



STI and DUI innovation modes: Scientific-technological and context-specific nuances

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ABSTRACT

In this paper, we join the debate on business innovation modes that originates from the wider literature on innovation systems. These specific contributions identify and study the impact of different innovation modes, particularly the mode focused on scientific and technologically-based innovation (STI) vs. the mode based on learning-by-doing, by-using, and by-interacting (DUI). Echoing the seminal contribution by Jensen et al. (2007) and a range of other studies, we confirm the importance of the combined STI&DUI interaction mode, which has a stronger impact on innovation output (technological and non-technological) than the two separate individual modes. Additionally, we propose a novel hypothesis on the effectiveness of firm's interaction modes. We argue that the independent STI mode has a stronger effect on technological innovation, whereas the independent DUI mode has a stronger impact on non-technological innovation. In addition, in line with works on the geography of innovation, and innovation systems, we try to determine the impact of regional vs. global DUI and STI interactions on technological and non-technological innovations. In this case, we expect that in diverse geographic locations, businesses tend to adopt their own context-specific interaction modes, which produce a differentiated impact on innovation output. This study is applied to a large sample of firms in the context of the Basque Autonomous Community in Spain.

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1. Introduction

In this paper, we join the debate on business innovation modes (i.e., approaches to produce effective innovation outputs) that is derived from the wider literature on innovation systems (Lundvall, 1992, 2007; Jensen et al., 2007). These contributions identify and study the impact of different innovation modes, particularly the mode focused on scientific and technology-based innovation (STI) vs. the mode based on learning-by-doing, by-using, and by-interacting (DUI). Echoing the seminal contribution by Jensen et al. (2007) and a range of other studies (Isaksen and Karlsen, 2010; Aslesen et al., 2011; Chen et al., 2011; Parrilli and Elola, 2012; Fitjar and Rodriguez-Pose, 2013; Nunes et al., 2013), we analyse in particular whether the combined STI&DUI interaction mode has a stronger impact on innovation output than the two separate individual modes. Following this classification, this study proposes a novel hypothesis on the effectiveness of business innovation modes. We argue that the STI interaction mode alone has a

stronger effect on technological innovation (i.e. product and process), whereas the DUI mode tends to have a stronger impact on non-technological innovation (i.e. commercial and organisational).

In line with the work of Fitjar and Rodriguez-Pose (2013) on the geography of innovation, we also attempt to determine the context-specificity of these business interactions and innovation modes and their impact on the range of innovation outcomes. Through this analysis, we assess the impact of the proposed technology-based divide in synergy with the potential effect of cultural, institutional and social idiosyncrasies on the geographical reach (global vs. local) of STI and DUI interaction modes. The latter is justified by the literature on innovation systems and the so-called “innovation paradox” from which the debate on STI and DUI modes originates (see next section). This study is applied to a large sample of firms in the context of the Basque Autonomous Community in Spain, a small region that borders France. Basques’ cultural and production distinctiveness might lead local economic agents to develop a dense set of thick and significant local interactions. This feature might generate a context-specific approach to innovation in which the regional linkages are weighted and developed more than global linkages.

The remainder of this paper is organised as follows. Section 2 provides a theoretical discussion of the relevance of innovation

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modes for business innovation. In Section 3, we discuss the methodology applied in this study. In Sections 4 and 5, we present the empirical evidence related to both the impact of innovation modes on different types of innovation and the effect of different geographical scales on innovation. Finally, Section 6 provides some concluding remarks and identifies further steps for research.

2. Theoretical rationale and debate

2.1. Innovation modes and types of innovation

This work on business innovation modes is directly derived from a strand of literature on the economics of innovation. The extensive literature on the economics of innovation takes an aggregated and/or systemic view of business and territorial innovation dynamics. In addition to the relevant macroeconomic strand on new growth theories (Romer, 1994; Aghion et al., 1998; Greunz, 2005), the study of sector/industry classifications and transformations (Pavitt, 1984; Dosi et al., 1990; Perez, 2009), and research on technological learning and formation of technological capabilities (Dosi, 1988; Lall, 1998; Bell, 2006), there is the meaningful development of a literature on the formation of different types of innovation systems (Lundvall, 1992; Nelson, 1993; Cooke and Morgan, 1994; Malerba, 2002). The topic discussed in this paper derives precisely from this latter strand of crucial literature on the economics of innovation (i.e. innovation systems). In particular, the selected topic refers to the type of knowledge bases and innovation approach developed by businesses in countries and regions, including territories that generate significant innovation and economic performance based on relatively small investments in science and technology (Lundvall, 1992, 2007; Archibugi and Lundvall, 2001).

This discussion helps to explain the so-called “innovation paradox” (Edquist, 2005; Asheim and Gertler, 2005). The situation of countries that are capable of generating comparatively higher innovation and economic output than others based on a given amount of inputs (e.g. R&D expenditure) represents a “positive innovation paradox” that at least partially explains the success achieved by Denmark and Norway over the past few decades. The inability to generate such output based on comparatively higher inputs represents a “negative innovation paradox” that at least partially describes the case of Sweden for many years (Asheim and Parrilli, 2012). Many countries and regions might find themselves in similar situations, thus justifying the importance of such a debate. For example, a positive paradox might be found in the context of Italian industrial districts and the Basque Country from the 1980s until the 2000s (Asheim and Parrilli, 2012). This discussion frames the behaviour of firms within country or regional perspectives – and their cultural idiosyncrasies – that should be considered when analysing the business contribution to the innovation output of their regional and/or national economies.

