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Unveiling the Black-Box of Innovation: A Methodological Tool for the Analysis of Efficiency of Regional Innovation Systems

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Abstract. In this paper we develop a methodological tool for the analysis of the efficiency of innovation systems (IS). This tool, the knowledge/innovation value chain, was earlier used in management to analyse the generation, development and exploitation of ideas from the prospect of individual companies. We apply it to the IS by segmenting its phases/functions; in this way this tool helps unveiling the black box of innovation by spotting bottlenecks and constraints that prevent an efficient and effective flow of knowledge inputs and innovation outputs between different phases and agents of the IS. In this paper we use it through a systematic comparison with representative countries. In general we target a key topic for many scholars and international organisations (EU, OECD) that query about the degree of efficiency of any innovation system on the basis of the recognition that the existence of a plurality of agents does not guarantee such efficiency and effectiveness. These agents may not fulfill their tasks or may duplicate each other's activity, or even compete with one another instead of cooperating and complementing their specialisations in a way that increases the IS innovation output. This topic is analysed through a systematic comparison between the Basque Country and a small group of representative countries. It is researched through an integrated approach to innovation that stresses not only the traditional focus on science and technology drivers, but also the importance of new interactive drivers (e.g. cooperation with clients and suppliers) identified by novel strands of research.

Keywords: innovation/knowledge value chain, innovation system, efficiency, Basque Country.

1. Introduction

Within the recent academic debate the regional/national innovation system is one of the most discussed concepts related to innovation processes (Asheim and Parrilli, 2012; Cooke et al., 2012; Pietrobelli and Rabellotti, 2011; Hollanders et al., 2009; Laranja et al., 2009; Navarro et al., 2009; Crescenzi et al., 2007; Tödtling and Trippl, 2005), In this exploratory paper we introduce a methodological instrument that is used within other research areas (e.g. globalization and the concept of 'global value chain'), and adapt it to knowledge, learning and innovation dynamics in regional contexts. This instrument will help unveil the black-box of innovation to a different extent than it is currently done through a number of other relevant approaches (Hollanders et al., 2009; Laranja, 2009; Navarro et al., 2009; Bitard et al., 2008; Crescenzi et al., 2007; Zabala et al. 2007). From the late 1980s, this concept, which started in terms of 'filiere' or 'subsector' (Boomgard et al., 1986), and later evolved into the global commodity chain (Gereffi and Korzeniewicz, 1994), the global value chain approach (Humphrey and Schmitz, 2004), and the global production network approach (Ernst and Kim, 2002), has been fruitfully used to analyse international exchange dynamics within and across countries, and the effective management of businesses. We transfuse this concept into a different scenario, which is that of knowledge and innovation generation and transfer within regional innovation systems. This effort has been made over the past few years by a few specialists that analysed the management and exploitation of knowledge within companies (Lee and Yang, 2000; Holsapple and Singh, 2001) and systems (Cooke, 2005; Gilsing and Noteboom, 2006; Brossard and Vicente, 2007; Hollanders et al., 2009). We prefer adopting a modified form (the 'innovation value chain' -IVC-), which is analysed by Hansen and Birkinshaw (2007) who have taken a focus on the corporation alone with the objective of managing economic innovations. In our case we target a different core actor (the regional innovation system -RIS-) and a different objective: analysing the flow and transmission of knowledge and innovations within the RIS as a whole.

Former contributions on value chains are important to identify actors that exchange goods and services through the various functional operations that also imply specific power and governance relations; this means identifying crop producers, processors, transporters and intermediaries, industries, distributors and consumers. In our case, the chain is constituted by those actors that produce knowledge (i.e. universities, research centers of excellence), that transform it into applied resources through experimentation activities (e.g. technology centers) and that exploit these applications/innovations through production and commercial uses (e.g. firms). This scheme is far from linear as it implies several feedbacks in accordance with several models of interactive, networked and open innovation flows (Nonaka and Takeuchi, 1995; Chesbrough, 2003; Jensen et al., 2007). In addition, it rarely functions automatically; in this context several institutions (e.g. cluster associations, local development agencies, science and technology parks) may act as catalysts to smooth the connection between the afore-mentioned actors (Porter, 1998; Edquist and Johnson, 2005; Navarro, 2008; Olazaran et al., 2009) by means of promoting specific institutions and systemic routines (e.g. setting standards within the system).

The key research question that motivates our work then is the following: how shall the efficiency and effectiveness of these knowledge and innovation production and distribution chains be assessed and later promoted? It is a key research question (really they are two, one is methodological and the other practical) because the existence of the core actors (e.g. universities, technology centers) does not guarantee the efficiency and effectiveness of the system (Edquist and Johnson, 2005; Laranja, 2009; Olazaran et al., 2009). These actors may simply not fulfill their tasks or may be duplicating each other's activity, competing with one another and subtracting funding to one another rather than cooperating and complementing specialisations in a way that increases the knowledge and innovation output within a specific territory. This is the overall argument drawn from former studies on the regional innovation system in the Basque Country (Navarro, 2008; Olazaran e al., 2009; Aguado and Parrilli, 2010) that is analysed systematically within the empirical part of this paper. This case deserves special attention as it represents the most apparent case of regional innovation systems across the Spanish peninsula (Navarro et al., 2009; Parrilli et al., 2010).

This paper is organised as follows: section two explores the theoretical development and the economic relevance of the proposed methodological instrument: the innovation value chain (IVC). The focus of this paper is presented and discussed in section two: efficiency issues across the IVC and the details of the selected research methodology. Section three provides the empirical evidence based on the most updated EU and regional statistical databases. Concluding remarks are presented in section four.

2. Knowledge and Innovation Value Chain

2.1. Theoretical Contributions

The concept of 'knowledge value chain' (KVC) is not new as it has been used by few academics and experts over the past 10-12 years (Lee and Wang, 2000; Holsapple and Singh, 2001; Cooke, 2005; Cooke et al., 2006; Gilsing and Noteboom, 2006; Brossard and Vicente, 2007). In particular, Lee and Wang (2000) developed this construct, which involves three main sub-concepts: infrastructures, the process of knowledge management, and the interaction among those infrastructures as a means to generate knowledge output (2000: 783). They identified a knowledge management model that establishes different phases in the process of value creation: knowledge acquisition, innovation, protection, integration and dissemination. Within these phases, the core 'knowledge innovation' is produced through the interaction between explicit and tacit knowledge[1] capital and flow in what are the 'socialisation', 'externalisation', 'combination' and 'internalisation' of knowledge (Nonaka and Takeuchi, 1995).

