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Systems and Modes of ICT Innovation

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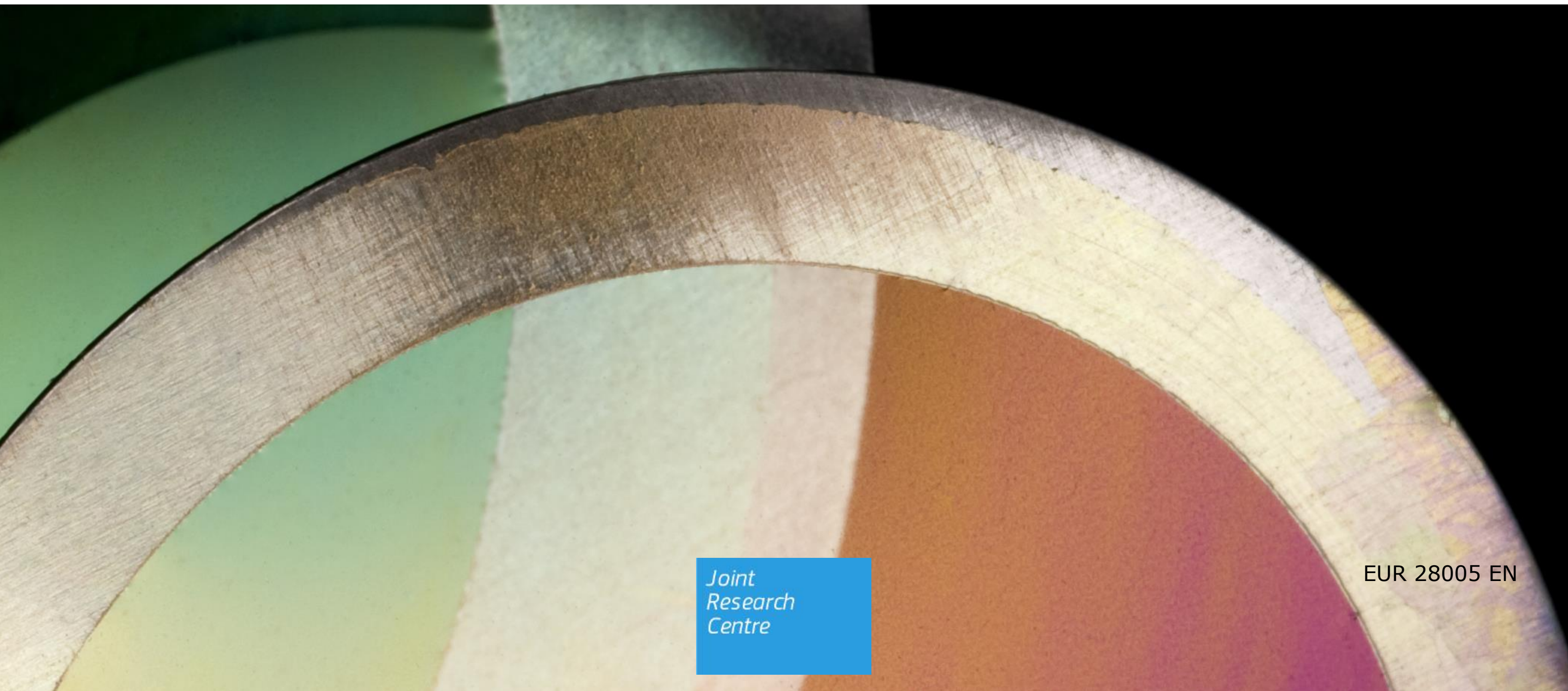

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Abstract
This report focuses on modes of ICT innovation at the meso level of systems and the micro level of firms. After a summary of the literature on national innovation systems, and its sectoral and regional applications, we discuss how the concept of innovation systems can be applied to the case of ICT innovation. A framework for indicators is proposed to characterize the performance of ICT innovation systems. Due to the multi-purpose and pervasive nature of ICT, it is relevant to extend the innovation systems concept to the societal level. The resource-based view of the innovative firm fits very well with the innovation systems perspective. Patterns in the firm-level sets (combinations, or mix) of resources and capabilities can be identified with factor-analysis and they give rise to the main types or modes of innovative behaviour.
Monitoring ICT innovation systems is important as it allows us to learn how to improve the policy and performance of current and future systems. It allows us to design and improve a mix of ICT innovation policy, which is tailored to specific ICT modes of innovation, and also to a mix of prioritized challenges (e.g. economic, social, environmental, health, or other impacts). Since ICT innovations emerge and diffuse fast, the timing of institutional change is crucial. Setting new standards, and updating regulations can create a competitive edge. ICT innovation policy has become (and should be addressed as) a horizontal policy field which maintains systemic linkages with other policy fields. At both the system and firm level, there are several modes of ICT innovation. Policy makers should not reduce diversity by favouring only one mode. We extend Lundvalls' theory on interactive learning between producers and users of knowledge by adding that policy for ICT innovation should be produced in interaction with its users.

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Executive summary

This report was prepared in the context of the three-year research project on *European Innovation Policies for the Digital Shift* (EURIPIDIS) jointly launched in 2013 by JRC-IPTS and DG CONNECT of the European Commission. The aim of the project was to improve understanding of innovation in the ICT sector and of ICT-enabled innovation in the rest of the economy.[1]

While innovation can be studied at micro, meso and macro level, this report focuses on the micro level (modes of innovation: how firms generate innovations), and on the meso level (systems of innovation: relations between firms, customers, suppliers, the public R&D infrastructure etc.). It does not look at the macro-economic level of the impact of innovation on social and economic change (e.g. growth, competitiveness, employment etc.).

The report has four main objectives. First, it summarizes the literature on innovation systems, from its origins to its development towards sectoral and regional applications. Second, it discusses how the concept of innovation systems can be useful in the context of ICT innovation, providing insights on how it would be possible to characterize the performance of an ICT innovation system using data at the firm, meso and macro levels. Third, it reviews the literature on firms' innovation modes, paying particular attention to ICT firms. Fourth, it provides useful insights on how it would be possible to extend our empirical knowledge of ICT firms' modes of innovation using firm level data analysis.

The underlying working hypothesis of the report is that in order to understand innovation one has to adopt an approach which looks beyond R&D investments, beyond intra-mural firm activities, and beyond market transactions, since innovative dynamics take place in a broader (global, national, regional, sectoral) context in which firms interact with other firms and non-firm actors, and with market and non-market factors.

Towards ICT innovation systems

The innovation systems concept was defined some 25 years ago, at a time when economists were discussing to what extent technological change should be seen as an external publicly-available driver of change which benefits all, or as an internal one (e.g. private benefit for R&D performers). The innovation systems solution to this debate can be found at the meso level, where various actors learn from their own experiences and from interaction with others in a specific common context. At this meso level, innovation and its context become interdependent, embedded in interactions between supply and demand –respectively producers and users of knowledge- generating spill-overs that are available to the other stakeholders in the system. The concept of national innovation systems -and the related concepts of regional and sectoral innovation systems- emphasizes the importance of interactions between a diversity of actors, and a diversity of innovation activities, resources and institutions.

Within this general context, ICTs play a special role, due to their distributive nature and pervasiveness in society (e.g. the role of ICT in emerging and 'smart policy domains'), to the speed of change (yesterday's ICT is outdated tomorrow), to their ability to enhance productivity and to offer advanced solutions for societal problems, and new services to consumers. The disruptive implications of ICT innovation go beyond industries, economies, and traditional value chains and business models. Therefore, especially for ICT, it is relevant to extend the innovation systems concept to the societal level. In terms of indicators to 'measure' innovation systems, this implies that it is important to integrate indicators traditionally used to monitor the Information Society.

Based on the literature review, we propose a matrix as a framework of indicators that can be used to measure ICT innovation systems. Horizontally, it distinguishes the main

[1] For more information, see the project web site: http://is.jrc.ec.europa.eu/pages/ISG/EURIPIDIS/EURIPIDIS.index.html

components of an ICT innovation system (knowledge and technologies; actors and networks; institutions; mechanisms of interaction) and its main purpose (in the sense of the impact or performance it aims for). The following processes (functions/resources) are distinguished vertically: knowledge for ICT innovation; skills for ICT innovations; supply of ICT innovations; demand for ICT innovations; finance for ICT innovations; and internationalisation for ICT innovations. Examples of ICT indicators that can be used to fill in this operational monitoring system are provided.

We also stress that it is important to continue the conceptual and empirical development process of the last few decades, by further broadening the perspective on innovation. This also requires a broadening of the relevant indicators used to measure and monitor what is happening at the system and firm levels, capturing the involvement of additional stakeholders and additional interactions.

Towards firm-level modes of ICT innovation

The resource-based view of the innovative firm fits very well with the innovation systems perspective. This view states that value creation arises from uniquely combining a set of complementary and specialized resources and capabilities (which are heterogeneous within an industry, scarce, durable, not easily traded, and difficult to imitate). Patterns in these firm-level sets (or combinations, or innovation mix) can be identified and they give rise to the main types or modes of innovative behaviour.

Multivariate methods of data-reduction (e.g., factor and cluster analyses) seem most appropriate for identifying these modes of innovation as a coherent (jointly reinforcing) mix or combination of innovation strategy ingredients, or routine components. Overall, firms in the ICT sectors are more innovative than firms in other sectors, but the mode of innovation differs between the sub-sectors of ICT products (e.g. telecom and ICT services). These multivariate methods are useful for identifying innovation patterns at the firm level, and at the systems level. Integration of factor scores on ICT modes of innovation at firm level with regional indicators at system level would allow us to define an EU typology of regional systems of ICT innovation, which can then be seen as regional 'modes' of ICT innovation. This would reduce the complexity in studying the interaction between firms and their geographical context concerning ICT innovation, by simplifying the diversity in system contexts, and the diversity in firm strategies.

Policy implications

Studying and monitoring ICT innovation systems is important as it allows us to learn how to improve the policy and performance of current and future systems. It allows us to design and improve an ICT innovation policy mix, which is tailored to the specific needs of ICT modes of innovation, and also tailored to the prioritized mix of societal needs (e.g. economic, social, environmental, health, or other impacts).

Since ICT innovations become outdated very fast and new disruptive ICT innovations emerge and diffuse equally fast, the relevant institutions and framework conditions also have to be updated relatively quickly. Technology standards or regulations are very important drivers or barriers for the growth of ICT innovation systems. The policy implication of this is that timing in institutional change is crucial. Setting new standards, and updating regulations can create a competitive edge. The relevant regulations concern not only the ICT industries themselves, but also the industries and policy fields of application, e.g. transport (e.g. automated driving), health (E-health), and finance (e.g. crowd-funding and block-chain applications). Due to the increased importance of ICT innovation in all sectors and policy domains, ICT innovation policy has become (and should be addressed as) a horizontal policy field which maintains systemic linkages with the other policy fields.

Taking a wider systemic view of ICT innovation at a societal level also implies a broadened perspective on policy that extends:

- Beyond R&D policy. A systemic view on ICT innovation policy goes beyond supply-side innovation policy which promotes R&D in ICT, and complements it with demand-side innovation policies which promote the demand and diffusion of ICT innovations. For instance, a region such as Tampere has successfully transformed its innovation policy from R&D funding to supporting innovation platforms such as Demola, where student teams solve problems, allowing business opportunities to materialize faster.

- Beyond promoting science-industry interactions. For many years innovation policy has focused on supporting linkages between scientific research in ICT and producers in ICT industries, but these interactions should be broadened, to include ICT users in the public sector and civil sector.
- Beyond triple-helix innovation policy initiatives. In many sectors, regions and cities, the concept of the triple-helix has been applied in developing and implementing innovation strategies which involve industry, universities and government. Furthermore, additional actors are increasingly involved, most notably citizens and civil society actors (including not-for-profit non-governmental organizations).
- Beyond aiming for a purely economic impact of ICT innovation. Traditionally the focus has been on economic impact, but awareness of the impacts of ICT innovation in other policy fields has increased. Today, ICT innovation is seen as serving any policy field or government department and ICT innovation should be part of policies addressing societal challenges.
- Beyond policies which aim for technological innovation. In the past, ICT innovation policy was still largely focused on supporting technological innovation, as was innovation policy in general. Increasingly, however, it has become apparent that most impacts are to be gained from a wide range of non-technological innovations. Unleashing these impacts calls for policies and policy instruments which promote non-technological modes of innovation (including policies promoting new enabling ICT business/innovation models, or policies promoting design-thinking among SMEs, etc.).
- Beyond old sector policy silos. There is a need for systemic interaction between policy domains, and between government departments/Ministries and DGs, concerning emerging ICT innovations. Governments must promote synergies from (policy) interaction across sectors in the economy, across parts of society, and across policy domains.
- Beyond policy interventions through the market/price-mechanism for ICT. Lowering the price of ICT is not enough to enhance uptake and diffusion. Policies should aim for behavioural change (additionality) by promoting experimentation and demonstration (e.g.: by organizing hackathons, 'bankathons', 'living-labs', boot camps, demonstrators, digital platforms, etc.).
- Beyond copying best practice in ICT innovation policies. Since there is no perfect 'one-size-fits-all' standard policy solution which all policy makers should adopt, policy makers have to interact with stakeholders, and organize for entrepreneurial discovery of appropriate fields of 'smart specialisation' in order to develop systemic innovation strategies and learn how to improve the innovation policy mix.

Since R&D and innovation supply-side policies have been dominant for decades, policies to strengthen the European demand-side of digital innovation are needed.

At both the system and firm level, there are several modes of ICT innovation. Policy makers should not reduce diversity by favouring only one of these (e.g. by mainly subsidizing R&D or product innovation). Instead, policy makers should tailor their innovation policy mix to the variety of modes of innovation. As an extension to Lundvalls' theory on interactive learning between producers and users of knowledge, we add that policy for ICT innovation should be produced in interaction with its users.

1 Introduction

This report was prepared in the context of the three-year research project on *European Innovation Policies for the Digital Shift* (EURIPIDIS) jointly launched in 2013 by JRC-IPTS and DG CONNECT of the European Commission in order to improve understanding of innovation in the ICT sector and of ICT-enabled innovation in the rest of the economy.[2]

The objective of this report is to verify how the concept of innovation systems can be fruitfully applied to ICT innovation. The literature on (national, regional and sectoral) innovation systems claims that in order to understand innovation one has to adopt an approach which looks beyond R&D investments, beyond intra-mural firm activities, and beyond market-transactions. Innovative dynamics takes place in a broader (global, national, regional, sectoral) context in which firms interact with other firms and non-firm actors, and with market and non-market factors.

Basically, innovation can be studied at micro, meso and macro levels. Fagerberg (2013) defines these three levels as follows:

- the making of innovations (at the micro-level: in firms and organizations),
- innovation systems (relations between firms, customers, suppliers, the public R&D infrastructure, etc.), and
- the impact of innovation on social and economic change (the macro-level consequences for growth, competitiveness, employment etc.).
- This report has its focus on the system and firm level of innovation, and not at the macro-economic level.

A side-effect of the insight that a broader and more dynamic view on innovation has to be applied in trying to explain innovation (at the micro-level of companies, the meso level of networks and systems, and the macro level of economies and societies) is the acknowledgement of this complexity. The acknowledgement that in social science there is no simplistic 'one-size-fits-all' set of scientific laws or equations which can explain it all, is one of the main reasons why system approaches have been developed and why these approaches have become popular in studying innovation, and in developing strategic policies. Because of the inherent complexity and diversity, innovation systems literature consists mostly of conceptual contributions and case-studies. This report will not discuss the benefits and limitations of quantitative versus qualitative research approaches, but since both approaches are complementary this report takes up the challenge of how to improve measuring the broad range of relevant aspects concerning innovation at firm-level and system level.

Section 1 of this report addresses the meso-level of relations in innovation systems and their performance at the level of countries, regions, and sectors. It provides an overview of the various innovation systems concepts: at national, regional and sector level. Specific focus will be on the question how to measure the various aspects of the concerned innovation systems. Since the interactions between producers and users of innovations are central in the innovation systems approaches, the study will include both innovation in the ICT producing sector (s) and ICT-enabled innovation in ICT using sectors.

Section 2 addresses the behavioural, micro-level question: how do ICT firms innovate? After an overview of taxonomies of innovation modes or models, the focus will again be placed on the empirical question of how to measure, capture or indicate these modes.

There is a large diversity within European ICT sub-sectors, as well as in the various national and regional contexts, e.g. the characteristics of ICT services and software are different from those of ICT manufacturing industries; and the framework conditions for

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[2] For more information, see the project web site: http://is.jrc.ec.europa.eu/pages/ISG/EURIPIDIS/EURIPIDIS.index.html

the various sub-sectors differ between countries and regions. Indicator-based monitoring and analysis provides insights in the various ICT innovation systems and the different modes of innovation among firms, which serves to come to better policies to promote the performance and impact of the concerning ICT innovation systems. Policy implications are addressed in Section 4.

2 The innovation systems approach: towards an application for ICT innovation

This section provides an overview of the literature on innovation systems (Sections 2.1 and 2.2). It also addresses the question of how these innovation systems concepts can be applied to ICT innovations, and how national and regional systems of ICT innovation can be measured and monitored (Section 2.3).

In a discussion of analytical and methodological issues in the literature of innovation systems, Carlson et al. (2002) start with referring to definitions of the word 'system' in dictionaries, where a system is often defined in terms like: "a set of rules, an arrangement of things, or a group of related things that work as an organic whole towards a common goal". Basically, systems consist of components, relationships among these, and their characteristics. Carlson et al. (2002) compare the various concepts of innovation systems and conclude that they all involve the creation, diffusion, and use of knowledge.

The notion of national innovation systems was first proposed by Freeman (1987) and Lundvall (1992). It should be seen as an attempt to broaden the innovation perspective and deepen the understanding of its dynamic processes explaining 'how the economic system generates the force which incessantly transforms it' (Schumpeter 1937, p. 158). The innovation systems concept was defined at a time when economists discussed to what extent technological change should be seen as an external (publicly available and benefitting all) or internal (e.g. private benefit for R&D performers) driver of change. The innovation systems solution to this debate (as is the answer in evolutionary, behavioral and institutional theories, and in concepts such as networks, open innovation or ecosystems) is at the meso-level where various actors interact in a specific common context. At this meso-level, innovation and its context become interdependent.

Many authors have used the concept of national innovation systems and have contributed to its development as a theoretical concept, but there is no commonly agreed definition. Often when new concepts emerge, institutes such as the OECD manage to come to a certain level of standardization, but the OECD (1997) report on national innovation systems does not provide such a standardized definition. Several years later, the Oslo manual (3rd edition; OECD 2005), produced by the OECD and Eurostat in cooperation, on how to measure innovation, shows that the development of the NIS concept has changed the conception of innovation:

> *"innovation is a more complex and systemic phenomenon than was previously thought. Systems approaches to innovation shift the focus of policy towards an emphasis on the interplays between institutions, looking at interactive processes both in the creation of knowledge and in its diffusion and application. The term "National Innovation System" has been coined for this set of institutions and flows of knowledge" (OECD 2005, p.6).*

Innovation is a social phenomenon: it does not occur in a vacuum, nor can it be regarded as an external given, which becomes accessible to us all like 'manna from heaven'. Many different actors and inputs from many different sources are involved in innovation processes. Innovation emerges from processes which take place in a certain context, and the innovations are used in a context, where they serve a purpose. The context may differ across technologies and sectors, but also between countries and regions. Various different, but inter-related sources, actors and processes are involved. The relevant context, from which new combinations emerge, can be specified in terms of institutional, political, historical and social aspects.

All this implies that innovation systems can be defined, studied and monitored in a variety of ways. The various innovation systems concepts which have been developed include: national innovation systems (Freeman 1987; Lundvall 1992; Nelson 1993), regional innovation systems (Cooke 2010; Cooke et al. 1997; Braczyk et al. 1998), and sectoral innovation systems (Malerba 2002; 2004). These three concepts will be defined and discussed (Section 2.2), but first we define innovation, and we discuss some older theoretical antecedents on which these three applications of the innovation system concept are based (Section 2.1). In doing so, most of the top 10 contributions on innovation (Table 1) will be discussed.

2.1 Theoretical antecedents of the innovation systems concept

While an invention concerns the creation of the first idea of a new product or process, innovation refers to the use of this new and better idea or method, the attempt to try it out in practice and to bring it on the market or deliver it as a public service. So where inventions can be seen as technological 'breakthroughs' in science, innovations can be seen as 'breakthroughs' in markets and societies. Schumpeter described this with his concept of creative destruction. This concept is more dynamic then the neoclassical strand of economics that emerged by then[3], and that according to Schumpeter was a too passive view on economic life. He wanted to explain:

> *"a source of energy within the economic system which would of itself disrupt any equilibrium that might be attained". (Schumpeter 1937/1989, p.166).*

Innovation is this dynamic source in capitalism. In order to turn an invention into an innovation, an innovative entrepreneur combines several different types of knowledge, capabilities, resources and skills. The person or organizational unit which combines all these factors in new ways was labelled 'entrepreneur'[4]. So, for Schumpeter the concept of innovation was indeed closely related to entrepreneurship. Although he often wrote about it as a person (and is sometimes criticized for that), he referred to the entrepreneurial function of coming to new combinations, which replace old ones. This process of creative destruction, is not limited to one person or a new product, or market, but also involves whole sectors or economies. The 'new combinations' include four types of innovations identified by Schumpeter (product innovation, process innovation, organizational innovation and market innovation). As such, these types are still visible in the definition of innovation as provided in the Oslo manual (3rd edition, 2005):

> *"An innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations"*.