On these bases, Jensen et al. (2007) explicitly identified the science and technology-based innovation mode (STI) that develops a relevant output based on high R&D expenditures, including investments in highly skilled scientific human resources and advanced technologies and infrastructures. The STI innovation mode supports interactions with centres producing new knowledge – mainly research centres and universities, scientific brokers and foundations for the diffusion of scientific research – which generate the codified and explicit knowledge that can be used by the firm to produce innovations (Fitjar and Rodriguez-Pose, 2013). This approach tends to generate analytical knowledge (i.e. scientific principles, discoveries, and formulas) and, to a lesser extent, synthetic knowledge bases (i.e. recombination of different analytical knowledge bases with a practical, engineering-based purpose; see Asheim and

Coenen, 2006). This knowledge output is typically associated with high-technology industries and firms that operate in pharmaceuticals, biotechnology, and nanomaterials, among others.

In contrast, the second approach stresses the importance of practice and interaction-based innovation that relies on learning-by-doing, by-using, and by-interacting (DUI). Innovation in the firm is mostly generated by the capacity of the firm to develop informal and formal exchanges internal to the firm, but also interactions with suppliers, customers and competitors (Fitjar and Rodriguez-Pose, 2013). These practices typically generate a type of synthetic knowledge base that is exploited in a large number of engineering-based industries, such as machine tools, shipbuilding, automotive, and energy, among others. Therefore, different types of interactions are at the base of the STI and DUI modes of innovation.

Overall, (firms in) Sweden, Finland, Japan, and the US, among others, tend to focus on the STI mode, whereas Denmark, Norway, Italy, and Spain traditionally tend to follow the DUI route to innovation. Of course, these features are never definitive; they can change over time, as indicated by the Swedish case and the Basque case (Zabala and Edquist, 2012; Asheim and Parrilli, 2012; Parrilli and Elola, 2012). Nevertheless, it is crucial to recognise such country/region idiosyncrasies, as this analytical operation may help to determine whether any of these innovation modes is more successful than others in specific geographical and cultural contexts and whether it is appropriate to identify and take specific routes to improve the business innovation pattern developed in a selected territory in a specific moment in time.

This debate has recently led to another hypothesis. Given the success of the afore-mentioned national economies (most of which are among the first 10 in the UN development index, UNDP, 2013) and the logical and differentiated strengths of these two innovation modes, some leading scholars anticipated that these “primordial” modes are not mutually exclusive. They proposed that these modes might complement each other in the production of higher outcomes in terms of both innovation and economic performance (Jensen et al., 2007; Isaksen and Karlsen, 2010; Aslesen et al., 2011). This approach has been successfully tested in the context of Denmark (2007), and Norway (Aslesen et al., 2011; Isaksen and Karlsen, 2010). With more nuanced results, it has also been tested in Portugal (Nunes et al., 2013), Belarus (Apanasovich, 2014), and China (Chen et al., 2011).

Despite the rationality of such an approach, other studies have been performed that have delivered contradictory outcomes. For example, the study of Parrilli and Elola (2012) in the Basque Country and Malaver and Vargas (2013) in Colombia indicate that currently the STI mode is more relevant than the DUI mode and that the combination of the two does not add any particular benefit vis-à-vis the adoption of the STI mode alone. This finding is partially explained by certain features which are required to combine the two approaches effectively, for example the existence of a well-educated workforce that is capable of interacting effectively with scientists and engineers.

A further theoretical issue raised in this debate refers to the concept of innovation output. Research on business innovation modes mainly focused on the technological or R&D-based type of innovation, which implies product and technical process innovation (Jensen et al., 2007; Chen et al., 2011; Parrilli and Elola, 2012; Fitjar and Rodriguez-Pose, 2013). However, this type of analysis has been criticised, suggesting that the ability to produce innovations is more likely to be based on firm-specific routines and firm-individual heuristics (e.g. routines, capabilities, skills and experiences of firms) instead of single, homogenous R&D-based innovation strategies (Som et al., 2012). Following this literature strand, the latest edition of the Oslo Manual of the European Commission and the OECD, which presents the methodological basis for innovation studies such as the European Community Innovation Survey (CIS),

follows an enlarged definition of innovation. It considers that, besides new products, services or production methods, markets or new sources of supply and new types of organisation structures can be interpreted as innovations if they help to increase competitiveness and economic performance. According to this view, innovations can be classified as ‘technological’ when they refer to new products or manufacturing processes, and ‘non-technological’ when they refer to marketing and organisational innovations. This technical classification is important for our discussion, as non-technological innovation forms are more likely to require a lower level of scientific and technological focus and expenditure. These ‘softer’ innovation forms are likely to rely on different types of human capital, such as skilled production or human resource managers, marketing experts, and well-connected distributors, among others. Following the initial definition of Jensen et al. (2007:13), these innovations are more likely to rely on the DUI mode.

If this is true, we might expect a different impact from the two types of innovation modes on innovation output depending on whether we consider product and process vis-à-vis organisational and commercial outcomes. This might also help in explaining the aforementioned ‘innovation paradox’, as those countries that do not invest significantly in R&D might be investing more in activities oriented to the generation of non-technological innovation. Beyond the hypothesis that the combined STI&DUI interaction mode is likely to have the highest impact on all types of innovation output, two additional hypotheses are proposed regarding the two individual innovation modes. In technological innovation, we expect the STI interaction mode to have a stronger impact, whereas for non-technological innovation, we expect the DUI mode to produce a more relevant effect. The empirical test of such hypotheses provides new knowledge within this debate.

Hypothesis 1. The combined STI + DUI mode of interaction is likely to generate the greatest impact on all types of innovation output vis-à-vis the individual interaction modes.

Hypothesis 2. The STI mode of interaction is likely to have greater impact (than the DUI mode) on technological innovation (product and process).

Hypothesis 3. The DUI mode of interaction is likely to have greater impact (than the STI mode) on non-technological innovation (commercial and organisational).

