used for the organisational structure; this results into an additional, similarly constructed factor, which assumes that the use of ICT (mostly in the classical sense) boosts the R&D activity and hence the total factor productivity. We maintain in this case too the hypothesis that the impact of the organisational capital and the R&D stocks interact mainly encompassed in the capital coefficient (β_2).

Based on the rich microeconomic evidence and the supporting approaches in macroeconomic research, we simply assume that there is indeed an additional link between ICT and output which is not accounted as contribution of ICT capital to total productivity, but as the contribution of ICT-induced knowledge (including innovation).

Indeed, acquiring a new, technologically better production line or an industrial robot is expected to enhance the productivity not only directly through the implicit cost reductions, but also indirectly through reorganisation of the production process.

The product innovation channel also is clearly marked by the existence of embedded ICT. Embedding additional ICT based functions into the final good is a significant value enhancing product innovation.

Hence both the product and the process innovation (the main two rent-bearing type of innovations) are potentially heavily influenced by the embedded ICT, and their impact on the total factor productivity are to be proxied by the contribution of ICT R&D to the total factor productivity. We will note this factor as:

$$\beta_{innov}(ICT\ R\&D_i)_v.$$

Both common sense and the evidence would support the assumption that ICT R&D helps maximising companies' profits on imperfect markets and generates impact on total factor

productivity at aggregate level. For an extreme example, we could refer to the recent research of IPTS [I Tuomi, 2009] who describes in detail the market for semiconductor fabless design, a market almost exclusively for trading advance applied ICT research. It is mainstream to consider information even as a production factor, but the exact ICT impact mechanisms and its evaluation are far from being settled in the literature[vi].

Our proxying basically translates into:

(eq.12) $a = f(\beta_{innov}(ICT\ R\&D)$

Hence the final functional form of the production function above will be:

(eq.13)

$$y = \frac{1}{(1-\beta_3)(1-\gamma_3)}\left(f(\beta_{innov}(ICT\ R\&D) + \alpha_1 l^{ICTs} + \alpha_2 l^{ICTp} + \beta_1 k^{nonICT*} + \beta_2 k^{ICT} + \gamma_1 m^{nonICT*} + \gamma_2 m^{ICT}\right)$$

The coefficient $\frac{1}{(1-\beta_3)(1-\gamma_3)}$ can be interpreted as an "embedding multiplier", since it cumulates the effect of ICT embedded into the capital and into the intermediate inputs. It affect equally all the factors of the production function. This also allows us to highlight the main argument for which we propose enlarging the object of the analysis from the embedded systems to the ICT intensity of production – the contribution of embedded ICT to production cannot be meaningfully isolated from the rest of ICT inputs.

This mathematical representation is a gross simplification of the actual value chains, and should not be implemented as such in empirical exercises. It is proposed here as an illustration of the fact that ignoring the embedded ICT from the current productivity function calculations, bears a clear cost in terms of understanding channels of ICT impact.

In a more realistic setting, although still heavily simplified, at each node *i* of the value chain, the ICT output will be:

(eq.14)

$$y_i^{ICT} = f(\beta_{innov}(R\&D)) + \prod_i \beta^i{}_2 k_{i=1}^{ICT} + \prod_i \gamma^i{}_2 m_{i=1}^{ICT} + \alpha^i{}_2 l_{i,i\in[1,..,n]}^{ICTs} + \alpha^i{}_3 l_{i,i\in[1,..,n]}^{ICTp}, where: i \in [1,..,n]$$

In this formula we allow for different coefficients at each node to vary. The ICT inputs at the beginning of the value chain, $k_{i=1}^{ICT}$ and $m_{i=1}^{ICT}$ will have at each node *i* a coefficient specific to the node, also dependent of the coefficient in the previous node *i-1*.

The so-called "technical coefficients" in the input-output analysis are reasonable approximations of the coefficients $\beta_2(\beta_{i-1,}, i)$ and $\gamma_2(\gamma_{i-1}, i)$. They will identify the share of the total inputs of a sector required to be purchased from another sector. Technical (input) coefficients represent direct backward linkages of an industry to other industries. Presumably, input-output coefficients reflect technology, and these coefficients measure the input requirements per unit of product. They will be used for a first estimation of the contribution of ICT to the final output in section 3. It is worth highlighting nevertheless that the method does not allow distinguishing between the basic ICT components ($k_{i=1}^{ICT}$ and $m_{i=1}^{ICT}$) that would

result into general purpose computers from those going into embedded systems. Moreover no method applicable to macroeconomic calculations is available that would allow to meaningfully allocate a part of value added created by the ICT skilled labour (either specialists or users) to embedding digital technologies into final products.

The main critique that this approach is susceptible to is simply the relevance of the aggregate production function for this type of exercise. Felipe and Fisher (2003) make a harsh critique to the growth accounting theory, explaining that the conditions under which a well-behaved aggregate production can be derived from micro production functions are so stringent that became unrealistic. In fact, this study does not propose a growth accounting exercise at all. We used the neoclassical theory to build up a measurement framework from statistically recorded data. This is the meaning of one-to-one identification that we make later (see section 2.4.):

$$\begin{array}{l} \textit{Intermediate consumption} \\ \left\{ \gamma_2(\gamma_{i-1}, i) m_{i=1}^{ICT} \subset \gamma_i m_i \right. \\ \textit{Value added} \\ \left\{ \begin{array}{l} \beta_2(\beta_{i-1,}, i) k_{i=1}^{ICT} \subset \beta_i k_i \\ \alpha_2(i) l_{i, i \in [1,.., n]}^{ICTs} + \alpha_3(i) l_{i, i \in [1,.., n]}^{ICTp} \subset \alpha_i \\ f(\beta_{innov}) \rightarrow a_i \end{array} \right. \end{array}$$

We do not therefore econometrically identify elasticities, but use average wages and prices according to the basic theory. However, when it comes to the link between (ICT) R&D and the operating surplus, a direct statistical identification is not possible. And it is at this point where the aggregation problem and the micro to macro bridging gets most acute.

We will rely for the moment on macroeconomic estimates only and assume that the share of the operating surplus that is attributable to the ICT R&D is simply equal with the elasticity of growth of total factor productivity with respect to the growth in ICT R&D stock.

It is one of the main conclusions of this study that the analysis on the (embedded and not)ICT impact on the aggregated sectoral profits is an issue which needs further, dedicated research. We also support deepening the understanding in linking micro and macro-level estimations as a very important element in tackling this issue.

ICT R&D and the Total Factor Productivity

The elasticity of the total factor productivity to the R&D stock in general is not a completely settled issue despite the very rich literature (for an overview, see for example the bibliography of Lööf and Heshmati (2006)). Because we are targeting the macro-level for measurement, we will refer here to the results of Guellec and van Pottelsberge de la Potterie (2001) who investigate the long-term effects of various types of R&D on total factor productivity growth using data for 16 OECD countries, over the period 1980-98.

They estimate that on average, an increase of 1% in business R&D generates 0.13% in total factor productivity growth. The effect is larger in countries which are intensive in business R&D, like Germany, where an increase of 1% in the business R&D can get to 0.17% in total factor productivity growth.

More recently, this relationship is investigated using macroeconomic models. Bayard (2010) uses a set of macromodels to assess the impact of reaching the Lisbon criteria on EU economies and establishes an elasticity of 0.15% growth in total factor productivity to a 1% increase in R&D stocks. Interestingly, the same source note that while R&D expenditures of the companies have substantially increased in the latest years with the progress towards the knowledge economy, the above elasticity have maintained relatively stable.

Breaking down the elasticity of total factor productivity to the ICT R&D stock adds a very challenging layer of complexity which in itself is a subject for further research.

We identify three main sources of difficulty in tackling this problem.

First difficulty in evaluating the impact of ICT R&D on the overall profitability is simply **the measurement of the ICT R&D**. This issue will be discussed in more detail in section 3.

The operating surplus is also absorbing the price movements as established on the market. The last two specific issues that we discuss here as relevant for the impact of (embedded) ICT on the price of final output at aggregate (sectoral) level are the **pattern of appropriation of ICT-related innovation rent along the value chains** and the **specific pricing of the embedded software**. Both these factors are seen as impacting on the elasticity of operating surplus with respect to the ICT R&D expenditures.

In a classical perfectly competitive framework, the innovation rent will be distributed along the value chain corresponding to the investment in innovation. We will further argue that this is not the case for the embedded ICT.

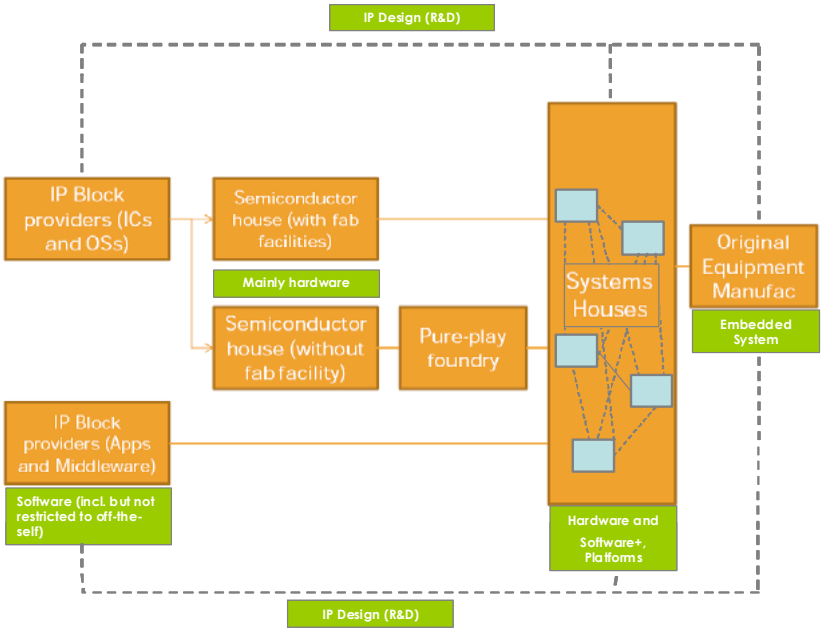
The final integrators of embedded ICT (that is the companies situated at the last node or Tier of the value chain in Porter's (1985) sense) act in markets that are often close to monopsony. They are mainly the so called OEMs (Original equipment manufacturers). They buy parts components or capital goods from specialised companies situated on lower Tiers. OEMs are particularly susceptible to the specificity described for example by Svensson (2003): a simple algorithm of incremental growth of value along the value chain does not take into account the fact that the realisation of the value of the final product takes place only on the market for the

final product. This has major implications for the mechanisms of distribution of the value along the chain:

"[...] the value chain only attains its established value at the final consumer market. Consequently, value is diffused to the firms that contribute to the fulfillness and satisfaction of the consumer driven values. Hence, what proportion of the value that corresponds to each firm in this consumer driven value chain diffusion process is a matter of competence, capacity, power, dependence, pricing and negotiations in the value chain within the firms concerned." (Svensson (2003))

The final integrator, not only acts as a gatekeeper of innovation realisation, but also holds the keys of the embedded design chain. To the original version of Martin and Schirrmeister (2002), we have added additional links between the System Houses, or OEMs, to IP Block providers in order to depict an increasingly integrated environment in which the final customer is a part of the production process. The relationships between actors are mediated through platform-based components where the software is the main tool to ensure flexibility and adaptability to various applications and needs.

Fig. 4: Stylized representation of the Design Chain for Embedded Digital Technologies



Adapted from: G.Martin and F.Schirrmeister (2002), "A Design Chain for Embedded Systems", IEEE Computer, Vol.35, issue 3, pg. 100-

Figure 4 depicts highly integrated knowledge flows driven by the OEMs requirements. The custom driven innovation and the consequent integration of the knowledge flows is the first candidate in explaining why, quite often, the second and further Tier suppliers fail to get paid fair share of the final product value added[vii].

Finally, with the increased software dependency, the role of software pricing for competitiveness of producing and using companies gathered increasing attention. It firstly

became apparent for the general-purpose computers and the enterprise/business software in the 90ties.