Besides building on ideas of Schumpeter, the innovation systems literature that we will discuss also builds on work of other authors. The theoretical antecedents are basically evolutionary and institutional theories. Without having the intention to discuss all the aspects which make part of this historical trajectory towards the concept of innovation systems, we will discuss a few.

As said, Schumpeter makes an important distinction between inventions and innovations, and emphasizes the process of combining several different kinds of knowledge and resources. Also in terms of actors the innovation process is more complex, since the person with the first idea of a new technology (the inventor) may be different from the innovator, or what Schumpeter called the entrepreneur. Later this distinction between invention and innovation has often been neglected, however:

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[3] As represented by Walras. Schumpeter admired his ideas on how price-mechanisms work, but he dis-agreed with the passive, steady state view on economies. Later this neoclassical school has developed. Some have formalised some insights from Schumpeter into macro-economic equilibrium models and labelled themselves as New Schumpeterian, but it is essential to note that according to Schumpeter the essence of capitalism is its non-steady, dis-equilibrium state. In a stationary state there would be no role for innovation and entrepreneurship. Formal evolutionary models are mostly based on Nelson & Winter. For a discussion on this, see Fagerberg (2014), and Hall & Rosenberg (2010).

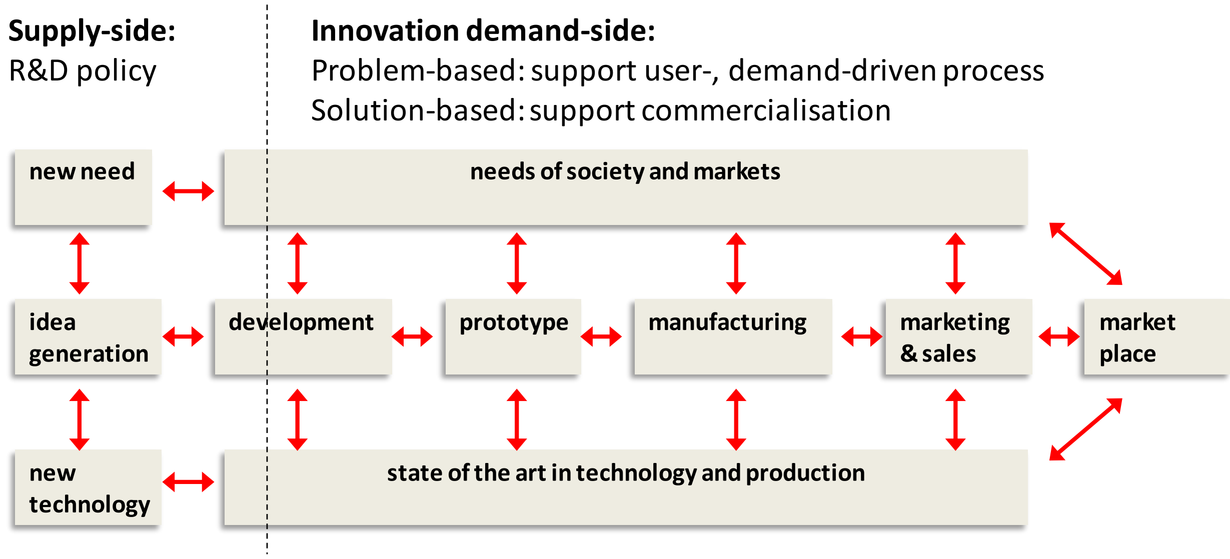
[4] More on the concept of entrepreneurship will be provided in Section 3 which has its focus on the firm-level.

> *"most important innovations go through drastic changes in their lifetimes – changes that may, and often do, totally transform their economic significance. The subsequent improvements in an invention after its first introduction may be vastly more important, economically, than the initial availability of the invention in its original form" (Kline and Rosenberg 1986, p.283*).

So, not only the supply-side of inventions matter, but also the demand-side, the improvements from their interaction and the improved benefit of usage.

The 'coupling model' of innovation developed by Rothwell & Zegveld (1985) also emphasizes the fact that both the supply- and demand-side of interactions matter for innovation. The model shows that there are many sources for innovation, many linkages and feed-back-loops from interactive learning (Figure 1). Generating new ideas and technologies by performing R&D, e.g. by scientists, is part of the process and a valuable source, but as the 'coupling model' shows it is not the only source of innovation and the flow of knowledge does not automatically lead to new prototypes, production and sales . Also the learning-by-doing from experiments in, for instance, manufacturing practices, and the lessons and new ideas from interacting with clients and suppliers are important sources of innovation. This implies that in order to explain innovation performance, one also has to study the relations between all the involved actors and (re)sources. Experimenting with existing inputs which are new to the concerning economy (at firm, region, sector or country level), such as new materials, and with new ways to organize supply-chains, and buying innovative machines which already exist on the market, are also innovative activities which should be taken into account (and measured) in case one wants to understand innovation dynamics and performance. Figure 1 indeed applies to several levels of analysis (the micro-level of the firm, the meso-level of a sector, or the macro-level of a region, country or group of countries like the EU). When we add to this conceptual framework the policy dimensions of supply-side innovation policy (which refers to public support for R&D aimed at increasing the supply of new technological innovation) and policies promoting the demand for innovation (which refers for instance to public procurement of innovations, or subsidies to promote the up-take of state of the art robots in production, or support for the commercialization of environmental friendly innovations), the coupling model also shows that at many instances it is beneficial to organize communicative linkages between the innovation supply and demand side (Figure 1). This touches on the importance of interactive learning between producers and users of knowledge. The coupling model can therefore be seen as a theoretical antecedent, of Lundvall's (1992) National Innovation Systems (NIS) framework that will be discussed in Section 2.2.

Figure 1: The coupling model of innovation



Based on Rothwell and Zegveld, 1985.

The 'coupling model' is also helpful in showing the important role of ICT as a pervasive and general purpose technology. ICT can affect both the way in which the different elements interact (as represented by the arrows) but can also impact the elements (boxes) of the framework in Figure 1. To give a few examples in relation to Figure 1, new ICT-applications such as Big Data, web-based platforms and the Internet of Things are affecting the red-arrows in the graph, and the communicative interactions which these arrows represent. Such new ICT applications result in new combinations and new business models.

For instance, the trend of crowdsourced manufacturing, or the 'maker-economy' shows how ICT platforms can actively involve customers in a demand-driven process of prototyping and manufacturing[5]. New ideas for innovations may also originate from introducing new ways to communicate with the market place, and new analytical tools to make predictions based on Big Data. Innovations may also emerge from automating analysis of large amounts of data on the concerning innovation or production processes. New prototypes or manufacturing processes or organizational innovations may also come from buying and experimenting with an existing, state-of-the-art 3D-printer. The link to such a printer can also be digital on a web-based platform. The case-studies and trend reports of the Business Innovation Observatory[6] provides many examples and explanations of how applying ICT leads to a wide variety of new ICT innovations.

Concerning the impact of ICT on the 'boxes', governments might prioritize and promote certain ICT-based solutions to societal problems, for example ICT solutions for an ageing society. Following this example, the needs of society call for generating new ideas and technologies in this field, e.g. in the form of a priority in the Horizon 2020 research programme of the EU. At regional level, some regions which are leading in terms of ageing, have Smart Specialisation strategies and programmes to support innovation in the e-health sector. The policy instruments also include demand-side policy tools. E.g. In the form of public procurement policy which promotes the development of new prototypes, and the role of the public sector as launching customer or lead-user. With cluster-policies buyers and suppliers in e-health are invited to interact and co-operate.

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[5] http://ec.europa.eu/enterprise/policies/innovation/policy/business-innovation-observatory/files/case-studies/27-smf-crowdsourced-manufacturing.pdf

[6] http://ec.europa.eu/growth/industry/innovation/business-innovation-observatory/index_en.htm

With the policy tool of living labs, solutions are tested by users, outside a research lab, but in real life conditions, such as a hospital. Innovation agencies can provide loans to producers of e-health for digitalizing their production process and for instance to hospitals for investing in the internet of things infrastructure (Avigdor & Wintjes 2015).

Rejecting the 'linear model of innovation' studies of innovating firms have indeed revealed that the multiple sources of knowledge creation, learning and innovation have become broader and more complex, regardless of the R&D intensiveness of their industry. Innovation surveys (CIS) have for instance shown that R&D is indeed not the sole source of innovation for firms (Arundel et al. 2008; Mairesse and Mohnen 2010). Also Fransman (2014) draws the same conclusion from studying global ICT companies. The traditional neo-classical notion that innovation is limited by the rate of R&D investment is useful at the macro-level, but it is not very helpful for a firm, industry or policy maker in deciding how, and what kind of innovation should be pursued. Since, as argued and shown by the innovation systems literature, there exists a large variety in the sources, nature and uses of innovations.

The work of Nelson and Winter (1982) on the 'Evolutionary Theory of Economic Change' is another example of insights that have served as building blocks of the innovation systems literature. They combine Schumpeter's work with behavioural theories such as the idea of 'bounded rationality'[7] (Simon 1947), emphasizing the importance of routines and procedural and organizational knowledge. Due to the uncertainty and complexity of innovation processes, the rationality of the decisions of firms is 'bounded'. Nelson and Winter explain that firms base their decision-making on 'routines' and habits for dealing with problems. Changing routines, disrupting habits, innovating business models (Chesbrough 2010) is not easy, but, these firm routines can accumulate (adopting new lessons) and be developed into 'dynamic capabilities' to address new problems, e.g.: the capability to absorb the technologies developed by others (Cohen & Leventhal, 1990). Instead of the term steady state, Nelson and Winter refer to steady change, a persistent process of transformation in an economy which is explained by the continuous generation, diffusion, accumulation and substitution of innovations by a diversity of economic agents. Neither the characteristics of the economic systems, nor those of the decision-makers are regarded as fixed. Rather the focus is on the non-equilibrium processes that emerge from actions of diverse agents with bounded rationality, who may learn (and so to say 'change their rationality or the boundaries of it') from experience and interactions, and whose differences contribute to the change.

Policymakers have a role in creating the conditions for firms which promote innovative behaviour and interactions, and which enhance capabilities for innovation. In the words of Metcalfe (2005, p.443): *"the evolutionary policymaker is not an optimizing supplement to the market, correcting for imperfect price signals in such a way as to guide private agents to a better innovation mix"*. Policymakers are not perfect either and are also boundedly rational. So a policymaker does not know what the best innovation mix would be for an SME, a sector or a region. This also means that there is no one-size-fits-all, 'best practice' policy. The policy argument moves away from a narrow focus on market failure arguments, to innovation support interventions which aim for a change in behaviour and routines (Nelson & Winter 1982). The uncertainties and risks involved with technological change, put a premium on learning by doing, learning by using and learning by interacting. This actually applies to all the stakeholders in a concerning eco-system, not only to firms, but also to the policymaker, the investors, the users, the teachers, the employees, the regulator, etc. All these actors learn. Also policy makers adopt new knowledge on ICT policies and influence each other towards adoption, e.g. on

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[7] With 'bounded rationality' Simon (1947) rejects the notion of an omniscient 'economic man' capable of making decisions that bring the greatest benefit possible. When individuals make decisions, their rationality is limited by the information they have, the cognitive limitations of their minds, and the time available to make the decision. Decision-makers in this view can only seek a satisfactory solution, lacking the ability and resources to arrive at the optimal one.

trends such as Big Data or the Internet of Things. Nauwelaers & Wintjes (2003) distinguish policy instruments along different logics of intervention: those which lower the price of inputs aiming to fund the best innovation projects (e.g. R&D subsidies) and those which aim for behavioural additionality (changing the boundaries of rationality) by providing firms a learning to innovate experience (see also Asheim et al. 2013), which can be an eye-opening experience, an opportunity to try new things, to increase capabilities, to get to know new partners, to get inspired, to discover export opportunities, etc.

Also on the top 10 list of publications in innovation studies is the contribution of Pavitt (1984) on Sectoral patterns of technological change. This study showed that firms from different sectors used different sources for innovation. This difference in sources (or knowledge-basis) defines the different modes of innovation. Pavitt showed that firms in, for instance, biotech and pharmaceutical industries have a more 'science-based' mode of innovation, which involves relatively high R&D investments. In more traditional sectors such as textiles, the innovation mode is more based on linkages with suppliers. These firms often innovate by buying new machinery or using innovative materials, such as new fibers developed by major global suppliers. The taxonomy developed by Pavitt has certainly served as a theoretical antecedent for development of the concept of sectoral innovation systems. However, this taxonomy will be discussed more in-depth in section 3.2 when we discuss taxonomies of firm innovation modes.

Next to the territorially defined innovation systems (2.2.1) and the innovation systems which are defined by sector borders (2.2.2), we therefore also discuss more recent innovation systems concepts which address certain societal challenges (2.2.3).

Concerning the theoretical antecedents we conclude that the innovation systems concept was defined some 25 years ago, at a time when economists discussed to what extent technological change should be seen as an external (publicly available and benefitting all) or internal (e.g. private benefit for R&D performers) driver of change. The innovation systems solution to this debate (as is the answer in evolutionary, behavioural and institutional theories, and in concepts such as networks, open innovation or ecosystems) is at the meso-level, where various actors learn from own experiences and from interaction with others in a specific common context. At this meso-level innovation and its context become interdependent, embedded in interactions between supply and demand, between the producers and users of knowledge.

Table 1: Innovation studies: top 10 contributions

No	Author	Country	Title	Type	Year
1	Nelson RR & Winter S	USA	An Evolutionary Theory of Economic Change	Book	1982
2	Nelson RR	USA	National Innovation Systems	Book	1993
3	Porter ME	USA	The Competitive Advantage of Nations	Book	1990
4	Schumpeter JA	Austria/USA	The Theory of Economic Development	Book	1912 (1934)
5	Rogers EM	USA	Diffusion of Innovations	Book	1962
6	Lundvall B-Å	Denmark	National Innovation Systems – Towards a Theory of Innovation and Interactive Learning	Book	1992
7	Freeman C	UK	The Economics of Industrial Innovation	Book	1974
8	Cohen W & Levinthal D	USA	Absorptive Capacity	Article	1990
9	Pavitt K	UK	Sectoral Patterns of Technical Change	Article	1984
10	Arrow K	USA	Economic Welfare and Allocation of Resources for Invention	Book Chapter	1962

Source: Fagerberg 2013.

2.2 Applications of the innovation systems concept

2.2.1 National and regional innovation systems

With the national innovation systems concept (Freeman 1987, and Lundvall 1992) the national boundaries are taken as the system boundaries, since there are many relevant institutional differences between countries. This perspective challenges a simplistic view on 'globalization, global markets and global economy', as if contextual differences no longer exist, or no longer matter for ICT innovations. One of the reasons why institutions concerning innovation differ between countries, is the difference in governance between countries concerning knowledge, technology and learning processes, e.g. concerning education, universities and industrial policies. In this respect, a main topic studied by the national innovation systems literature is the issue of science-industry linkages within countries. These science-industry linkages (and the technology 'transfers' between these knowledge producing and using sectors) are very sensitive to (institutional, political, historical and cultural) differences between countries.

National innovation systems studies have broadened the view on innovation policy. R&D is not the only source for innovations and the main role for policy makers is not to secure funding for individual innovation projects, but in creating the conditions for firms that promote innovative behaviour and interactions, and conditions which enhance capabilities for innovation. In this respect the national innovation systems studies have been quite successful, since 25 years later, even neoclassical economists are convinced that R&D is not the only driver of innovation.

The main authors who have developed[8] the national innovation systems concept are: Freeman (1987), Lundvall (1992), and Nelson (1993).

Freeman defined a national innovation system as:

> *" .. the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies."* (Freeman, 1987).

In his study of the success of the Japanese economy, Freeman came to his idea (of national innovation systems) that could explain differences between countries in terms of technological innovations.

In his publication titled: 'National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning' Lundvall builds on the ideas of Freeman and extents its theoretical background. Lundvall (1992) defined a national innovation system as:

> *" .. the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge ..."* (Lundvall, 1992).

This definition shows that this approach to innovation is broadened from technological knowledge to economically useful knowledge. Lundvall has also extended the factors that promote innovation to also include social and cultural factors.

The important theoretical contribution by Lundvall concerns the notion of interactive learning between producers and users of innovations. This notion explains how many non-market aspects play a role in innovation processes. Users and producers of knowledge and innovations learn from communicating with each other, from interactive communication and not from exchanging price signals in mere market relations of buying and selling. With interactive learning actors adapt to each other and influence each other towards adoption: they co-evolve. Instead of passive selling (exchanging and extracting value), learning with users is about co-creation of value (Avigdor et al. 2014). Learning with users in value chains and systems implies a role for users and consumers that contradicts the dictionary definition of "consume": meaning "destroy", "use up", or "waste", since users of innovative solutions continue the value creation process through use (Vargo et al. 2008). In Lundvall's theory of interactive learning between producers and users of economically useful knowledge, the starting point is K. J. Arrow's 1962 paper "Learning by Doing", which shows that closing knowledge gaps and helping laggards learn are central to growth and development of any economy.[9]

Concerning social and cultural factors, later studies (as for instance discussed by Soete et al. 2009) have indeed shown empirically that differences between countries (and regions) in terms of for instance social capital, trust, and entrepreneurial culture, do indeed explain differences in innovation performance.

The third definition of national innovation system we provide is from Nelson (1993):

> *"... a set of institutions whose interactions determine the innovative performance ... of national firms."* (Nelson, 1993).

The book "National Innovation Systems" (Nelson, 1993) for the first time made a systematic comparison between countries, discussing organizational innovation practices at system level. Together with the 'Evolutionary Theory of Economic Change' this book is in the top 10 (Table 1) of the most cited publications in innovation studies (Fagerberg 2013). The theoretical perspective builds on the evolutionary theory from Nelson & Winter (1982). Firms in a given country have a certain commonality in their micro-level

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[8] See for instance Soete et al (2009).

[9] In "Creating a Learning Society" Stiglitz & Greenwald (2015) also start from Arrows paper when they explain (as Lundvall did) why the production of knowledge and innovation differs from that of other goods and why market economies alone typically do not produce and transmit knowledge efficiently. Policy makers should promote learning and interactive learning.

'routines' which can be explained by the common institutional environment of the national innovation system in which they learn and innovate. The same holds for the other type of stakeholders, including policy makers. As Malerba (2004, p. 14) puts it:

> *'in an evolutionary framework there is not a sharp distinction between the learning environment and the unit of learning'*.

National systems of technical innovation are based on a strong belief that technological capabilities of a nation's firms are a key source of national competitiveness, and can be built by national action. The book contains studies of seventeen countries, including a number of newly industrialized states[10].

One of the main contributions of Nelson (1993) was showing convincingly the importance of the State, the institutions and public policies in enhancing technological capabilities of firms in a country. The successes of companies from Japan, and Asian Tigers like South Korea and Taiwan, could be traced back to national technology strategies and national systems of technological innovations.

The concept of NIS has therefore become quite popular among policy makers, as it provides a framework for strategic action at the societal level. This strategic governance aspect has later also become apparent in strategies addressing grand challenges, and for instance in 'Smart Specialization'.

Although in the early studies on innovation systems the comparison between countries is based on descriptions of rather static profiles, more in-depth and qualitative studies have focused on the dynamics and (path-dependent) change of systems over time, also including a policy perspective. See for instance the NIS framework synthesis provided by Fagerberg 2013 (as illustrated in Figure 2).

In this framework knowledge, skills, demand, finance and institutions are highlighted as the main factors (resources, activities) which each interact with technological change. These dynamic processes generate innovation. The role of public policy is complex, which is illustrated by the list of policy domains. Indeed, all the policy domains somehow touch on the mentioned processes. We can interpret the domains as ministries of the concerning country. In order to prevent that each ministry builds an innovation system for its own 'purpose' as a 'policy silo', strategic management is needed to organize for a systemic approach. The idea that the institutions of various policy domains influence the innovation performance of innovation systems has been part of the NIS concept from the beginning, but over the years the number of policy domains which are considered relevant has increased, moving beyond the ministries of industry and economy and the ministries of science and education. For instance, also ministries concerning health, transport, energy, ICT, finance, and regional development, are involved.