An apparent limitation of this model is its focus on the individual corporation alone rather than on the innovation system as a whole. In fact, the bulk of knowledge infrastructures are much wider and the outcome of the RIS knowledge

1. The distinction between tacit and explicit/codified knowledge refers to the characterization of the first as a bulk of practical and experience-based knowledge gained through observation, imitation, learning-by-doing, by-using and by-interacting, while the second implies the transformation of knowledge into codified and normed standards, codes and formulas that are easily transferable through ICT systems, textbooks and manuals and technical specifications (Polanyi, 1966; Lundvall, 1992; Nonaka and Takeuchi, 1995; Jensen et al., 2007),

management process has a wider span than that of the individual corporation. Among the components of the 'knowledge management infrastructures', Lee and Wang (2000) include the customer/supplier relationship; however they consider it from the company perspective as opposed to the system point of view. The prospect changes when the reference point is the system of production and the knowledge value chain embedded in a territory that has certain constraints and opportunities. This is the typical focus of public policy that targets the growth/ innovation pattern of regional and national territories. Public policy points at a set of territorial interactions that emphasises the role of local production systems and their social embeddedness (Crescenzi et al., 2007; Parrilli, 2009). Simultaneously, beyond the individual and the local context there is the global market and a significant number of global knowledge networks that can be connected and whose knowledge repository can be acquired, assimilated and exploited. Within Lee and Wang's model (2000), the organisation is the principal repository of knowledge. In a wider (international network) framework this knowledge is stored in individuals and in documents, projects files (i.e. codified knowledge), as well as in interactions, observations and routines (i.e. tacit knowledge). These are developed across the network and can be activated at a different extent on the basis of the frequency and intensity of interactions and the (geographical, but also cognitive, social, institutional and cultural) proximity of the relationships among the members of the network (Boschma, 2005). This is why we suggest to take this wider framework for the analysis of innovation processes, the 'Innovation Value Chain' (from the system perspective) since we stress the important final outcome of the process (innovations) rather than the nature of the main input (knowledge). This also relates to our main objective, which is to understand how innovation – taken in the broad sense of product, process, organisation and commercial innovation over the regional territory (see the Community Innovation Survey elaborated on the basis of the Oslo Manual for Innovation, OECD, 2006) – is produced on the basis of specific inputs. We stress the relevance of the efficiency and effectiveness of the territorial value chain in the generation, selection and development of innovations rather than in the simpler generation of knowledge inputs (Holsapple and Singh, 2001: 80-81). The IVC perspective makes it possible to integrate the territorial dimension: the way in which knowledge is transferred and converted in added value may differ from one nation/region to another (Lundvall, 1992; Cooke, 2004; 2005).

Focusing on knowledge management from a system (territorial) perspective, Cooke (2005) and Gilsing and Noteboom (2006) have identified the main learning processes across the KVC: 'exploration', 'examination' (the latter only in Cooke) and 'exploitation' of knowledge. The first refers to a process of mainly radical innovation through basic research and development activities (the analytical knowledge spelled out by Asheim and Coenen, 2005). The second includes an intermediate phase that is based on the fragmentation of knowledge inputs that are fed back to other poles in the network that react to such inputs (e.g.

testing) and help refine and apply the knowledge generation process (e.g. prototypes, technologies and patents). The third phase implies leveraging innovation through successive product developments and adaptation to market demand and market change through IPRs protection and through other means of exploitation such as sale of licenses, brands and trademarks. These processes are relevant for the externalisation and exploitation of knowledge that are useful also for our conceptualisation of the IVC. Cooke (2005) has applied these chain concepts to the bio-scientific knowledge value chain, and observes the changing weight assumed by various actors within this KVC (the big pharma industries lose ground in the 'examination' of knowledge while maintaining their power in the 'exploitation' activity, whereas small biotechnology firms acquire power within 'examination' activities). His purpose is to identify regional (bottom-up) innovation policies and strategies that promote the growth of biotech clusters and of its main actors. Other applications have also taken place, including Cooke et al. (2006), on the role of business incubators within KVCs, and Brossard and Vicente (2007) on the relevance of different types of networks in the three phases of the KVC in the ICT sector.

In the business management literature, the very concept of 'innovation value chain' has been developed (Hansen and Birkinshaw, 2007). In contrast with the general approach of KVC, Hansen and Birkinshaw recognise that companies need to consider their existing processes and address their specific challenges when looking for better ways to innovate. This innovation value chain concept offers a comprehensive and firm-specific framework to address business innovation as a multiple-phase process that involves ideas generation and development as well as the diffusion of the developed models and prototypes (Ibid.: 2007:4). However, these authors prefer stressing the role of ideas as key content within the value chain, rather than their innovative outcome; in addition, and more importantly, they apply the IVC concept only to companies and corporations, avoiding its implications for wider economic contexts such us regions, clusters or industrial districts.