Saphiro and Varian (1999) are among the first economists to gather together a theory of information pricing based on the main economic feature of information goods: high sunk costs and low reproduction cost. The cost of embedded software is not negligible. Fisher et al (2005) give the example of the SonicBlue RIO MP3 player, whose software cost surpasses the cost of the processor, reaching up to 30 to 40% of total cost. Even more interesting, the same authors point that software programmer productivity is growing much less quickly than hardware designer productivity, which means that the share of EDT cost is bound to increase.

However, Saphiro and Varian (1999) argue that the software companies base pricing and license agreements on the dimensions that are most closely correlated with the value of the software as perceived by the client company than with the cost. A lot of factors contribute to this perception, among which the size and industry of the client company as well as the existing network effects. "Versioning" and price differentiation became leading strategies to lock-in customers. In 2002, the managers of the US Software Company ASG, specialized in IT business solutions, published a white paper on restructuring the software cost model (Bladich, Foret and Rowlands (2002)) which starts with a provocative statement *"There is no clear relationship between the cost, price, and value of enterprise software. This apparently simple fact has involved the buyers and sellers of enterprise software in expensive contract management and acrimonious negotiation, and put IT strategy at risk of short-term tactical purchasing decisions*".

"Pricing of software" stabilised nevertheless as theme in marketing literature since the last decade. Sites as http://www.pragmaticmarketing.com have collections of papers discussing concrete, and by now stable, strategies. This is to say that we can expect today that the average price of a given enterprise software to differ from an industry to another, while achieving to absorb the relevant part of the innovation rent.

This is not the case for the pricing of embedded software, except perhaps for the standardised software products, typically operating systems and some device drivers[viii].

The enterprise/business software benefit from a much higher level of standardisation than the embedded software without equally stringent resource constraints, operational quality and safety requirements, high hardware dependencies, and ever increasing complexity. The level of customisation is very high in the case of Embedded Software hence the per-unit cost is often more important than initial software development cost and actually used as base in the pricing models. Puissochet (2005) claims that the bulk of Embedded Software is still sold together with the hardware, and that the price of Embedded Software is simply estimated at cost value. Usually, the cost for software is decided based on estimates of development costs and paid as a lump sum, added to the subsystem cost. From this perspective there is no innovation rent arising from Tier 2 levels providing software[ix].

Unlike the enterprise or basic customer software, the Embedded Software, manages interaction with the physical work and quite often can affect directly the health and life of humans. Error-free software does not exist and the risks of software failures in running

healthcare devices, industrial robots or vehicles, put a very high value on insuring their reliability and safety. Due to the inner nature of embedding, the liability cannot but stay shared between the software providers of embedded software and their clients (Tier 1 or the OEMs). It is usually the client who assumes the cost of software failure; hence it is the client who appropriates the bulk of the related value added along the value chain[x].

Consequently, the embedded software generates (for the client enterprise) value added that is disproportionately higher than its acquiring cost, typically settled at the unit development costs. It will appear as a specific ICT-related contribution to the mark-up or the total factor productivity in the Tier-1 and OEMs companies. To our knowledge, no study was yet dedicated to analysing this effect in a production function approach, and data availability would stay a major issue in resolving this.

Notes in this section

[ii] The value chain as presented above is inherently linear while the economic process has much more complex dynamics. The linear representation has nevertheless the merit of eliminating irrelevant complications in our approach, bearing in mind that the methodology that we will propose later is based exctly on liniarising the value chains by triagularisation of the Input-Output tables.

[iii] The most important of the adjustments are related with accounting for the quality of human capital (Aghion and Howitt (2009), Sianesi and Van Reenen (2003) , Bart van Ark, Mary O'Mahony, and Marcel P. Timmer (2008) etc.

[iv] Some macroeconomic models account for ICT as factor of TFP growth (see for instance the IFs model (www.ifs.du.edu; Szewczyk (2009) implements such estimates into the GTAP model and describes the functional form of this impact).

[v] The alternative method is to introduce the R&D as a form of capital. This option does not fundamentaly change the discourse of this study. We prefer looking for the elasticity of total factor productivity to the R&D expenditures because input-output statistics does not include so far the R&D stock as a form of capital

[vi] IPTS plans to dedicate an important share of the running project of Modelling the Digital Economy to estimating the sectoral elasticity of total factor productivity to ICT R&D and integrating it into a macro model.

[vii] For a discussion on the Automotive industry case, see Booz/Allen/Hamilton "Tier 1 Automotive Suppliers Building Advantaged Positions", available at: http://www.boozallen.de/media/file/tier_1_auto_suppliers.pdf.

[viii] Fisher et al.(2005) report payments of royalties for software intellectual property for such standardised embedded software on the order of 2 to 3% of the cost of the core itself.

[ix] The structure of the EDT design is not stable, but reflects the transition of the underlying technology from high hardware dependency to high software dependency. There is a process of slicing the value chain fed by the increased separation between the HC and SC. Software companies (IP block providers) will increasingly specialise in providing standardised Open Source and other software such as off-the-shelf commodity products; semiconductor houses will continue to advance in materials and hardware-dependent solutions; and applications will remain at the level of OEMs and their first tier suppliers (system integrators).

Puissochet (2005) as well as iSuppli (2009) see AUTOSAR (an open and standardized automotive software architecture, jointly developed by automobile manufacturers, suppliers and tool developers) as additionally contributing towards a more "software as a product" business model.

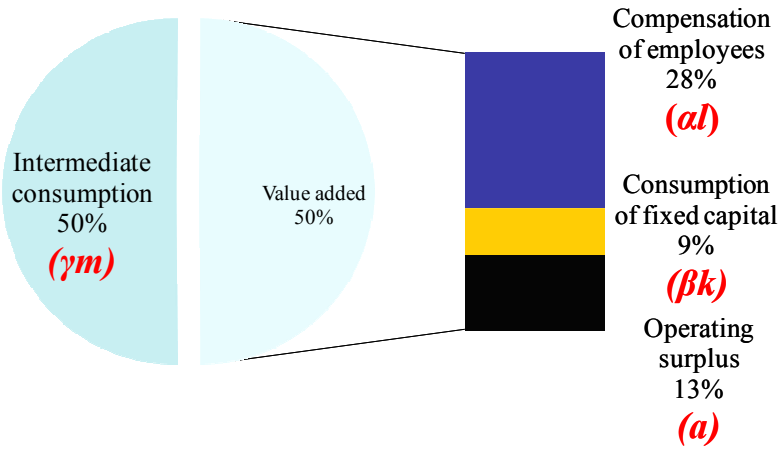
ITEA Roadmap 2009 (http://www.itea2.org/attachments/508/ITEA_Roadmap-3.pdf) points instead towards the possibility of a future ecosystem led by the "software as a service" business model on the basis of a more industrial approach, where a software integrator combines various products in order to provide the final customised solution. From an economic point of view, the increased slicing of the value chain implicit in both cases means more horizontal markets, the structure of which will determine the way the value added is distributed along the vertical value chain. The restructuring of the markets is expected to be first seen only by 2014 (ITEA Roadmap (2009) and the liability issue is nevertheless likely to remain longer an important determinant of the value chain structure.

[x] The software provider does not control the use that the final OEM or the Tier1 give to the software and, more importantly, can not normally participate to the testing of the final product. For these reasons, the recommendations of the Association of European Suppliers for Automotive Software AESAS (http://www.aesas.org/Texte/AESAS_liability.pdf) are to limit de responsibility of the providers. Puissochet (2005) also highlights that the software suppliers simply cannot afford the cost of a car recall. Hence, sales of software continue to be associated with some hardware and covered by the Tier 1 or the OEMs. Forge & Blackman (2010) analyse in detail the issue of robots safety (industrial robots and healthcare robots) and reach similar conclusions.

2. Applying the proposed methodology

The statistical decomposition of the (eq.1b) $y = a + \alpha l + \beta k + \gamma m$ corresponds with the structure of output as estimated in the input/output table, as follows:

Fig.5: Structure of the output value, Germany, 2005



Source: EUROSTAT

This decomposition is available at sectoral level, and is at this level that we will try to identify the ICT component in each subcategory as follows:

Intermediate consumption

$$\{\gamma_2(\gamma_{i-1}, i)m_{i=1}^{ICT} \subset \gamma_i m_i \qquad \gamma_i = inputs\ prices$$

Value added

$$\begin{cases} \beta_2(\beta_{i-1,}, i)k_{i=1}^{ICT} \subset \beta_i k_i & \beta_i = capital\ \ prices \\ \alpha_2(i)l_{i,i\in[1,..,n]}^{ICTs} + \alpha_3(i)l_{i,i\in[1,..,n]}^{ICTp} \subset \alpha_i & \alpha_i = wages \\ f(\beta_{innov}) \rightarrow a_i & \end{cases}$$

This section will approach each of these categories in detail (except the total factor productivity, a_i where we will limit to providing some hints on evaluating the ICT R&D investments).

2.1. EDT intermediate consumption ($\gamma_2(\gamma_{i-1}, i)m_{i=1}^{ICT} \subset \gamma_i m_i$)

The objective of this section is to suggest methodological solutions to the basic question of the share of ICT intermediate consumption in various groups of products.

The main sources of data that can be used for this purpose are the Supply-Use Tables (SUTs)[xi] and symmetric Input-Output tables (IOTs)[xii]. Data is in monetary values.

2.1.1. The method

According to Eurostat, the European System of Accounts ESA95 has established that European Member States must transmit tables of their input-output frameworks. This

obligation has been in force since the end of 2002. In detail, they must submit annual SUTs, five-yearly symmetric IOTs, symmetric IOTs of domestic production and symmetric IOTs of imports. All these collections cover the period from 1995 onwards. The data publicly available at Eurostat covers 60 product groups (classification CPA[xiii] P60) and 60 industries (NACE Rev.1 A60).

Much more detailed data is available at a working level of the SUT tables. For instance in Germany, tables are available for about 1,700 kinds of goods (Greiner, 2007). According to Statistics Sweden, SUTs could be made available for 400 products. This immediately makes the use of a SUTs and IOTs–based approach very suitable for exploring the production and use of EDT-based products and services.

Moreover, regarding the underlying National Accounts methodology, important progress has been already made in identifying the production and diffusion of ICT at detailed level using SUTs, especially in the case of Germany. Greiner (2007) translates the OECD definitions of ICT goods and services (containing ICT goods and services of an ICT nature[xiv]) to the CPA classification (which only groups the products and services likely to be produced in certain industries) and also to the National Accounts Framework. Greiner (2007) essentially proves that the above analysis can be implemented at a much higher level of breakdown leading to a more refined measurement at product level.

It is worth noting that, for a selection of European countries (France, Germany, Denmark, Sweden, Italy, Finland, Netherlands and Czech Republic), the share of ICT goods and services produced by the non-ICT sectors is estimated in the vicinity of a statistical error (5% of the total supply of ICT, respectively 0.2% to 0.4% of the total supply)[xv,xvi]. This calculation, based on the intermediary consumption tables, includes computer services, but not software produced in-house (the own-account software). It basically substantiates our assumption that the ICT sector is the main producer of ICT goods and services, excluding software. Software, either bought or produced in-house, is instead treated as an investment, and hence becomes a direct component of the value added.

For the <u>estimation of the share of ICT intermediate inputs in total domestic output</u>, we would propose that the central input-output analysis model is applied at detailed product level, on IOTs. This approach is in line with the methodology used in several recent policy papers (see EC (2007 a,b))[xvii].

Input-output analysis has often been used to study the impact of final demand on output (quantity model) and value added changes on prices (price model). Appropriate extensions of the input-output system also allow us to evaluate the direct and indirect impact of economic policies on other economic variables such as labour, capital, energy and emissions (joint product). Most of these policy issues (labour policy, structural policy, fiscal policy) have to be analysed with macroeconomic models which provide a minimum of sector disaggregation (ESA Manual, 2008).