2.2. The context-specificity of innovation modes

Some scholars have applied this debate to the geographical localisation of the innovation agents with which businesses interact and collaborate. Fitjar and Rodríguez-Pose (2013) have analysed whether these different innovation modes, taken separately, generate distinct innovation capacities and outcomes.¹ In particular, they focus on the dichotomy between regional and global relationships within the supply chain (i.e. with clients and suppliers) and outside the supply chain (i.e., competitors) – both DUI – and compare these relationships with the STI type of relations developed on the regional and global scales. Their results indicate that the DUI linkages diverge sharply across regional and global distances, whereas the STI linkages matter in a similar positive way. The local

DUI linkages matter only slightly, whereas the global DUI linkages are the most important. The latter are even more important than both types of STI linkages. It is an interesting and challenging result that modifies previous approaches and assessments of the critical agents for innovation. Consistent with previous theoretical contributions (Gertler, 2003; Bathelt et al., 2004; Parrilli, 2012), this research demonstrates the importance of tacit knowledge sources aside from the well-known criticality of global codified knowledge sources.

Local and global types of interaction exhibit advantages and limitations. The decision about which linkages are most important is not a straightforward issue but instead a topic that should be analysed and tested empirically in several geographical contexts. Both types of collaboration present relevant advantages, although differentiated. Local partnerships favour exchanges of tacit knowledge,² in addition to helping to reduce lead/delivery times and transaction costs due to physical, cultural/social, and institutional proximity (Malmberg and Maskell, 2002). Other external economies are measured in terms of information flows and the presence of skilled human resources, especially in the context of clusters of specialised firms (Schmitz, 1995). However, physical proximity and local/regional partners might favour knowledge lock-ins, which also restrict the learning capacity of local businesses (Boschma, 2005; Fitjar and Rodríguez-Pose, 2013; Alcalde, 2014). Collaboration with foreign partners may particularly favour access to distant codified knowledge (Bathelt et al., 2004) and promote flexible work models as long as firms are able to gain access to diverse external knowledge pools, new culture, and new markets (Chung and Kim, 2003), which in turn increase the likelihood of innovating and accessing new global markets (Venkataraman, 1997; Amara and Landry, 2005). Simultaneously, such relationships are likely to lead to an increase in transaction costs as well as to stronger management control as a means to avoid critical knowledge spillovers that benefit external firms and competitors (Laursen and Salter, 2006). These synthetic arguments lead us to query about the impact of regional vs. global collaboration for effective innovation processes. This impact is tested in the present work, with a particular emphasis on a wide range of innovation outputs (both technological and non-technological) as well as to the novelty of such outcomes (i.e. radical innovation).

Additional issues may be considered aside from these crucial considerations of innovation modes over geographical distances. The results generated by the Norwegian study (Fitjar and Rodríguez-Pose, 2013) may also depend on some context-specific idiosyncrasies. Together with former cultural and/or institutional interpretations of innovations system’s paradoxes (Edquist, 2005; Asheim and Gertler, 2005), this work leads to a further complementary hypothesis that we discuss here. Some countries and regions might find themselves localised in quite integrated international geographical contexts in terms of cultural and social linkages, and institutional and cognitive frameworks. This might facilitate collaborations and synergies between production and innovation agents across (global) distance. Other countries and regions might be localised in less integrated contexts, which lead to higher cognitive, institutional, social, and cultural distances that lead the way to more difficult exchanges and cooperation across borders. This may lead to a different weight and reliance on regional vs. global relations, which become context-specific. The first situation might

¹ We also attempted to combine STI and DUI collaborations on a geographical scale, but this analysis was generating an excessive number of combinations (three types of innovation mode with two types of collaborations with two types of geographical scale: 12 different combinations). For simplicity, we preferred to consider only six combinations, including the three types of collaborations multiplied by the two types of geographical scale.

² The reality can be more nuanced. Local collaborations can also bring in codified knowledge flows, whilst global interactions can convey tacit knowledge inputs. However, in general it is not unreasonable to think that tacit knowledge needs physical proximity (Malmberg and Maskell, 2002), thus occurs typically in exchanges across local agents, whereas codified knowledge needs less physical proximity, thus can be transferred very often at a distance, e.g. through intense use of ICT systems.

be the case of Norway, which is highly integrated with other Scandinavian countries, such as Denmark, Sweden, and Finland. In this case, the cultural/social, institutional, and cognitive proximity, in addition to excellent infrastructural assets and synergies, ease the development of effective global DUI and STI linkages (as it seems to emerge from Fitjar and Rodriguez-Pose study in Norway). In other geographical contexts, where cognitive, social and institutional proximities and synergies with other countries and regions are less automatic, the global (DUI and STI) exchanges might become less effective, whereas more effective innovation relationships might be activated through regional interactions. This situation may occur in regions and countries that find themselves more inward-oriented for cultural and historic reasons, as in the case of the Basque Country, among others.

Hypothesis 4. In more bounded, context-specific geographical location, i.e. the Basque Country, businesses adopt stronger local patterns of interaction for innovation, which are likely to have an impact on innovation outputs.

This dichotomist behaviour across different countries and regions might be less neat in practice, since different behaviours are at work simultaneously in any specific context. In addition, this hypothesis does not imply restricting oneself to the current regime (e.g. effective regional exchanges) is the optimal solution. In the long run, it might be critical to modify the traditional form of developing collaborations as a means to create new innovation capabilities. However, these context-specificities might explain why a selected regional or national production system is currently more oriented towards effective innovation processes at the regional level vis-à-vis the global. We test this hypothesis in this empirical work.