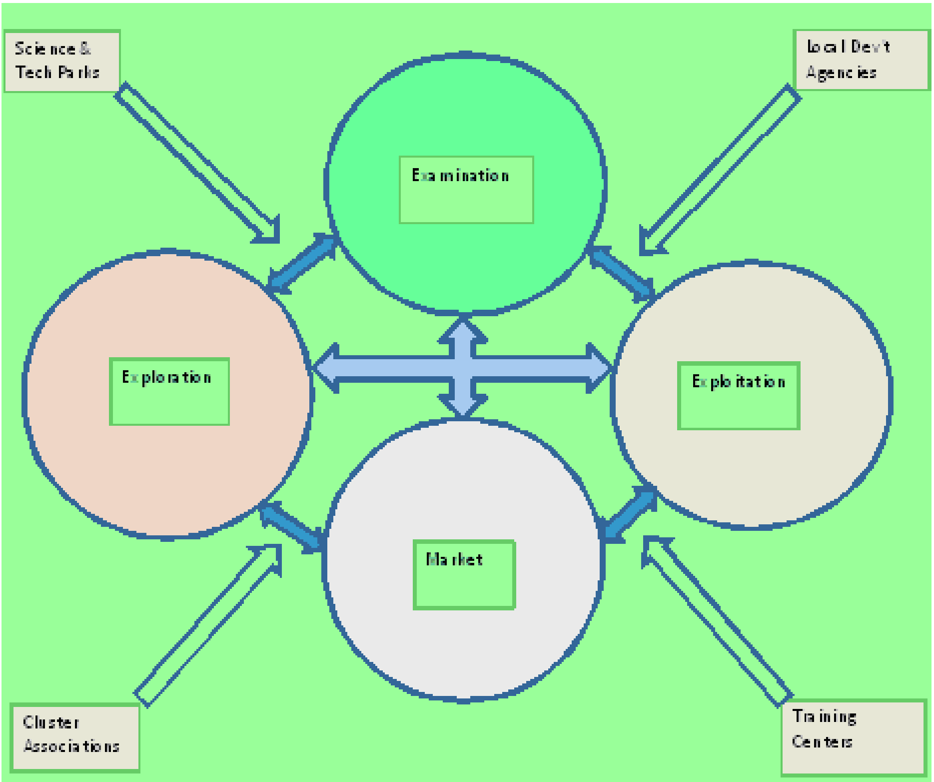
Apart from focusing on the IVC as a means to pull together different activities with the objective to produce innovations (rather than managing knowledge as in most KVC frameworks), this contribution focuses on the need to go beyond the apparently static concept of KVC to study the dynamics, and the sometimes inefficient and ineffective working of the territorial chain. We stress the IVC capacity to coordinate functions and activities, and to finally deliver intermediate outputs that can be further exploited by the local firms that can appropriate such knowledge and applications (innovations) and can transform it into economic output and performance. As a result of the specific characteristics and institutional set ups, the innovation capacities may thus differ from region to region (Cooke, 2004; Edquist and Johnson, 2005).

A key issue about the innovation system and the IVC refers to the type of knowledge flows and in particular to the tacit vs. codified knowledge flows that in recent analyses have been captured through the dichotomist approach to innovation: STI (Science and Technology-based Innovation) vs. DUI (Innovation based on learning-by-Doing, by-Using and by-Interacting; see Jensen et al., 2007; Parrilli and Elola, 2012). It is extremely important to recognise that knowledge is not only codified but also tacit and that this latter flows through informal activities and interactions that go well beyond the work of R&D departments, the capital goods import department and the hiring of scientific human capital (whose impact is measured in standard indicators of patents and scientific publications). In contrast, knowledge also includes work practice, the exchange of ideas and the commitment of all workers and partners along the value chain. This current argument has important methodological implications as it is clear that we cannot rely upon R&D expenditure and patents as the main measures of innovation inputs and output. We have to include qualitative and quantitative 'interactive' and practice-based constructs and information in the assessment process (as we propose in section 3.4). Few of these are currently available in statistical databases (e.g. Community Innovation Surveys); however, this lack is felt by academics who are urging international (OECD, EU) and national/regional organisations (e.g. EUSTAT in the Basque Country) to define and include new quantitative variables and qualitative information in their routine surveys.

2.2. Efficiency Issues across the IVC

Our next objective here is quite exploratory as we aim to identify the universe of actors that contributes to this broad IVC in regions, and to propose a more general framework for the analysis of efficiency in RISs. In this way, we contribute to a hot topic currently debated worldwide (Hollanders et al., 2009, for Europe; Laranja, 2009, for Portugal; Navarro et al., 2009, for Spain; Olazaran et al., 2009, for BC; Zabala et al, 2007). We start with a survey of many relevant actors that include the universities and other research centers that focus on basic research or 'exploration' activities (e.g. in chemistry, physics, biotechnology, nano-materials, etc.). These organisations employ a very high percentage of PhDs, resources and infrastructures devoted to the generation of knowledge and the elaboration of controlled experiments and their publication in specialised journals. In addition, we analyse here the contribution of technology centers, and a number of R&D units of large corporations that absorb the basic knowledge produced within the former phase and tests, prototype and apply it in order to transform inventions into innovations (the 'examination' activities). The wider universe of firms and the market are the final, key actors responsible for the decision about the economic feasibility of the adoption of these innovations in the market (the 'exploitation' phase). Overall, the exploration and examination activities have to pass the market and firms' test. Until that moment, they remain idle and useless in economic terms. This is why we prefer stressing the IVC construct to the former knowledge value chain that has a lower reference to the final economic output of knowledge and innovation activities.

Figure 1: The Innovation Value Chain (IVC)



Source: own elaboration.

We introduce some dynamism within this quite rigid framework (three separate phases). First of all, there may be significant overlapping between these phases and the related organisations. This is the case of universities, research centers of excellence and technology centers that produce scientific publications, or the case of technology centers and service firms investing in R&D to invent new products or processes for their clients or sometimes competing for public funds to support their innovation activities. This may be right if this situation creates a useful competition that promotes innovation, while it becomes inefficient when it promotes waste of resources and energies with reduced innovation and economic outputs. For these reasons, we consider that, in addition to the three different activities and afore-mentioned organisations, a few 'catalysts' (i.e. organisations such as management bodies of science and technology parks, cluster associations, local development agencies, training centers) need to be taken into account and analysed as they can accelerate the knowledge transfer across the chain, enhancing the efficiency and effectiveness of the whole process (figure 1). Thus, we propose an IVC in which these agents represent catalysts of effective interaction for innovation, supporting the flow of knowledge, information and innovations, and promoting the creation of joint actions that would hardly occur on a self-sustained basis. Without such catalysts this flow may be stopped (e.g. as a result of competition among the different actors), interrupting the transmission of knowledge from the actors that create it (i.e. exploration activities) to the ones that use it to produce new applications, goods and services (i.e. examination and exploitation activities). If the flow does not work, the core agents may try to develop the three types of activities altogether, raising duplication and inefficiency to a maximum (and simultaneously limiting their specialization). Instead, the active presence of such catalysts may help create a systemic logic within the RIS and the regional IVC that may help to close market and system failures and maximise coordination across regional innovation agents.