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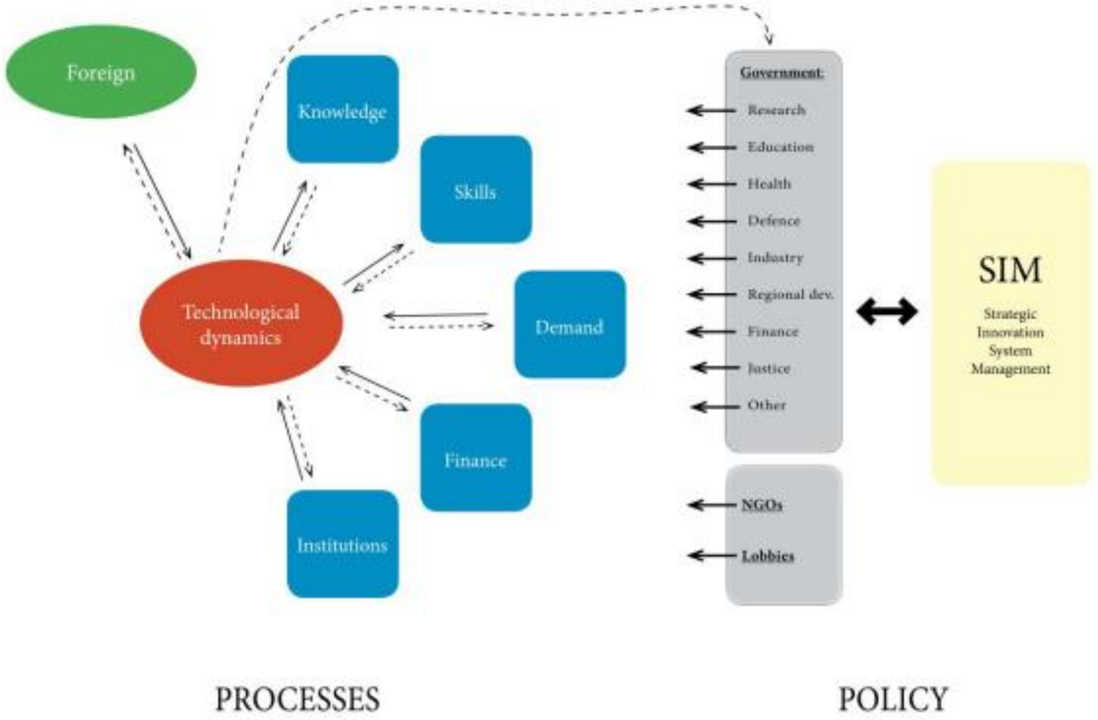
[10] Empirically, the authors of the book edited by Nelson (1993) saw a 'techno-nationalism' in the rise of Japan as a major economic and technological power and in the enhanced technical sophistication of Newly Industrialized Countries such as Taiwan and South Korea.

Figure 2: The national innovation system: dynamics, processes and policy



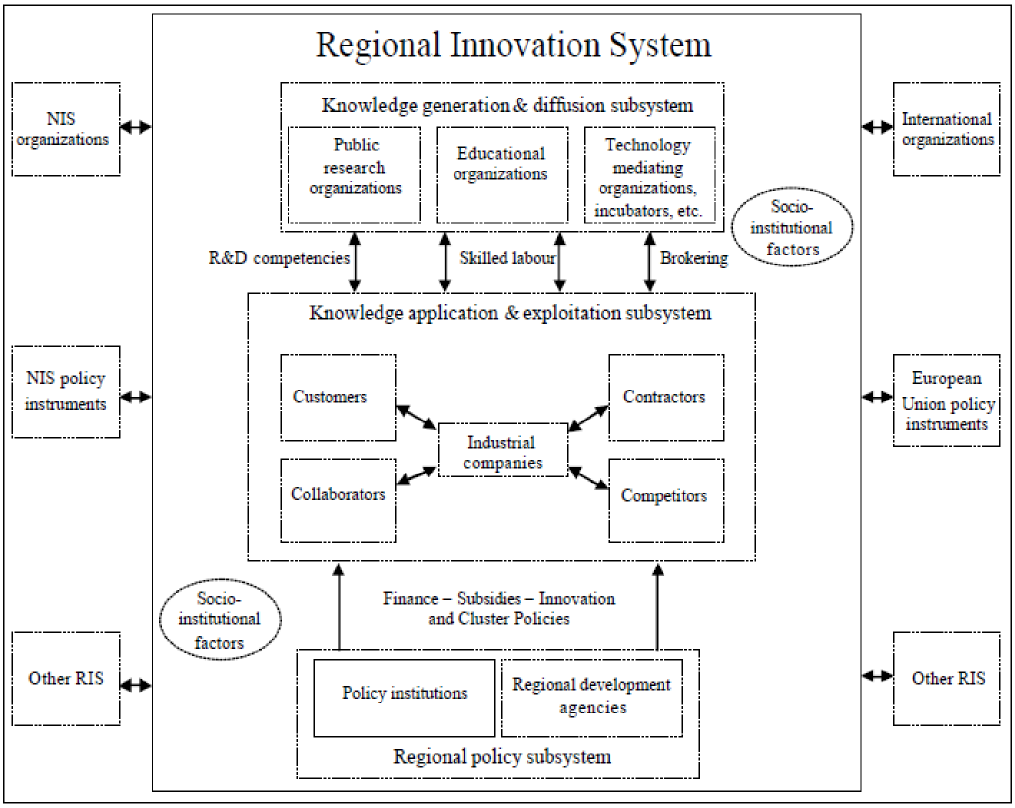
Source: Fagerberg 2013.

After the emergence of the national innovation systems concept, other applications of the innovation systems concept have followed. Focusing on the geographical aspect several have applied the NIS concept to study regional innovation systems. Cooke (1997) applied the NIS theoretical background and suggested that: "this approach may be complemented in important ways by a sub-national focus". There are some differences with the NIS literature due to the reduced scale and policy competencies, but it is difficult to interpret these differences as conceptual. Regional Innovation Systems (RIS) studies have developed into quite a large strand of literature and the RIS approach has been widely adopted by policy makers to develop regional innovation strategies.

In Figure 3, one example of a schematic overview of the concept of regional innovation systems (Trippl 2006) is provided. The figure clearly illustrates that the RIS is not seen as a closed system, but that it interacts with other systems at national and regional level. The science-industry linkages have been the central focus for decades, especially at the regional level. Trippl discussed this as interactions between sub-systems, and added a policy sub-system (Figure 3). The importance of collaboration between government, firms and education institutes (defined as three regional sub-systems in Figure 3[11]) has also been emphasized with the concept of 'triple helix' (Etzkowitz & Leydesdorff (2000).

[11] Namely: the regional policy sub-system, the knowledge application and exploitation sub-system, and the knowledge generation and diffusion sub-system.

Figure 3: The regional innovation system: a conceptual framework



Source: Trippl (2006).

The importance of the interaction between the three RIS subsystems of Figure 3, indicates the need for co-designed regional innovation strategies, which is also emphasized in the more recent concept of Smart Specialization developed by Foray et al. (2009, 2015) and the RIS3 innovation strategies at regional level. The notion of Smart Specialization describes the capacity of an economic system (a region for example) to generate new specialities through the discovery of new domains of opportunity and the local concentration and agglomeration of resources and competences in these domains. Choosing the fields of regional specialization should not be done by scientific discovery, or top-down by policy-makers, but in a joint 'entrepreneurial discovery' (Foray et al. 2009, 2011) process based on interaction with companies and other stakeholders. As Foray (2015) explains later, they (Foray et al. 2009, 2011) referred to the concept of 'entrepreneurial discovery' as a practical process in development economics, inspired by the 'self-discovery' process as described by Hausmann & Rodrik (2003). Also for the design of policy instruments and appropriate framework conditions, interaction among stakeholders is essential. Cooke (2007) and Asheim et al. (2013) refer in this respect to co-designing of regional innovation strategies and systems in terms of 'constructing regional advantage'[12]. Nauwelaers & Wintjes (2002) explain in this respect the need for 'interactive policies'.

Although some authors claim that either the national or the regional (sub-national level) is more important for innovation than the other, most authors appreciate analysis at multiple geographical scales: e.g. the (Nuts1, Nuts2 or Nuts3) regional level and the national level. One of the most common arguments applied when selecting the appropriate level, is the relevance of boundaries of jurisdictions, but the way in which administrative areas are organized differs to a large extent within Europe and within

[12] See also Ron Boschma (2014) for a comparison between the concepts of 'Smart specialization' and 'Constructing Regional Advantage'.

countries. In some countries the most relevant regulations, infrastructure, strategies and policy instruments are governed at the national level, while in other countries there can be quite remarkable differences between regions. For example, in the case of Estonia or Luxembourg there is no reason why the sub-national level should be addressed, but for Spain there is.

2.2.2 Sectoral innovation systems

An important insight of the sectoral systems approach, developed by Malerba (2002, 2004), is that innovation systems operate at multiple levels and within and across (national/regional) economies and technologies. Indeed, not only the geographical differences matter, but also the differences between sectors and their sector-specific innovation processes, institutions and resources. Malerba (2002) actually labelled the concept: 'Sectoral systems of innovation and production', but most others refer to it without adding the word 'production'. According to Malerba:

> *"a sectoral system is a set of products and the set of agents carrying out market and non-market inter-actions for the creation, production and sale of those products. A sectoral system has a specific knowledge base, technologies, inputs and demand. Agents are individuals and organizations at various levels of aggregation. They interact through processes of communication, exchange, co-operation, competition and command, and these interactions are shaped by institutions. A sectoral system undergoes change and transformation through the co-evolution of its various elements." (Malerba 2002, p. 247).*

In the above mentioned definition of sectoral innovation systems only products are used and not services. Indeed, one of the critical remarks on the early innovation systems studies was their focus on technological innovation in manufacturing sectors. In the definition we see again (as in the definitions on national innovation systems) the attention for both market and non-market factors. A difficulty concerns the boundaries of sectors and the various levels of aggregations, because the boundaries change, new sectors and sub-sectors emerge. This issue of sector-definition is especially relevant when studying a general purpose technology such as ICT, which is used across all the sectors of the economy. The actors involved in sectoral systems also include those which are classified in other NACE categories. A recent study of Adams, Montana & Malerba (2013) for instance shows how important industrial users are in the sectoral innovation system for semiconductors. They show for instance that a large share of the inventions in semiconductors is done not by semiconductor firms but in user industries such as instruments, industrial machinery, automotive and defence.

Malerba (2002) specified the various mechanisms of interaction as processes of communication, exchange, co-operation, competition and command. These interactions are shaped by institutions which often differ by sector. Next to this institutional theoretical aspect, also the evolutionary aspect is addressed in the above definition of Malerba by stating that the transformation is the result of co-evolution of its various elements. This co-evolution creates development paths for the various sectors.

The concept of Sectoral Innovation Systems (SIS) is less often used, compared to the geographical innovation systems concepts of NIS and RIS. One of the reasons is the popularity of the cluster concept, which is a 'rival concept' to the SIS concept. Although there is no commonly agreed upon definition of clusters, they often combine territorial and sectoral aspects. For example, OECD studies, such as the one titled: 'Boosting Innovation: The Cluster Approach' describes clusters as sector-specific systems of innovation, which operate under national systems of innovation. Also the OECD study: 'Innovative Clusters: Drivers of National Innovation Systems', belonged to the second phase of the OECD NIS project which was devoted "to deepening the analysis" of national innovation systems.

The term 'ecosystem' is another 'rival concept' which is often used (especially in the US), but it basically refers to the same sectoral innovation systems concept. In Europe, another, even more recent, rival concept concerns Smart Specialisation. As a pre-condition for regions for the new period of Structural Funds (of which a large share is available for innovation), Smart Specialisation (RIS3) strategies revolve around a regionally as well as sectorally defined system of innovation approach.

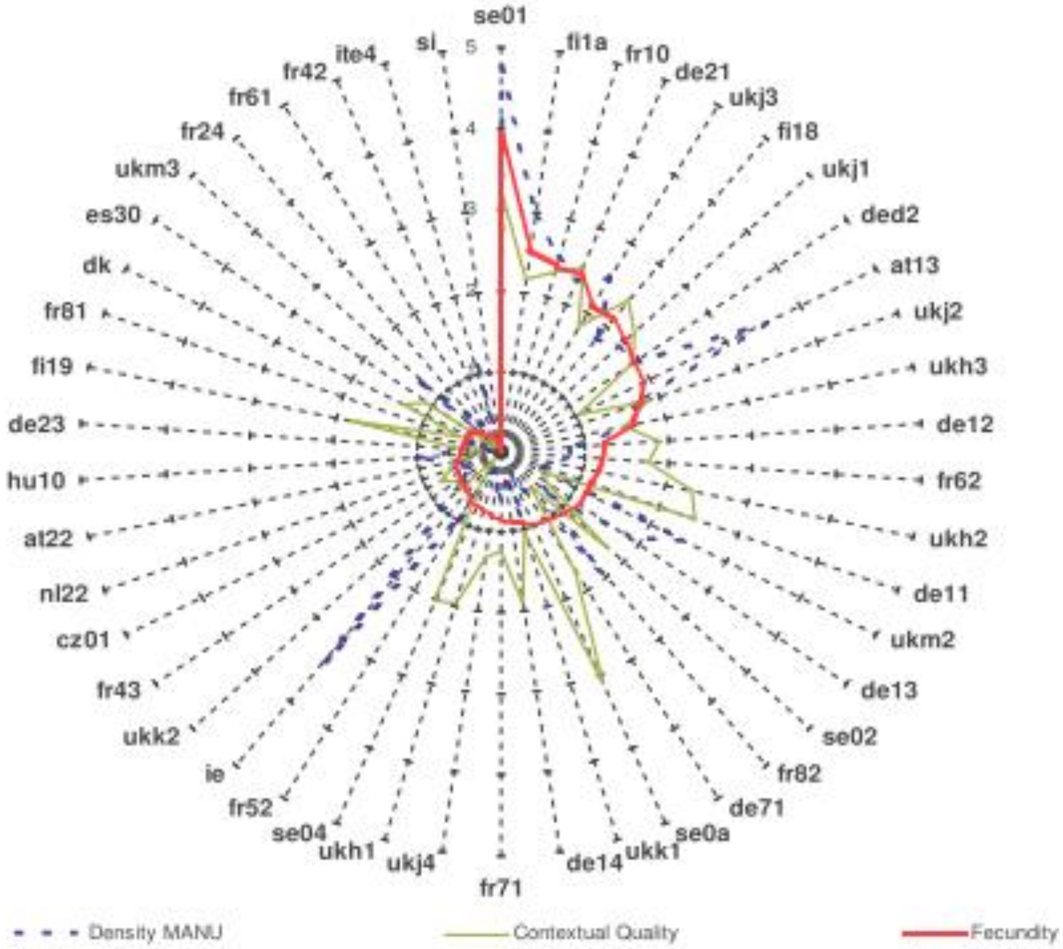
Although most studies on clusters and other types of sectoral innovation systems studies are of a qualitative, in-depth and case-study nature[13], there are some studies which have tried to test some innovation systems hypothesis in a more quantitative (indicator based way) for certain sectors, such as the ICT sector. For instance, Wintjes & Dunnewijk (2008) report on ICT clusters at regional level. ICT clusters settle in fecund regions, where fecundity is defined as a combination of high density of ICT employment and high quality of the surroundings or contextual quality. Ranking the most fecund European regions (EU25) which have above average contextual quality and above average ICT employment density (at the Nuts 2 level), the study reveals that Stockholm (se01), two Finnish regions Pohjois-Suomi (fi1a) and Etelä-Suomi (fi18), Île de France (fr10), Oberbayern (de21), Hampshire and Isle of Wight (ukj1), Dresden (ded2), Vienna (at13), Surrey, East and West Sussex (ukj2) hold the top-10 positions of this list. Figure 4 exhibits all the regions with above average contextual quality and density of ICT manufacturing activities. Overall this analysis supports the view that a high sector density co-evolves with contextual quality, as suggested by innovation systems literature.

The IPTS project[14] on Poles of Excellence in ICT provides a more recent and more detailed (e.g.: at NUTS3) confirmation. In Nepelski et al. (2014) the key findings are reported. A composite indicator shows that the concentration for ICT innovation seems to have increased with Munich, London and Paris standing out. Other results in line with innovation systems literature are that excellence builds on high performance across all activities, and that 'diversity dominates' (although ICT sub-sectors are not considered).

13 e.g. Larosse et al. (2001) on ICT clusters.

14 http://is.jrc.ec.europa.eu/pages/ISG/EIPE.html

Figure 4: Top ICT regions based on ICT manufacturing density and contextual quality of environment

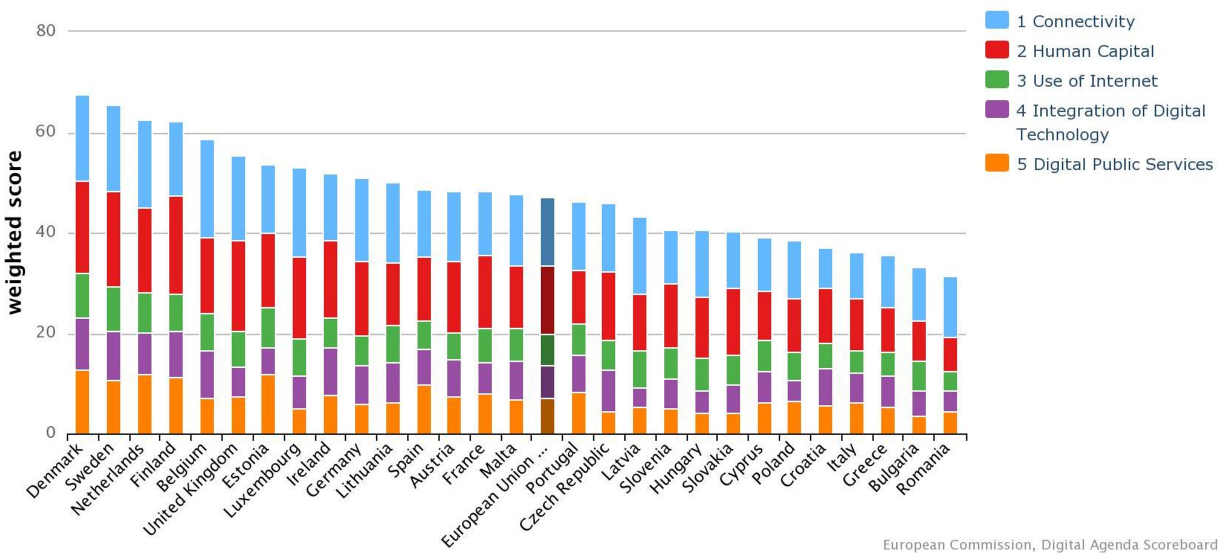


Source: Wintjes & Dunnewijk (2008).

Also within the sectoral innovation systems literature, most of the attention has for a long time, been given to research and technological development as input for generating business innovation. Soete et al. (2009) state that one of the shortcomings of these early systems of innovation concepts is the limited attention for the increase of innovations which do not need 'particular leaps in science and technology': the combination, use and diffusion of known practices has become more important for innovation and its economic impacts.

By adding the word 'production' to the definition of the concept of 'sectoral systems of innovation and production' Malerba (2002) already stressed that indeed the sectoral system should involve more than R&D. Especially concerning ICT innovations, more and more emphasis has been put on the innovation demand side, which, for ICT goods and products, can be found in almost every other sector. In many ways a shift has occurred in the emphasis of many national ICT policies from targeting the R&D as the innovation supply side to supporting the innovation demand side. Even within R&D policies (e.g. the European Horizon 2020 programme or the EIT institutes), the interaction with users in Europe has been given more attention. Overall the awareness has increased that mere excellence in ICT research and export of ICT patents, does not bring much economic impact, without production and usage of ICT in Europe.

Figure 5: Digital Economy and Society Index, by main dimensions (2014)



Source: European Commission, Digital Agenda Scoreboard.