3. Methodology

3.1. Sample and data

The source of the empirical analysis is the Community Innovation Survey (CIS). This is a firm-level panel of data compiled by EUSTAT (Basque Institute of Statistics) from 2006 to 2011 and sampled to be representative at the regional level (Eurostat, 2006). The data are generated by a self-administered survey questionnaire based on the homogenised and thoroughly tested European CIS. CIS data are used for generating official innovation statistics of the EU and its member countries that have been used extensively for analysis in economics (Cassiman and Veugelers, 2002; Cefis and Marsili, 2006; Czarnitzki, 2005; Hollanders et al., 2009), in management studies (Laursen and Salter, 2006; Frenz and Ietto-Gillies, 2009; Schmiedeberg, 2008), and in economic geography (Simmie, 2004; Ebersberger et al., 2011). Participation in the Basque Country Innovation Survey (BIS) is compulsory for sampled firms, and non-respondents are fined. This results in a comparatively large dataset that is not plagued by a non-response bias. The data refer to activities conducted during the six-year reference period from 2006 to 2011. The panel contains 3165 firms that incurred in R&D expenditures. We include innovating and non-innovating businesses to avoid biased results (Tether, 2002; Cassiman and Veugelers, 2002).

3.2. Measures

3.2.1. Dependent variables

According to other critical studies (Christensen, 1993; OECD, 2006), this study presents a categorisation of innovation performance according to the mission of the final outcome. To test the hypotheses that different modes of innovation result in different types of innovation, we rely on the latest (3rd) edition of the Oslo

Manual to distinguish between two different types of innovations according to its technological dimension:

- *Technological innovation.* Technological innovation indicates whether the firm has introduced product innovation (good or service that is new or significantly improved with respect to its characteristics or intended uses) or process innovation (which involves the implementation of a new or significantly improved production or delivery method, new techniques, equipment, and/or software).
- *Non-technological innovation.* Non-technological innovation refers to firms which developed commercial innovations (i.e. implementation of a new marketing method involving significant changes in product design or packaging, product placement, product promotion, or pricing) or organisational innovation (i.e. implementation of a new organisational method in a firm's business practices).

Thus, we considered two dichotomous variables to gauge each innovation outcome during the period of reference. In addition, we wanted to measure the effect of the innovation modes on the “radicality” of innovation.³ In this manner, we may have some additional indications regarding the business capacity to introduce effective novelties in the product market (Christensen, 1993).

- Radical innovations refer to new or significantly improved products (goods or services) introduced in each year, which represent a novelty not only for the company but also for the market in which the firm operates.

3.2.2. Independent variables

The BIS is limited in terms of the internal innovation features (e.g. use of teamwork, bottom-up communications, R&D departments), but collects information on the types of collaboration that we might associate with the STI or DUI innovation mode. As posited before, different types of interactions are at the base of the STI and DUI modes of innovation. Thus STI and DUI-modes of innovation are linked to different forms of interaction both within the firm and with its external environment (Jensen et al., 2007; Chen et al., 2011; Fitjar and Rodriguez-Pose, 2013). For the characteristics of our database, we rely on the latter type of information (i.e. types of collaboration) to address our concern about the utilisation and effectiveness of different business innovation modes. The BIS allows us to control for different collaborator profiles according to their nature. The independent variables are built around three different types of partnerships: the “STI.Exclusive” mode of cooperation (the firm only collaborates with science-based partners: universities, research centres, and scientific laboratories), the “DUI.Exclusive” mode of cooperation (the firm only collaborates with clients, competitors, and suppliers), and the STI&DUI mode of cooperation (including both types of cooperation simultaneously).⁴ These variables take the value of 1 if the firm has collaborated with this type of partner within each period and 0 otherwise. These mutually exclusive variables avoid potential problems of multicollinearity and capture the impact of each partner more clearly by separating it from the effects attributable to other partner types in heterogeneous networks (Nieto and Santamaría, 2007; Alcalde and Guerrero, 2014). Regarding the fourth hypothesis, we distinguish

³ Due to data limitations, radical innovation captures product innovation novelties. The Basque BIS does not measure any other type of radical innovation.

⁴ Other possible partners are excluded as their nature is mixed and does not help in clearly separating the different impacts of STI and DUI innovation/collaboration modes (e.g. consultants, public institutes).

Table 1
Descriptive statistics: innovation modes and outputs in 2006–2011.

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Inno.tech	18,990	0.32	0.47	0.00	1.00
Inno. Non-tech	18,990	0.27	0.44	0.00	1.00
Inno. Radical	18,990	0.10	0.30	0.00	1.00
STI.Exclusive	18,990	0.03	0.17	0.00	1.00
DUI.Exclusive	18,990	0.01	0.11	0.00	1.00
STI&DUI	18,990	0.06	0.23	0.00	1.00
DUI Regional	18,990	0.06	0.24	0.00	1.00
DUI Global	18,990	0.05	0.23	0.00	1.00
STI Regional	18,990	0.07	0.27	0.00	1.00
STI Global	18,990	0.04	0.22	0.00	1.00
R&D expen.	18,990	0.30	15.28	0.00	1920.00
Size	18,990	2.91	1.59	0.00	8.26
International market	18,990	0.25	0.43	0.00	1.00
Group Nationality	18,990	0.40	0.67	0.00	2.00

Source: Own elaboration on the basis of Eustat (BIS, 2011).

between regional and global⁵ cooperation across the following categories: the STI mode of cooperation (includes interactions with universities, research centres, and scientific laboratories), the DUI mode of cooperation (related to interactions with clients, suppliers, and competitors). Therefore, we added 4 independent dummy variables in the analysis. These variables take the value of 1 if the firm has collaborated with this type of partner within each period and 0 otherwise.

To test the effect of cooperation variables on innovation, we use lagged variables (2 periods) to allow for the delay between the start of the collaboration and obtaining effective innovations.

3.2.3. Control variables

As it is typical in firm-level analyses, the model controls for a set of factors that are likely to relate both to innovation and the use of partners. These include firm "SIZE" (measured as the logarithm of net sales), "INTERNATIONAL MARKET" (which controls for the firms' capacity to operate in international markets and to absorb new sources of knowledge as a means to become more innovative; see Filippetti et al., 2011), and a categorical variable ("GROUP NATIONALITY") coded 0 if it is a single-unit firm, coded 1 if an enterprise is part of a national business group, and coded 2 if an enterprise is part of a multinational business group. The last variables ("INTERNATIONAL MARKET" and "GROUP NATIONALITY") control for the "global" dimension of these firms. More specifically we control for the capacity to identify and absorb external knowledge according to the connection with international markets and foreign production based on belonging to a foreign-owned company.