This flowchart (figure 1) shows the main phases in the IVC and their mutual interactions. Interactions are not lineal as there are significant feedbacks from downstream to upstream stages. For example, once exploration has taken place, some of the scientific products will be tested in labs in order to apply principles, methods, and processes that have been identified in that first stage. However, when the lab tests come back rejecting the hypothesis, the agents working specifically in the 'exploration activities' will go back to their hypotheses and formulate new hypotheses, conditions, mechanisms and factors that explain why it did not work and what new conditions and factors may help reach the desired outcome. The same occurs with more advanced phases such as knowledge examination and exploitation. For example, if the 'exploitation' phase shows that a certain process or product is not economically feasible or more simply the market does not accept the new product, this result feeds back the 'examination' and 'exploration' phases that may attempt to apply the basic principle or method to another good or process or to another market segment. This situation shows a circular model structure where different phases and actors collaborate, compete and purchase the output of other agents in a process that may have a number of different intermediate and final outcomes. Within this circular model, the catalysts may intervene to improve the knowledge flow between phases, although this is not a sufficient condition for a positive outcome as these catalysts may be inefficient themselves; a specific analysis should be implemented to identify what drivers help them work effectively for the sake of the system. This implies for example that each IVC is not a self-contained reality; on the contrary, in adopting the language of the 'related-varieties' literature (Asheim et al., 2011), it is fully interacting with other IVCs at the national and international levels exchanging information, knowledge and innovations.

2.3. Methodological Approach

Among our main objectives, this exploratory case study (Yin, 2003) focuses on the development of a methodological tool for the research on innovation processes within regional innovation systems. This is the innovation value chain. In developing the IVC, our second objective then concerns assessing whether this system works efficiently and effectively or not[2]. With these objectives in mind, we first segment the core phases of the IVC and then select a set of input and output indicators for each of the key stages as a means to verify the innovation capacity of the actors involved.

We consulted data from the Community Innovation Survey (CIS) and Statistical Research Survey and Technological Development and Innovation (SRTDI) databases provided by EUSTAT (2011) in 2010 and 2011 respectively. For data related to scientific publications we mainly relied on the ERAWATCH database (2011). The SRTDI is very useful to provide information about the so called STI type of indicators based on science and technology, whereas the CIS database is helpful to obtain information about DUI-type of indicators, which stress the relevance of interactive and practice-based innovation. In this way we guarantee a more thorough assessment of regional economies (such as the Basque Country (BC)) that traditionally focus on incremental innovations based on process upgrading, rather than on intensive R&D activities (Parrilli and Elola, 2012).

In this respect our methodological approach differs from other analyses on innovation agents and systems (Crescenzi et al., 2007; Hollanders et al., 2009; Iammarino, 2005; Laranja, 2009; Navarro et al., 2009; Olazaran et al., 2009; Zabala et al, 2007) for the attempt to introduce variables that respond to a more complete conceptual interpretation of knowledge flows as well as innovation inputs and outputs across the IVC. In particular, we focus on the three main stages/activities of the IVC: exploration, examination and exploitation, and identify a few indicators that may help us assess the flow of inputs and output across each specific phase and along the whole value chain. With regard to Hollanders et al. (2009) 'Regional Innovation Scoreboard', which is also developed with a systematic approach and purpose, our endeavour is of a different nature although complementary as we analyse the specific stages and functions in which the RIS can be disassembled. In this way, we provide additional and complementary information to realise proper stage-by-stage assessments. This effort helps localising the phase (and agents) that suffer specific bottlenecks and/or constraints that render the innovation output lower than expected.

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2. With 'efficiency' we refer here to the capacity of transforming knowledge inputs into a relevant output of knowledge and innovations. With 'effectiveness' we refer here to the capacity of the system to generate an outstanding innovation output, independently on the inputs that are utilized.

Exploration activities are focused on scientific research in universities and research excellence centers. The knowledge they mostly develop and utilise is 'analytic' and centres on the identification of concepts, principles, formulas and methods that represent brand-new knowledge –inventions- (Asheim and Coenen, 2005). STI measures of input in exploration activities include expenditure in public R&D and in human capital, whereas DUI measures include formal and informal interactions with non-scientific agents (e.g. participation to local, national and international projects). The number of scientific publications is a key measure of innovation output for this phase. Examination activities usually take place in technology centers and other applied R&D units that apply 'synthetic knowledge', which combines pre-existing analytical knowledge bases in applicable devices, mechanisms and actions (Asheim and Coenen, 2005). Tests, trials and developing prototypes and applications are among the main activities in this phase. Also in this case STI process inputs (e.g. Business R&D –BERD- and human capital in applied research, joint-ventures in R&D) and DUI innovation inputs (e.g. sharing researchers with universities, collaboration with firms, participation to multi-agents networks) may be considered. The innovation output can be measured in terms of patents, designs, trademarks, prototypes, and sales of IPRs to businesses and in terms of PhD researchers transferred from technology centers to the business sector, among others. The exploitation of innovations refers primarily to the work of companies, whose STI innovation inputs (e.g. BERD and human capital in the development of products) and DUI inputs (e.g. formal and informal collaborations with other firms, learning-by-doing and by-using practices, technical assistance provided by practitioners/consultants) can generate important innovation outputs (e.g. new-to-the-market innovations; new product sales; high-tech exports).

In this way, a specific assessment of efficiency can be initiated; this can be improved through further applications and evaluations that involve additional STI and DUI types of indicators, which may become available with increased efforts by EUSTAT and other European statistical organisations. In the present paper, we suggest a number of 'available' indicators that may help assess the working of each phase, and to identify bottlenecks which need specific solutions. Overall, this methodological instrument offers the possibility to systematically assess in a stage-by-stage form, the overall efficiency and effectiveness of the IVC and its innovation system.

Table 1: Selected Indicators for the Measurement of the Efficiency of the IVC

Type of Variables	Indicators
STI exploration inputs	- Public R&D expenditure R&D (QN); - Personnel in Public R&D (QN);
DUI exploration inputs	- Research projects in cooperation with non-scientific agents (QL)
Exploration outputs	- International Scientific publications (QN);
STI examination inputs	- Private R&D and human capital in technology centres (QN); - International R&D projects (QN)
DUI examination inputs	- Interaction and projects with scientists and with user/firms (QL);
Examination outputs	- Patents (QN); - Designs and Trademarks (QN)
STI exploitation inputs	- Patents (QN); - Private R&D within firms (QN)
DUI exploitation inputs	- Designs and Trademarks (QN); - Cooperation among firms in innovation (QN);
Exploitation outputs	- Innovating firms in product, process, marketing & org. (QN); - New-to-market product sales (QN).

Source: own elaboration. QN: quantitative indicators provided; QL: qualitative information provided.