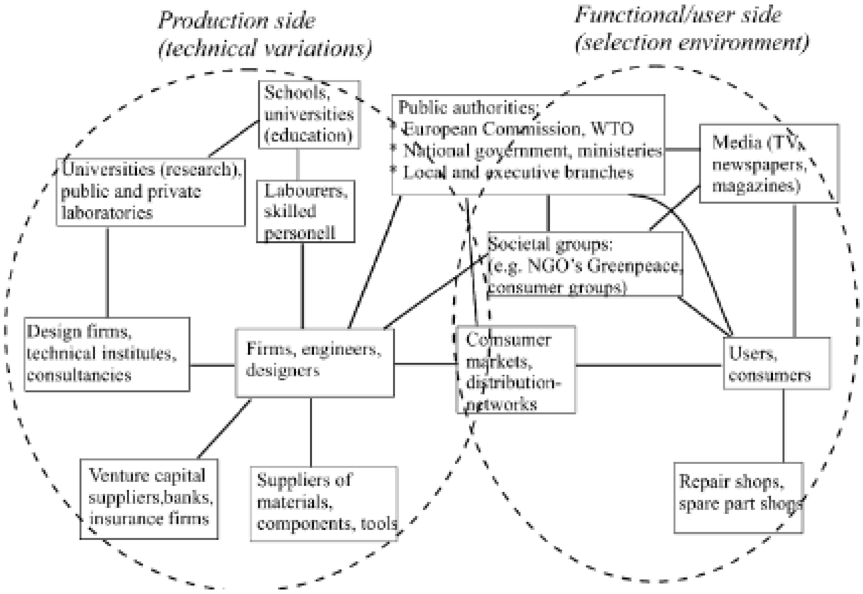
Many initiatives in the EU involve stimulation of the market for ICT by encouraging ICT take-up in every sector of the economy. ICT can serve as a means of achieving goals in many policy domains. Also for the future ICT developments such as the Internet of Things, the applications and implications are linked with other emerging sectors and smart policy domains. Also at the regional level the Smart Specialisation strategies often involve a focus on ICT applications in certain other, existing sectors. While the old ICT for growth narrative had its focus on R&D at the innovation supply-side, the new EU narrative on the role of ICT and growth is more on: un-leashing the potential and by increasing focus on enabling the demand side (van Welsum et al. 2013). This implies a shift to a more systemic ICT narrative where the interaction between producing and using ICT knowledge is in focus. Also the OECD follows this new narrative, and suggests that concerning 'measuring the digital economy', this shift should be apparent in the monitoring indicators used. Therefore they turn to indicator-sets which formerly were referred to as indicators for monitoring the Information Society (OECD 2015). In this respect the indicators of the Digital Economy and Society Index (Figure 5) serve to integrate the many dimensions (geographical, sectoral, institutional) of 'e-readiness' into a systemic approach to measure ICT innovation systems. In Section 2.3 we come back to this point.

2.2.3 Innovation system approaches extending to the societal level

The earlier mentioned innovation systems literature originally focused merely on firms and the general economic impact. However, innovation and innovation policy may also have other aims, addressing challenges in other domains of society. In recent applications of the concept, innovation systems are no longer seen as merely instrumental for economic benefits, but also for addressing societal challenges (see also Turkeli & Wintjes, 2014).

The 'socio-technical system of innovation' (Geels, 2004) is an influential example of an innovation systems approach designed to study 'eco-innovations' and the transformation to a society which is not depending on fossil fuel. Geels (2004) and Coenen (2013) describe the shift from sectoral systems of innovation to what they call socio-technical systems of innovation (Figure 6), which adds another sub-system, namely a user-sub-system. In this framework a functional/user side serves as the selection environment (Figure 6). This concept is however quite technocratic, since users and citizens only have a rather passive role.

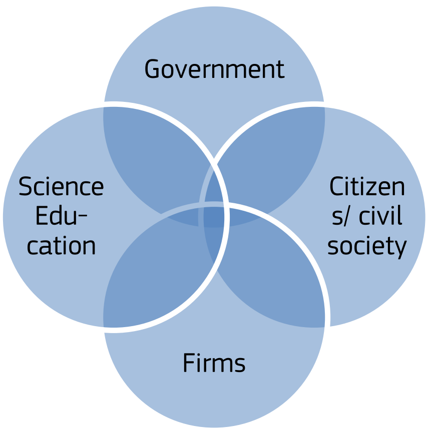
Figure 6: Conceptual framework of socio-technical system of innovation



Source: Geels (2004)

Recently there has been an increase in the attention for the role of customers and citizens in innovation, and civil society is seen as valuable partner in innovation systems (Figure 7), as for instance also discussed by Gabison and Pesole (2014) and Türkeli & Wintjes (2014). The role of citizens is not limited to expressing what they need or seek. Especially in the case of social innovation, citizens may also contribute to the design and implementation of solutions. The involvement of the 'crowd' in innovation is enabled by ICT. The 'crowd' has become a source of innovation in many ways. E.g., in the case of crowd-sourced manufacturing users and customers provide input in the co-design of innovative products. In new ICT based business models of the sharing economy such as Uber and AirB&B, citizens are integrated in the business model. Citizens are also actively involved in many Smart City programmes and systems aimed at addressing societal challenges at city level. Citizens have also been involved in 'entrepreneurial discovery' meetings, which regions have organized to development strategies for Smart Specialization at regional level.

Figure 7: The four types of stakeholders in societal innovation systems: beyond the triple helix



Source: Wintjes et al. (2014).

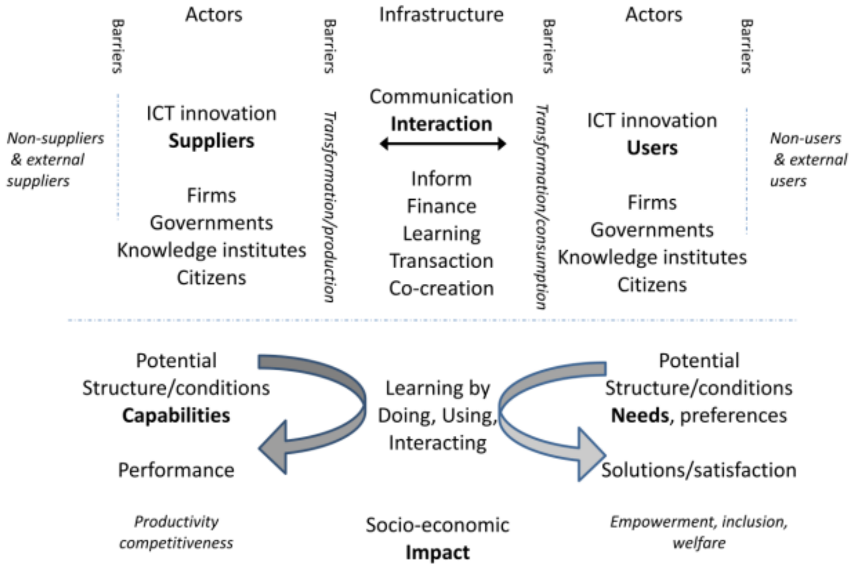
As mentioned before, Carlson et al. (2002) pointed at an aspect which is not often explicitly addressed in innovation systems literature, namely: the 'common goal' of the system, or the purpose, the 'mission' or 'finality' of innovation. The original concepts of national, regional and sectoral innovation systems, which have been developed some 25 years ago, had a focus on firms as the main actors and on the economic benefit of innovations. However, the issue of the objective of innovation deserves our attention, since it defines which components and system boundaries are most relevant, and which type of interaction among components would be relevant to analyse. The original innovation systems concepts merely had a focus on the economic impact (or purpose) of innovation (Foray, Mowery & Nelson 2012), while more recent applications of the innovation systems concept have been developed which also have broadened the perspective of innovation in terms of impacting on societal challenges, e.g.: climate change or healthy aging.

Examples of 'thematic' systems of innovation addressing a specific societal challenge are those concerned with 'security and safety' (Weber, 2014), or 'health' (e.g. in relation to challenges of an aging society). As general-purpose-technologies, ICT innovations are of special relevance among thematic systems of innovations. ICT innovations or ICT-enabled innovations can be instrumental in solving problems in other (than economic) policy domains in an Information Society (e.g.: health, security, education, defence, social innovation, climate change, transport, public sector innovation).

The conceptual model in Figure 6 is designed to monitor ICT innovation systems at the societal level. It is based on the monitoring framework developed for the E-Flanders initiative (Wintjes, Dunnewijk & Hollanders 2002), which aimed at monitoring the information society at the level of Flanders. The four type of actors (same as in Figure 7) on the ICT innovation supply-side (namely: firms, governments, knowledge institutes and citizens) appear also on the innovation demand-side, since each of these so-called quadruple-helix actors can be both a producer and a user. Barriers separate these users [15] from non-users, and users outside the concerning region or country. ICT Infrastructures refer to the channels for interaction. The interaction mechanisms include not only trade as economic transactions, but also financing/investing, learning, co-creation, and even (institutional changes from) regulation and standardisation (Figure 8).

[15] Typical indicators to report on the use of ICT by various kinds of actors refer to a certain percentage of the sample which uses a specific ICT application.

Figure 6: A framework to monitor ICT innovation systems at the societal level



Source: adapted after Wintjes, Dunnewijk & Hollanders (2002).

ICTs are notably a distributive source for increased productivity, of advanced solutions for societal problems, and of new services to consumers. A key characteristic of ICT innovations is their pervasiveness in the whole society. The disruptive implications go beyond sectors, economies, value chains and business models. As a result it has become difficult to distinguish ICT sectors from other sectors. Among newly emerging sectors and 'smart policy domains', ICT is always part of it somehow. Also public sector innovation and social innovation are to a large extent based on ICT innovation.

We conclude that for ICT it is relevant to extend the innovation systems concept to the societal level. In this respect we can refer to the concept of Information Society, which has been applied to national and regional levels. In the recent OECD (2015) report 'Measuring the Digital Economy' this, what they call 'new perspective', is presented. It involves selecting indicators traditionally used to monitor the Information Society.

Based on a combination of the three types of innovation systems described in 2.2, the next section addresses the issue of how to monitor national and regional systems of ICT innovations.

2.3 Monitoring national and regional systems of ICT innovation: an operational framework

In the scientific contributions on national and regional innovation systems, often abbreviated respectively as NIS and RIS studies, the sector component has always remained an important aspect. Several case-studies on a specific national or regional system of innovation have focused on ICT innovation (its emergence, up-take and impact on the wider economy and society) for the concerned territorial area. Studies on sectoral innovation systems (SIS) often focused on certain countries, or Europe, or for instance compared industries in different parts of the globe.

Fransman (2014) for instance studied global ecosystems of ICT firms (structured in three ICT sub-sectors) and sometimes compares US versus EU and Asian companies. So the difference between the sectorally bounded and the geographically bounded concepts of innovation systems is often not very sharp. Meijers et al. (2008) is another example of a study that combines both the sectoral and geographical aspect of innovation. With their focus on internationalisation of European ICT companies, they touch on differences between territorial systems of ICT innovation in which the international ICT companies operate.

In his book on 'Sectoral Systems of Innovation' Malerba (2004) also does not exclude the territorial dimension. This important contribution on the concept of sectoral innovation systems actually consists of six sectoral systems of innovation in Europe, of which two chapters address ICT sub-sectors, namely: 'The fixed Internet and mobile telecommunications sectoral system of innovation: equipment production, access provision and content provision' (Edquist 2004), and 'The European software sectoral system of innovation' (Steinmueller 2004). These two case studies apply the concept of sectoral systems of innovation in a qualitative way, describing the processes which make the systems change. They also show that defining especially the ICT sector boundaries, or ICT sub-sectors is rather arbitrary[16].

Edquist (2004) makes clear that there "is a certain degree of arbitrariness when it comes to the specification of sectoral boundaries. [...]Some minimum degree of coherence is nevertheless required to make it useful to talk about a sectoral system". Since it is most useful to analyse the dynamics of sectoral innovation systems over time, it is interesting to analyse converging, diverging, emerging and barely surviving ICT fields. Edquist (2004) discussed several converging fields in ICT, such as between fixed internet and mobile telecoms. He first describes the functions (e.g: develop equipment, R&D, provide internet access, education, create standards) and organisations in the system who perform these functions. Institutions are defined as "sets of common habits, routines, established practices, rules or laws that regulate the relations and interactions between individuals, groups and organizations" (Edquist 2004, p.161). He then described the historical development of (and ways to get access to) the fixed internet and the various generations of mobile telecommunication starting with the NMT 450 or Nordic Mobile Telephone standard in 1970. Later the GSM standard followed. A first policy conclusion is that institutions (including technology standards) are crucial for policy and the performance of sectoral systems of innovation. Organisations provoke institutional changes, and when the new institutions come into effect they may greatly influence the same or other organizations. The main policy conclusion of Edquist (2004) is that:

> *"It is of crucial importance that public policy intervention occurs early in the development of the sectoral system. Public technology procurement was crucial for the very early development of the Internet in the United States and the formulation of standards was crucial for the very early development of mobile telecommunications in the Nordic countries"*.

In the chapter 'The European software sectoral system of innovation' Steinmueller (2004) describes more than three decades of growth dynamics in the software industry. According to Steinmueller the nature of the sectoral innovation systems for software creation and exchange activities, and the technologies supporting these activities, are shaped by three fundamental issues: the nature of software as an economic commodity; the historical patterns of the division of labour involved in software creation; and distinctions in the design and use of software.

In a more quantitative approach the earlier mentioned study on Poles of ICT Excellence (Nepelski et al. 2014) measures the level of excellence at the level of Nuts 3 regions in Europe for ICT 'as a whole'. A selection of indicators is based on the idea of interdependency between R&D, innovation and business activities, which implies that these are often co-located. The EIPE project looked at three characteristics of these activities: agglomeration, internationalisation and networking. The result allowed us to rank the top cities in Europe concerning ICT excellence ('as a whole'): Munich, London and Paris.

The issue of defining ICT subsectors and measuring the producer and user side of the involved ICT knowledge, has recently become more relevant. Due to the fact that ICT

[16] In the above mentioned study of Edquist (2004) the equipment production, access provision and content provision are studied as one innovation system, while in the above mentioned study of Fransman (2014) these are actually considered as separate sectoral systems.

has become integrated in many sectors and daily life and not only serves economic purposes, it has become rare to develop innovation system frameworks which do not involve any kind of ICT technology, any kind of ICT producing and using industry, as well as any kind of impact (or system objective). The multi-purpose or general purpose nature of ICT has led to the need for more specific granulated sub-system approaches, ranging from specific local ICT-clusters (a concept defined by OECD (2001) as micro-systems of innovations) or newly emerging technologies or industries, e.g. the Internet of Things (PwC 2015). This need for more granulation, diversification within ICT 'as a whole' is especially a strategic (public and private) policy need which is most urgent for new emerging themes or fields of ICT applications; applications for which no institutions or markets may exist yet, or which may be disruptive to existing institutions and markets. Defining the boundaries and objectives of an ICT innovation system can, in this respect, be part of a politically-motivated strategy concerning a certain niche of 'Smart Specialisation'.

Defining the most relevant sub-sector boundaries within the ICT sector remains therefore a challenge for those academics or policy makers who want to apply an innovation systems approach to ICT. Relevant sub-sectors within the ICT manufacturing as well as ICT service sector are for instance those which supply ICT innovations to industrial markets, e.g. robotics and automation. The German programme Industry 4.0 is in this respect linking a vision on the Internet of Things to a new industrial renaissance[17]. On this specific theme Ronald Berger (2014) has developed an indicator based index for EU Member States of their 'readiness' for Industry 4.0 which goes beyond indicators for global excellence on the supply side, concerning robotics and automation.

Other examples for emerging ICT sub-sectors can be found in case studies and trend reports of the EU Business Innovation Observatory[18] (e.g.: Wintjes 2013). Based on company interviews, innovation systems narratives emerge and show how a diversity of actors are involved in producing, using, financing, regulating, investing, teaching and standardizing certain ICT innovations in an interactive learning setting of a national or regional ICT innovation system. The cases (e.g. concerning Big Data, Advanced Manufacturing, Internet of Things, or Sharing Economy) show the importance of being located and embedded in a local innovative environment that is particularly relevant to the concerned ICT innovation; a region with potential partners, (lead) clients, universities, a pool of high skilled experts, end -users, access to finance, and relevant public support mechanisms for the concerning ICT innovation. Specific for the newly emerging ICT sub-sectors (such as: Big data, Advanced Manufacturing, Internet of Things, or Sharing Economy) are the lack of institutions such as standards and regulations and laws. The risks and uncertainties are high, markets may not exist yet, and typical concerns are about data security.

As an example we refer to the European Roadmap on 'Smart Systems for Automated Driving' (EPoSS, 2015). The roadmap shows that many, different kinds of stakeholders have to cooperate on a wide range of activity fields, such as: technology inside the car, infrastructure, big data, system design, standardisation, legal frameworks and awareness measures. For example: cars have to communicate with traffic lights, and this makes the issue of software and data security a matter of life or death. The autonomous car is therefore not only about introducing a new car on the market, but about transforming a whole traffic system (Swedish Transport Agency 2014). This transformation is necessarily a collaborative public-private undertaking. Furthering such emerging fields of ICT innovation can therefore not be left to individual companies or to price-competition in existing markets. Institutions and (co-evolving) processes of

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[17] For an innovation systems approach to advanced manufacturing at regional level, see the EU Regional Innovation Monitor (Wintjes 2014).

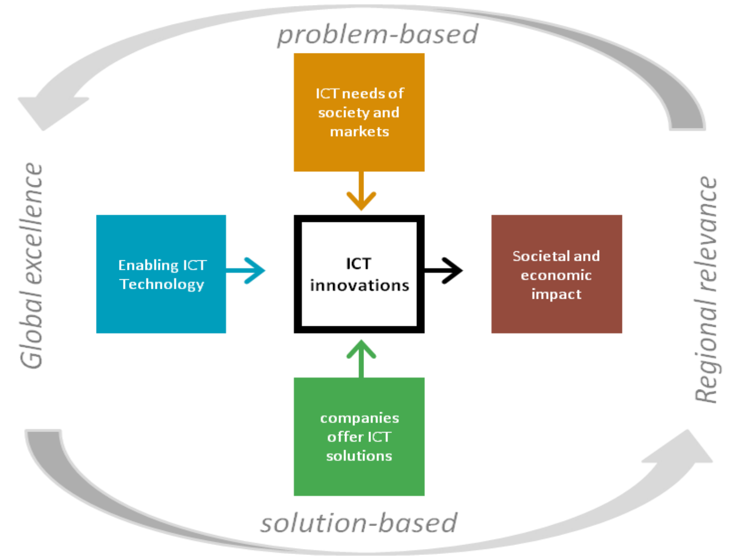
[18] http://ec.europa.eu/growth/industry/innovation/business-innovation-observatory/index_en.htm

institutional change are crucial in understanding the dynamics of innovation in the field of ICT; in explaining how ICT enabled systems innovate.

Institutions also have soft aspects like entrepreneurial spirit, innovative culture, mentality, awareness of, and readiness for the concerning ICT trends.. Linkages with a conducive and receptive environment and partnerships with relevant players in specific ICT environments provide access to and transform relevant resources (knowledge, suppliers, skills, science, end-users, investors, international networks). Each of these learning or transformation processes play a role in the emergence of a path dependent specialization trajectory of the concerning system of ICT innovation (e.g. towards an emerging Smart System for Automated Driving).

As sketched in a simplified conceptual framework of regional ICT innovation systems (Figure 9) the main components are the ICT technologies, the actors which supply ICT innovations and those who need them. The arrows represent the mechanisms of interaction, the involved institutions which govern these interactions are not visualized. The societal and economic impact refers to the performance aspects or objectives of the concerning innovation system, e.g. employment, innovative turnover or health benefits.

Figure 7: Regional ICT innovation systems



Source: adapted from Wintjes (2014; 2013).

Based on the above mentioned examples of ICT innovations from the Business Innovation Observatory and on earlier discussed innovation systems literature (especially Carlsson et al. 2002; and Malerba 2004), we can conclude that the following are the main components of an ICT innovation system:

1. knowledge and technologies;
2. actors and networks;
3. institutions (regulation, habits, culture, policy, procedures);
4. mechanisms of interaction.

In addition the following processes (functions/resources/activities) as provided by Fagerberg (2013; recall Figure 2) in the synthesis of the innovation systems literature, and here specified for ICT innovations, concern:

- Knowledge for ICT innovation;
- Skills for ICT innovations;
- Supply of ICT innovations;
- Demand for ICT innovations;

- Finance for ICT innovations;
- Internationalisation for ICT innovations.

These processes are not mutually exclusive, e.g. there is knowledge (and learning) involved in all the processes, but studies in the past have shown that they point at the main potential barriers or drivers. By combining the main processes with the main components and impacts, as is done in Table 2, an operational matrix emerges which serves as a tool to capture all the aspects which have been pointed out in the innovation systems literature discussed in the earlier Sections 2.1 and 2.2.

Table 2 has been filled with illustrative examples which could capture the concerned aspect. This is not an attempt to define a quantitative macro-economic model, but a first step in identifying the building-blocks and dimensions for which individual indicators could be developed. The matrix framework of Table 2 should be seen as a tool to make the innovation systems concept operational. It translates the theoretical concept and fills it with a broad set of individual indicators (which could be fine-tuned to a chosen theme, e.g.: e-health innovation systems at the level of EU Member States, or Industry 4.0 at regional level). Later, in a second step (Section 2.3.8) a method will be provided on how to come to systemic patterns and composite indicators, which can be used to analyse and compare the dynamics of ICT (sub-) systems of innovation, and identify the main types.

For each of the processes, there are a variety of relevant components (technologies, actors, institutions and inter-action mechanisms). The components are specified by column: e.g. the second column shows the diversity of actors along the various processes. A last column in Table 2 refers to the purpose (outcome/aimed performance/impact) of the concerning process/function in the ICT innovation system. But again these aspects of impact and performance are indicative, and in reality they are the result of complex variety of interactions. Taken together they generate the societal and economic impact from the concerning ICT innovation for the concerning country or region.