We include a measure of R&D intensity (RDEXPEN), measured as firm R&D expenditure divided by firm sales, used as a proxy for a firm's technology base derived from current and past R&D activities (Ahuja and Katila, 2001; Laursen and Salter, 2006). This variable captures the notion of absorptive capacity (Cohen and Levinthal, 1990) in so far as firms that conduct their own R&D are better able to use externally available resources. Finally, we also include controls for the firm sector (a set of dummy variables referring to two-digit NACE codes) and six-year variables (from 2006 to 2011). Tables 1 and 2 report the descriptive statistics for the whole period 2006–2011.

⁵ Based on the available database, we differentiate between 'regional' collaborations and 'global' collaborations, where the second include both collaborations with other regions in Spain and abroad. This is consistent with our hypothesis that in the Basque case there is a higher emphasis on regional collaborations, whereas the other geographical collaborations represent a different option that can be pulled together as a distinct approach to innovation collaborations.

4. The impact of STI and DUI interaction modes on the types of innovation

4.1. Descriptive statistics

Tables 1 and 2 refer to the whole sample over a period of six years. These general statistics show that "technological innovations" tend to happen more often than any other types of innovation (32%). Radical innovations, which are part of the former, only represent 10%, while "non-technological innovations" are produced by around 27% of the sampled firms. Firms that combine STI&DUI type of interactions are the most common firms (6%) except those which do not (appear to) adopt any type of (formal) collaboration.

Table 3 shows the most typical business innovation patterns in 2011. The first indication is about the type of innovation performed by businesses. As in the more general statistics (Table 1, 2006–2011), also in this case most firms produce technological types of innovation (31.8%), of which radical innovations represent again around 10%. Non-technological innovations are produced by 25.2% of the firms. A wide number of firms seem not to produce any type of innovation (43% or more). In terms of the interaction modes adopted by firms, the STI&DUI is the most relevant mode for all types of innovation (23.7% for technological innovation, with 34.3% for radical innovation, and 24.9% for non-technological innovation). STI.EXCLUSIVO and DUI.EXCLUSIVO achieve significantly lower levels with DUI.EXCLUSIVO ranking quite higher than STI.EXCLUSIVO. In all these cases, it is visible a larger number of firms that do not adopt any of the afore-mentioned types of interaction. This is because they tend to focus on less interactive modes of innovation, while stressing their internal capacities such as R&D departments, scientific human capital or more experience-based features (e.g. teamwork, bottom-up and top-down communications, job rotation, etc.).

This descriptive analysis is useful to understand what kind of interaction modes firms tend to use. However, these data do not give us any strictly significant correlation between these modes and the final innovation output. For this we need to run a proper econometric analysis, which is presented in the following sub-section. Thus, in connection with our first general hypothesis, we tested the effective impact of these innovation modes on innovation performance, with special reference to our first, second, and third hypotheses. This evidence helps to discriminate between those collaboration modes that have a more significant impact and those that have a negligible or uncertain impact.

4.2. Econometric results

We used a logit model because the dependent variables are dichotomous categorical variables, which express the ability of the firm to achieve different types of innovation. According to database properties we adapt logit model to panel characteristics following this assumptions:

$$Pr(y_{it} \neq 0 | x_{it}) = P(x_{it}\beta + v_i)$$

for $i = 1, \dots, n$ panels, where $t = 1, \dots, n_i$, v_i are i.i.d., $N(0, \sigma_v^2)$, and $P(z) = \{1 + \exp(-z)\}^{-1}$.

Underlying this model is the variance components model

$$y_{it} \neq 0 \Leftrightarrow x_{it}\beta + v_i + \varepsilon_{it} > 0$$

where ε_{it} are i.i.d. logistic distributed with mean zero and variance $\sigma_\varepsilon^2 = \pi^2/3$, independently of v_i .

Specifically, we fit logistic regression models for each type of innovation outcome (e.g. technological, non-technological) and the degree of novelty (radical). Table 4 presents the results of this analysis.

Table 2
Correlation matrix.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Inno.tech	1.00													
Inno. Non-tech	0.48	1.00												
Inno. Radical	0.48	0.34	1.00											
STI.Exclusive	0.20	0.14	0.14	1.00										
DUI.Exclusive	0.14	0.10	0.08	-0.02	1.00									
STI&DUI	0.33	0.30	0.36	-0.04	-0.03	1.00								
R&D expen.	0.01	0.01	0.02	0.01	0.00	0.00	1.00							
Size	0.30	0.26	0.19	0.14	0.08	0.23	0.00	1.00						
International market	0.24	0.17	0.2	0.11	0.07	0.18	0.00	0.29	1.00					
Group Nationality	0.10	0.12	0.12	0.03	0.06	0.11	0.01	0.25	0.006	1.00				
DUI Regional	0.34	0.30	0.33	-	-	-	0.00	0.23	0.18	0.08	1.00			
DUI Global	0.33	0.28	0.35	-	-	-	0.00	0.23	0.17	0.07	0.77	1.00		
STI Regional	0.36	0.30	0.35	-	-	-	0.01	0.26	0.20	0.09	0.59	0.66	1.00	
STI Global	0.30	0.27	0.32	-	-	-	0.00	0.22	0.15	0.06	0.67	0.58	0.59	1.00

Source: Own elaboration on the basis of Eustat (BIS, 2011).

Table 3
Percentage and number of firms adopting modes of interaction and innovation types in 2011.