The selected indicators for the different phases of the IVC are assessed here in comparative terms. We recognise the difficulty to compare different regional/ country innovation systems, which have their own specificities that general analytical frameworks cannot fully represent. However, we present a tool that may assist in the assessment of the stage-by-stage efficiency of the RIS. The Basque Country (BC) is a special region within Spain and Europe. It has been granted the status of fiscally autonomous region, which is combined with a complete autonomy in the definition of industrial and innovation policy. This is framed in the Triennial Innovation Plan (2010-2013) that the Basque Government approves and supports (e.g. with an important funding of the thick network of technology centres and research centres of excellence). For this reason we propose a set of tables that compare the BC with a few national economies which represent useful benchmarks. As it is noted in the case of the BC, Denmark's economy is typically comprised of small and medium enterprises in traditional manufacturing (similarly to the BC). Spain signals the average for the country in which the BC is located, and the EU-27 average delivers a representative measure for comparing BC achievements vis-à-vis other European standards. Of course, the identification of relevant regions in Spain, Denmark and the EU-27 could have been considered more appropriate, but the indicators and data that we collected here are not available for such regions. In contrast, other data, available within the Regional Innovation Scoreboard, would not have provided the same quality of information proposed here. On these comparative bases, we would expect Denmark to represent the top scorer in terms of both inputs and outputs, whereas the BC should perform better (in output and efficiency terms) than the

EU-27, whose overall result is restrained by the lower performance of new accession countries, and Spain, where the BC represents one of the wealthiest and technologically most powerful regional economies. If this does not occur, efficiency problems are the most likely explanation.

The overall efficiency and effectiveness of the system, and of the different phases and agents of the IVC, are realised by matching STI + DUI stage inputs with the specific stage outputs, and then with the related values for Denmark, Spain and the EU-27). When the relation shows a clearly-below-average level in inputs vs. outputs, it will be assessed as a lack of efficiency and effectiveness in the stage which may later transfer its limitations in the efficiency of the following phases and of the IVC as a whole.

The role of the catalysts is only briefly sketched in the final section of this paper and only a general qualitative overview is proposed, because it would require a much deeper work on its own, probably a paper in itself. The objective here is to establish the bases for a more thorough discussion on the key role played by such complementary actors in the IVC (the 'technology gatekeepers' of Giuliani, 2005).

3. Empirical Evidence

3.1. The Innovation Value Chain in the Basque Country (BC)

Based on the Regional Innovation Scoreboards (Hollanders et al., 2009), a general picture of the inputs to innovation and the related performance of the Basque RIS in comparison with the best and worst European performers can be observed in figure 2.

These data do not support the picture of a strong knowledge/learning economy; some aspects are improving and steady (i.e. BERD, and the output of new-to-firm innovations) whereas others are worsening (i.e. product or process innovations). In general, this situation is more likely to depict an average regional economy that faces many challenges in the current era of globalisation.

Former studies on the BC innovation system in comparison with the European average (Navarro et al., 2009; Olazaran et al., 2009; Aguado and Parrilli, 2010) indicated that in comparison to the European average (mostly EU-27), the BC performed quite well in most of the innovation drivers/enablers (e.g. human capital and expenditure in total R&D). On the contrary, results in 'innovation outputs' (both 'intellectual property' and applications) were poorer than the EU-27 average in most fields (especially in new-to-the-firm and new-to-the-market products). This situation creates a sort of 'hourglass' since a good level of innovation inputs result in a low level of innovation output, which later intriguingly transform into a significant economic output (€32,000 per capita income). This situation exemplifies the 'innovation paradox' studied in an inverse version in the much studied case of Sweden (Edquist, 2005). Since current economic output is the cumulative result of a long-term growth based upon traditional manufacturing, and since traditional manufacturing is becoming a more and more competed ground with plenty of emerging countries and companies, future growth perspectives need to be based on new competitive advantages. Within the context of the globalised knowledge economy, these general indications justify the concern of Basque economic agents and policy-makers about the current poor capacity/inefficiency to convert innovation inputs in output, and its possible effects in the medium-term.

Table 2: Innovation Performance of the Basque Country vis-à-vis other EU regions (scale from 0 to 1)

Key Indicators	**2004**	**2006**
Public R&D	0.41	0.41
EPO patents	0.41	0.41
Business R&D expenditure	0.62	0.62
Non-R&D innovation expenditure	0.41	0.42
SMEs innovating in-house	0.56	0.45
Innovative SMEs collaborating with others	0.44	0.47
Product or process innovation	0.63	0.53
Marketing and/or organisational innovators	0.37	0.38
New-to-firm sales	0.59	0.68
New-to-market sales	0.48	0.49

Source: based on Hollanders et al. (2009), European Innovation Scoreboard 2004-2006.Note: values are between 0=min for the worst performer and 1=max for the best. Within this work the indicators in grey are outputs whereas indicators with no colours are enablers.

Total R&D expenditure in the BC is similar to the EU-27 average (1.98% vs. 2.01% in 2009, EUSTAT, 2011), and significantly above the average level of Spain (1.38%). The share of business R&D expenditure is significantly higher than public expenditure (81.1% vs. 18.9% in 2008, EUSTAT, 2012 online), although the first includes not only pure private enterprises, but also technology centers. These are private foundations that receive an important stream of public funds, thus a separation between the two sources of funding is complicated. Simultaneously, in comparison to EU countries, the weight of public research institutions in the BC is quite low (18.9% of public funding vs. 35.7% in Germany and France, and 33.7% in the UK in 2008, EUSTAT, 2012 online), though rising, through the recent creation and support for research centres of excellence (e.g. Nanogune, Biomagune). In other countries the weight of basic research centres (e.g. CNRS in France, Max Planck Institutes in Germany) is critical, which may point towards an ‘institutional gap’ in the BC that may indicate a relative weakness in ‘exploration activities’. In these activities, the Basque university is responsible for most of this activity, with little, though increasing contributions for the recently founded (in the 2000s) network of public research centres of excellence.

Let us now turn to the analysis of each phase in the IVC as a means to identify their respective efficiency and effectiveness and to more systematically confirm or disprove the anticipated ‘hourglass’ hypothesis.