Table 2: Operational framework to monitor ICT innovation systems: components, processes and purposes

	Components of ICT innovations systems				**Innovation systems purposes**
Processes (functions/ activities) for ICT innovations:	1 Technologies	2 Actors	3 Institutions	4 Mechanisms of interaction, infrastructure	(5) Impact/ performance
Knowledge for ICT innovations	R&D, patents, publications on ICTs such as: robotics, nanotechnology, software, Internet of Things	ICT firms, Universities, public research institutes, start-ups	Patent-system, patent application procedures Standardisation Tech Transfer Offices STI policy strategy	Tech-transfer, licensing, technology platforms, co-author-ship; citation	Scientific performance emerging industries
Supply of ICT innovations	Technological specialization of R&D on ICT	RTD performance and structure	Start-up support; RTD infrastructure	ICT Sector and cluster, OEM-supplier network, incubators	innovation output, turnover
Skills for ICT innovations	ICT research skills, ICT manufact-uring skills; coding, basic user skills	Users and providers of skills (firms, governments, citizens, investors, etc.	Education, Certification	e-learning platforms, traineeships	Employment
Demand for ICT innovations	KETs (Key Enabling Technologies) Strategic Objectives (societal challenges)	Actors from various private sectors, public sector, consumers, smart factories	Licences, standards, regulation; Privacy concerns, lobby	Public procurement platforms; Living Labs; demonstrators; user-innovation	Catching-up, productivity e-health, advanced manufact-uring
Finance for ICT innovations	Subsidies for R&D, subsidies for demand	Banks, VC, Crowd-funding	Laws on crowd-funding	Web-based crowd-funding platform	investments
Inter-nationalisation for ICT innovations	Global excellence, lead suppliers	Foreign firms, multi-nationals,	FP7, HORIZON EU Digital Agenda and internal market	export/import collaborations integration, e-commerce platforms	Trade, internal market

For each cell in the matrix (Table 2) one can think of indicators which identify the interactions or systemic linkages (concerning the mechanisms of interaction in column 4). For example, with patent applications one can indicate the generation of technology, and with for instance patent-citations, cooperation or licenses one can also capture the involved systemic innovative interactions[19].

In the next section each of the identified processes/functions in innovation systems, as described in Table 2, will be addressed by suggesting some possible individual indicators to measure and monitor the concerned aspect of ICT innovation systems. In Section 2.3.8 a methodology is provided which combines these individual ingredients of the operational framework (Table 2) into a systemic view on how different types of ICT systems in Europe innovate.

2.3.1 Knowledge for ICT innovations

Knowledge for ICT innovations concerns: all kinds of knowledge involved in the generation, design, production, marketing and distribution of ICT innovations. Along the columns of Table 2 this can relate to specific ICT technologies; the activities of the actors involved in generating, sourcing and diffusing knowledge; institutions concerning knowledge (e.g. ICT patents, or ICT policy strategies) which serve as a barrier or driver of learning; and mechanisms such as licensing, technology transfer, citations, co-authorship and other forms of cooperation between actors. In order to capture these aspects of knowledge for ICT innovations we can think of indicators concerning patents, publications, citations and R&D expenditure. Besides data on patents and publications per ICT sub-sector, one can also think of indicators which capture certain systemic mechanisms of interaction, e.g.: co-authorship and citation (in ICT patent applications or ICT publications).

Knowledge for ICT innovations can also be detailed per actor, e.g. specifying the business expenditure in R&D for the various ICT sub-sectors in Europe. Although R&D is not the only relevant knowledge for ICT innovations, data availability allows for instance to measure ICT R&D intensity, as is done in the Digital Agenda Scoreboard 2014.

The EU research programme FP7 is an institutionalized mechanism to generate knowledge, also for ICT innovations. Data on participation in this policy framework can be used to indicate the embeddedness in collaborative European R&D networks in which a diversity of public and private actors are involved focussing on specific strategic objectives of ICT innovation. In the period 2007-2013, the FP7 has funded under the ICT Theme €6.125 billion for almost 2000 R&D projects, which involved more than 5,000 different organizations. About half of the funding (46%) from FP7 ICT went to governmental organizations; private commercial organizations have received 34.5%.

In the period 2007 – 2012, the top 50 Regions in Europe (NUTS3 level classification) attracted 63% of total FP7 funding. In terms of overall EC funding received over this period, Munich is the European city that leads, followed by Paris, London and Madrid. The available data can be used to differentiate between countries and regions the extent to which their ICT R&D activities are specialized in certain ICT research fields (FP7 Strategic Objectives). Germany for instance is the top recipient of funds in all categories but three and the country attracts 32% of funding in 'ICT for the Enterprise' and 29% in 'ICT for Transport'. The United Kingdom is the leading country in the Strategic Objectives 'ICT for learning' and 'Digital libraries', with 19% and 18% of total funding respectively, and together with Germany accounts for 15% in 'ICT for Health'. Italy is relatively strong in 'ICT for ageing' (15% of total funding), 'Cognitive Systems and Robotics' (14%), FET and Language Technologies (13%). France has a relatively strong presence in nano-electronics (17%), Future Networks and Internet (16%) and International Cooperation (15%), whereas Spanish organisations excel in ICT for inclusion (16%) and ICT for Energy efficiency (14%). The Netherlands are relatively strong in Organic and large area electronics (14%), while Belgium has a relatively strong presence in nano-electronics research (10%). Greek companies are active mostly in ICT for Governance and Policy

[19] Possible indicators could also come from network analysis, e.g. indicating the centrality in the concerned network of interactions.

Modelling (11%) and ICT for Health (8%). Austria stands out for its share (13%) in ICT for Governance and Policy. These details on the ICT sub-sectors are very helpful in deviating from the generic global ICT innovation systems (or poles of excellence) and identify specific systems of ICT innovation, specific in terms of sub-global and sub-sectoral perspective, and the dynamics in terms of convergence and divergence between sub-systems.

Table 3: Top 10 regions in EC funding for R&D on cognitive systems and robotics in FP7

FP7 Strategic Objective: 05 Cognitive Systems and Robotics		
EC Funding in M EURO (2007-2013)	**City**	**Region level NUTS3**
46	MUNCHEN	DE212
21	LONDON	UKI11
21	EDINBURGH	UKM25
20	GENOVA	ITC33
20	PARIS	FR101
20	ZUERICH	CH040
16	PISA	ITI17
13	NAPOLI	ITF33
12	ROMA	ITI43
12	BREMEN	DE501
11	KAISERSLAUTERN	DEB32
10	STOCKHOLM	SE110
10	KOELN	DEA23
9	ENSCHEDE	NL213

Regional level data are available for each of the 24 Strategic Objectives. This allows for developing regional level indicators concerning for instance Strategic Objective 5: Cognitive Systems and Robotics (Table 3). Also for individual organizations FP7 research data is available. Various mechanisms of interaction can be captured with FP7 data, e.g. concerning cooperation in consortia.

2.3.2 Supply of ICT innovations

Besides general indicators for the size and structure of national and regional ICT sectors, it is important to include indicators that measure the innovativeness of these ICT innovations supplying companies.

The 2005 Trend Chart report "European Sector Innovation Scoreboards" (Hollanders and Arundel, 2005) analyses the innovation performance of European countries at the sector level. They use 12 indicators for constructing the Innovation Sector Index (ISI) which showed that ICT is the most innovative sector in Europe. Similar indicators could be constructed based on more recent survey data. For most of the indicators used for the Innovation Sector Index Table 4 provides more detail, which allows us to identify differences in innovation characteristics between ICT (sub-sectors) and other sectors in the EU. It shows that indeed on average the ICT sector is more innovative than the average industry, but the innovation performance gap differs per indicator and per ICT sub-sector. Regarding the share of employees with higher education and the share of firms that use training, the performance is especially high in the Computer service industry (NACE 72), where almost 51% of the employees have a higher education degree, compared to 13% in all sectors of the EU (Table 4). The share of sales due to new-to-market and new-to-firm products is way above average, especially for ICT hardware. This is in line with the notion that the life-cycle of ICT products is indeed very short.

Table 4: Innovation performance of the ICT sector versus all sectors in the EU

	ALL SECTORS	ICT		
		Computer Mnf. (NACE 30)	**Communication Mnf. (NACE 32)**	**Services & Software (NACE 72)**
-% higher educated employment	13	18	25	51
-% firms innovating in-house	35	59	57	58
-% of firms co-operating with others	6	13	16	15
-% sales from new-to-market products	6	26	25	13
-% of firms that patent	8	19	20	9
-% of firms that use trademarks	12	30	16	23

Source: Community Innovation Survey 3, Arundel and Hollanders (2005).

Collaboration is an important mechanism for interactive learning in innovation systems. The ICT sector has the highest share of firms that innovate in collaboration with others. However, some types of collaborators are more common than others. Although the number of ICT firms collaborating with others has increased over time, and it is higher than in other sectors, the large majority of innovative ICT firms still do not collaborate with national research institutes. On average only 18% of all innovative ICT firms in Europe collaborate with universities and 11% with research institutes, 28% collaborate with clients and suppliers, while 42% of the innovative ICT firms collaborate with other (firms). The national differences in collaboration of innovative ICT firms with third parties are remarkably large (Annex Table a). Innovative ICT firms that collaborate with others are most often found in Norway, the UK, Sweden, Hungary, Lithuania, and Cyprus. Less collaborative however are innovative ICT firms in Germany and Spain. Least collaboration with research institutes are reported by innovative ICT companies in Southern European countries like Italy, Cyprus and Portugal.

There are many ways to measure innovation performance of the suppliers of ICT innovations. The CIS data which is based on individual firm data includes an indicator on innovation output in terms of the share of turnover which is new (new to the firm or new to the market). There are also more macro-level indicators. An example of this is given in Table b in the Annex, where indicators constructed by Marin et al. (2008) are given. They have based their index on 3 indicators for competitive ICT innovative advantage for European countries: respectively on ICT patenting, ICT export and total factor productivity for the ICT sector.

2.3.3 Skills for ICT innovations

Skills for ICT innovations are relevant in many ways (at home, at the lab, office, factory, etc.) and for many of the other innovation processes. According to an OECD (2015) analysis, changes in the number of jobs in various ICT industries indicate changes in the demand for skills. One could however argue that it is also necessary to include information on functions and have task descriptions. Lack of qualified personnel is one of the main barriers for innovation. The share of ICT firms which report a lack of qualified personnel as obstacle for innovation is therefore a relevant indicator to monitor this ‘systemic mismatch’ in the concerning national systems in Europe (see Table c in the Annex).

Skills in performing ICT R&D can be measured by using data on ICT R&D personnel for the ICT sub-sectors in Europe. According to the 2015 PREDICT report, the rise in EU ICT R&D personnel was driven by the ICT service sector, which saw its personnel increase from 161.6 thousand in 2009 to 192.7 thousand in 2012. On the other hand, the number of R&D personnel in the ICT manufacturing sector remained constant at around 82 thousand in the same period. They also report that:

> *"The two ICT sub-sectors with the highest BERD share of total BERD in 2012 are Computer programming (5.96% of total BERD), which belongs to the ICT service sector, and Manufacturing of communication equipment (3.56% of BERD), which belongs to ICT manufacturing"*. (Mas et al. 2015)

While in the past the focus in measuring knowledge and skills for innovation was on R&D (which was often seen as the single source for new knowledge and innovation) there is an increased awareness that also other kinds of knowledge and skill in ICT companies are important, e.g. employees involved in marketing (innovations) and organizational (innovations). In this respect there are good arguments to include all employees in ICT sectors, expanding the type of skills relevant for innovation to include ‘learning by doing, using and interacting’ skills. Measuring ICT employment in ICT using sectors (which include almost all other sectors) is a complex issue and it is therefore necessary to have additional info on the use of ICT by firms/organizations and on the link between such use and innovation.

A further relevant extension is to capture the skills of citizens in using ICT. The skills, experience and eagerness to use new ICT applications at home are relevant for innovative companies. It not only increases the demand for certain ICT innovations, but in terms of interactions with these skilled users, ICT companies learn and these lessons feed back into the innovation processes as user-innovations. Irrespective of the sector in which people work it is therefore relevant to capture the ICT content and relevance of the Human Capital in general in a country or region. As an example, we refer to the EU digital scoreboard where the basic and advanced ICT skills of the population are captured as a dimension of human capital.

According to Digital Europe (a forum representing the digital technology industry in Europe)[20], digital skills in Europe are lagging behind in term of population "IT literacy" as well as specialized ICT competence of the skilled work force. This situation is discussed in their reports as a barrier for the development of a digital society and Digital Single Market as well as for the innovation capacity of the European economy. Data of Digital Europe indicates that the demand for ICT practitioners in Europe is growing around 4% a year, which would imply a shortage of 509,000 jobs in 2015 compared to 274,000 today. According to data of the Digital Agenda Scoreboard 2014 the deficit of ICT professional skills is estimated to reach 900,000 by 2020.[21] Digital Europe provides data allowing for comparison of Member States, which for instance shows that the bottlenecks are largest in the UK, Germany, and Italy[22]. Institutionalized strategies such as The ‘Grand Coalition for Digital Jobs’ which have been launched to tackle the lack of digital skills could provide relevant indicators to capture the efforts and improvement concerning skills for ICT innovations.[23] Other EU initiatives which could generate relevant indicators in this

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20 47% of the EU population has insufficient digital skills, 23% has none at all (Digital inclusion and skills in the EU, 2014).

21 Digital Agenda Scoreboard 2014 – Digital Inclusion and Skills.

22 DigitalEurope.org

23 https://ec.europa.eu/digital-agenda/en/grand-coalition-digital-jobs; Davos Declaration on the Grand Coalition for Digital Jobs

respect include "Opening up education"[24], the e-Skills Campaign[25], and the European Coding Initiative[26]. The EC also encourages the use of Massive Open Online Courses (MOOCs) focused on web skills by establishing creation of a network of universities and business schools in Europe interested in developing MOOCs for web talent. Massively Open Online Courses (MOOCs) are indeed gaining importance and the online education market could also be considered to be an emerging ICT-sub-sector. Such initiatives might generate data which could be used for monitoring the issue of skills for ICT innovation. Relevant in a systems perspective are measures of mismatches between the supplied skills and demanded skills, as well as the mechanisms and institutions which serve to improve the interactions, e.g. through cooperation between industry and education institutes concerning for instance e-learning platforms, MOOCs, traineeships, training on ICT-entrepreneurship.

2.3.4 Demand for ICT innovations

The report 'Importance of Intelligent Demand' (OECD 2014) discusses the increased importance of the innovation demand-side. The reason of its importance is in the interactive learning effects between producers and users of innovations. A study on the decision of multinationals on the location of their R&D and innovation activity showed that the cost of doing R&D are not the most important reasons, but the location and interaction with market demand are (Leitner et al. 2011). For some ICT products the EU is still in a leading R&D position, e.g. concerning robots (EC 2014), but since Europe is not a leading user, the concerning innovation capacity may deteriorate because of lack of the interactive learning between producers and users of the concerning ICT innovation. Even German machinery manufacturers have started to shift R&D expenditures to China, which is their main market[27]. Another example is the US company GIRAFF which produces robots for the health care sector, and which moved to Sweden because of the high reputation of its innovative health care system (Avigdor & Wintjes 2015).

Several indicators of the EU Digital Scoreboard could be relevant to monitor the demand for certain ICT innovations; for instance, the demand for internet services, as indicated by the use of internet for content, communications and transactions (Figure 10).

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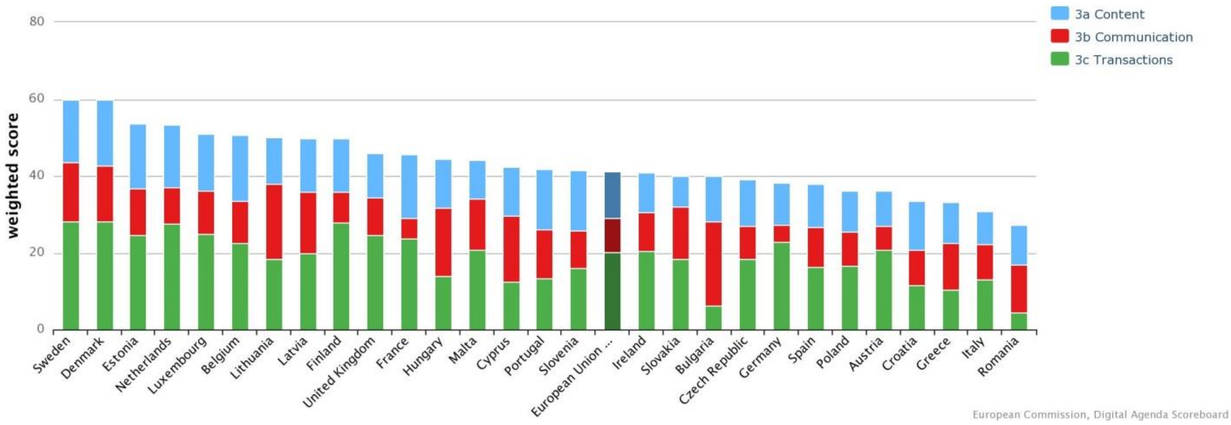
[24] eSkills campaign is an action plan to facilitate schools and universities to deliver high quality education through ICT and digital content, as well as the digital skills which 90% of jobs will require by 2020. The initiative focuses, inter alia, on ICT-based innovation in learning and teaching, underpinning the delivering of skills for the 21st century.

[25] Initiative based on the Communication 'e-Skills for the 21st Century'

[26] Initiative led by ICT-companies and European Schoolnet to bring coding skills to teachers, kids and adults.

[27] See: http://eeas.europa.eu/delegations/china/documents/eu_china/research_innovation/4_innovation/sti_china_study_full_report.pdf

Figure 8: Three dimensions in EU digital scoreboard 2014 of use of internet: content, communication, transaction



Since the public sector is an important customer of ICT innovations, the provision of digital public services in a country has a positive impact on the demand for ICT innovations. Innovative public procurement is, in this respect, an important mechanism to enhance interactive learning and innovation in the concerning national or regional system of ICT innovations. The EU digital agenda scoreboard sub-dimensions of digital public services concerning e-Government and e-Health are in this respect interesting indicators to capture the concerning demand for ICT innovations.

When the objective is to design a monitoring framework for a system of eHealth innovations, data on the use of medical data exchange and e-prescription are essential. This has been indicated by eHealth companies interviewed for case studies of the EU Business Innovation Observatory. For example, a Spanish e-health company stated that the German market is not that interesting for them, because the use of Electronic Health Records is relatively low (Avigdor and Wintjes 2015). Figure a in the Annex does indeed show that the eHealth indicators for Germany are relatively low compared to other EU countries.

An interesting indicator to capture the demand for ICT innovations concerning Smart Industry and Smart Factories could be the number of enterprises sharing electronic information on the supply chain (data included in the EU Digital Agenda). This indicator refers to sending/receiving all type of information on the supply chain (e.g. inventory levels, production plans, forecasts, progress of delivery) via computer networks or via websites, but excluding manually typed e-mail messages. This innovative digital communication in manufacturing actually concerns an innovative ICT mechanism of interaction which also serves the supply of ICT innovations.

Whereas the public funded R&D programmes can be mainly used to capture the institutionalized knowledge generating activities and the strengthening of the innovation supply-side, data on the EU Structural Funds programme can be used to capture the institutionalized effort to promote the up-take of ICT innovations. For 2007-2013 the EU Structural Funds allocated to regional policy support for ICT projects showed an increase to over EUR 15 billion or 4.4% of the total EU cohesion policy budget. There is a clear shift in the investment priorities from infrastructure to support for content development, and promoting the up-take both in the public sector (eHealth, eGovernment, etc.) and SMEs (eLearning, eBusiness, etc.).

2.3.5 Finance for ICT innovations

The diversity and complexity in financing of innovations has increased. Important sources include internal funding, banks, Venture Capital (VC), public funding (e.g. subsidies/tax benefits), public procurement, but increasingly also crowd-funding. In the CIS survey there are some questions concerning finance and funding for innovation.