The following extension of the input-output equation system offers multiple approaches for analysis:

$$Z = B[I - A]^{-1}Y$$

B = matrix of input coefficients for specific variable in economic analysis (intermediates, labour, capital, energy, emissions, etc.)

I = unit matrix

A = matrix of input coefficients for intermediates (that is the breakdown of the intermediate costs per products)

Y = diagonal matrix for final demand

Z = matrix with results for direct and indirect requirements (intermediates, labour, capital, energy, emissions, etc.).

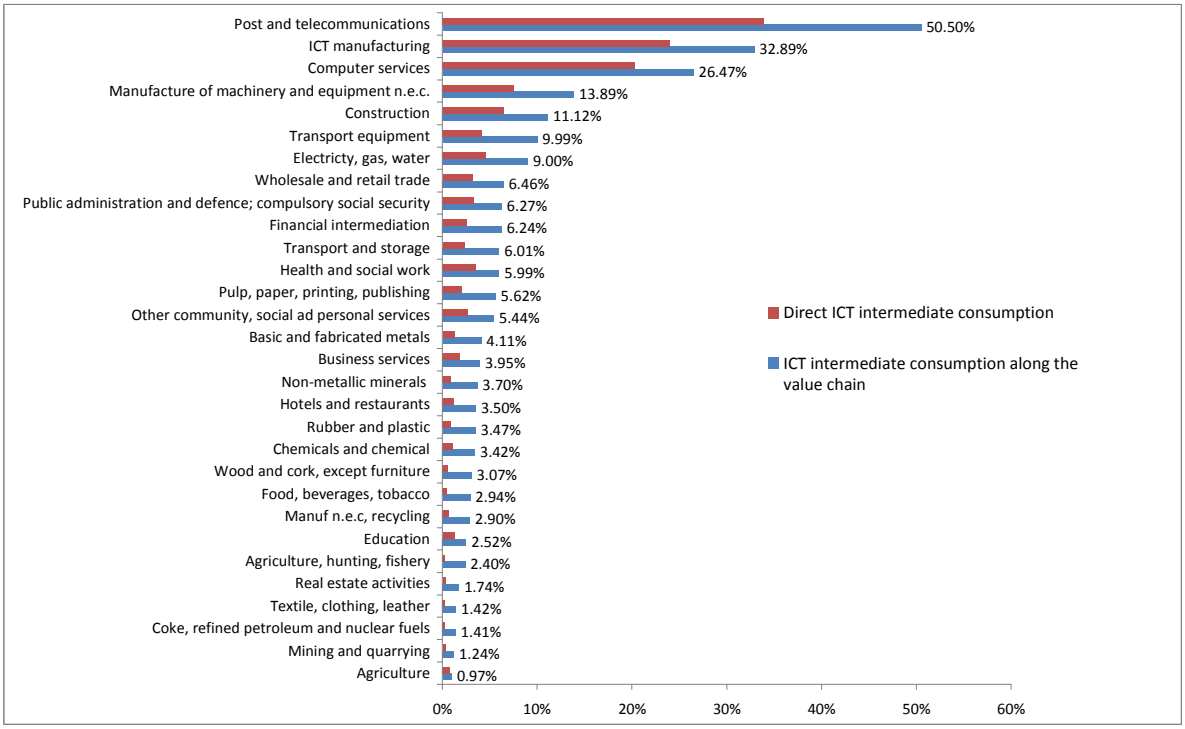
2.1.2. An example

To illustrate the proposed methodology, we will start by running this exercise for ICT goods and services following an extended definition, namely NACE 30 (IT Equipment) to NACE 33 (Measurement Instruments), NACE 64 (Post and Telecommunications) and NACE 72 (Computer Services).

The matrix: $X = B[I - A]^{-1}$ will give the amount of ICT goods and services that would be created through the entire value chain for every euro of the final demand. We will call this **ICT intermediate consumption per product, or in the mathematical notation in Section 2, the** $\gamma_2(\gamma_{i-1}, i)m_{i=1}^{ICT}$. In essence, this approach allows us to assess the total (direct and indirect) primary ICT requirements for the production of the final demand which can be observed at all stages of production.

The results for Germany are presented in Figure 5.

Fig. 6: ICT intermediate consumption per output, Germany, %, 2005



Source: Own calculations based on German SIOT for 2005, as published by Eurostat

If we use as an example the Transport Equipment industry, the results above read as follows: for every €100 of final demand for a vehicle (transport equipment) there will be an expense of €9.99 for hardware and IT services along the value chain.

Most of the software is not included in the above calculations. According to the National Accounts methodology, the software, either bought separately or together with the hardware or produced in house, is considered as Gross Fixed Capital Formation if its span of use is over 1 year[xviii].

2.2. Consumption of EDT capital ($\beta_2(\beta_{i-1,}, i)k_{i=1}^{ICT} \subset \beta_i k_i$)

The objective of this section is to suggest methodological solutions to the basic question of the share of ICT capital services in various groups of products.

The main sources of data that can be used for this purpose are the Supply-Use Tables (SUTs)[xix], symmetric Input-Output tables (IOTs)[xx] and the EUKLEMS database (http://www.euklems.net/). Data are expressed in monetary values.

2.2.1. The method

The availability of investment series by asset type and by industry is one of the most important characteristics of the EU KLEMS database. The data is based on series obtained from national statistical institutes, and allows a detailed industry-by-asset analysis. According to the SNA93 methodology, the data is collected for 18 product groups, which include three ICT assets (office and computing equipment, communication equipment and software). Timmer et al (2007) describe in detail the methodology behind the calculation of all series on

investment. For the 11 countries for which data on capital is available for the last EU KLEMS data release (2008), the project provides various capital data series, including the capital compensation broken down into ICT and non-ICT. This is an excellent basis for illustrating the proposed methodology.

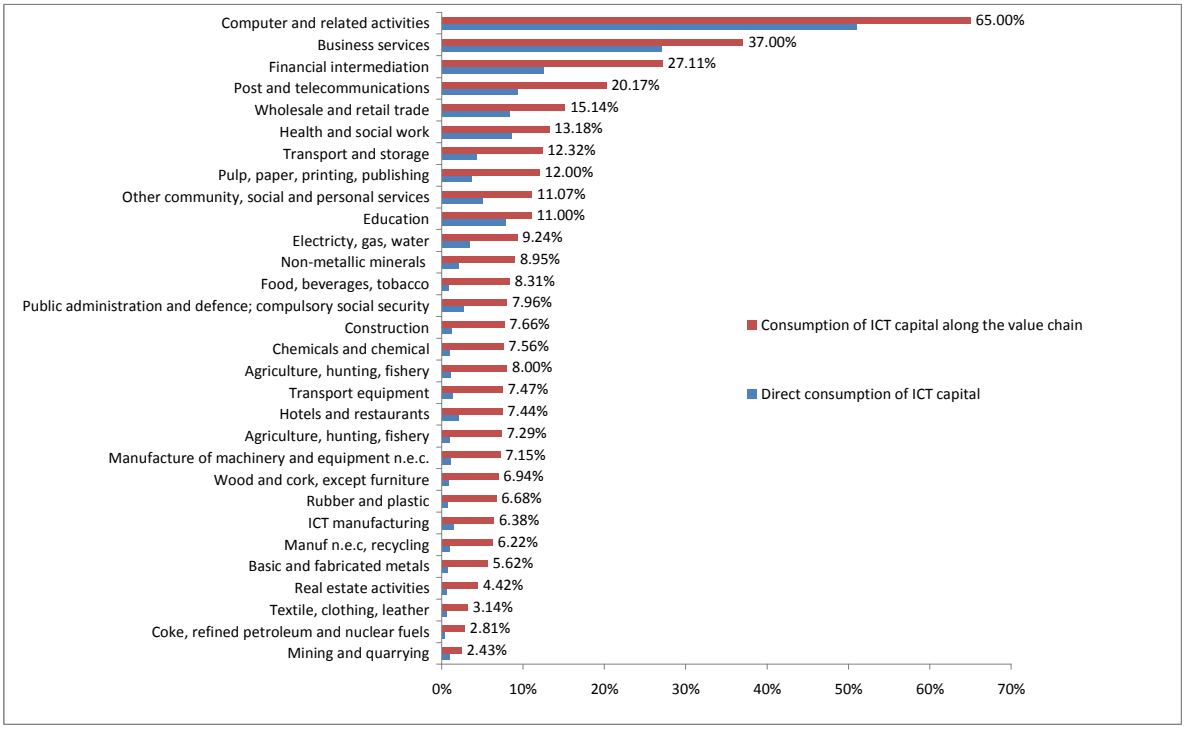
The method of calculating the consumption of ICT capital, direct and along the value chain is the one used for the ICT intermediate consumption.

2.2.2. An Example

We will use the same extended definition of the ICT goods as in the previous section. In this case the vector B will be represented by the consumption of ICT capital and the matrix: $X = B[I - A]^{-1}$ will give the consumption of ICT along the entire value chain for every euro of the final demand. We will call this **ICT capital consumption per product, or in the mathematical notation in Section 2, the** $\beta_2(\beta_{i-1,}, i)k_{i=1}^{ICT}$. In essence, this approach allows us to assess the total (direct and indirect) ICT capital requirements for the production of the final demand which can be observed at all stages of production.

The results for Germany are presented below.

Fig. 7: ICT capital consumption per output, Germany, % 2005



Source: Own calculations based on German SIOT for 2005, as published by Eurostat

This result reads as follows: for each €100 of final demand for transport equipment goods, along the value chain an equivalent of €7.47 of ICT capital is consumed[xxi]. This includes the software purchased or produced in-house, as well as ICT equipment used in the production process. Adding the ICT intermediate consumption and the consumption of ICT capital allows us to say so far that for each €100 demand of an average transport vehicle, €17.46 will

be spent along the value chain for ICT goods and services. This figure might seem rather low when compared with the existing sector studies which claim that a share of 20% - 30% of the value of a top range car is due to ICT.

Some qualifications apply: first of all, the level of aggregation at which our calculations are made is relatively high, in the sense that the industry called "Transport Equipment" produces cars, trucks, boats, bicycles etc, with various degrees of sophistication and also spare parts, containers, trailers, repair and maintenance services etc. The results might look different if similar calculations are made at an even higher level of disaggregation, because it would allow us to concentrate on higher tech products of the sector (like cars). However, the estimation made by Juliussen and Robinson (2010) for cars and light trucks situate the share of embedded ICT in the retail value of these vehicles at 18% (worldwide average)[xxii].

Secondly, the dependence of these types of calculations on the current quality of estimations of software production and usage, in particular of the own-account software, is equally important. There are statements in the literature[xxiii] which claim that current methodologies underestimate software investment. The focus on improving the quality of these estimations is central to the new Eurostat pilot study on IT investment, and should ideally help obtain a better measurement of Embedded Software throughout the economy. At the moment, it does not seem likely that this will be possible soon.

Thirdly, a more difficult implementation - related problem regards the treatment of imports. Imports of course will also have an digital content that need to be taken into account, while input – output technique above allow calculating the $\prod_{i=1}^{n}\gamma_2^i, \prod_{i=1}^{n}\beta_2^i$ *and* $\prod_{i=1}^{n}\alpha_{2s}^i, \prod_{i=1}^{n}\alpha_{2p}^i$ coefficients on domestic tables only[7].

To conclude the discussion on the use of the general national accounts framework, it is worth mentioning that once this framework is put in place, it will be possible to run a myriad of analyses[xxiv].

2.3. Digitally skilled labour input ($\alpha_2(i)l_{i,i\in[1,..,n]}^{ICTs} + \alpha_3(i)l_{i,i\in[1,..,n]}^{ICTp} \subset \alpha$)

The objective of this section is to suggest methodological solutions to the basic question of the share of ICT labour inputs in various groups of products.

The main sources of data that can be used for this purpose are the Labour Force Survey data and Revenues Survey data.