3.2. Exploration Activities

The analysis now involves a more specific discussion of each relevant type of activity within the IVC. With reference to ‘exploration activities’, the importance of public R&D expenditure in scientific research and the number of scientists working in the regional system can be identified as key indicators for inputs. Other DUI input indicators based on formal and informal cooperation in projects among scientists and non-scientists/technology agents, though more difficult to obtain, are added in this exploratory work on a qualitative basis. Scientific publications are analysed as an output indicator displaying the quality of production and of the public and private infrastructures where scientists operate (e.g. universities, research centers). In the BC context, we assume that exploration activities are mainly based on the scientific work realised within universities and public research centres. Table 3 shows that the BC does not have a significant investment in public R&D as proportion of GDP vis-à-vis the aforementioned representative countries. Furthermore, in terms of number and proportion of researchers, the BC shows lower attainments, which are however in line with the most productive Danish case (not in absolute terms, but as a percentage of total research personnel).

Table 3: STI Exploration Inputs and Exploration Outputs (grey area) – 2006/2008

	EU-27	**Denmark**	**Spain**	**Basque Country**
Public expenditure in R&D over GDP (%)	0.75	0.99	0.67	0.47
BC in % of these countries/regions	62.6	47.4	70.1	100
Personnel in Public R&D (in % of total research personnel)	53.0	35.9	64.4	34.7
BC in % of these countries/regions	65.5	96.7	53.9	100
International Scientific Publications (per mln inhabitants)	948	1,738	754	885
BC in % of these countries/regions	93.4	50.9	117.4	100

Source: own elaboration on the basis of EUSTAT. R&D and technology survey, 2011 (online); for public personnel in R&D and publications see ERAWATCH for countries and EUSTAT, 2011 (online), for the Basque Country.

In the BC, the comparatively lower investment of (national+regional) government in universities and public research centres is apparent, although this trend may be changing as the BC has invested significantly in setting up a network of BERC and CIC (the correspondent of Max Planck, CNRSs and CNRs in Germany, France and Italy) over the past ten years. They are in their early stages, thus are likely to produce more significant outputs in the future. Overall, this comparison with leading economies (i.e. Denmark) shows lower investments in exploration activities; this needs to be addressed in case the BC wants to improve its overall scientific performance.

Former information shows an additional problem that resides (or at least resided up to 2005) in the per capita investment in research. In fact, the financial expenditure per (public) researcher was half of the expenditure made in the EU-15 (€55,000 vs. €95,000, see EUSTAT and EUROSTAT, 2009, in Aguado and Parrilli, 2010). This aspect indicates the constraints for an effective scientific research which should also be addressed as a means to improve the performance in exploration activities.

In terms of more qualitative DUI input indicators, the collaboration in research projects with non-scientific agents can also be considered. No statistics are available that represent this factor and only qualitative information can be collected. In this respect, the innovation agents of the Basque Country have established a network called Basque Network of Science, Technology and Innovation Agents (RVCTI), which includes government agencies, universities, technology centres and research centres of excellence, but also firms. It is deemed to promote joint activities and interactions in a way that helps the production system to perform innovation activities effectively. Simultaneously, another public network, called 'Innovanet', has also arisen - promoted by the Basque government in accordance with other agents, such as the local development agencies ('Garapen'), the public society for industrial promotion (SPRI) as well as Chambers of Commerce, in order to promote the existence of a forum which favours joint innovation processes. This 'softer' type of network takes a broad approach to innovation which includes exchanges of information, common training programmes, as well as organisational changes and mutual knowledge exchanges among Basque innovation agents. These networks and forums represent additional DUI inputs for innovation in the exploration phase as well as in the following phases of the IVC.

After the introduction of some STI type of input indicators, we turn now to the analysis of the output produced in this exploration phase by public institutions. The grey area of table 3 shows the productivity of the Basque exploration system vis-à-vis the reference countries. The key indicator of scientific research output is scientific publications per million inhabitants. In this respect, the BC exhibits slightly better indicators than Spain, although lower than the EU-27 average, and significantly lower than Denmark. However, this output indicator looks far better than the two input indicators presented in table 3 (from a 60-70% in inputs in relation to EU-27 and Spain to 90-110% in output). It shows an efficient and effective performance of the human resources that operate within the exploration phase. Of course, if the objective of the BC is to reach outstanding results, the much higher performance of Denmark is to be taken into account. In the Danish case, public R&D is much higher, whereas the research personnel are the same in percentage terms. This might depend more on the volume that is invested in this phase than on the quality of the BC researchers: half of the budget invested in public R&D delivers half of the overall productivity in terms of scientific publications.

3.3. Examination Activities

In the BC the 'examination' activities are performed by technology centres and firms that transform scientific knowledge into applied knowledge, models and prototypes that may be used by firms to create new products and services, or to change their productive systems. As STI input measures we take into account the former output of exploration activities (scientific publications) as well as the private expenditure in R&D as a percentage of total R&D expenditure and also private R&D as a percentage of GDP (Table 4). In qualitative terms we may also consider international R&D projects with foreign innovation agents.

Table 4: STI Examination Inputs and Overall Examination Outputs (grey area) - 2008

	EU-27	Denmark	Spain	BC
BERD on total R&D expenditure	63.9	69.5	54.9	81
BC in % of these reference countries/regions	126.8	116.5	147.5	100
BERD as a % of GDP	1.25	2.02	0.72	1.51
BC in % of these reference countries/regions	120.8	74.8	209.7	100
International Scientific Publications (per mln inhabitants, 2006)	948	1,738	754	885
BC in % of these reference countries/regions	93.4	50.9	117.4	100
Patents per million inhabitants	116.5	194.01	32.6	79
BC Patents in % of the other countries/regions	67.8	40.7	242.3	100
Patents per bln. € PPP worth of GDP	4.00	8.02	1.28	1.14
BC Patents in % of the other countries/regions	28.5	14.2	89.1	100
Designs per bln. € PPC worth of GDP	4.75	7.97	3.37	3.21
BC Design in % of the other countries/regions	67.6	40.3	95.3	100
Trademarks per bln. € PPC worth of GDP	5.41	7.06	6.17	5.49
BC Trademarks in % of the other countries/ regions	101.5	77.8	89.0	100

Source: For the examination inputs, own elaboration on the basis of EUSTAT, 2011; for examination outputs, Erawatch, 2011, Country profile (online). Patents: EUSTAT for the BC.

Table 4 shows that BERD as a percentage of total R&D. In the BC it is much higher than in Spain, the EU-27 and even Denmark. In percentage of the GDP (in PPP terms), the BC has made significant efforts over the past few years and has attained higher results than Spain and the EU-27. Yet Denmark reaches much higher levels, thus it remains a reference for a region that wants to improve its overall innovation attainments and the resulting economic performance. Overall, the BC shows a very good attainment in terms of resources devoted to applied research and development.