	Inno.tech	Inno.non-tech	Radical innovation	Number of firms	% Over total number of firms
STI.Exclusive	6.23% (70)	4.82% (43)	9.77% (34)	87	2.46
DUI.Exclusive	14.60% (164)	15.68% (140)	21.84% (76)	185	5.23
STI&DUI	23.69% (266)	24.86% (222)	35.34% (123)	276	7.81
Number of firms	1123	893	348		
% Over total number of firms	31.76	25.25	9.84		

Total number of firms in 2011: 3536

Source: Own elaboration on the basis of Eustat (BIS, 2011).

Table 4
Impact of interaction modes on innovation output I.

Dependent variable	Inno.tech		Inno.non-tech		Radical innovation	
	Coefficient	S.E.	Coefficient	S.E.	Coefficient	S.E.
STI.exclusive	3.98***	0.56	2.27***	0.47	2.23***	0.38
DUI.exclusive	3.52***	0.74	3.32***	0.71	1.14***	0.59
STI&DUI	4.16***	0.43	3.70***	0.41	3.27***	0.33
R&D expen.	0.03**	0.01	-0.01	0.03	0.01**	0.02
Size	1.05***	0.08	0.89***	0.07	0.47***	0.08
International market	0.98**	0.22	0.66***	0.21	0.62***	0.20
Group nationality						
- National	0.14	0.25	0.13	0.24	-0.03	0.24
- Foreign	0.31	0.37	-0.22	0.36	0.02	0.38
Sector		Yes		Yes		Yes
Year		Yes		Yes		Yes
No. of obs		5401		5401		5401
No. of groups		3164		3164		3164
Log likelihood		-2477.73		-2344.84		-1362.37
Chi-square		461.3		326.42		184.53

Note: Level of statistical significance: *** $p \leq .01$, ** $p \leq .05$, * $p \leq .10$.

The regression analysis provides a number of insightful results. In particular, technological and non-technological innovations are strongly and positively correlated with the adoption of the combined STI&DUI interaction mode. This represents a result that is consistent with previous seminal and empirical studies conducted in Denmark (Jensen et al., 2007), Norway (Aslesen et al., 2011; Isaksen and Karlsen, 2010), Sweden (Isaksen and Nilsson, 2013), and, in a more nuanced form, Portugal (Nunes et al., 2013), China (Chen et al., 2011), and Belarus (Apanasovich, 2014).

Regarding our second and third hypotheses, we divided the evidence between technological and non-technological types of innovation. The individual STI interaction mode is significantly correlated with technological innovation, in which it presents similar parameters to the combined STI&DUI approach. In relation to non-technological innovations, the individual STI mode

is significantly correlated, although with a considerably lower coefficient than the combined mode and the DUI exclusive mode. This preliminary result shows the relevance of STI type of interactions for technological innovation in which the provision of explicit knowledge flows based on R&D activities are crucial means to develop such innovative capacities (e.g. joint R&D projects for new pharmaceutical or chemical products). STI drivers also matter – though to a lesser extent – in non-technological innovation by providing a codified and systematic knowledge basis that serves the purpose of structuring a more comprehensive strategic approach to organisational and commercial innovation. The DUI innovation mode is also significantly and positively correlated with both technological and non-technological innovation. In the first case, its parameter is significantly lower than both the STI&DUI and the STI exclusive parameters. In the second case, it shows a slightly lower

Table 5
Percentage of firms that adopt regional vs. global DUI type of interaction.

	% DUI regional	% DUI global
2006	6.10	4.84
2007	5.73	5.07
2008	5.54	5.31
2009	5.36	4.69
2010	6.22	5.29
2011	8.51	7.27

Source: own elaboration on the basis of Eustat (BIS, 2011).

level than the combined mode STI&DUI and it is higher than the STI exclusive interaction mode.

Overall, our second and third hypotheses are well supported as the DUI mode is very relevant (more than the STI mode) in the context of non-technological innovation. This is justified by the important learning processes that are activated through practice and across-the-board interactions inside and outside the supply chain for organisational and commercial innovations (e.g. speeding up delivery times, or adapting sale strategies to personalised customer demand).

Another perspective is added when considering radical innovation. The STI&DUI collaboration mode is highly correlated with radical innovation insofar as both the STI individual mode and the DUI mode also are. However, the combined mode displays a significantly higher parameter than both individual modes, whereas the STI mode parameter is significantly higher than the DUI mode parameter (see Annex 1 which confirms the different effect on radical innovation). These results are expected because radical innovation is centred on product innovation, and the STI factors are more likely to take the lead in this case. For instance, scientists are typically more inclined than suppliers or clients to study radically novel product combinations. Notwithstanding this evidence, the DUI factors also matter here as tacit knowledge, for instance when supply and non-supply chain-based interactions provide insights that help re-arranging former product configurations (e.g. tablets and smartphones were done not only in R&D departments, but also benefiting from important collaborations and feedbacks from end-users).

When looking at control variables it is interesting to stress that the “globalised” dimension captured by “INTERNATIONAL MARKET” is highly significant across the three models. This result confirms the relevance of the connection with international markets firms’ to reinforce the capacity to identify and absorb external knowledge as a means to become more innovative (Filippetti et al., 2011). However, “GROUP NATIONALITY” is not a significant variable across the different models; it confirms the importance of having international market connections rather than the mere ownership nature.

5. The relevance of geographical, context-specific linkages for innovation

5.1. Descriptive statistics

In the following section, a geographical application is developed to understand what types of geographical relationships (regional vs. global) are more typically used and developed by firms. This analysis follows the approach taken by Fitjar and Rodríguez-Pose (2013) in search of effective geographical patterns of collaboration. In addition, this application enables us to deliver a preliminary response to our fourth hypothesis, i.e., whether different geographical locations lead firms to adopt own patterns of collaboration that lead to varied impacts on innovation outputs.

Table 5 illustrates that within the DUI type of relationships, regional relationships are more developed than global-based DUI

Table 6
Percentage of firms that adopt a regional vs. global STI type of interaction.