2.3.1. The method

The main source of labour data available for all 27 Member States is the European Union Labour Force Survey (LFS). EU LFS results are classified in accordance with the following international systems:

[7] IPTS currently attempts to develop a solution using multi-region input-output tables.

- **Geographical distribution**: the **country codes** are based on (but do not fully conform to) the ISO 3166 (International Organisation of Standardisation; the **regional codes** are the NUTS II and the corresponding statistical regions for the EFTA and Candidate Countries.
- **Education:** the **level** and **field of completed and current education**, are based on ISCED-97.
- **Occupation** uses ISCO-88 (Com) on 4 digit level (3 at the minimum) for the main job and 3 digit level for the previous occupation.
- **Economic activity** uses NACE rev. 1 (from 2005 NACE rev.1.1) on the 3 digit level (2 at the minimum) for the main job and the 2 digit level for the other job descriptions. **Professional status** is based on ICSE-93.

  (http://circa.europa.eu/irc/dsis/employment/info/data/eu_lfs/LFS_MAIN/LFS/LFS_STATISTICAL_CLASSIFICATIONS.htm).

For the purpose of this exercise, the following selection seems useful:

- **geographical**: EU27 country level;
- **economic activity**: two digit level NACE Rev.1.1., matching the breakdown of Input-Output tables;
- **professional status:** all employed
- **occupational status:** ICT-related occupations defined by OECD publications using ISCO-88:

Narrow definition: IT specialists or practitioners group[xxv]:

213: Computing professionals
312: Computer associate professionals
313: Optical and electronic equipment operators
724: Electrical and electronic equipment mechanics and fitters

Broad definition: attempt to capture those classified as IT specialists, as well as those who can be considered as sector specific users and generic users

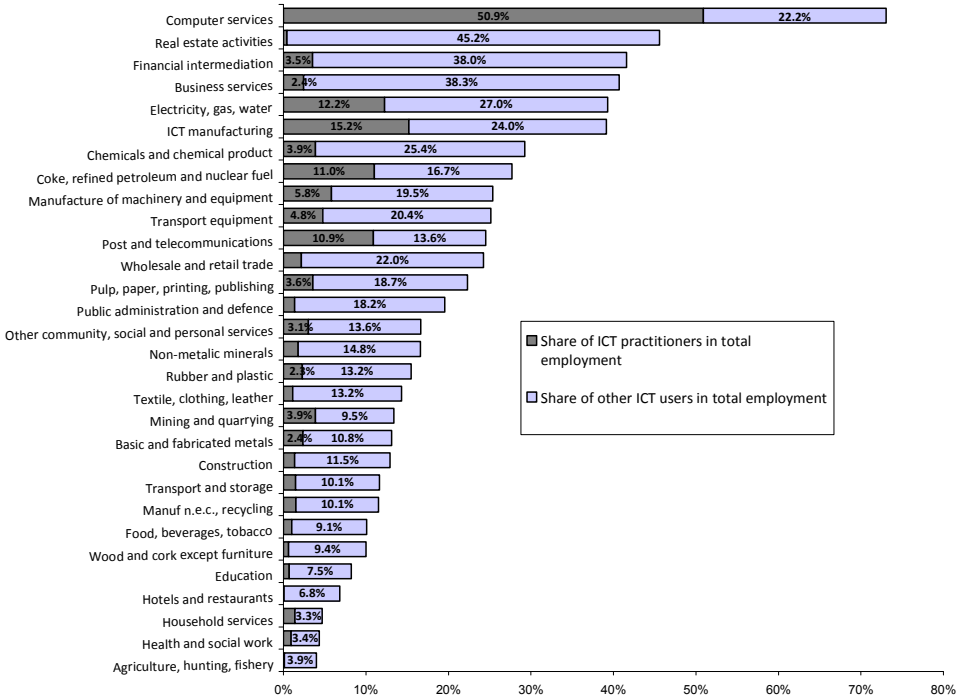
121: Directors and chief executives
122: Production and operations managers
123: Other specialist managers
211: Physicists, chemists, and related professionals
212: Mathematicians, statisticians and related professionals
214: Architects, engineers, and related professionals
241: Business professionals
242: Legal professionals
243: Archivists, librarians, and related information professionals
341: Finance and sales associate professionals
342: Business services agents and trade brokers
343: Administrative associate professionals
411: Secretaries and keyboard-operating clerks
412: Numerical clerks

We need to gather separately information on labour inputs and wages to compute the labour cost variable. Data on wages is collected at national level from revenues surveys.

2.3.2. An example

The purpose of the exercise is to identify the share of the ICT skilled labour cost in total labour cost and apply the same methodology as for indicators 1 and 2 to evaluate the ICT labour inputs along the value chain.

Fig. 8: Share of ICT-skilled personnel, Germany, % 2005



Source: Own calculations based on German Labour Force Survey for 2005

At the national level, 20% of the total employment is made up of ICT users and 3.2% of ICT practitioners. Although the ICT users contribute through their ICT secondary skills to value added, it is impossible to estimate share of the working time that they spend performing ICT related tasks. We suggest restricting the proposed type of calculations to the ICT practitioners.

German National Statistical office[xxvi] kindly provided data on wages (labour costs/employees) on ISCO88[xxvii] codes at aggregated level. According to these data, in Germany, 2005, the labour cost of ICT practitioners surpassed the national average by 34% and the wages of ICT users surpass the national average by 24%. Hence, at the level of the entire economy, the labour costs of ICT practitioners represent 4.2% of total labour costs and of the ICT users 23.6%. Labour costs instead reach 56% of the total GDP (total value added), hence the labour costs of the ICT skilled staff cover 13.2% to the GDP (users) out of which 2.3% of the GDP are the labour costs of the ICT practitioners.

This information allows completing the full calculation of this indicator (not provided here).

2.4. ICT/EDT R&D research expenditures ($f(\beta_{innov}) \rightarrow a_i$)

The objective of this section is to suggest methodological solutions for the measurement of EDT's contribution to overall research expenditures and performance. Once evaluated, this measure will help estimate the contribution of ICT to average sectoral profitability $f(\beta_{innov}) \rightarrow a_i$

The main instruments that can be used for this purpose are labour data, and R&D data, possibly corroborated with company surveys and patent data.

2.4.1. The method

The data on ICT R&D in non-ICT sectors available today comes from the OECD (2008), Stifterverband (2007) and Vinnova (2007) and is based on stand-alone, non-harmonised surveys. Their conclusion is that the share of ICT R&D performed in non-ICT sectors in total ICT R&D is: 30% in Germany, 24% in Japan, 20% in Denmark, 25% in Norway, 25% in Check Republic, 25% in Sweden and up to 60% in Australia (mainly due to the banking sector).

The data for Sweden presented in VINNOVA (2007) relies on two types of questionnaires, one on enterprise level research and one on research on main groups of products, very similar to the OECD R&D questionnaires. Mainly, the industry and the product groups can be separated into ICT sector and non-ICT sector. The data results simply from cross-checking the two, and is the closest to the potential objective of this research. However, very few countries collect R&D data on both activity and product levels. Data for Sweden stopped being published in 2005.

Knowledge on the use of R&D data for such estimations is gathered by the OECD, in particular as part of the efforts around the construction of the ANBERD database. Currently, Eurostat and the OECD conduct harmonised data collections for R&D data. At industry-level, this is done through 2 tables, one based on principal activity (C.E.8.1), and, recently, one on product field (C.E.8.2). The ANBERD database is used for several OECD reports, such as the Research and Development Statistics (RDS) publication (annual) and MSTI (biannual) and should be consistent with what Eurostat publishes. ANBERD is an "analytical" database which means that the OECD makes some estimation to reclassify data so as to adjust for some differences in methodologies across countries. In principle, it tries to be closer to a product field approach, so it uses as a basis Tables C.E.8.2 when these are available, additional submissions from countries, and other external data. Therefore, ANBERD figures will in principle often not be the same as those published by Eurostat, except for countries which collect data only by product field (and submit it via C.E.8.2).

Analytically, ANBERD data may be more suitable for our purpose. However, country coverage is reduced and it is not entirely compatible with other similar data published elsewhere. Moreover, since 2005, the OECD has harmonised its R&D data collection with that of Eurostat, without any further processing.

Regarding country coverage, the countries providing data both at enterprise level R&D and at product level R&D are the Czech Republic, Finland, Italy and Malta. Sweden could be added to this list as it publishes similar data, but does not send them to OECD. However, according to Perani (2009), due to the sample selection of companies for the survey, the results of the data collection on fields are, as expected, close to the results on principal activity.

Currently, countries can choose to fill out the questionnaires for either the OECD database or the Eurostat database, depending on how they collect their data[xxviii].

It does not appear to be feasible to impose the obligation on countries to collect data for both questionnaires. This is why we welcome Eurostat's proposal to collect the data on a questionnaire containing main activity and socio-economic objectives of intra-mural R&D.

The data is collected and provided on voluntary basis. No results are yet available. Moreover, both the cross data on NACE/NABS and the national R&D data cannot be made available through Eurostat and have to be requested from the NSIs.

Last but not least, the level at which data would be collected is NABS 1 digit, from which ICT R&D would be difficult to isolate because the NABS classification is on the final objective of the research, and not on the nature of the research.

Dedicated surveys could be another source of data. However, we expect huge sectoral variation, and setting-up EU-wide, or even country level, surveys representative at sectoral level would be a lengthy and costly exercise. A reasonable starting point could be a dedicated survey at the level of one sector (see Chapter 6).

In this study we will use labour data to proxy the distribution of R&D expenditures to make a rough estimation of the ICT R&D intensity of various products.

Our basic assumption is that ICT R&D for non-ICT products is mostly dedicated to DT embedded in the respective goods (see Section 4.2, paragraph "Some limitations and the way forward"), the share of ICT researchers' labour cost in total researchers labour cost would proxy the ICT R&D effort.

It is also reasonable to assume that ICT R&D would be performed by ICT specialists (see Section 4.1.5 for a description of the LFS data and the definition of ICT specialists).

In general, ICT R&D staff is defined as ICT staff with a higher education level. Hence the variable education status is needed from the EU LFS when we are looking for ICT R&D personnel in this understanding. However, according to VDC (2006), developers with higher degrees amount to about 50% of the total number of staff working on the development of EDT. For this reason, we suggest considering the total number of ICT specialists as a proxy for the staff involved in ICT research.

We define ICT R&D workers as ICT specialists with or without higher education (ISCED 5 and 6), then at the level of the economy, specialists in all fields with or without higher education (ISCED 5 and 6), as proxy of the R&D workers. In practice, the accepted corresponding definition and terminology refers to the *highly-qualified workers in science and technology* (HRST in Eurostat definition, elaborated from EU LFS data following the guidelines of the *Canberra Manual, OECD, Paris, 1994*). It is defined as it follows:

• **HRST — Human Resources in Science and Technology**

Individuals who fulfil at least one of the following conditions: having successfully completed tertiary-level education in an S&T field of study (ISCED'97 version levels 5a, 5b or 6) or/and working in an S&T occupation as professionals or technicians (ISCO '88 COM codes 2 or 3).

• **HRSTC — Core of Human Resources in Science and Technology**

Individuals who have both successfully completed education at the third level in an S&T field of study (ISCED '97 version levels 5a, 5b or 6) and are employed in an S&T occupation as professionals and technicians (ISCO '88 COM codes 2 or 3).

• **HRSTO – HRST in terms of occupation**

Individuals who are employed in an S&T occupation: professionals (ISCO '88 COM code 2) or technicians and associate professionals (ISCO '88 COM code 3).

• **SE — Scientists and Engineers**

Individuals employed as physical, mathematical and engineering professionals (ISCO '88 COM code 21) or life sciences and health professionals (ISCO '88 COM code 22).