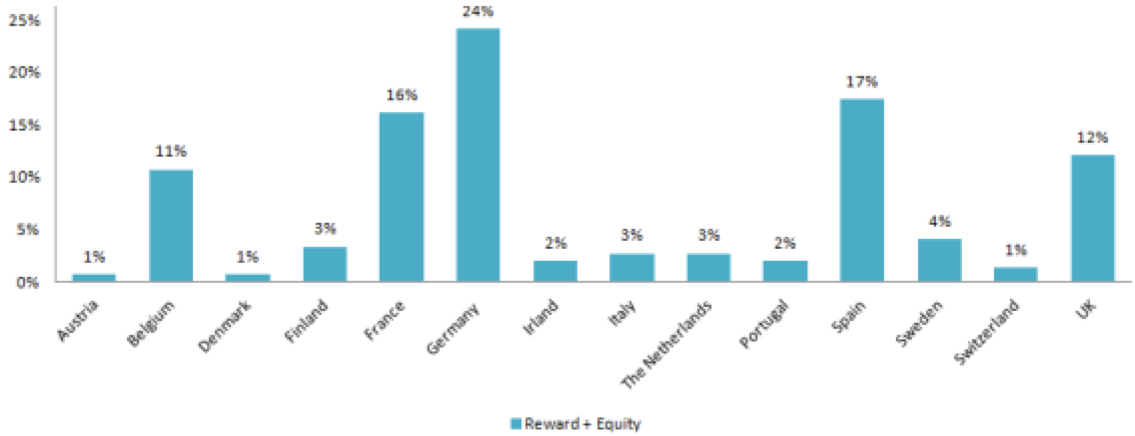
Answers from ICT firms to three of these questions are used in Table d in Annex. The first question was if companies had received public funding for innovation. For Norway, Finland and the Netherlands more than 45% of the responding ICT firms reported that they have received public funding for innovation. The concerning CIS question also allows to differentiate public funding from EU, National and regional sources. However, CIS data in some EU countries cannot be used at regional level. The other two CIS answers are derived from the question to firms about barriers to innovation. The share of ICT firms stating that lack of internal finance is a barrier for innovation is higher than for external finance of innovation.

Concerning finance and funding in ICT, Van Welsum et al. (2013) report three barriers: difficult access to VC for small innovative projects; legacy of vested interest in old technology and systems; difficult access to funding for EU ICT SMEs. These three obstacles are also evident in other sectors, but due to the fast technological changes in the ICT sector, the second barrier seems higher in ICT sectors than in many other sectors.

The rules and practices concerning public procurement of (ICT) innovations differ per country and sometimes even regions, but we are not aware of standardized data in Europe on this funding mechanism.

A similar across-country variability of rules and practices can also be found for crowdfunding. Although crowdfunding mobilizes a relatively small total amount of funding, it seems especially helpful for small innovative ICT projects. According to a report of the Start-up Europe Crowdfunding Network (2014), Germany is the country where the largest share of web entrepreneurs' projects (24%) has been crowdfunded, mostly through equity and reward crowdfunding platforms (Figure 11). The German equity crowdfunding market has been developing with good results for a few years already, which might contribute to the large number of web entrepreneurs using crowdfunding there. Spain holds a considerable percentage in the chart, too. However, in Spain equity crowdfunding is actually not yet allowed and online investing is forbidden by law. However, crowdfunding platforms can operate as matchmakers, bringing private investors and web entrepreneurs together. Both markets also do not tout a strong venture capital or business angel industry, so the funding gap might be more pronounced than for example in countries that offer tax benefits to investors in early stage companies.

Figure 9: Share of web entrepreneur's projects funded by crowdfunding in EU countries, 2014



Source: Start-up Europe Crowdfunding Network (2014).

2.3.6 Institutions for ICT innovations

Institutions refer to a broad range of formal and informal rules, arrangements and procedures. Formal institutions include the organizations setting the 'rules' for metrology, standards, testing and quality, etc. Other examples of formal institutions affecting ICT innovation are State laws that govern for instance: universities, technology institutes, education, start-ups, R&D tax-credits, patenting law, financing, trade-tariffs, etc.

Van Welsem et al. (2013) identified a number of institutional 'policy' barriers of the ICT growth potential, which have also been identified by the Business Innovation Observatory Trend reports[28]. Some of these barriers are not sector-specific, e.g. the barrier of red tape, especially for SMEs and the lack of flexibility in the labour market. One of the most persistent and ICT specific barriers to innovation are the fragmented legal and regulatory frameworks, which are not adapted to the fast and disruptive developments of ICT innovations. However, it is not easy to construct indicators on these formal institutional aspects for ICT innovations.

Burgelman and Barrios (2007) show that regulatory strictness impact economic growth negatively. They use measures of strictness of regulation like business regulation, credit market regulation, and labour market regulation. They have shown that the more stringent the regulation is, the higher the negative impact on GDP growth and the more application of ICT is hampered.

Concerning soft and informal institutions Wintjes and Dunnewijk (2008) report on an index measuring the quality of the socio-cultural environment for innovation, based on indicators for cultural capital, consumer behaviour, social capital, organisational capacities and entrepreneurship. This index is however not ICT specific.

Concerning social values the European social values survey can serve to construct indicators, e.g. in terms of 'trust', and approach to 'risk-taking' and 'entrepreneurship'.

2.3.7 Internationalisation for ICT innovations

The national and regional boundaries of national and regional systems of ICT innovations are not closed. International linkages can benefit all the innovation processes within the concerning systems of ICT innovations.

Obvious indicators to capture internationalisation are data on ICT export/import, and on Foreign Direct Investments in ICT (Meijers et al. 2008).

The CIS also enables to develop indicators on internationalisation in terms of export and interactions with other parts within an international corporation.

A way to measure the international competitiveness of industries is by calculating RCA's (Revealed Comparative Advantages) based on the specialisation (in terms of export and import) in that industry. Revealed Comparative Advantage per ICT sub-sector differs very much among countries. Figure b in the Annex gives an outdated example of RCA in Computer manufacturing (ISIC 30) in 26 countries during 1993 – 2003, such RCA's would have to be up-dated.

An alternative indicator constructed at a national level could be export of ICT goods and services. The definition of ICT goods include: Computers and peripheral equipment, Communication equipment, Consumer electronic equipment, Electronic components and Miscellaneous. ICT services include: Communications services, Computer and information services. The value of exports covers both intra- and extra- EU.

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[28] http://ec.europa.eu/growth/industry/innovation/business-innovation-observatory/trend-reports/index_en.htm

2.3.8 Towards a typology of regional systems of ICT Innovation in Europe

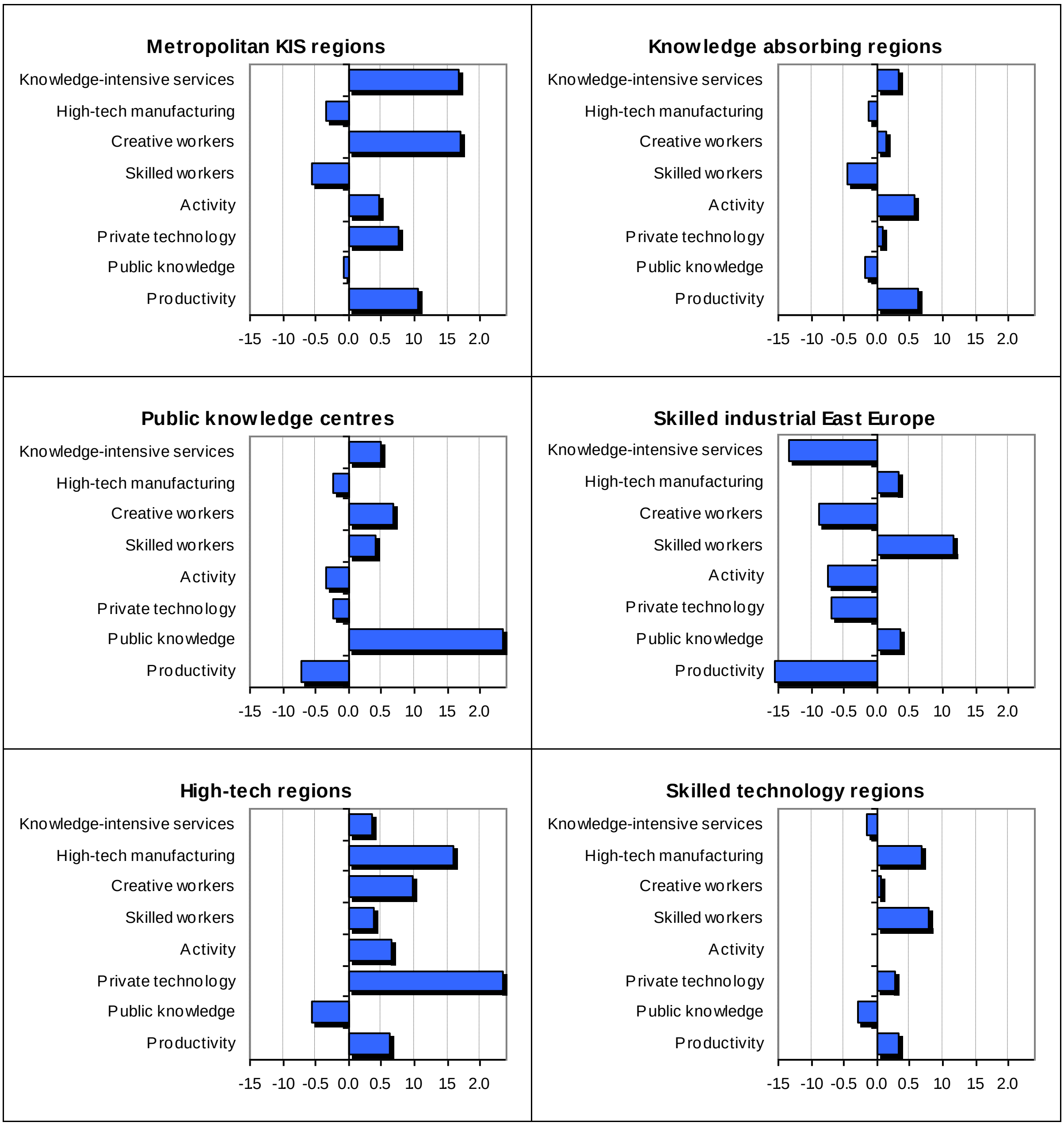
We conclude from Section 2.3 that a broad range of individual indicators is needed to capture the potentially relevant aspects of emerging ICT innovation systems in Europe. This is also true for monitoring the development of ICT innovation systems over time, for comparing ICT innovation systems, and for explaining differences in performance. Irrespective of some thematic choices (to focus on only a part of the ICT sector or a part of Europe, or a specific objective) following the (theory-based) operational framework suggested in Table 2 assures a sufficiently broad coverage of system components, processes and purposes. The framework could be used to design a qualitative case-study analysis, but in case one wants to analyse more than a few ICT Innovation Systems in Europe, statistical tools can help in reducing the complexity.

In order to identify the main types of ICT innovation systems at regional level, multi-variate methods of data-reduction (principal component or factor-analysis, and cluster-analysis) are very appropriate to identify patterns in the innovation indicators which can be used to make a typology of systems. As explained in the *OECD/JRC* Handbook on constructing composite indicators (Nardo & Saisana 2005) Principle Component Analysis and Factor analysis are useful in constructing composite indicators. Since there are many potentially relevant indicators concerning knowledge, innovation, economy and society, there is a need for data reduction techniques. These statistical methods identify the statistical relations between the various individual indicators and based on that provide the main factors or components. The same methodology is used in the literature discussed in Section 4 answering the question 'how firms innovate?', by identifying different modes of innovation at firm level. This methodology can also be used at the systems level, for identifying different modes of innovation at systems level.

As an example of applying the method of factor analysis for identifying types of national/regional innovation systems in Europe, we refer to Wintjes & Hollanders (2011). After applying a two-step factor-analysis[29], they use a cluster-analysis to come to the main types (or modes/models) of regional innovation systems (see Figures 12 and 13). Figure 12 shows the regional averages for the 8 composite indicators (factors scores which resulted from the first step of the factor analysis) per type of innovation system. The High-tech type of regions and the Metropolitan KIS regions have similar levels of GDP per capita, but they innovate in very different ways. For policy makers such typologies of innovation systems are very relevant in terms of policy learning, e.g. attempts to transfer good practice policies from totally different innovation systems are more likely to fail. The types of innovation systems displayed in Figures 12 and 13 refer to innovation in general, but should be specified for ICT innovation, following the framework suggested in this paragraph for selecting indicators for ICT innovation (Table 2). Such an analysis could also focus on a specific ICT subsector (e.g. ICT products, telecom/network providers, or ICT services) or a more fine-grained focus on a newly emerging industries, e.g. concerning the Internet of Things, e-health, smart factories, the sharing economy, automated driving, et cetera.

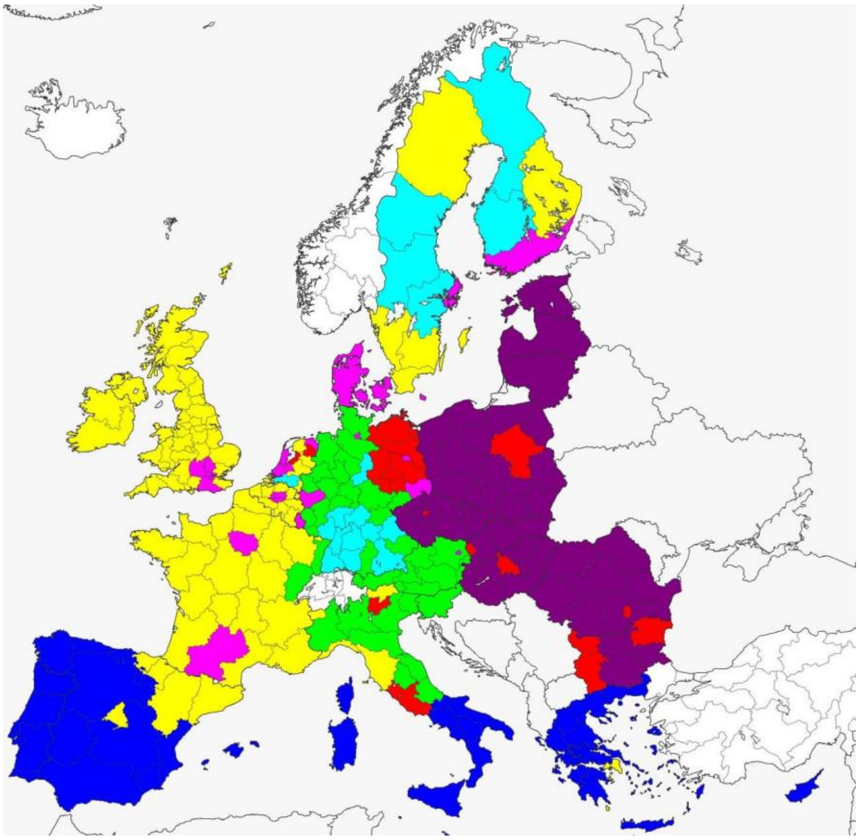
[29] In a first step for some theoretically-justified groups of indicators, a factor analysis was performed. From the results, 8 factors were selected for a second factor analysis which resulted in 3 main components. For these components, a cluster-analysis was performed to make groups of regions which have similar scores on these main components.

Figure 10: Average factor scores for 6 types of regional innovation systems in Europe



Source: Wintjes & Hollanders (2011); Note: 0 is the average of all European regions.

Figure 11: Typology of regional systems and modes of innovation in Europe



Pink: Metropolitan knowledge-intensive services regions

Yellow: Knowledge absorbing regions

Red: Public knowledge centres

Purple: Skilled industrial Eastern EU regions

Turquoise: High-tech regions

Green: Skilled technology regions

Blue: Traditional Southern EU regions

Source: Wintjes & Hollanders (2011)

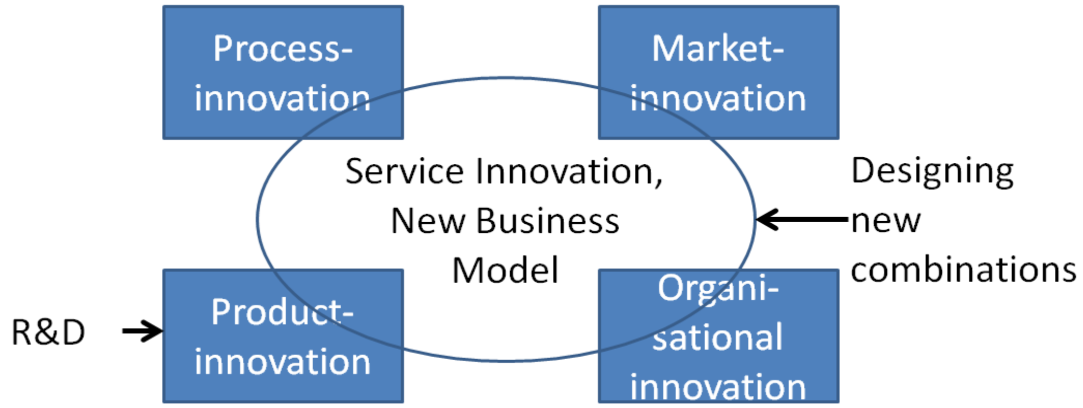
3 How firms innovate: modes and models of ICT innovation

How firms innovate, is traditionally a micro-level issue, which builds on the theory of the (innovative) firm. Again we will start with a short overview of theory and concepts concerning innovating firms in general (3.1) and will then discuss examples from the literature in identifying modes of innovation mostly based on quantitative analysis of firm level data-sets. Each firm innovates in its own way, but there are some existing taxonomies of innovation modes that identify certain patterns on how firms innovate (3.2). Subsequently, we will discuss some possibilities to identify specific modes of ICT innovation (3.3).

3.1 Conceptual insights from the literature on innovating firms in general

Schumpeter distinguished five different types of innovations: new products, new methods of production, new sources of supply, the exploitation of new markets, new ways to organize business and new inputs (material, components). In economics, most of the focus has been on the two first of these. The terms "product innovation" and "process innovation" have been used to characterize the occurrence of new or improved goods and services, and improvements in the ways to produce these good and services, respectively. Together with organizational innovation and market innovation these four types of innovation (see Figure 12) are still distinguished in many innovation surveys, such as the Community Innovation Survey (CIS)[30].However, the distinction between these four types of innovation, does, not capture very well the fact that innovation involves new combinations of these four, which are often very hard to separate from each other. This is especially the case concerning new ICT services and ICT enabled business models (See Figure 12)

Figure 12: Schumpeter types of innovation



The Resource-Based View of the firm (Penrose, 1959), built on Schumpeter's perspective on value creation, views the firm as a bundle of resources and capabilities. The Resource-Based View states that uniquely combining a set of complementary and specialized resources and capabilities (which are heterogeneous within an industry, scarce, durable, not easily traded, and difficult to imitate), may lead to value creation (Penrose, 1959). Teece and Pisano (1994) applied this evolutionary view of the firm to innovation and extended it into the concept of "dynamic capabilities", defined as "the skills, procedures, organizational structures and decision rules that firms utilize to create and capture value" (Teece 2010, p. 680).

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[30] Although, what Schumpeter referred to as 'market innovation', has been changed to a question in the CIS asking about innovative 'marketing'.

Many authors have showed that indeed the way firms innovate involves a complex combination of resources, activities and capabilities concerning innovation. Some of them use survey data to identify different modes (types, models, strategies) of innovation, mostly based on CIS data which relates to a variety of answers from firms to questions concerning innovations. A selection of these taxonomies of firm innovation modes will be discussed in Section 3.2.

As can be concluded from the development of the concept of innovation systems, the micro-view on innovation at firm level as a unique combination of complementary resources and capabilities fits quite well with the innovation systems view at the meso- and macro level (Martin 2012). Differences in the modes of innovation at firm level are therefore often used (as is done in Section 2) to indicate differences at the systems level (e.g. between national/regional systems of innovation, or between sectoral systems of innovation).

However, although sector and country are indeed useful in explaining differences between firms in how they innovate, Srholec and Verspagen (2012) show that there is still a high level of heterogeneity among firms within such systems. An evolutionary interpretation of the resource-based theory of the firm holds according to Srholec and Verspagen (2012, p.1224) that:

> *"firms may adopt widely differing strategies, even in a similar selection environment such as a sector or country, because they start from different resource bases, interpret the environment differently, and use different models for reaching decisions on their strategy"*.

In the next section, we will discuss some studies which identify in an indicator-based way (mixing theory and empirical observations) taxonomies of firm innovation modes.

3.2 Taxonomies of firm innovation modes in the literature

As a first taxonomy of innovation modes we can refer to the distinction between the early and later work of Schumpeter, often referred to as Schumpeter Mode 1 and 2. Mode 1 refers to his work on the individual entrepreneur who sees and tries new opportunities before others do. His later work acknowledges the importance of team work in departments and between departments in large firms, including a research department.

Pavitt (1984) showed with his taxonomy of innovating firms that the sources and purposes of innovation are diverse and that one can identify different modes of innovation. He also related the types and modes of innovation to sectors, showing that they are industry-specific in the sense that some modes are more frequent in certain industries. 'Science-based' innovating firms are dominant in high-tech industries which mainly innovate by performing in-house R&D for product innovation, or external R&D at universities. 'Supplier-dominated' include mostly small firms in traditional industries like textiles, where the process innovations of new machines coming from suppliers are typically more important (or the more dominant innovation mode/strategy/or routine). Scale-intensive refers mainly to large firms producing basic materials and consumer products, e.g. automotive industries. Sources of innovation may be both internal and external to the firm. The 'specialised suppliers' in Pavitt's taxonomy refer to smaller, more specialized firms producing technology which is sold to other firms, e.g. specialized machinery and instruments. There is a high level of appropriability of the knowledge concerned.