	% STI regional	% STI global
2006	8.16	4.97
2007	7.59	4.50
2008	6.71	4.30
2009	6.54	4.56
2010	7.66	4.36
2011	9.47	6.62

Source: own elaboration on the basis of Eustat (BIS, 2011).

relationships. Despite the growing trend in all aspects, these data also indicate that the vast majority of firms (approximately 85%) do not use such relations in a significant way (consistent with the data in Table 1).

Table 6 presents the graded importance of STI relationships between the regional and global scales. The descriptive data illustrate that the regional type of linkages was and is still more developed than the global type. Both are increasing, and the relationship between the two is becoming more balanced (from a ratio of approximately 60% to a ratio of 70%). However, a better balance is yet to be found with the wider group of firms (again approximately 84%) that do not realise the importance of either the first or second geographical scale of STI activities.

The descriptive statistics displayed in Table 7 demonstrate the prevalence of both STI and DUI-regional collaborations for all types of innovations: technological, non-technological, and radical. STI-regional relationships are even more widespread than DUI-regional collaborations in all innovation types, and in technological and radical innovation to the highest extent. With a significant gap, global-STI and global-DUI collaborations are applied by businesses. In general, DUI-global interactions reach a higher (percentage) value vis-à-vis STI-global collaborations.

This preliminary descriptive outcome is in line with the proposed hypothesis of a possible geographical, context-specific nuance. In a rather geographically-circumscribed region such as the Basque Country, in which relationships with other national or international partners face some historic and political constraint, local relationships of collaboration are highly developed, with the hope that they help producing both technological and non-technological innovations. However, we need to undergo a confirmatory econometric analysis as a means to verify our fourth hypothesis and provide more evidence to the ‘context-specific nuance’ on business innovation.

5.2. Econometric results

The econometric analysis helps discussing our preliminary evidence in a more robust form (Table 8). Regarding both technological and radical innovations, the STI-regional interactions show the highest significance level and coefficient. STI-global and DUI-global collaboration are also quite significant, although present lower coefficients vis-à-vis the former type of collaboration. DUI-regional collaborations seem not to matter at all. Also the control variables ‘size’ and ‘international markets’ are significant. In non-technological innovation, the DUI-global collaborations as well as the STI-regional collaborations count, whereas both DUI-regional collaborations and STI-global collaborations do not. “Size”, “international market” and belonging to a business group’ also exercise a significant impact on non-technological innovation.

This evidence is in line with the former study of Fitjar and Rodríguez-Pose (2013) that indicated that global-DUI collaborations and then regional-STI and global-STI are relevant for technological innovations, while DUI-regional are not. In our case, a peculiar difference refers to the pre-eminence of STI-regional collaborations over the other two types, which seems to be in

Table 7
Percentage and number of firms adopting modes of interaction and innovation types in 2011.

	Inno.tech	Inno.non-tech	Radical innovation	Number of firms	% Over total number of firms
DUI regional	24.93% (280)	26.76% (239)	34.77% (121)	301	8.51
DUI global	22.08% (248)	23.29% (208)	29.60% (103)	257	7.27
STI regional	27.52% (309)	27.21% (243)	41.09% (143)	335	9.47
STI global	19.41% (218)	20.38% (182)	28.74% (100)	234	6.62
Number of firms	1123	893	348		
% Over total number of firms	31.76	25.25	9.84		

Source: own elaboration on the basis of Eustat (BIS, 2011).

Total number of firms in 2011: 3536.

Table 8
Impact of interaction modes on innovation output II.

Dependent variable	Inno.tech		Inno.non-tech		radical innovation	
	Coefficient	S.E.	Coefficient	S.E.	Coefficient	S.E.
DUI Regional	0.23	0.27	-0.23	0.28	0.09	0.3
DUI Global	1.82***	0.55	1.88***	0.52	1.30***	0.4
STI Regional	2.58***	0.46	1.82***	0.43	1.61***	0.32
STI Global	1.70***	0.58	0.70	0.52	1.05***	0.41
R&D expen.	0.01**	0.01	-0.01	0.03	0.01**	0.24
Size	1.08***	0.08	0.93***	0.07	0.46***	0.07
International market	1.02***	0.22	0.70***	0.21	0.62***	0.20
Group Nationality						
– National	0.15	0.25	0.13	0.24	-0.08	0.23
– Foreign	0.30	0.38	-0.23	0.37	0.09	0.37
Sector		Yes		Yes		Yes
Year		Yes		Yes		Yes
No. of obs		5401		5401		5401
No. of groups		3164		3164		3164
Log likelihood		-2483.30		-2356.29		-1365.11
Chi-square		432.75		340.71		192.71

Note: Level of statistical significance: *** $p \leq .01$, ** $p \leq .05$, * $p \leq .10$.

Table 9
Association between innovation modes and innovation outputs.

	STI interaction	DUI interaction	STI&DUI interaction	DUI Regional interaction	DUI Global interaction	STI Regional interaction	STI Global interaction
Technological innovation	++	+	+++	=	++	+++	+
Radical innovation	++	+	+++	=	++	+++	+
Non-technological innovation	+	++	+++	=	+++	++	=

Source: Table 9 is elaborated according to the results obtained in Tables 4 and 8.

Note: This table is made on the basis of two criteria: significance, and parameter levels. Three 'pluses' for the significant and highest positive parameter; two 'pluses' for the significant intermediate positive coefficient; one 'plus' for the significant lowest positive parameter; '=' if it is not significant at all.

line with the region-specific importance attributed to regional collaborations for innovation (in accordance with our hypothesis). DUI-regional collaborations do not matter as, in technological innovation, the codified knowledge base is a *conditio-sine-qua-non* to introduce effective innovations. The control variables “size” and “international market” are significant, which might be explained with the importance to produce and trade in international markets to be able to absorb relevant knowledge that is later transformed in innovative products and processes (Filippetti et al., 2011).