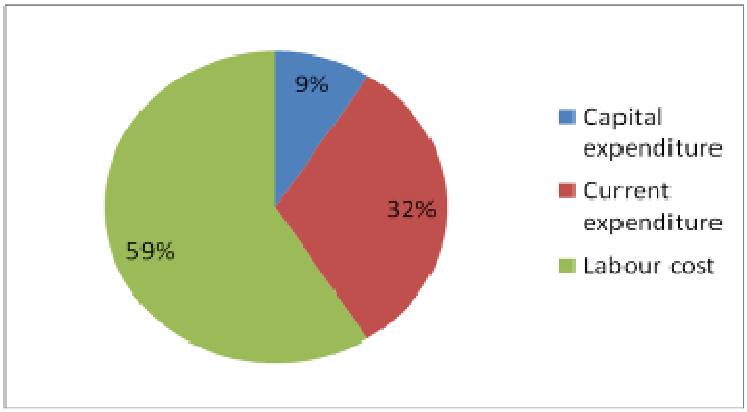
Our definition of ICT researchers is HRSTO_ICT, or Human resources in ICT Science and Technology, or HRSTO_ICT)[xxix].

The method simply uses the labour force to breakdown the overall Business R&D expenditures on field of research.

2.4.2. An example

According to Eurostat, Germany´s BERD for 2005 breaks down as follows:

Fig.9: Composition of total R&D expenditures, Germany, 2005



Source: Eurostat database

The main results of an exercise done for Germany are presented below.

Germany	2005
Share of Human Resources in Science and Technology (HRSTO) in total employment	37%
Share of ICT-related occupations in HRSTO (narrow definition)	8.7%

Source: Author's calculation based on EU LSF micro data

For 2005, the year we are interested in, and the last indicator in the table above, we first disaggregate the total economy into ICT and non-ICT sectors:

Germany		2005
1.1	Share of ICT-related occupations in HRSTO (narrow definition)	8.7%
1.2	- in ICT sectors	47.9%
1.3	- in non-ICT sectors	5.9%
2	Labour cost ratio: HRSTO_ICT / HRSTO	1.02

Source: Author´s calculation based on EU LSF micro data German National Statistical office data on labour costs on ISCO88 codes (indicator 3).
Note: Data on labour costs has been made available for us only for 2006 and only on two digits ISCO88, hence we use as definition of ICT employment the ISCO88 codes 12, 21, 24, 34 and 41 (broad definition) and the ISCO88 codes 21, 31 and 72 for the narrow definition.

According to Eurostat, the total economy Business Expenditures for Research and Development (BERD) for Germany was €38,651.04 million in 2005. BERD in ICT sectors is estimated by Ulbrich et al. (2008) at: €8,630.9 million.

If we assume that:

1. the human resources market in science and technology is perfectly competitive,
2. ICT and non-ICT sectors have the same ratio between the current and capital R&D expenditure / researcher,
3. human resources in ICT science and technology is a good proxy for the distribution of the ICT research staff,
4. irrespective of the nature of capital and current expenditures, the nature of the R&D activity for which they will be used is dictated by the distribution of R&D staff,

……then we may conclude that BERD financing the research which is ICT by nature will be:

$$BERD^{ICT}_{all\ sectors} = BERD^{ICT}_{ICT\ sectors} + BERD^{ICT}_{non-ICT\ sectors} == \left(\frac{1}{(1+\frac{0.521}{0.479*1.02}}\right) * (8630.9) +$$

$$\left(\frac{1}{(1+\frac{0.941}{0.059*1.02}}\right) * (38651.04 - 8630.9) = 4177 + 1804.5 = 5981.5\ mill.euro$$

which breaks down into:

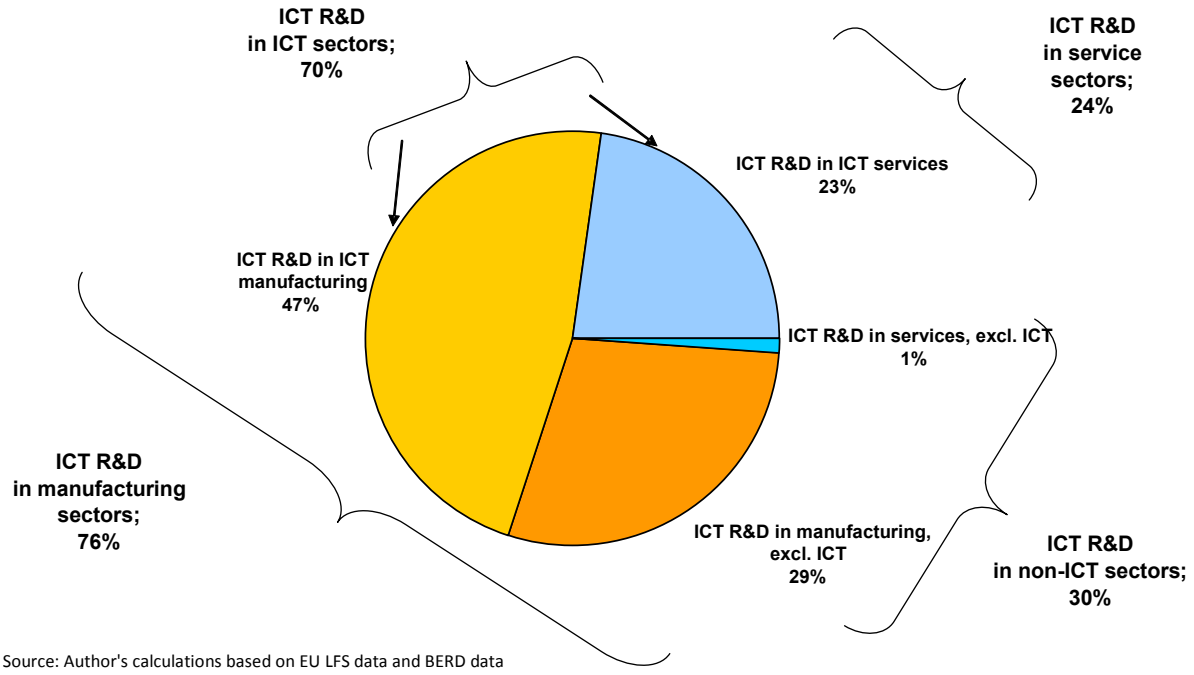
$$BERD^{ICT}_{ICT\ sectors} = 4177\ mill.euro$$

$$BERD^{ICT}_{non-ICT\ sectors} = 1804.5\ mill.euro$$

This estimation is used in Section 4.2. It is also perfectly in line with the estimations of the OECD (2008), which calculate the share of ICT R&D developed outside the ICT sectors at about 30% of total ICT R&D.

A simple further breakdown on manufacturing and services sectors gives a first impression of the breakdown of ICT R&D expenditures:

Fig. 10: ICT R&D by major sectors of activity, Germany, 2005



Source: Author's calculations based on EU LFS data and BERD data

Note: "sector of activity" means the sector in which the company is registered. Hence, if an automotive company performs research in software (service activity), the spending will be registered under *ICT R&D in manufacturing sectors, excl. ICT*, because the activity sector of an automotive company is "manufacturing".

Most of the ICT R&D outside the ICT sector can be found in manufacturing. Further disaggregation (not shown here) would suggest that about half of the very limited ICT R&D in services sectors excluding ICT is concentrated in sectors such as Business Services and Financial Intermediation.

ICT R&D will represent more than 15.5% of total R&D expenditures, out of which more than 4.8% is outside the ICT sector. From the total ICT R&D in Germany 2005 almost 40% was performed outside the ICT sectors.

Firstly, it is worth noting that the overall ICT R&D results are smaller than total R&D in the ICT sectors. It might be the case that ICT specialists are a too restrictive proxy for the size and composition of R&D teams in both the ICT and non-ICT sectors. This calls for more careful consideration through micro-studies and sectoral in-depth studies.

Secondly, although LFS data allows further sectoral disaggregation, this is not recommended, because the basic assumptions above (in particular, assumptions 2 and 3) do not hold at a higher level of granularity. A similar calculation to the one above can be performed for all the EU countries, but the limitations should not be underestimated. Nevertheless, this calculation offers some indicative measure for total ICT R&D, and the study is worth pursuing to allow tuning and further interpretations. We strongly recommend, however, that this measure is

used only in conjunction with other estimates to cross-check the results and try to avoid potential biases. All the limitations mentioned previously for labour data hold here as well.

Notes in this section

[xi] SUTs are matrices by industry and product describing production processes and the transactions in products of the national economy with great detail. A symmetric IOT is a product-by-product or industry-by-industry matrix. It rearranges both supply and use in a single table with identical classification of products (or industries respectively) applied for both rows and columns.

[xii] The IOTs are similar to the Use table, but instead of presenting output of industries on columns, it includes output of homogeneous branches, as proxies for groups of products. Each column of the IOT would refer to the main output of an industry, broken down on the products used as intermediate consumption and the value added.

[xiii] The CPA classification reflects goods and services likely to be produced in the companies registered in the corresponding NACE codes (see Annex X, from COMMISSION REGULATION (EC) No 204/2002 of 19 December 2001 amending Council Regulation (EEC) No 3696/93 on the statistical classification of products by activity (CPA) in the European Economic Community) and is harmonised with NACE at 4 digit level.

[xiv] See OECD, DSTI/ICCP/IIS(2003)1/REV2) and OECD, DSTI/ICCP/IIS(2006)11/FINAL definitions of ICT goods and services.

[xv] It is of course possible to analyse the contributions of various industries to the total production. This is straightforward and not presented here for the sake of simplicity.

[xvi] In fact, even those shares are probably over evaluated. Besides the ICT industries themselves, the main supplier of computer and related services in France is NACE 51, Wholesales trade (which alone covers almost 10% of the supply of computer and related services), followed from far by research and other business services. This type of influence is to be seen, although at a lower scale, in Czech Republic, Italy, Netherlands and Sweden. Wholesale and retail trade (NACE 51-52) as well as Manufacture of electrical machinery (NACE 31) seems to be responsible for an important part of production of ICT goods in almost all the countries in our sample. Parts of these industries would be included in the ICT sector if the level of the breakdown of the existing data would allow using the more detailed OECD definitions of ICT on industries (including into the ICT parts of NACE 51 and 31, and excluding non-ICT parts of 33). As well, the use of detailed OECD definition of ICT on products will result into lower shares of ICT produced outside the ICT sectors (see Greiner (2007)).

[xvii] For the purpose of EC (2007b), computation of forwards and backwards linkages was developed inside IPTS and the methodology as well as the results is fully accessible to the project.

[xviii] Our result is in line with the results from EC (2007b), where the ICT sectors did not emerge directly as key sectors for the EU economies. The explanation given there is that the calculations are made on the basis of intermediate consumption, while the ICT manufactured goods especially are mostly bought as investment goods. It is only when the capital was included in the calculation that the ICT became more important.

[xix] SUTs are matrices by industry and product describing production processes and the transactions in products of the national economy with great detail. A symmetric IOT is a product-by-product or industry-by-industry matrix. It rearranges both supply and use in a single table with identical classification of products (or industries respectively) applied for both rows and columns.

[xx] The IOTs are similar to the Use table, but instead of presenting output of industries on columns, it includes output of homogeneous branches, as proxies for groups of products. Each column of the IOT would refer to the main output of an industry, broken down on the products used as intermediate consumption and the value added.

[xxi] Other works (Rim, Cho, Moon (2005), make the same calculation using the whole IT capital stock, contrary to only the capital consumed as we use here.

[xxii] The iSuppli estimate takes into consideration the following figures:

- iSuppli worldwide retail sales value of the autos sold in 2008 is $1,421B or an average.
    - Value (mostly cost) of the embedded electronics and software: $120.6 B ($ 90.6 B hardware and $ 30 B software).
    - Average mark-up for embedded electronics: 230% (many of the electronics systems are marked up anywhere from 30% to 300% or more).

- Share of the software value are additive to the electronics value: 70% (the rest of software should be included in the products that are sold to the auto manufacturers).

With this assumptions electronics and software account for 18% of auto retail value for 2008. It will be growing and will account for a higher value in the next decade—probably 20%+ in 2020 and possibly even 25%.