It would be relevant to propose also a few DUI examination inputs. One of these is the public-private co-publication per million inhabitants, which is measured by Pro-INNO for the EU-27 countries. It is an indicator that shows the capacity of applied research centres to work together with firms in order to produce outputs that are useful for the latter. However, it is not collected by EUSTAT within the BC, thus cannot be compared with these reference countries[3]. Of course, there are other qualitative indicators of (DUI) examination inputs, such as for example the creation of joint projects between technology centres and firms. EUSTAT does not collect this kind of data. The main indication available in this respect is that a few years ago (2000) the largest part of funding for the activity of technology centres was public, whereas today it is shared in equal parts between public sources (competitive/tenders and non-competitive funding) and private contracts with clients that are large and medium-sized firms as well as local administrations that require specific service or product innovations. In the case of the main group of technology centres, the corporation Tecnalia, 54% of its funding comes from private contracts. In the seventh Framework Programme, Tecnalia joined 78 cooperative projects, of which it leads 11. They also participate in 38 CENIT Spanish projects (Strategic Spanish Consortia for Technical Research) with a total budget of 44 million euros. The group has also installed 13 subsidiaries worldwide as a means to increase collaboration with other international innovation and production agents (Tecnalia, 2011). The second group of technology centres (the alliance IK4 that pulls together 8 previously independent centres) is participating in 58 European projects in very innovative sectors and technologies (ICTs and audiovisuals, energy, health industry, nanomaterials, among others), in 12 of which it is leader of the project (IK4, 2011).

3. Denmark attains much higher levels than the EU-27 average and even higher than Spain (123.2 private-public co-publications per million inhabitants vs. 36.2 in EU-27 and 15.9 in Spain).

Table 5: Technology Centers in the Basque Country

	Tecnalia Corporation (8 technology centres)	**IK4 Alliance (8 technology centres)**
Turnover (mln. €)	128	80
Employees	1,378	1,250
Researchers (%)	15.7*	20
Number of current EU projects	78	58
Leader in EU Projects	11	12
Budget in EU projects (mln. €)	44	22
Clients	3,800	1,500

* It only refers to the number of PhDs in these centres. Sources: Tecnalia and IK4 webpages, 2011.

The impressive development of the network of technology centres in the BC and their insertion in the market does not change their limited contribution to innovation processes in this territory. In spite of such big numbers, it seems that these technology centres work with a reduced number of firms in the territory, whose average size is between 50 and 150 employees. This means that they tend to work with medium-sized firms, whereas tend to neglect small-sized firms (with less than 50 employees), which are the wide majority of businesses in the region. This aspect reduces the impact of these technology centres on the production system in the region.

In terms of examination outputs, Table 4 exhibits a set of relevant results that can be later exploited by firms in the third phase of the IVC. Patents are the classical indicators for examination activities. The information delivered by ERAWATCH and EUSTAT is that Denmark scores much higher than these other representative countries. The BC rates much better than Spain although lower than the EU-27. However, when this indicator is measured in relation to the region's GDP the BC rates far worse, even worse than Spain (this is because the BC has one of the highest GDP per capita of all Spain). With regard to the other two variables, which are more representative of economies based on SMEs and on traditional manufacturing sectors in which innovation takes place incrementally -on the basis of DUI practices-, we do not find particularly good results. In fact, the production of designs per billion of GDP is significantly lower not only than Denmark but also of Spain, and the EU-27. With regard to trademarks it seems to be slightly better than the EU-27, but still lower than Spain and Denmark. Overall, it seems that much remains outstanding in this respect.

This set of indicators may not be exhaustive, but are available on a scale that allows for systematic comparisons with meaningful European countries. In addition, these indicators offer a more comprehensive view of both STI and DUI approaches to innovation (and the related performance). Overall, this section shows the important amount of resources (expenditure, infrastructures, applied research personnel) that are operating in applied examination activities (i.e.

higher than in the other reference countries) vis-à-vis a below-the-average output produced on those bases in the BC. It is quite interesting to observe these regional weaknesses not only in classical STI-type of indicators such as patents, but also in more DUI-related indicators such as community designs (whereas community trademarks seem to be quite positive compared to these other cases). An aspect of 'stage inefficiency' seems to be in place within examination agents (both technology centres and independent R&D units/firms). This aspect should be seriously taken into account in the fine-tuning of policy measures. Let now see whether this inefficiency is transmitted along the IVC to the following phase, the exploitation of innovations.

3.4. Exploitation Activities

Exploitation activities refer to the utilisation in the market of inputs that are produced within the examination phase (e.g. prototypes, processes, tests, designs, patents, brands). This phase effectively transforms practical knowledge (output of the former phase) into innovations, thus justifies the formation of the 'innovation value chain' concept vis-à-vis the 'knowledge value chain' construct. In this section we also identify a few STI and DUI type of indicators and match them with the results that are expected in terms of new-to-market production innovations and sales, and high-tech exports.

First of all, the former output (patents, designs, and trademarks) constitutes inputs for this exploitation phase. Patents are to be taken as STI type of inputs into the process of innovation exploitation. We identified a set of DUI-type of indicators, which helps identifying the interactive relationship pattern of Basque SMEs. In particular, on the basis of the BC Community Innovation Survey (EUSTAT, 2008), Table 6 exhibits the attitude of small and medium firms towards developing cooperation for innovation with distinct kinds of value chain actors (suppliers, clients, service providers, etc.). The results are quite striking, since they are far lower than Denmark's (expected) and the EU-27's (the BC represents 42% and 86% respectively of DK and the EU-27), although significantly higher than Spain's (185%). In general, these data illustrate a traditionally individual approach to innovation whereas the richness of being part of a wider network of expert firms and agents is not taken into account at a significant extent.