Table 5: Overview of studies identifying innovation modes

Innovation modes	Methodology	Measures feeding into modes	Data	Study
Mode 1: 'Science-based high-tech firms ' Mode 2: 'IT-oriented network-integrated developers' Mode 3: 'Market-oriented incremental innovators' Mode 4: 'Cost-oriented process innovators' Mode 5: 'Low-profile innovators'	Exploratory	Inputs and outputs, linkages	Swiss Innovation Survey 1999 Private services sectors	Hollenstein (2003)
Mode 1: 'Strategic innovators' Mode 2: 'Intermittent innovators' Mode 3: 'Technology modifiers' Mode 4: Technology adopters'	Prescriptive	Technological inputs and outputs	Eurostat NewCronos (largely Eurostat CIS3 data)	Arundel and Hollanders (2005)
Mode 1: 'Science, Technology and Innovation' Mode 2: 'Doing, Using, Interacting'	Prescriptive	Inputs, organisational	2001 Danish DISKO Survey	Jensen, Johnson, Lorenz, Lundvall (2007)
Mode 1: 'Science-based' Mode 2: 'Specialised suppliers' Mode 3: 'Supplier-dominated' Mode 4: 'Research-intensive'	Exploratory	Inputs and outputs, Linkages, organisational	Survey of SMEs in the Netherlands 2003	de Jong, Marsili (2006)
Mode 1: ' Science-based' Mode 2: 'Supplier-dominated' Mode 3: 'Production intensive' Mode 4: 'Market driven'	Exploratory	Mainly inputs, linkages	CIS2 for Denmark and Finland	Leiponen and Drejer (2007)
Mode 1: 'Research' Mode 2: 'User' Mode 3: 'External' Mode 4: 'Production'	Exploratory	All CIS variables available	Eurostat CIS3	Srholec and Verspagen (2008)
Mode 1: 'New-to-market innovating' Mode 2: 'Marketing-based imitating' Mode 3: 'Process modernising' Mode 4: 'Wider innovating'	Exploratory	Inputs and outputs	Innovation surveys of 9 OECD countries	Frenz and Lambert (2009)
Mode 1: 'Organizational innovations' Mode 2:' Technological innovations'	Exploratory	Mainly outputs	UK CIS4	Battisti and Stoneman (2010)

Source: Frenz and Lambert (2012).

Table 5 gives an overview provided by Frenz and Lambert (2012) of some studies which have followed-up the search for patterns in firm-level data, hence identifying main types or modes of innovation.

Frenz and Lambert (2012) refer to these modes as 'mixed modes', as they indeed refer to certain combinations of innovation resources, activities and outputs which often can be found in (the CIS answers for) one firm. There are two methods to come to such a typology: either prescriptive or exploratory.

Arundel and Hollanders (2005) and Jensen et al. (2007) use a prescriptive method, as they a-priory 'design' their modes informed by theory. Firms which satisfy certain criteria are assigned to the corresponding mode. Hollanders and Arundel (2005) first define criteria to differentiate innovators from 'non-innovators'[31], and they subsequently report on four types of innovators based on CIS data:

- *Strategic innovators* are active on international and national markets and have introduced (at least) a product or process innovation that they developed (partly) in-house. Their R&D is a continuous activity and they did introduce at least one product that is new to their market as well. These firms are the source of many innovative products and processes that are also adopted by other firms.
- *Intermittent innovators* develop innovations (at least partly) in-house and have introduced new-to-market innovations. But, they are unlikely to develop innovations that diffuse to other firms.
- *Modifiers* all developed an innovation (at least partly in-house) but none of them perform R&D. If they are active on national or international markets, they have not introduced a new to market innovation (otherwise they would be classified as an intermittent innovator). If they are active in local and regional markets, they may have introduced a new to market innovation and have slightly modified it for this market.
- *Adopters* depend on adopting innovations developed by other firms, hence innovate through diffusion.

Others use exploratory methods, they 'let the data speak' by identifying patterns with for instance factor analysis (also known as data-reduction and principle component analysis). We focus in this report on this second methodology, because it combines the insights from theory and empirical observations. An example of this approach is Srholec and Verspagen (2008; 2012)[32] who take the broadest set of CIS variables into the analysis and use a two-step factor analysis[33]. In a first round they perform a factor analysis on the variety of innovation activities, ranging from: performing in-house R&D, to acquisition of inputs, and the activities of marketing and design. This results in three types of activity sets (mix or constellations) which can be differentiated. Another first round of factor analysis identifies three types of effect of innovation; another identifies the three main sources of information for innovation: science, clients and suppliers. Another first step factor analysis on variables regarding knowledge appropriation behaviour identifies a formal and an informal method of IP protection. A last first step identifies a factor addressing non-technological innovation. On these ingredients of innovation strategy (the 13 factor-scores of the first stage, see first column of Table 6) a second stage factor analysis is performed. The result leads to four innovation strategies or modes, which Srholec and Verspagen have given the following labels: 'Research', 'User', 'External' and 'Production' (Table 6).

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[31] They first constructed a set of criteria and then selected only those firms which met the criteria of the concerning mode, the remaining are considered to be non-innovators.

[32] Srholec and Verspagen (2008) in Table 10 refer to a working paper which has been published in 2012.

[33] However, they do not include all possible variables since factor analysis is sensitive to the inclusion of similar or overlapping variables.

Table 6: The 4 modes of Srholec & Verspagen (2012), Hierarchical factor analysis (2nd stage) on ingredients of innovation strategies

	(1) **Research**	**(2)** **User**	**(3)** **External**	**(4)** **Production**
R&D	0.70	0.07	−0.16	0.09
Marketing	0.07	0.65	0.01	−0.16
External inputs	0.16	−0.13	0.65	0.02
Product effects	−0.01	0.69	−0.03	0.15
Process effects	−0.08	0.06	0.02	0.81
Social responsibility	0.08	−0.07	0.01	0.83
Information from science	0.62	0.01	0.31	0.06
Information from clients and industry	−0.01	0.61	0.28	−0.07
Information from suppliers and events	−0.07	0.23	0.69	0.10
Formal protection	0.36	0.37	−0.27	0.05
Informal protection	0.42	0.35	−0.18	0.01
Non-technological innovation	0.00	0.53	0.02	0.12
Innovation co-operation	0.78	−0.06	0.06	−0.09

Source: Srholec & Verspagen (2012, p.1237).

The 'Research' mode puts together strong R&D capabilities, extensive use of information from science, and a tendency to participate in joint innovation projects with other organizations. This mode is similar to the 'Science-based' mode of Pavitt (1984), which has also been identified by Hollenstein (2003), and Leiponen and Drejer (2007).

The second mode is the 'User-driven/oriented' mode which is dominated by product effects as a reaction to information from clients for which marketing and organizational innovations are important. According to Srholec and Verspagen (2012) this dimension is similar to the 'Product market-orientation' of Hollenstein (2003) and 'Market-driven' innovation by Leiponen and Drejer (2007). The 'External' mode *"exploits opportunities for innovation from diffusion of technology embodied in new capital goods and acquisition of existing technology from other organizations by purchase of rights to use patents, licenses, or software"* (Srholec & Verspagen 2012, p.1238). Also part of this dimension is the importance of external sources of information, especially from suppliers. Methods to protect IP do not seem to matter for firms following this route. According to Srholec & Verspagen (Ibidem):

> *"This pattern seems to reincarnate the "IT" dimension of service innovations detected by Hollenstein (2003), although we do not have direct variables on diffusion of information technologies in our dataset; and the "supplier-dominated" factor identified by Leiponen and Drejer (2007)"*.

The "Production" mode is oriented at process effects of innovation (Table 11). Again, firms that use this mode do not tend to use any methods of protection extensively.

> *"This dimension appears to be most closely related to the principal factors identified as the "cost reductions based on process innovation" by Hollenstein (2003) and "production-intensive" by Leiponen and Drejer (2007), while the "process modernizing" mode detected by Frenz and Lambert (2009) overlaps with both of the External and Production factors." (Srholec & Verspagen 2012, p.1238).*

The OECD report by Frenz and Lambert (2012) on mixed modes of innovation argues that the data allow the characterization of 5 innovation modes, which are named as follows: Mode 1: 'IP/technology innovating'; Mode 2: 'Marketing based innovating'; Mode 3: 'Process modernising'; Mode 4: 'Wider innovating'; and Mode 5 'Networked innovating'. Mode 4 refers to a non-technological mode of innovation based on organizational innovations and marketing innovations. The 5^{th} mode combines cooperation in research and buying-in of R&D, e.g. through licensing. Although internal R&D also loads high in this 5^{th} mode, it is way more open than the first mode.

Studies which try to measure which kind of innovations (Product/process/organisational/marketing) generate more growth in terms of turnover or jobs give mixed results. Lachenmaier and Rottmann (2010) conclude that process innovations have a higher positive effect on employment than product innovations. Product innovations on the other hand are more often associated with growth in turnover. For policy makers, however, the lesson is that there are no good reasons to promote only one type of innovation, or one mode of innovation. Innovation policies which apply to a broader understanding of innovation and which are not limited to R&D or product innovation, are more likely to impact on growth of firms, and SMEs in particular (Wintjes 2014).

The fact that there are clear similarities in the modes which are found in the various studies (using various methods and indicator sets, and with different focus of analysis in terms of countries or sectors), support the conclusion of Srholec and Verspagen (2012) that to a high degree these modes (and the heterogeneity they represent) can be found in all sectors and all countries. There is, so to speak, no convergence to a single best practice mode of innovation. From an evolutionary, (eco-)system perspective, it is healthy to have this diversity, which allows for novel combinations. So, policy makers should not reduce the variety of modes, but rather maintain the diversity, and for instance strengthen 'weak modes'. This also implies that there is no single best practice policy which policy makers can copy as a 'one-size-fits-all' policy from other regions or sectors. Designing the appropriate innovation policy mix for a given innovation system, calls for an interactive process in order to come to a tailored policy mix.

3.3 Identifying ICT modes of innovation

Based on qualitative analysis, Fransman (2014) proposes a taxonomy for global ICT firms, making a distinction between three types or sub-sectors and their related innovation ecosystems: ICT equipment providers; network operators; and platform/content and application providers. The entrepreneurial mode of the 'app firms' that operate on internet platforms has actually some similarities with the Schumpeter Mark I Mode of innovation, which is characterized by low entry costs/barriers. This contrasts with the mode of the telecom sector (network operators) which has some similarities with the Schumpeter Mark II situations with high entry barriers/costs. The third model of Fransman (2014) refers to the IT hardware manufacturers.

In the more quantitative empirical attempts to identify modes of innovation (e.g. the studies listed in table 5), the information concerning innovation inputs, outputs, activities and effects, are not 'ICT-specific', except in one study: Hollenstein (2003). Based on a Swiss survey with a large set of innovation indicators which includes data on IT inputs (hard+software) and outputs, Hollenstein (2003) identified with cluster-analysis 5 different groups of ICT service firms which can be interpreted as specific "innovation modes" within ICT services:

1. "Science-based high-tech firms with full network integration";
2. "IT-oriented network-integrated developers";
3. "Market-oriented incremental innovators with weak external links";
4. "Cost-oriented process innovators with strong external links along the value chain";
5. "Low-profile innovators with hardly any external links".

The other studies do not focus on ICT sectors in particular, nor are the modes based on ICT variables like those that Hollenstein (2003) had in his Swiss survey. However, interestingly the modes he identified have similarities with some of the modes found in the other studies, as we have above referred to while discussing the results of Srholec and Verspagen (2012). Hollenstein (2003) concluded that although R&D is less important for ICT service firms (actually only in mode 1), and although non-technological innovation is more important for innovation in ICT services than for ICT manufacturing, the differences between ICT services and manufacturing are not as large as it is often claimed to be. Hollenstein (2003) also found that the economic performance of the five groups of ICT service firms did not differ that much.

One way to identify if ICT sectors (and sub-sectors) innovate in a different way is by comparing the firm-level data of firms in ICT sector(s) with those in other sectors. This is mostly done by first identifying the modes of innovation for all firms in the dataset, and then analysing which of these modes can more frequently be observed in ICT sectors.

An example is given by Wintjes & Dunnewijk (2008) which make use of the prescriptive method of Arundel and Hollanders (2005) and Hollanders (2007) to identify their types of innovators (Strategic, Intermittent, Modifiers and Adapters) for firms in several ICT-sectors (Table 7).

Table 7 shows that across all firms 6% are strategic innovators, 17% are intermittent innovators, 11% are technology modifiers and 4% are technology adopters. When comparing this with the total for the ICT sectors we notice that in the ICT sectors the share of strategic (18%) and intermittent innovators (29%) are much higher than for firms across all sectors (Hollanders 2008; Wintjes & Dunnewijk 2008).

Table 7: Innovation performance and types of innovators by sector (share of firms)

Industry	Average innovation performance	Type of innovator			
		Strategic	Intermittent	Modifiers	Adopters
NACE 30 Office machine etc.	65%	20%	37%	3%	5%
NACE 32 Radio, TV & Comm Eq.	61%	21%	18%	8%	5%
DL Electrical and Optical	63%	19%	24%	7%	3%
NACE 72 Computer services etc	63%	18%	29%	11%	5%
ICT (total)	61%	18%	29%	10%	5%
D All Firms	47%	6%	17%	11%	4%

Source: Wintjes & Dunnewijk (2008), based on the typology prescriptions of Hollanders and Arundel (2005) and Hollanders (2007).

Table 8 summarizes the 'performance' characteristics of each innovation mode in the ICT sector compared to the average performance of that mode over all industries. It shows that the share of innovative firms among Strategic innovators and Intermittent innovators are higher than for the same modes in other sectors. The turnover from new-to-market products and the growth of total turnover for Strategic and Intermittent innovators is higher in ICT than in other sectors.

The fact that the average ICT firm is smaller than the average firm in other sectors is especially true when we compare strategic innovators in the ICT sector with strategic innovators in other sectors. Strategic ICT innovators have on average 313 employees, whereas for all sectors Strategic Innovators are on average three times larger, with 948 employees. The average size of Strategic innovators in NACE 30 is 108, and 250 in NACE 72. Strategic innovators in NACE 32 with an average of 699 are also smaller than in other sectors, but almost 7 times as large as strategic innovators in NACE 30 (these classifications refer to the previous: Rev. 1.1 NACE classification).

The share of high-educated employees is for each of the innovation modes for firms in the ICT sector higher than for same modes in other sectors. The share of higher educated employees is especially high in the NACE 72 (computer services).

Among the innovating ICT firms, turnover growth is highest in NACE 32, employment growth and export growth is highest in NACE 72. Among the Strategic Innovators in the ICT sub-sectors, those from NACE 72 outperform those in NACE 30 and 32 in terms of growth in turnover, employment and export.

Unfortunately, Frenz and Lambert (2012) mostly use the results of their typology of innovation modes to analyse differences between countries. They test and confirm the National Innovation Systems concept, and devote less attention to the differences by sector. Also the relevance (or use, occurrence) of the 5 modes of innovation differs by sector, but their sectors are rather broadly defined. For our purpose we selected the three sectors which include ICT sub-sectors (Table 9).

Table 8: Summary of 'performance' of each innovation mode for the ICT sector compared to the average of that mode over all sectors

	Strategic innovators	**Intermittent innovators**	**Technology modifiers + Technology adopters**
Share of innovative firms	++	++	-
Turnover of new-to-firm products	+	+	-
Turnover of new-to-market products	++	+	+
Firm size	--	-	--
Turnover growth	++	--	+
Employment growth	+	+	+
Labour productivity	-	-	--
Share of employees with higher education	++	++	++
International markets most significant	--	--	-
Innovation activities (top 3 used by most firms)	- own R&D - buying advanced machinery - training of personnel	- own R&D - training of personnel - buying advanced machinery	- buying advanced machinery - training of personnel - market introductions
Innovation expenditures (top 3 highest spending shares)	- own R&D (64%) - buying advanced machinery (29%) - buying external R&D (4%)	- own R&D (59%) - buying advanced machinery (29%) - buying external R&D (6%)	- buying advanced machinery (54%) - buying other external knowledge (29%) - own R&D (49%)
Use of formal IP (most used)	0 (trademarks)	+ (trademarks)	0 (trademarks)
Use of non-formal IP (used by most firms)	++ (lead-time advantage)	++ (lead-time advantage)	++ (lead-time advantage)
Use of non-technological change (used by most firms)	- (aesthetic changes)	+ (new organisational structures)	0 (new corporate strategies)

Source: Wintjes & Dunnewijk (2008).

Within the 'Machinery, electrical, communication, medical equipment' sector firms more often apply the 'IP/Technology' mode of innovating, and the 'Marketing' mode. The 'Process modernising', and 'Wider innovating' modes of innovation are under-represented in that sector.

Firms in the 'Post and telecoms' sector are highly 'Marketing based' and also the non-technological mode of 'Wider innovating' occurs more often in this sector than in the average for all firms. The 'IP/Technology' mode is less often used by firms in this sector. The occurrence of the modes in the sector which includes: 'KIBS, computer, R&D, legal, accounting', is closer to the average (0) of all firms, but values for 'IP/Technology' and 'Process modernising' are lower, and those for 'Wider' and 'Networked' modes of innovating are higher (Table 9).

Table 9: Occurrence of the 'mixed modes' of innovation from Frenz and Lambert (2012), by sector

Industry	IP/Technology innovating	Marketing based innovating	Process modernising	Wider innovating	Networked innovating
Machinery, electrical, communication, medical equipment	0.39	0.22	-0.07	-0.13	0.14
Post and telecoms	-0.21	0.17	-0.09	0.18	-0.12
KIBS, computer, R&D, legal, accounting	-0.09	0.03	-0.13	0.11	0.12

Source: Frenz and Lambert (2012, p. 51) Note: cross country average factor scores per sector. When positive the mode is more often used by firms in the concerning sector, when negative the mode is less often used by firms in the concerning sector (less often than in other sectors).

3.4 Conclusion and discussion

We conclude from this paragraph on firm-level innovative behaviour that the theoretical concept of the Resource Based View (RBV) on innovation at firm-level fits with the innovation systems view. The innovative firm uniquely combines a value creating set of complementary and specialized resources and capabilities. These firm-level sets (or combinations, or innovation mix) may be unique, but with firm-level indicators it is possible to identify some patterns which refer to the main types or modes of innovative behaviour.

Overall the method to identify modes of innovation by multi-variate methods of data-reduction (factor and cluster-analysis) seems most appropriate to identify modes of innovation as a coherent (jointly reinforcing) mix or combination of innovation strategy ingredients, or routine components.

The availability of data on ICT specific aspects of innovation at firm level is rather limited in Europe. However, the studies referred to in this paragraph show that firms in ICT sectors are more innovative than firms in other sectors. The kind of innovation behaviour (or in other words the mode, or model of innovation) differs between the ICT sub-sectors (of ICT products, telecom and ICT services).

Towards the future, it would be interesting to have an up-date on some of the referred indicator based work. Moreover, it would be interesting to have a more fine grained coverage of the ICT subsectors, and to compare for instance the preference for certain modes in the ICT manufacturing industries with the average factor score for manufacturing industries. Also a comparison between the average factor scores for ICT services with those for other services, would be relevant for identifying ICT specificities in the innovative behaviour of firms in service industries. In order to identify modes which are specific for ICT innovation, one could also run a separate factor analysis for firms in the ICT sector, but then the results (the factor-scores and modes) will be difficult to compare with those of other sectors.

Since the Community Innovation Survey does not include specific questions on ICT, e.g. ICT inputs, it is difficult to specify an ICT-enabled mode of innovation. An option to differentiate between ICT producing and ICT using sectors, could be based on macro-data (e.g. input-output data from national accounts) at national level, and subsequently compare the modes (factor scores) for the 'ICT producing' sectors versus the 'non-ICT producing' sectors, and the 'ICT using' sectors versus the 'non' or 'less ICT using' sectors.

Besides modes of innovation for firms, taking a wider view on ICT innovations in society, implies that also modes of innovation of other type of actors are relevant. Innovation in the public sector for instance[34].

[34] http://ec.europa.eu/enterprise/policies/innovation/files/epsis-2013_en.pdf

4 Conclusions and policy implications

Innovation systems: from concept to operational suggestions on how to apply it to ICT and extend it to the societal level

Concerning the theoretical antecedents discussed in Section 2, we conclude that the innovation systems concept was defined some 25 years ago, at a time when economists were discussing to what extent technological change should be seen as an external (publicly-available and benefitting all) or internal (e.g. private benefit for R&D performers) driver of change. The innovation systems solution to this debate is at the meso-level where various actors learn from their own experiences and from interaction with others in a specific common context. At this meso-level, innovation and its context become inter-dependent, embedded in interactions between supply and demand, between the producers and users of knowledge.

The concept of national innovation systems emphasizes the importance of interactions between a diversity of actors, a diversity of innovation activities, resources and institutions. The innovation systems concept has also been applied to regions and sectors.