[xxiii] See Ahmad, N. (2003) and TNO/IDATE (2005) a.o.

[xxiv] Just to name few of them:

- it is possible to construct independent prices and quantities models. In particular, in an area where the introduction of innovation goes hand in hand with falling prices upstream, the impact of the evolution of prices is crucial to be understood. See Friedman and Soete (2007) for extensive discussion on this topic.
- it is possible to check the economic distance (that is the number of nodes through which a product goes from its production to the final consumption). This method is described in detail in Dietzenbacher et al. (2005).
- it is possible in a direct and straightforward manner to link this exercise with an analysis of the trade deficit for Embedded Systems[xxiv].
- one of the major drawbacks of the classical static IO analysis is that it regards investment demand only as a category of final demand. In a dynamic context however, investment demand is derived demand, as is the intermediate demand. Once capital matrices are available, implementation of Leontief and Duchin (1986) type of model could be achieved without too many complications (Vespagen, (2002)).

[xxv] The Eurostat methodological Manual proposes other alternative/more detailed definitions for IT specialists, also based on the occupational classifications (ISCO-88): 1236 Computing services managers; 2131 Computer systems designers, analysts and programmers; 2139 Computing professionals not elsewhere classified; 2144 Electronics and telecommunications engineers; 3114 Electronics and telecommunications engineering technicians; 3121 Computer assistants; 3122 Computer equipment operators; 3132 Broadcasting and telecommunications equipment operators.

[xxvi] We gratefully acknowledge the help from German Statistical Office (Mr. Sven Gundrum) who kindly provided the data on labour costs.

[xxvii] Data on labour costs has been made available for us only for 2006 and only on two digits ISCO88, hence we use as definition of ICT employment the ISCO88 codes 12, 21, 24, 34 and 41 (broad definition) and the ISCO88 codes 21, 31 and 72 for the narrow definition.

[xxviii] According to Eurostat, countries collect data as follows: by product field: BE, CZ, DK, IT, RO, FI, UK, RU and by main activity: BG, CZ, DE, EE, IE, EL, ES, IT, CY, LV, LT, LU, HU, MT, NL, AT, PL, PT, RO, SI, SK, FI, SE, TR, IS, NO, CH.

[xxix][xxix] It is easy to see though that the ICT specialists are not a straightforward sectoral component of HRSTO. In fact, it includes at least one occupational group from other ISCO-88 classes. In our calculations we included in the definition of overall economy HRSTO the ISCO-88 group 724: *Electrical and electronic equipment mechanics and fitters* to ensure full compatibility between HRSTO and ICT specialists. This explains the slight difference between the data on HRSTO as published by Eurostat for Germany and our data below.

3. Conclusions and suggestions for further research

This methodological report indicates a way forward in estimating the economic role of embedded digital technology from the supply side. The measurement framework is reconsidering the research field and suggests a broad understanding of the role of ICT.

We strongly support the statement that ignoring the economic impact of embedded digital technology is increasingly misleading when evaluating and explaining the technology driven growth and the patterns of its distribution.

From ICT Capital, to Embedded Systems, to ICT inputs along the value chain: tracking the economic value of the embedded digital technology

The concept of *Embedded Systems* was for several decades the archetypal image of pervasive ICT, a computer-controlled system having at its core is a microprocessor, programmed to perform one or a few tasks. This contrasts with general purpose computer systems like PCs which have general purpose hardware platforms and externally loaded software.

Two important technological developments make this understanding of embedded ICT increasingly difficult to operationalise for the purpose of statistical measurement and economic analysis, and indeed increasingly less appropriate to describe the pervasiveness of ICT in the economy. Firstly, the technological convergence trends keep blurring the line between embedded and non-embedded ICT. Secondly, the shift from hardware dependency to software dependency means that powerful, networked, multi-core micro processors, can accommodate a variety of reprogrammable tasks performed by volatile hardware-software architectures, virtually impossible to capture by any attempt of statistic measurement.

We propose, with the support of technological, economic and statistical arguments, a more holistic approach to the production and diffusion of ICT and we develop the foundation of a methodology that would ultimately take into account the overall use and impact of the embedded digital technology in the productive process.

Semiconductors remain central to our approach, as they are the backbone of the ICT. The software and services contribute at various nodes of the value chain to building up of the ICT-based functionalities. The systemic behaviour of the tandem hardware-software is rather implicit than imposed by a definition. In line with the observed technological trends this approach does not distinguish between embedded ICT and general-purpose computing.

Theoretical framework for measuring the ICT inputs: directions for further research

Our proposed economic framework searches to identify for each final product, the consumption of ICT (hardware, software, ICT services and ICT-skilled labour) along the value chain in order to account for the contribution of ICT to the final output. The framework used for this representation is the neoclassical production function.

We establish that the total contribution of various ICT inputs along the value chain is given by the formula:

$$y_i^{ICT} = y_i^{ICT} = f(\beta^i{}_{innov}(R\&D^{ICT})) + \prod_{i=1}^{n}\beta_2^i k_{i=1}^{ICT} + \prod_{i=1}^{n}\gamma_2^i m_{i=1}^{ICT} + \prod_{i=1}^{n}\alpha_{2s}^i l_{i=1}^{ICTs} + \prod_{i=1}^{n}\alpha_{2p}^i l_{i=1}^{ICTp},$$

where:

$i \in [1,..,n]$, n – *the nodes of the value chain*

y^{ICT} – *ICT – based output*

$a = \beta_{innov}(ICTR\&D)*$ = *Total Factor Productivity*

β_2 – *elasticity of output to the ICT – based capital*

α_{2s}, α_{2p} – *elasticity of output to the ICT – skilled (specialists and users) labour*

γ_2^i – *elasticity of output to the ICT intermediate consumption*

*- *based on an overview of the rich available literature we choose ICT-driven innovation, (proxied in the standard manner by the ICT R&D expenditures) as the main channel of ICT impact on productivity*

Once this framework is adopted, the purpose of the methodology becomes the estimation of these coefficients at macroeconomic level.

Several theoretical challenges appear in the implementation of this methodology. We refer below to the two most important, in our opinion.

The first is related to the aggregation of micro-level dynamics into macroeconomic performance in the case of the digital technology. The use of digital technology induces extreme variations between companies' performances (though it was shown that a well-behaved aggregate production function can be derived from micro production functions only when they are in compliance with very stringent conditions of homogeneity). These variations appear especially, albeit not exclusively, in companies' *innovation-related* performance, as supported by a long string of literature showing the link between innovation and ICT. This first theoretical challenge arises when trying to aggregate companies within the same sector or node of the value chain.

The proposed method also leaves unsolved the complicated issue of the distribution of ICT-related innovation along the value chain. The elasticity of profits from the ICT R&D is subject, ultimately, to the pricing of information, and more precisely to specific components of price such as the distribution of innovation rents along the value chain or the specific pricing of customised software. Several IPTS studies support this view (Puissochet, 2009). We therefore indentify the sub-issue of *determinants of profit margins for embedded ICT* as the second main avenue for theoretical research emerging from this study.

Methodological framework for measuring the ICT inputs: data needs and directions for further research

In the National Accounts practice the value of output is the sum of the intermediate consumption and the value added. The ICT inputs along the value chain corresponding to each category are identified from the theory above as follows:

$$Intermediate\,consumption: \left\{ \prod_{i=1}^{n} \gamma_2^i m_{i=1}^{ICT} \subset \gamma^i m^i \right.$$

$$Value\ added: \begin{cases} \prod_{i=1}^{n} \beta_2^i k_{i=1}^{ICT} \subset \beta^i k^i \\ \prod_{i=1}^{n} \alpha_{2s}^i l_{i=1}^{ICTs} + \prod_{i=1}^{n} \alpha_{2p}^i l_{i=1}^{ICTp} \subset \alpha^i l^i \\ f\left(\beta^i{}_{innov}(R\,\&\,D^{ICT}\right) \rightarrow a^i \end{cases}$$

The "technical coefficients" in the input-output analysis are good approximations of the coefficients β_2^i, γ_2^i and α_2^i.. They will identify the share of the total inputs of a sector required to be purchased from another sector. Technical (input) coefficients represent direct backward linkages of an industry to other industries. Presumably, input-output coefficients reflect technology, and these coefficients measure the input requirements per unit of product.

Through standard matrix manipulation the coefficients it is straightforward to obtain estimations of $\prod_{i=1}^{n} \gamma_{\acute{e}}^i, \prod_{i=1}^{n} \beta_2^i\ and \prod_{i=1}^{n} \alpha_{2s}^i, \prod_{i=1}^{n} \alpha_{2p}^i$

The challenges of application of this method reside in the details of its practical implementation. Conceptually, the method starts from the primary DT inputs (semiconductors and alike), and adds at various stages of the value chain various other DT inputs, among which software.

The first practical challenge is the *definition of primary DT inputs*. The most recent OECD definition of ICT goods and services (see Annex 2 of this report) provides the basis for this potential choice.

This definition will necessarily be formed at very detailed level of implementation hence *input – output data will be needed at the same level of detail*. Fortunately, in many countries, the National Statistics Offices collect data at high level of detail and the method can be successfully implemented at a rather high level of detail.

The reliability of these calculations heavily depends on the *current quality of estimations of software production and depreciation rates, in particular of the own-account software*. This is a general issue irrespective of the method adopted here. IPTS studies like [G de Prato, C Feijoo, D Nepelski, M Bogdanowicz and J P Simon, 2010] highlight the difficulties in establishing the true value of software. The focus on improving the quality of these estimations is central to the recent Eurostat pilot study on IT investment and various other international efforts. The research on the determinants of the software valuation and pricing might contribute to improving this measurement. However, the process of better measurement of economic value of software will accompany not only the understanding of the process, but its evolution as well; hence it is expected to be a long term process. At the moment, it does not seem likely that a solution will be made available soon.

The most serious measurement problems are raised by the labour data. Labour data is instrumental in understanding DT-related developments. Refinements are needed to take into account specific issues like the DT-related skills inner to non-DT jobs (often recognised by certifications additional to the main profession). Various efforts to improve the quality of the labour data are ongoing and involve both statistical institutes and academia. However, the accurate measurement of DT-related labour would have to refer to hours per DT-related task. Such information exists at company level for certain occupation, but there is no ongoing effort to collect them.

IPTS leads a unique project focused on collecting and interpreting the ICT R&D in Europe and its main competitors (Turlea et al. (2010)) However, the project is looking at the R&D performed in the ICT sectors, rather than to the *DT R&D spending across all the economic sectors*. Several attempts to collect this data existed, but they met limited success.

IPTS had developed expertise in analysis of patent data and we are proposing a secondary analysis based on patent statistics to counteract the lack of R&D data above. The hypothesis behind using patent data is that patents afford ways of identifying relations among different technologies (within one patent, or within a company's portfolio of patents). IPTS ascertained already in other studies that a relevant fraction of ICT patents also report one or more IPC class that is non-ICT. But even drawing up a list of these ICT multi-technology patents would be a huge step forward, for proxying the domains that are requiring the frontier ICT technologies.

R&D efforts and the participation in innovation networks of various actors at different levels of the value chain is the area least covered, yet it is the most interesting from a policy-making point of view. Finally, the role of the public ICT research in boosting the production function rises both theoretical and practical challenges which need to be addressed.

General assessment of the methodology

As a general assessment we conclude that even if the proposed methodology has various limitations, it can be implemented at the targeted (macroeconomic) level and complies with the original objective of relying as much as possible on cross-European available data. The application of a methodology of this kind, which accounts for the DT intensity of various groups of products and the ICT R&D efforts of their producing companies, could provide valuable support to DG INFSO in formulating policies related to:

- Information Society strategies. These would be based on data which better represents European production and diffusion of DT, giving policy makers the opportunity to take into account fully the economic impact of DT at sector, national and European levels. Thus, the economic impact of DT production and use would be much better appreciated, both at sector and national level. The technological density approach, a departure from the usual appreciation of the share of the ICT industry VA in national GDP, or that of ICT investment on productivity, would allow insights into the true DT content of European goods and services.