In the context of non-technological innovation, STI-regional collaborations count as much as DUI-global collaborations. In this respect, our study delivers similar results to Fitjar and Rodriguez-Pose, although also in this case STI-regional collaborations are comparatively more important than in the above-mentioned study based on Norway. This evidence remarks the importance of the “technological nuance” discussed in the previous part of this study, while at the same time delivers some nuanced – yet positive – evidence about the higher importance of certain types of regional interactions (STI) than in the Norwegian case. To a certain extent, this result provides graded evidence about our fourth hypothesis. It represents a good insight to promote a round of new studies on the importance of geographical proximity and the related cultural idiosyncrasies for business and regional innovation prospects.

Regarding control variables it is interesting to stress that the “globalised” dimension captured by “INTERNATIONAL MARKET” is highly significant across the three models. This result confirms the relevance of the connection with international markets firms’ to reinforce the capacity to identify and absorb external knowledge as a means to become more innovative (Filippetti et al., 2011). Moreover, it is consistent with the significance of “DUI GLOBAL” collaborations across the different models, stressing the relevance of interactions with global market agents (clients, suppliers, and competitors). Instead, “GROUP NATIONALITY” is not a significant variable across the different models; this outcome confirms the importance of having international market connections rather than having a multinational ownership nature.

6. Concluding remarks

This paper is framed within the specific debate on the innovation modes applied by businesses that is a sub-strand of the literature on innovation systems (Lundvall, 1992, 2007; Jensen et al., 2007; Isaksen and Karlsen, 2010; Aslesen et al., 2011; Parrilli and Elola, 2012; Isaksen and Nilsson, 2013; Fitjar and Rodriguez-Pose, 2013; González et al., 2015). Over the past few years, several issues and research questions have been addressed, and additional questions

have risen. This work attempts to respond to some of these questions. In particular, we worked on the issue of whether different interaction modes are associated with specific innovation outputs, finding a meaningful association (see synthetic results in Table 9).

Our first hypothesis (STI&DUI is the most important interaction mode) is generally proven and confirms other studies that realised the relevance of different and combined innovation modes (Jensen et al., 2007; Aslesen et al., 2011; Chen et al., 2011; Isaksen and Karlsen, 2012; Isaksen and Nilsson, 2013; Apanasovich, 2014). In this work, we focused on STI and DUI interactions/collaborations, thus neglecting internal business organisation. On this basis, this study adds value in the literature on innovation modes by stressing the importance of inter-firm and inter-organisation relationships. In particular, the combined STI&DUI mode is the most beneficial in all types of innovation, including technological, radical and non-technological innovation. Our second and third hypotheses are more original, arguing that the STI mode is more related to technological innovation, whereas the DUI mode is more connected with non-technological innovations. These hypotheses are accepted in our study, which sheds further light on the ‘technological nuance’ that we hypothesise in this work.

Our fourth hypothesis relies on the geographical application of the innovation mode debate with a special focus on the potential effect of cultural, social and institutional idiosyncrasies (the ‘context-specific nuance’) that may justify the differentiated application and impact of innovation and interaction modes across different countries and regions. This is also in line with the positive ‘innovation paradox’ argument for countries and regions that are able to reap good innovation outputs thanks to thick regional collaborations. In this case, we obtain nuanced, yet positive evidence. We hypothesised a stronger pattern of ‘regional’ STI and DUI collaborations for innovation output in the Basque context (vis-à-vis more internationally integrated contexts, such as Norway), and we observed a strong impact of regional STI linkages on both technological and non-technological innovations, but a very poor impact of regional DUI linkages on any type of innovation. As a result, the regionalisation of innovation dynamics works well for most innovation outputs in this specific region provided that it includes important codified knowledge bases (STI). More experiential and supply-chain-based knowledge is not enough to help generating substantial innovations. All in all, this could denote that context-specificities are important, but the differentiated nature of knowledge in relation to innovation output (the ‘technological nuance’) matters the most.

From a research perspective, more studies and applications are needed in other geographical contexts to understand whether the cultural, social and institutional idiosyncrasies matter to a higher extent or they are very much dependent on the ‘technological nuance’ highlighted in this work. It would also be very interesting to understand whether this pattern can be identified within the innovation modes themselves, i.e. beyond interactions and taking into account also the internal organisation and approach taken by the firm in its innovation activities (whether through specialised R&D departments or through more interactive intra-firm practices). It would also be interesting to build novel indicators which specifically capture the “context-specificity” notion (e.g. territorial cohesion index, specific language, and fiscal autonomy, among others). Finally, due to data limitations it would be necessary to refine the control variables regarding wider ‘global’ issues. Specifically future studies should consider firm’s foreign dimension according to different internationalisation modalities and connection with foreign production.

From a policy-making and a business practice perspective, some critical implications may be drawn. In particular, the fact that most businesses adopt a DUI type of interaction does not imply that it is an effective interaction mode. It delivers lower impact (than STI

factors) in technological and radical innovation, whereas it matters more for non-technological innovation. And it is inadequate when it is bounded to the regional environment (DUI-regional). These results may help in designing more effective innovation promotion programmes that do aim at obtaining feasible results, and that stress the importance – in a geographically and culturally-specific context – to focus on interactions that imply a codified knowledge basis as a *conditio-sine-qua-non* for the effective generation of both technological and non-technological innovations.

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Annex 1. T-test significance STI. Exclusive and DUI. Exclusive on radical innovation.

Variables	Inno.radical					
	Obs.	Mean	S.E.	S.D.	C.I. (95%)	
STI.Exclusive	1052	0.10	0.01	0.31	0.09	0.12
DUI.Exclusive	1052	0.03	0.00	0.17	0.02	0.04
Difference	1052	0.07	0.01	0.36	0.05	0.09
t-Test	mean(diff) = mean(STI.Exclusive – DUI.Exclusive)					
	t = 6,63					
	Pr(T > t) = 0.0001					

Note: Level of statistical significance: *** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.10$.

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