ICTs are a distributive source of increased productivity, advanced solutions for societal problems, and new services to consumers. The disruptive implications of ICT innovation go beyond industries, economies, and traditional value chains and business models. A key characteristic of ICT innovations is their pervasiveness in society as a whole. ICT is always part of it in some way, especially in newly emerging sectors and 'smart policy domains'. Also, public sector innovation and social innovation are to a large extent based on ICT innovation. We have concluded that, especially for ICT, it is relevant to extend the innovation systems concept to the societal level.

In terms of indicators to 'measure' innovation systems, this implies that it is relevant to integrate indicators traditionally used to monitor the Information Society, e.g. indicators for the readiness of an innovation system for the Internet of Things (in terms of the various actors, institutions, interaction mechanisms, knowledge generation and transmission, supply, skills, demand, finance and internationalization of ICT innovations). Suggestions have been given on how to apply the systems of innovation approach to ICT innovation.

In short, we propose that the conceptual and empirical development process of the last few decades should be continued, by further broadening the perspective on innovation. A broadened perspective would increase the number of relevant indicators to measure and monitor what is happening at systems and firm levels, and it would also increase the complexity through the involvement of additional stakeholders and additional interactions. We have suggested a framework to ensure broad coverage, when selecting relevant indicators, and have also given some examples of indicators from this framework.

Innovation modes at firm-level: from concepts to operational suggestions on how to identify modes of ICT innovation

In Section 3, we turned to innovation at the firm-level, and concluded that the resource-based view of the innovative firm fits very well with the innovation systems perspective (Martin 2012). The resource-based view states that a unique combination of complementary and specialized resources and capabilities (which are heterogeneous within an industry, scarce, durable, not easily traded, and difficult to imitate), may lead to value creation (Penrose, 1959). These firm-level sets (or combinations, or innovation mix) may be unique, but with firm-level indicators it is possible to identify some patterns which refer to the main types or modes of innovative behaviour.

Multivariate methods of data-reduction (factor and cluster-analysis) seem the most appropriate to identify models or modes of innovation as a coherent (jointly reinforcing) mix or combination of innovation strategy ingredients, or routine components. Overall, firms in ICT sectors are more innovative than firms in other sectors, but the mode of innovation differs between the ICT sub-sectors of ICT producers, telecoms and ICT services.

The exploratory method of factor - or principal component - analysis (and cluster-analysis) is useful for identifying innovation patterns not only at the firm-level, but also at the systems level. Advancements in identifying firm-level ICT modes of innovation, as discussed in Section 3, could subsequently be used to improve the monitoring of national and regional systems of ICT innovation, as discussed in Section 2. The deviation from the average factor-scores (referring to ICT modes of innovation) could serve to identify national or regional-specific modes of ICT Innovation. Integration of factor-scores on ICT modes of innovations at firm-level with regional indicators at systems level would allow us to arrive at an EU typology of regional systems of ICT innovation, which could be seen as regional 'modes' of ICT innovation[35]. This would reduce the complexity in studying the interaction between firms and their geographical context concerning ICT innovation, by simplifying the diversity in system contexts, as well as the diversity in firm strategies.

Policy implications

Studying and monitoring ICT innovation systems is important as it allows us to learn how to improve policy and the performance of current and future systems. It will make it possible to design and improve an ICT innovation policy-mix, which is tailored to the specific needs of ICT modes of innovation, and also tailored to the prioritized (mix of) societal needs (e.g. economic, social, environmental, health, or other impacts).

Before we address the policy implications of this (which are linked to the 'general purpose' nature of ICT and its pervasiveness in society), we first address the policy implication of another characteristic of ICT innovation, namely the rate of technological change in ICT, which tends to be very high.

ICT innovations become outdated very quickly and new disruptive ICT innovations emerge and diffuse equally quickly. This means that the relevant institutions and framework conditions need to be up-dated at relatively often. We have seen in the previous paragraphs that institutions such as technology standards or regulations are very important drivers or barriers for the growth of ICT systems of innovation. The policy implication of this is that timing in institutional change is crucial. Setting new standards, and up-dating regulations can create a competitive edge. The relevant regulations concern not only the ICT industries themselves, but also the industries and policy fields of application, e.g. transport (e.g. automated driving), health (E-health records), finance (e.g. crowd-funding and block-chain applications). Due to the increased importance of ICT innovation in all sectors and policy domains, ICT innovation policy should be addressed as a horizontal policy field.

We mention one example (Wintjes et al. 2016): the policy response to the disruptive impact of block-chain applications (Table 10). Block-chain applications utilize an innovative open source IT architecture that allows financial transactions to be carried out with anybody, while keeping an authoritative record of all the changes made. They were originally developed in the context of peer-to-peer digital payment systems such as Bitcoin. They make decentralised and verifiable exchanges possible, overcoming the need for verification processes provided by a trusted third party (e.g. a bank). A clear example of their potentially disruptive impact is given by the time it currently takes to move funds between different institutions and geographic.

[35] For those ICT innovation processes which take place at international or global level, the national perspective would be more relevant.

Table 10 Blockchain applications: disruption and policy challenges

Disruption	**Block-chain technology provides a safer, faster and more cost-effective way to implement transactions**
Impact on societal challenges	Optimise cost, transparency, time efficiency, stability of the financial system Enhance the operability of Internet of Things networks Facilitate blockchain-based transactions by a large portion of the population
Market opportunity	Reduction of banks' infrastructure costs by EUR 13.8-18.4 billion per annum by 2022.[36] Fintech-related business contribution of more than EUR 28.2 billion to the UK economy in 2014.[37] Opportunities in industries such as finance, insurance, engineering, manufacturing Can redefine role of cloud-based computing
Policy challenges	Stable and clear regulatory framework Provision of support for creation of standards Foster awareness

Source: Wintjes et al. (2016, p.10).

Block-chain start-ups face important barriers from governments and financial institutions, for instance when they want to register as legal entities or open trading bank accounts. A major policy challenge is to promote collaboration between the ICT start-ups and the established banking sector, and the respective government departments (Ministries) and DG's at EU level. In this respect, the 2015 "green paper" from the European Commission 'Building a Capital Markets Union' only mentions ICT innovation twice. While the paper acknowledges it as "an important driver of integration of capital markets", it remains vague on how this transformation will affect the sector. This rather reserved and conservative approach could be due to the obstacle identified in the case study on block-chain applications concerning lobbying pressures from the establishment[38]. Most promotion, demonstration and awareness-raising about block-chain applications has perhaps been done in the preparation of the Digital Single Market initiative. Events such as the recently held workshop on block-chains and digital currencies[39] organized by the European Commission in the context of the Digital Agenda for the EU, have contributed to an increased awareness of the benefits of block-chain applications.

Organizing formal platform meetings is not the only support provided for the creation of standards. Informal 'playgrounds' also play a part. For instance, in 2015 the first 'bankathons' (https://www.bankathon.net/) were organised in Frankfurt (Germany). At a bankathon, banks, fintech start-ups, developers and designers come together 'to create products customers dream of'. In a few days, 30 hours in total, a new product is developed from scratch and launched

36 Santander InnoVentures, Oliver Wyman and Anthemis Group. (2015). The Fintech 2.0 Paper : Rebooting Financial Services.
Available at: http://santanderinnoventures.com/wp-content/uploads/2015/06/The-Fintech-2-0-Paper.pdf

37 Sillicon Valley Bank (2015). Investment trends in Fintech. Available at http://www.finextra.com/finextradownloads/featuredocs/SVB-Fintech-Report-2015-digital-version.pdf

38 http://ec.europa.eu/growth/industry/innovation/business-innovation-observatory/case-studies/index_en.htm

39 https://ec.europa.eu/digital-agenda/en/news/blockchain-and-digital-currencies-workshop

Coming back to the 'general purpose' nature of ICT and the pervasiveness of ICT innovations in society, we can draw several conclusions. Taking a wider systemic view of ICT innovation at a societal level has policy implications, as it implies a broadened perspective on policy:

- Beyond R&D policy: a systemic view of ICT innovation policy goes beyond supply-side innovation policy which promotes R&D in ICT, and complements it with more demand-side innovation policies which promote the demand and diffusion of ICT innovations. The Tampere region has successfully transformed its innovation policy from R&D funding to supporting innovation platforms such as Demola (see text-box), where student teams solve problems, often leading to quicker take up of business opportunities.
- Beyond promoting science-industry interactions: for many years innovation policy has focused on supporting linkages between scientific research in ICT and producers in ICT industries, but these interactions should be broadened to include ICT users in the public sector and civil sector.
- Beyond triple-helix innovation policy initiatives: in many sectors, regions and cities the concept of triple-helix (industry, universities, and government) has been applied to developing and implementing innovation strategies. Increasingly, additional actors are involved, most notably citizens and civil society actors (including not-for-profit non-governmental organizations).
- Beyond focusing on the purely economic impacts of ICT innovation: traditionally the focus has been on economic impact, but today there is more awareness of the impact of ICT innovation on other policy fields. ICT innovation now serves any policy field or Ministry, and ICT innovation policy affects many societal challenges.
- Beyond policies which aim for technological innovation: in the past, ICT innovation policy was largely focused on supporting technological innovation, as was innovation policy in general. Nowadays, however, it has become increasingly apparent that impacts can be gained from all kinds of non-technological innovations. Un-leashing these impacts calls for policies and policy instruments which promote non-technological modes of innovation, for example new ICT business models, or design-thinking among SMEs.
- Beyond old sector policy silos: there is also a need for systemic interaction between policy domains, government departments/Ministries and DG's as regards emerging ICT innovations. Governments have to promote synergies from (policy) interaction across sectors in the economy, across parts of society, and across policy domains.
- Beyond policy interventions through the market/price-mechanism for ICT: lowering the price of ICT is not enough to enhance up-take and diffusion. Policies should aim for behavioural change (additionality) by promoting experimentation and demonstration (e.g.: by organizing hackathons, 'bankathons', 'living-labs', boot camps, demonstrators, digital platforms, etc.).
- Beyond copying best practice in ICT innovation policies: there is no single perfect 'one-size-fits-all' standard policy solution which all policy makers should adopt. Policy makers should therefore interact with stakeholders, and encourage entrepreneurial discovery of appropriate fields of 'smart specialisation'. Thus, they would be able to develop systemic innovation strategies and learn how to improve the innovation policy mix.

Traditionally, the policy focus in NIS, RIS and SIS was on promoting science-industry interactions, and the main aim was to have impact on economies (at firm, sector, country and regional level). If we build on Information Society concepts, however, a wider symbiotic view emerges in what can be called the societal system of ICT innovations.

Since R&D, or innovation supply-side policies have been dominant for decades, policies to strengthen the European demand-side of digital innovation are needed. Linking up to a strengthened demand-side would help firms cross the 'valley-of-death' by linking global excellence and regional relevance through problem-based and solution-based policy modes. Centres of ICT research excellence still receive public funding mainly for R&D. They receive less funding for diffusion and interaction with potential SMEs or civil users within the innovation systems in which they operate in Europe. In this respect, we have argued in this report in favour of paying more attention to the 'demand-side' of ICT innovations. An obvious policy implication is the call for more 'demand-side policies'. This for instance includes policies concerning: the up-take of certain ICT innovations; cross-sector innovation initiatives; innovation platforms; regulation as a driver of demand for ICT innovations; developing lead-markets for ICT innovations; ICT living-labs, developing standards for ICT innovations; investments in the skills of potential users; facilitating demonstrations and proof-of-concept; public procurement programmes for ICT; support for internationalization.

Demola

Although Tampere is one of the most R&D-intensive (and ICT-intensive) regions in Europe, the Council of the Tampere region, has shifted from traditional R&D-driven cluster policies to innovation platforms such as Demola, for multi-disciplinary, collaborative innovation and demonstration. Demola platforms combine people, processes and facilities, and provide a new 'needs-driven or problem-based' method of funnelling the flow of innovation in a sustainable way. The key drivers for these platforms include communities, talents and global ecosystem orchestrators. In addition, they create attractive environments for co-creation ('trying out new stuff') speed-up going-to-market, build capacity, facilitate systemic projects, and react to demand pull instead of technology push. The platform concept is based on the following guiding principles: create new combinations of knowledge (by tapping into young talent); move faster (from an idea (kick-off) to prototype (pitch) in just 4 months); and demos do not require a lot of financial support. The Demola platform matches companies or other organisations which have problems to be solved, with multidisciplinary teams of students and university staff who will come up with solutions which they demonstrate in a short time. The platforms have achieved encouraging results: 535 innovation projects which respond to real life problems, challenges and needs; 2500+ innovation community members and 170 partner companies; 100+ start-ups; 500+ jobs; and €18 million funding for start-ups and innovators. Demola is applied at 13 (mostly EU) locations. For further information, see: http://tampere.demola.net/

Source: Wintjes et al. 2014, p.22

At both the system and firm levels, there are several modes of ICT innovation. Policy makers should not reduce diversity by favouring one mode of innovation over another (e.g. by only subsidizing R&D or product innovation). Instead, policy makers should tailor their innovation policy mix to the variety of modes of innovation. As an extension to Lundvall's theory on interactive learning between producers and users of knowledge, we add that policy for ICT innovation should be produced in interaction with its users.

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Annex: Tables and Figures

Table a: Share of ICT firms collaborating with others, universities, research institute, suppliers and clients

	cz	de	gr	es	fr	it	cy	lt	hu	nl	pl	pt	sk	fi	se	uk	no
Others	45	25	45	25	43	27	50	48	51	41	49	37	48	49	48	40	36
Universities	22	16	24	11	:	12	14	24	20	16	8	17	:	40	20	11	16
Research Institutes	12	7	12	7	10	2	0	17	:	12	11	6	:	27	:	:	14
Suppliers	37	8	20	10	26	11	41	45	37	30	32	28	38	41	33	27	24
Clients	35	12	28	10	26	11	14	36	:	29	20	25	41	48	39	28	30

Note: =no data available

Table b: Competitive Innovative performance of the ICT sector at national level

Country	Index Level of innovation (1)	Patenting Advantage (1a)	Market Advantage (export) (1b)	Total Factor Productivity (1c)	Index of Growth in innovation performance (2)
Finland	0.75	2.33	2.94	3.66	0.79
Netherlands	0.58	1.93	4.50	1.50	0.74
France	0.48	0.91	0.82	3.97	0.20
UK	0.47	0.66	1.11	4.15	0.28
Belgium	0.46	0.72	2.26	3.29	0.32
Germany	0.45	1.75	1.11	1.94	0.67
Austria	0.41	0.99	1.49	2.61	0.49
Sweden	0.25	1.55	1.66	-0.46	0.57
Denmark	0.23	1.04	1.30	0.37	0.62
Spain	0.13	0.27	0.50	0.84	0.28
Portugal	0.11	0.05	0.66	0.96	0.38
Italy	0.06	0.49	0.39	-0.30	0.22
Norway	0.05	0.62	0.46	-0.68	0.31
Hungary	-0.13	0.12	1.69	-2.66	0.35
Poland	-0.19	0.04	0.19	-2.53	0.20
Czech Rep	-0.54	0.05	0.60	-7.24	0.19
Slovakia	-1.18	0.03	0.20	-15.08	0.14
Ireland		0.45	7.68		
Greece		0.18	0.22		
USA	0.50	0.97	0.56	4.19	0.35
Japan	0.43	1.45	1.24	2.20	0.18
Average	0.17	0.76	1.83	0.02	0.38

Source: Marin et al. (2008)

Table c: Share of ICT firms which report a lack of qualified personnel as obstacle for innovation, CIS3

	cz	de	gr	es	fr	it	cy	lt	hu	nl	pl	pt	fi	no
lack qualified personnel	15	5	13	10	13	11	27	26	11	12	5	31	11	4

Table d: Public funding, external funding and internal funding, % of innovative ICT firms in Europe

	cz	de	gr	es	fr	it	cy	lt	hu	nl	pl	pt	ro	fi	se	no
public funding	22	21	41	32	23	41	41	7	23	49	9	17	8	48	0	56
lack of external finance	:	14	35	31	:	27	27	26	20	17	23	17	27	11	19	16
lack of internal finance	10	18	54	35	34	25	45	42	:	26	29	20	:	18	27	19

Source: Wintjes & Dunnewijk 2008, based on most recent CIS data available in 2008.

Figure a: EU digital agenda scoreboard E-health sub-indicators: medical data exchange, e-prescription

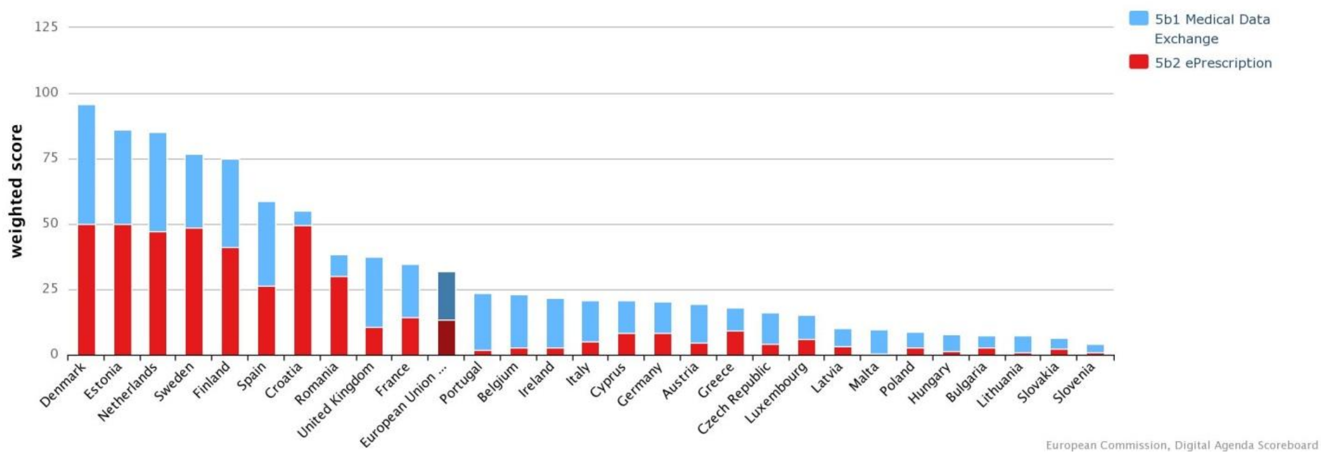
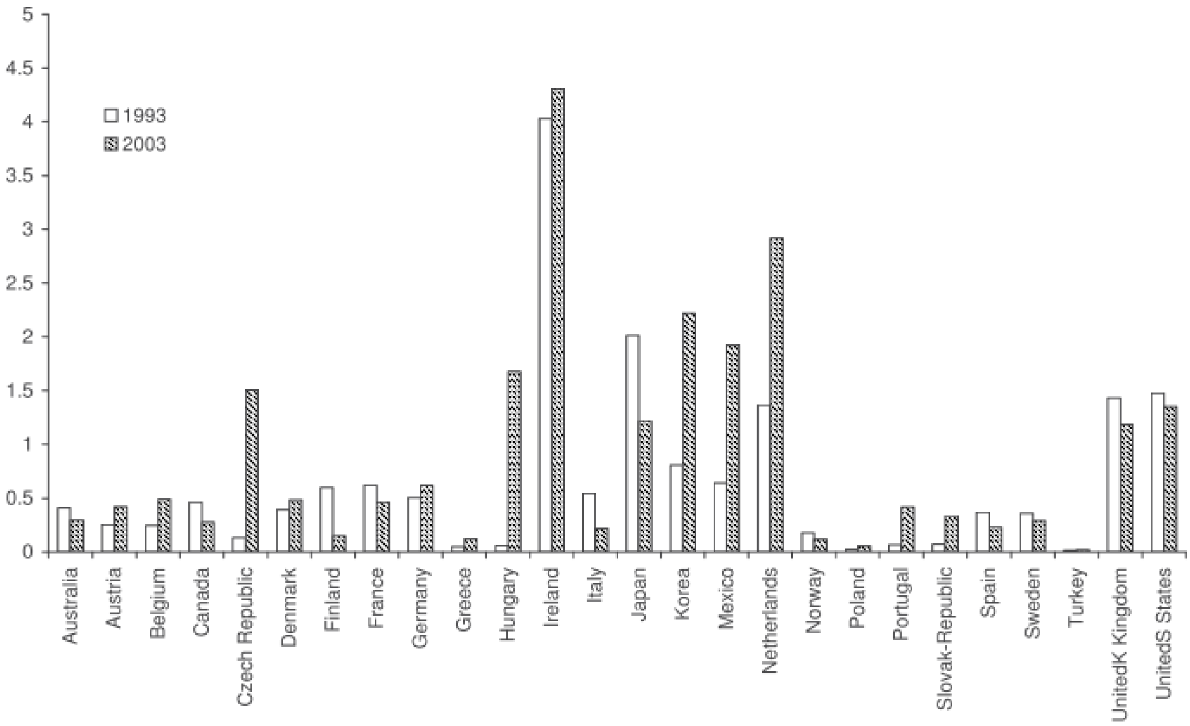


Figure b: Revealed Comparative Advantages in Computer Manufacturing (ISIC 30)



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