- Information Society measurement issues. Methods could be explored for producing more flexible and timely indicators according to the i2010 impact assessment requirements.
- Research policy (under FP7), including understanding what future goods and services may develop as a result of increasing contribution of EDT to productivity and growth.

Annex 1

Annex 1 is dedicated to substantiate from the data availability point of view the limitations of an attempt to separate the EDT from the rest of the ICT.

1. **Available data needs to distinguish between ICT and non-ICT final goods hosting EDT**. There are numerous cases of ICT goods referred to as embedding DT: mobile telephones, multimedia equipment etc. If the intention is to study the Embedded Systems domain separately, this part of the ICT sector (as understood today) needs to be singled out. The products and services lists as Annex 2 of this report provide the basis for this potential choice. Relevant data is available within business consultancies that could be used to help quantify this distinction, offering for instance estimations of the shares of semiconductor spending by markets using big OEM buys. However, such a choice would be difficult to make, since, as argued in section 2.2. the frontier between the Embedded Systems and General Purpose Computers is not sharp and keeps fading. Further difficulties arise because the detailed product definition will need to implemented using various classifications at detailed level.

2. **Available data need to distinguish various categories of ICT capital, especially software**.

According to the transmission programme of Eurostat, data on gross fixed capital formation is compulsory for 6 industries and voluntary for up to 60 industries. Gross and net fixed asset figures have to be delivered every year in a cross-classification by 17 industries and by 6 groups of non-financial assets. The level of detail requested by Eurostat does not separate software from the rest of intangible assets. The availability of detailed data on software acquisitions, at working level varies from country to country. Data on software in the Gross Fixed Capital Formation is available from the EU KLEMS database. The Eurostat pilot surveys on ICT investment is an additional source. However, both sources are too aggregated to allow us to distinguish between ICT for business processes and ICT for production processes.

The system of national accounts (SNA93) recommends that purchases of software (and any own-account production of software) should be capitalised as long as the acquisition satisfies conventional asset requirements. In 2001, these changes added about 1% to GDP in most European economies. Own-account software is responsible for around half of these changes. Indeed, the amount of own-account software considerable: for instance, in 2003, we estimated that own-account software was already about 1.3% of GDP[xxx].

Although the ESA Manual 2008 recommendation is to collect data on own-account software from dedicated surveys, it is very important to observe that currently, there is very little information in the major business surveys that would allow further understanding of the nature and destination of the software produced inside a company. The new Eurostat pilot study on IT investment seems to be the only source of data which treats software in a more detailed manner. The level of aggregation is high on industries (one digit NACE), and the

only separation available is on purchased and own-account software, which is too general to allow EDT to be singled out from the broader ICT world.

Provision of internationally-harmonised data on ICT investment/expenditure for the National Accounts is the main target of the ICT investment project mentioned above and the estimation of own-account software is the most prominent issue in this context.

Eurostat (2008) presents the conventions governing current data collection on ICT investment, the most relevant of which is the actual list of variables to be collected:

- IT goods
- Telecommunication goods
- Other ICT goods
- Software, pre-packaged and customised[xxxi]
- Own-account software (and databases)
- Financial leasing of ICT goods
- Operational leasing of ICT goods
- ICT services.

JRC-IPTS participated in the elaboration of the terms of reference, the methodological manual and the questionnaire. The final meeting of the relevant Eurostat Task Force for defining the Methodological Manual for data collection on IT investment in 2010 took place at the end of March, 2009. However, our proposal met limited interest.

3. **Available data need to distinguish between ICT labour input and the labour input for embedding DT or using EDT**

The Labour Force Survey the main database, the main source of EU data does not allow identifying and or even proxying EDT-related labour input using the existing ISCO-88 classification. This is simply because various ICT tasks are provided by non-ICT occupations (the case of EDT is the most obvious), and ISCO-88 is a classification by occupations not by qualifications. For more on other sources of labour data, see Annex 3.

In fact, identifying the EDT-related workforce from the ISCO-88 classification on occupations raises the very same problem as identifying EDT products from various classifications of goods and services: in as much as DT is embedded in other ICT or non-ICT products, the digital skills needed to produce them seem to be "embedded" into other main ICT and non - ICT occupations. Within the ISCO-88 classification it is very difficult to pinpoint the occupations that would handle these specific types of operations and even less the share of time allocated for those.

For these reasons, we consider that using the EU LSF data not help us with the problem of the basic definition of EDT, and worse, it would generate further confusion[xxxii].

Notes in this section

[xxx] Estimation based on corroborating the SUT tables for Sweden 1999,2003 and info in Ahmad (2003).

[xxxi] It is interesting to note that that embedded software is treated as part of the hardware.

[xxxii] However, the direct utility of the labour data in this case would be to estimate the number of ICT jobs that would be generated by an increase in total demand. This is not illustrated here, but can be easily done using the same methodology as above:

$$Z = B[I - A]^{-1}Y$$

B = matrix of input coefficients for specific variable in economic analysis (labour in this case).
I = unit matrix.
A = matrix of input coefficients for intermediates (that is the breakdown of the intermediate costs per products).
Y = diagonal matrix for final demand.
Z = matrix with results for direct and indirect requirements of labour for every unit of extra demand of final products.
When this would be done for the labour costs of the ICT specialists, the result can be interpreted as the cumulated ICT R&D expenditure generated by an increase in the final demand.

Annex 2

OECD classification of ICT products (DSTI/ICCP/IIS(2008)1)

CPC Ver. 2 sub-class Product description (CPC sub-class title)

ISIC Rev. 4 class

Computers and peripheral equipment

45142 2620 Point-of-sale terminals, ATMs and similar machines capable of being connected to a data processing machine or network

45221 2620 Portable automatic data processing machines weighing not more than 10 kg, such as laptop and notebook computers

45222 2620 Personal digital assistants and similar computers

45230 2620 Automatic data processing machines, comprising in the same housing at least a central processing unit and an input and output unit, whether or not combined

45240 2620 Automatic data processing machines presented in the form of systems

45250 2620 Other automatic data processing machines whether or not containing in the same housing one or two of the following types of units: storage units, input units, output units

45261 2620 Input peripherals (keyboard, joystick, mouse etc.)

45262 2620 Scanners (except combination of printer, scanner, copier and/or fax)

45263 2620 Inkjet printers used with data processing machines

45264 2620 Laser printers used with data processing machines

45265 2620 Other printers used with data processing machines

45266 2620 Units performing two or more of the following functions: printing, scanning, copying, faxing

45269 2620 Other input or output peripheral devices

45271 2620 Fixed media storage units

45272 2620 Removable media storage units

45289 2620 Other units of automatic data processing machines

45290 2620 Parts and accessories of computing machines

47550 2620 Solid-state non-volatile storage devices

Communication equipment

46921 2630 Burglar or fire alarms and similar apparatus

47211 2630 Transmission apparatus incorporating reception apparatus

47212 2630 Transmission apparatus not incorporating reception apparatus

47213 2630 Television cameras

47221 2630 Line telephone sets with cordless handsets

47222 2610, 2630 Telephones for cellular networks or for other wireless networks

47223 2630 Other telephone sets and apparatus for transmission or reception of voice, images or other data, including apparatus for communication in a wired or wireless network (such as a local or wide area network)

47401 2630 Parts for the goods of subclass 47221 to 47223

Consumer electronic equipment

38581 2640 Video game consoles

47214 2630, 2640 Video camera recorders

47215 2670 Digital cameras

47311 2640 Radio broadcast receivers (except of a kind used in motor vehicles), whether or not combined with sound recording or reproducing apparatus or a clock

47312 2640 Radio broadcast receivers not capable of operating without an external source of power, of a kind used in motor vehicles

47313 2640 Television receivers, whether or not combined with radio-broadcast receivers or sound or video recording or reproducing apparatus

47314 2640 Monitors and projectors, not incorporating television reception apparatus and not principally used in an automatic data processing system

47315 2640 Monitors and projectors, principally used in an automatic data processing system

47321 2640 Sound recording or reproducing apparatus

47323 2640 Video recording or reproducing apparatus

47330 2640 Microphones and stands therefore; loudspeakers; headphones, earphones and combined microphone/speaker sets; audio-frequency electric amplifiers; electric sound amplifier sets

47402 2640 Parts for the goods of subclasses 47321, 47323 and 47330

Miscellaneous ICT components and goods

45281 2610 Sound, video, network and similar cards for automatic data processing machines

47130 2610 Printed circuits

47140 2610 Thermionic, cold cathode or photo-cathode valves and tubes (including cathode ray tubes)

47150 2610 Diodes, transistors and similar semi-conductor devices; photosensitive semi-conductor devices; light emitting diodes; mounted piezo-electric crystals

47160 2610 Electronic integrated circuits

47173 2610 Parts for the goods of subclasses 47140 to 47160

47403 2630, 2640 Parts for the goods of subclasses 47211 to 47213, 47311 to 47315 and 48220

47530 2680 Magnetic media, not recorded, except cards with a magnetic stripe

47540 2680 Optical media, not recorded

Miscellaneous ICT components and goods (continued)

47590 3290 Other recording media, including matrices and masters for the production of disks

47910 2220 Cards with a magnetic stripe

47920 2620 "Smart cards"

48315 2610 Liquid crystal devices n.e.c.; lasers, except laser diodes; other optical appliances and instruments n.e.c.

48354 2610 Parts and accessories for the goods of subclass 48315

Manufacturing services for ICT equipment

88741 2610 Electronic component and board manufacturing services

88742 2620 Computer and peripheral equipment manufacturing services

88743 2630 Communication equipment manufacturing services

88744 2640 Consumer electronics manufacturing services

88749 2680 Magnetic and optical media manufacturing services

Business and productivity software and licensing services

47811 5820 Operating systems, packaged

47812 5820 Network software, packaged

47813 5820 Database management software, packaged

47814 5820 Development tools and programming languages software, packaged

47821 5820 General business productivity and home use applications, packaged

47829 5820 Other application software, packaged

73311 5820 Licensing services for the right to use computer software

83143 5820 Software originals

84341 5820 System software downloads

84342 5820 Application software downloads

84392 5820 On-line software

Information technology consultancy and services

83117 7020 Business process management services

83131 6202 IT technical consulting services

83132 6202 IT technical support services

83141 6201 IT design and development services for applications

83142 6202 IT design and development services for networks and systems

83151 6311 Website hosting services

83152 6311 Application service provisioning

83159 6311 Other hosting and IT infrastructure provisioning services

83161 6202 Network management services

83162 6202 Computer systems management services

Telecommunications services

84110 6110, 6120, 6130 Carrier services

84121 6110 Fixed telephony services. access and use

84122 6110 Fixed telephony services. calling features

84131 6120 Mobile telecommunications services. access and use

84132 6120 Mobile telecommunications services. calling features

84140 6110, 6120, 6130 Private network services

84150 6110, 6120, 6130 Data transmission services

84190 6190 Other telecommunications services

84210 6110 Internet backbone services

84221 6110, 6120, 6130, 6190 Narrow-band Internet access services

84222 6110, 6120, 6130, 6190 Broad-band Internet access services

84290 6110, 6120, 6130, 6190 Other Internet telecommunications services

Leasing or rental services for ICT equipment

73124 7730 Leasing or rental services concerning computers without operator

73125 7730 Leasing or rental services concerning telecommunications equipment without operator

73210 7729 Leasing or rental services concerning televisions, radios, video cassette recorders and related equipment and accessories

Other ICT services

83325 7110 Engineering services for telecommunications and broadcasting projects

87130 9511 Maintenance and repair services of computers and peripheral equipment

87153 9512 Maintenance and repair services of telecommunication equipment and apparatus

87331 3320 Installation services of mainframe computers

87332 6209 Installation services of personal computers and peripheral equipment

87340 3320 Installation services of radio, television and communications equipment and apparatus

OECD classification of Content and media products (DSTI/ICCP/IIS(2008)1)