These different types of inputs (STI+DUI) need to have a proper, effective and efficient impact in the output of exploitation activities. Following (EUSTAT, 2011), we identify the following results summarised in the grey part of Table 6:

Table 6: STI and DUI Exploitation Inputs (% of the reference countries/regions) and Overall Exploitation Outputs (2008)

	EU-27	Denmark	Spain	BC
BC Patents per mln inhabitant in % of the other countries/regions	67.8	40.7	242.3	100
BC Patents per bln GDP PPP in % of the other countries/regions	28.5	14.2	89.1	100
BC Design in % of the other countries/regions	67.6	40.3	95.3	100
BC Trademarks in % of the other countries/regions	101.5	77.8	89.0	100
BC Innovating SMEs that cooperate on total SMEs in % of other c'trs/regions	86.4	42.5	180.3	100
Innovating SMEs in product or process as % of total SMEs	34.18	37.63	27.50	35.50
BC in % of the other countries/regions	103.9	94,3	129.1	100
Innovating SMEs in marketing or organization as % of total SMEs	39.09	40.02	30.35	27.36
BC in % of the other countries/regions	70.0	68.4	90.1	100
New Product Sales as % of Total Sales	13.26	11.44	15.91	8.08
BC in % of the other countries/regions	60.9	70.6	50.8	100

Source: own elaboration on the basis of EUSTAT, CIS, 2010. Patents: Own elaboration based on ERAWATCH online; EUSTAT for the BC.

In terms of innovating in product and process -as a percentage of total SMEs- table 6 shows that the Basque SMEs are not structurally different from other SMEs across Europe. Where Basque SMEs show significant weakness is in marketing and organisational innovations. This represents quite a traditional pattern for manufacturing SMEs that have not yet learnt how to approach innovation from a broader perspective. In addition, the BC shows a particular weakness in the percentage of sales of new products on total sales (lower than both the EU-27 and Spain). Overall, these statistics exhibit a poor performance of the exploitation agents (the firms). However, the comparison between inputs and outputs in % of the EU-27, Spain and Denmark show that such limited outputs seem to reflect both the weak STI and DUI inputs delivered by agents that operate in previous phases of the IVC.

4. The Gap in the IVC and the Potential for Catalysts: issues for further research

With this paper we propose a novel methodological instrument in the analysis of innovation processes at the system level: the innovation value chain. With respect to known 'knowledge value chain' approaches we propose a framework that more directly points at the importance of the output of knowledge and learning processes: innovations. Instead of taking the company perspective as in most analysis on KVC and IVC, we take a systemic perspective. This helps to analyse the efficiency and effectiveness of the innovation system by means of separating it in different phases of a 'value chain'. This includes generating ideas, transferring and applying these in models and/or prototypes, and then marketing and selling these products and services to the changing market demand. In general, this is a different segmentation of the innovation system, in which we do not represent typical interactions among agents (Lundvall, 1993; Johnson and Lundvall, 1994; Asheim and Parrilli, 2012), but rather the flow of inputs and outputs from some phases and agents to other phases and agents so as to measuring their overall efficiency and effectiveness (without forgetting the number of intangible inputs and outputs that return from more advanced phases to former agents in a series of reversed flow of knowledge and information). Through updated statistics available at EUSTAT and ERAWATCH, we identify a number of key inputs and outputs that help drawing a first approximation of the working of the value chain that benefits from additional inclusion of more comprehensive indicators taken from the Community Innovation Survey (EUSTAT in the BC), in line with an approach that identifies DUI learning processes as a substantial element that overcomes and complements the aspects of science and technology (Jensen et al., 2007). Through this methodological instrument we go beyond the general assessment of regional innovation systems developed in other initiatives (e.g. Regional Innovation Scoreboard), because we identify the efficiency of each specific stage separately. We do this by comparing the BC inputs and outputs with those of comparable countries and regions (EU-27, Denmark and Spain). Of course this effort meets the challenge of comparing different regions and contexts which may respond to different models and idiosyncrasies. However, with this exploratory work we capture the critical aspects (i.e. bottlenecks) of the selected regional innovation system and set the bases to target appropriate actions for improving the specific phase output as well as the global innovation outcome.

Coming to the main empirical results of this analysis, we identified a gap between 'examination' inputs and outputs, which seem to have an important effect on the final output of 'exploitation' activities. Significant resources are devoted to R&D within the 'examination' phase, whereas relatively little is produced in terms of new-to-the-market products sales, among other relevant output indicators.

On these bases, we spot the main 'IVC' gap in the 'examination' phase and in its connection with the two other phases. In fact, it seems that the productivity (input/output) of the 'exploration' phase is not so poor given the low inputs received in this phase (Table 3). The analysis of this phase underlines the poor resource endowment (i.e. number of researchers and R&D expenditure per researcher), which does not favor a proper working of scientists (i.e. low infrastructure endowment). The 'examination' phase seems not to be lacking much in terms of inputs, but more in terms of output as the generation of patents and designs does not look appropriate. Finally, the 'exploitation' phase seems to accumulate and pay the relative failure of the previous phase as the firms do receive mixed inputs from upstream phases. In addition, the firms tend to use any DUI inputs at a low extent; as a consequence they perform rather poorly in terms of recognised indicators such as sales of new-to-the-market products, among others.

In leading international experiences (e.g. Germany), basic research is ensured by universities and specific research centers (e.g. Max Planck), whereas applied research is developed by other institutions (e.g. Fraunhofer institutes). The latter act as catalysts between the former organisations and local firms. These firms benefit from the abundant R&D applications developed by the Fraunhofer Institutes as well as from the input of a significant number of PhDs who are valuable to translate the invention into useful applications. In this case, firms have simply to identify the most interesting products, processes and applications and pay licenses to the former organisations. The sizable and dense network of technology centres and independent R&D units operating in the BC could adopt some of the mechanisms that the Fraunhofer institutes utilise (e.g. number of PhDs that pass from Fraunhofer to firms every year, chair in the university for the director of the local/sectoral Fraunhofer institute as a means to stimulate relations between universities and applied research and development activities).

In addition, some sort of catalyst agents may be needed in the BC (as well as in other similar contexts worldwide) to promote interactive relations between phases and between the core agents that operate in specific phases and activities, but that may work in a rather individual/isolated way. This aspect points at the potential role that cluster associations, business associations, management bodies within S&T parks, and technical schools may play in the regional innovation system. These organisations might work, on the one hand, to produce higher capabilities (e.g. human capital) to be exploited by the core agents, and on the other, to favour coordination between agents by means of identifying and promoting collective projects (e.g. European applications, 'territorial pacts', etc.). Specific analyses of the role played by such actors, their effectiveness and acknowledgement by the core agents of the IVC would be useful to measure what is currently accomplished and what can be done to promote a more efficient and effective IVC. All these (e.g. mechanisms to promote the RIS efficieny, the role of catalysts, finer efficiency measurements), represent relevant topics for future research on the efficiency of regional innovation systems.

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