CPC Ver. 2 sub-class Product description (CPC sub-class title)

ISIC Rev. 4 class

Printed and other text-based content on physical media, and related services

32210 5811 Educational textbooks, in print

32220 5811 General reference books, in print

32230 5812 Directories, in print

32291 5811 Professional, technical and scholarly books, in print

32292 5811 Childrens' books, in print

32299 5811 Other books n.e.c., in print

32300 5813 Newspapers and periodicals, daily, in print

32410 5813 General interest newspapers and periodicals, other than daily, in print

32420 5813 Business, professional or academic newspapers and periodicals, other than daily, in print

32490 5813 Other newspapers and periodicals, other than daily, in print

32510 5811 Maps and hydrographic or similar charts (including wall maps, topographical plans and globes), printed, other than in book-form

32530 5819 Printed or illustrated postcards; printed cards bearing personal greetings or messages, with or without envelopes or trimmings

32540 5819 Printed pictures, designs and photographs

Printed and other text-based content on physical media, and related services (continued)

32620 5819 Trade advertising material, commercial catalogues and the like

32630 5819 Transfers (decalcomanias) and printed calendars

32690 5819 Other printed matter

47691 5811 Audio books on disk, tape or other physical media

47692 5811, 5812, 5813 Text-based disks, tapes or other physical media

47699 5920 Other non-musical audio disks and tapes

83631 5812, 5813, 5819 Sale of advertising space in print media (except on commission)

Motion picture, video, television and radio content, and related services

38950 5911, 5912 Motion picture film, exposed and developed, whether or not incorporating sound track or consisting only of sound track

47620 5911 Films and other video content on disks, tape or other physical media

83632 6010, 6020 Sale of TV/radio advertising time (except on commission)

84611 6010 Radio broadcast originals

84612 6020 Television broadcast originals

84621 6010 Radio channel programmes

84622 6020 Television channel programmes

84631 6010, 6020 Broadcasting services

84632 6110, 6120, 6130 Home programme distribution services, basic programming package

84633 6110, 6120, 6130 Home programme distribution services, discretionary programming package

84634 6110, 6120, 6130 Home programme distribution services, pay-per-view

96121 5911, 6020 Motion picture, videotape and television programme production services

96122 6010 Radio programme production services

96123 5911 Motion picture, videotape, television and radio programme originals

96131 5912 Audio-visual editing services

96132 5912 Transfers and duplication of masters services

96133 5912 Colour correction and digital restoration services

96134 5912 Visual effects services

96135 5912 Animation services

96136 5912 Captioning, titling and subtitling services

96137 5912 Sound editing and design services

96139 5912 Other post-production services

96140 5913, 6010 Motion picture, videotape, television and radio programme distribution services

96150 5914 Motion picture projection services

Music content and related services

32520 5920 Music, printed or in manuscript

47610 5920 Musical audio disks, tapes or other physical media

96111 5920 Sound recording services

96112 5920 Live recording services

96113 5920 Sound recording originals

Games software

38582 5820 Software for video game consoles

47822 5820 Computer game software, packaged

84391 5820 On-line games

On-line content and related services

73312 5812 Licensing services for the right to use databases

83633 5813, 5819, 6311, 6312 Sale of Internet advertising space (except on commission)

84311 5811 On-line books

84312 5813 On-line newspapers and periodicals

84313 5812 On-line directories and mailing lists

84321 5920 Musical audio downloads

84322 5920 Streamed audio content

84331 5911 Films and other video downloads

84332 5911 Streamed video content

84393 5819 On-line adult content

84394 6312 Web search portal content

84399 5819 Other on-line content n.e.c.

Other content and related services

73320 5811, 5920, 5913 Licensing services for the right to use entertainment, literary or artistic originals

83611 7310 Full service advertising

83620 7310 Purchase or sale of advertising space or time, on commission

83639 5911 Sale of other advertising space or time (except on commission)

83812 7420 Advertising and related photography services

83940 581215 Original compilations of facts/information

84410 6391 News agency services to newspapers and periodicals

84420 6391 News agency services to audio-visual media

85991 6399 Other information services

89110 58 Publishing, on a fee or contract basis

96330 9000 Original works of authors, composers and other artists except performing artists, painters and sculptors

OECD classification of ICT Services (DSTI/ICCP/IIS(2006)11)

CPC Ver. 2 sub-class Product description (CPC sub-class title)

ISIC Rev. 4 class

OECD Classification of ICT services based on CPC version 2.0

Code Title

84110 61 Carrier services

84121 6110 Fixed telephony services – access and use

84122 6110 Fixed telephony services – calling features

84131 6120 Mobile telecommunications services – access and use

84132 6120 Mobile telecommunications services – calling features

84140 61 Private network services

84150 61 Data transmission services

84190 61 Other telecommunications services

8421 61 Internet backbone services

8422 61 Internet access services

8429 61 Other Internet telecommunications services

73123 7730 Leasing or rental services concerning office machinery and equipment (excl. computers) without operator

73124 7730 Leasing or rental services concerning computers without operator

83131 6202 IT technical consulting services

83132 6202 IT technical support services

83141 6201 IT design and development services for applications

83142 6202 IT design and development services for networks and systems

8315 6311 Hosting and information technology (IT) infrastructure provisioning services

83151 6311 Website hosting services

83152 6311 Application service provisioning

83117 7020 Business process management services

83159 6311 Other hosting and IT infrastructure provisioning services

83161 6202 Network management services

83162 6202 Computer systems management services

87130 9511 Maintenance and repair services of computers and peripheral equipment

478 5820 Packaged Software

83143 5820 Software originals

8434 5820 Software downloads

84392 6311 On-line software

73310 7740 Licensing services for the right to use computer software

Annex 3

This Annex analyses the difficulties in using labour data to proxy for the digitally skilled labour input. The inadequacy of using occupation classifications to estimate the usage and skills is recognised already for the ICT in general since the beginning of this century. Studies on sectors such as the automotive indicate a need for ICT skill profiles and ICT competences for as much as 93% of the workforce.[8] Pioneering work as OECD (2002, 2004), Welsum & Vickery (2005) or RAND (2005) as well as the European e-Skills Forum (2004) were set with the ambition to come up with a framework for defining the ICT skills needed in various sectors of the economy.

The European e-Skills Forum (2004) discussion on e-skills has resulted in definitions for the following three types of skills:

- ICT user skills: the capabilities required for effective application of ICT systems and devices by the individual. ICT users apply systems as tools in support of their own work, which is, in most cases, not ICT. User skills cover the utilisation of common generic software tools and the use of specialised tools supporting business functions within industries other than the ICT industry;
- ICT practitioner skills: the capabilities required for researching, developing and designing, managing, producing, consulting, marketing and selling, integrating, installing and administrating, the maintaining, supporting and service of ICT systems.
- e-Business skills: the capabilities needed to exploit opportunities provided by ICT, notably the Internet, to ensure more efficient and effective performance of different types of organisations, to explore possibilities for new ways of conducting business and organisational processes, and to establish new businesses.

The *OECD (2002; 2004)* distinguishes between:

- basic skills (using generic tools like word processors, internet browsers and email clients);
- advanced skills (using advanced and often sector-specific tools for the administration and manipulation of data and digital media); and
- specialist skills (developing, maintaining and operating ICT systems).

Thus, compared to the European e-Skills Forum definitions, *ICT user* skills have been separated out into *basic* and *advanced*, while "specialist" is preferred to "practitioner" for those whose work is fully dedicated to ICT activity for the benefit of others.

Level of basic computer skills are measured using a self-assessment approach, where the respondent indicates whether he/she has carried out specific tasks related to computer use, without these skills being assessed, tested or actually observed. Six computer-related items are used to group the respondents into levels of computer skills: copy or move a file or folder; use copy and paste tools to duplicate or move information within a document; use basis

[8] See: http://www.trainingvillage.gr/etv/Upload/Information_resources/Bookshop/383/5147_en.pdf

arithmetic formula (add, subtract, multiply, divide) in a spreadsheet; compress files; connect and install new devices, e.g. a printer or a modem; write a computer program using a specialised programming language. Instead of the item on having connected and installed new devices, the 2005 items included the use of a mouse to launch programs such as an Internet browser or word processor. Low level of basic computer skills: Individuals who have carried out 1 or 2 of the 6 computer-related items. Medium level of basic computer sills: Individuals who have carried out 3 or 4 of the 6 computer-related items. High level of basic computer skills: Individuals who have carried out 5 or 6 of the 6 computer-related items. (epp.eurostat.ec.europa.eu/.../Eurostat_Table_tsdsc460NoFlagDesc.xls*)*

This is even more complicated in a world where the ICT qualifications are acquired through various training and certification programs or even non-formal training and the ICT skills became a norm. One can imagine that it is possible to proxy EDT-related qualifications by looking at the ICT skills in various industries. However, the data availability is very poor. Eurostat provides data only on IT/ICT specialists and on a very aggregated (and incomplete) sectoral level. More detailed level data is not collected. The available data suggest that the share of ICT R&D staff in non-ICT sectors is indeed rather low (between 3% in manufacturing and 15% in transport and telecommunication). This corresponds to our estimation of 8.7% in the previous chapter.

R&D personnel data

The Frascati manual (OECD, (2002)), states that "Researchers are professionals engaged in the conception of creation of new knowledge, products, processes, methods and systems and also in the management of the projects concerned", and that "R&D surveys are the most appropriate instrument for collecting headcount data". "Population censuses, labour force surveys or population registers are useful complementary data sources but cannot be used systematically to obtain R&D personnel data". Moreover, the difference between the HRST and R&D personnel (headcount) is not negligible.

HRST, sub-groups of HRST, scientists and engineers, R&D personnel and researchers in the EU-25 in 2004

	In thousands	*In percentage of active population*
Active Population	213 834	100.0
HRST	86 338	40.4
HRSTE	61 322	28.7
HRSTO	56 843	26.6
HRSTC	31 827	14.9
Scientists and engineers	9 411	4.4
Total R&D personnel (HC)	2 905	1.36
Researchers (HC)	1 787	0.84
Researchers (FTE)	1 217	0.57

Source: Moguérou, Di Pietrogiacomo (2008)

The main reason for this difference is the coverage of data collection. R&D personnel measure excludes the following categories:

- personnel employed on education and training,
- personnel employed on other scientific and technological activities (E.g. information services, testing and standardisation, feasibility studies etc.),
- personnel employed on other industrial activities (E.g. industrial innovations n.e.s.),
- personnel employed on administration and other indirect supporting activities http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=DSP_GLOSSARY_NOM_DTL_VIEW&StrNom=CODED2&StrLanguageCode=EN&IntKey=16537435&RdoSearch=CONTAIN&TxtSearch=R&D&CboTheme=&IntCurrentPage=1.

We rather consider this as an argument for the use of HRST data, because the R&D in ICT is, in many cases, very close to innovation and includes extensive testing and rich information services. Moreover, similarly with the data on R&D expenditures, data collected through the R&D surveys on R&D personnel are not broken down on fields of science, hence this data can not be used directly for our purpose, except for the very few cases when R&D data are collected both on enterprise level and on product level (see Section 4.3, paragraph "The Method"), and with the limitations mentioned there.

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Abstract

This methodological report indicates a way forward in estimating the economic role of embedded digital technology (EDT) from the supply side.

We propose a more holistic approach to the production and diffusion of ICT and we develop the foundation of a methodology that would ultimately take into account the overall use and impact of embedded digital technology in the productive process.

Technological, economic and statistical arguments support our approach. Current technological development no longer accommodates clear borderlines between ICT and non-ICT goods or between general purpose computers and embedded digital devices.

The economics and statistics of ICT reveal the complex and multi-channel contributions of ICT to the productive process. The methodology we propose uses the input-output method known as backward linkages to give a measure of EDT as ICT consumption generated along the value chain by the demand of final goods. We give an account of the methodological limitations of applying the method and an overview of data availability and shortages for its implementation. A simplified application of the methodology to German data is used as an example.

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