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Business innovation modes and their impact on innovation outputs: Regional variations and the nature of innovation across EU regions

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ABSTRACT

This work contributes to the literature on innovation systems and, in particular, delivers a thorough analysis on business innovation modes across a range of regional contexts. This analysis refers to the strand of literature on STI (Science and Technology-based Innovation) and DUI innovation modes (Innovation based on learning-by-Doing, learning-by-Using, learning-by-Interacting) that have been intensely debated over the past few years. It is a relevant area of research because it discusses the most effective innovation mode adopted by firms and their regions in the context of increasing global competition. In this scientific area, we inquire whether and how the regional context and its specific technological capabilities produce a differentiated impact of STI and DUI innovation modes on innovation outputs, alongside the nature of innovation outputs. In this respect, this study advances the literature on regional innovation systems that have not been analyzed by other scholarly contributions in this strand who have mostly discussed the differentiated impact of innovation modes across individual countries, industries, and business networks. Based on the large heterogeneity of regions across the European geography, we move beyond the set of individual country studies and develop a thorough analysis based on the Community Innovation Survey (CIS 2014) data from the Eurostat office about EU regions. Empirical evidence based on the application of a multiple treatment model suggests that both regional specificities and the nature of innovation matter. In addition, the DUI innovation mode proves to be often more important than expected for most types of innovation output.

1. Introduction

A few years ago, a special economic phenomenon was identified by lead scholars. It is the “innovation paradox” for which countries that invest significant amounts of resources in R&D are not able to extract as much output (innovation and economic performance) as other countries that invest comparatively less in R&D (Edquist, 2005; Asheim and Gertler, 2005). This led to a sub-strand of the literature on innovation systems that focus on the reasons for such regional specificities of innovation in different countries and regions (Lundvall, 1992; Cooke, 2001; Asheim and Gertler, 2005; Uyarra and Flanagan, 2010; Asheim et al., 2011; Isaksen and Trippl, 2017; Coenen et al., 2017). This strand of the literature studies the way in which firms innovate based on their economic, institutional and social background. This debate generated the literature on STI and DUI innovation modes, which was first developed by Jensen et al. (2007), and later extended through a number of country-based studies (Chen et al., 2011; Fitjar and Rodriguez-Pose, 2013; Nunes and Lopes, 2015; Lee and Miozzo, 2019; among others). It is the literature that flows in parallel to the leading innovation management literature focused on the importance of collaborations for innovation (Von Hippel, 1988; Chesbrough, 2003; Laursen and Salter, 2006; Tether and Tajar, 2008; Vega-Jurado et al., 2008), but that has a specific focus on the “regional” patterns of context specificities. Important elements are taken from this earlier literature, especially the collaborative patterns, but the focus in this study is not on businesses in general or their industry context. Instead, this study explores the way regional specificities influence firms’ innovation performance.

The results produced by previous studies generate a common pool of knowledge, although they simultaneously present significant variations. These might be related to specific technological, institutional and cultural contexts that may convey different ways of igniting innovation within specific regions (Rodriguez-Pose and Crescenzi, 2008; Uyarra and Flanagan, 2010; Isaksen and Trippl, 2017). This is our

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central line of inquiry that focuses on understanding whether firms in different regions innovate differently and compete through the application of particular innovation modes. If the regional context matters, we need to understand it in more depth as a means to promote higher innovation capacity within countries and regions. This aim is relevant for firms that face increasing global competition under tight budget constraints that affect their strategic investment decisions (De Marchi et al., 2017). It also matters for regional development prospects and for policy-makers who recognize how critical is the promotion of specific regional innovation trajectories (Uyarra and Flanagan, 2010; Asheim et al., 2011; Camagni and Capello, 2013; Boschma, 2015; Isaksen and Trippl, 2017; Coenen et al., 2017).

In this study we go beyond the range of single-country studies (Jensen et al., 2007; Chen et al., 2011; Thoma, 2017; among others), and previous exploratory meta-studies (Parrilli et al., 2016) to produce a thorough analysis based on one of the largest datasets on innovation. We use the Community Innovation Survey (CIS) 2014 data from the Eurostat office in Luxembourg and its first -and up to date only- survey of EU regions. We analyze the data based on a taxonomy of innovative regions identified by the PRO-INNO EU project "Regional Innovation Scoreboard" that sheds light on regional variations for innovation in Europe (Hollanders and Es-Sadki, 2014). A multiple treatment model is applied to compare the impact of different innovation modes taken by firms that belong to specific regional technological contexts. This is our first contribution as we investigate whether the application of innovation modes depends on regional assets and capabilities. It is something that has neither been covered in this literature nor in the broad literature on innovation management. Our second contribution is about the nature of innovation output. Here, we have an opportunity to verify whether some types of innovation modes (STI or DUI) have a stronger effect on specific types of innovation output, either technological (i.e. product and process innovation according to the OECD, 2006, definition) or non-technological (i.e. marketing and organizational innovation).

In what follows, Section 2 and 3 discuss the literature on innovation systems and business innovation modes, and presents our specific approach and arguments. In Section 4, the specific methodology is presented together with the selected database. Empirical findings are elaborated in Section 5, whilst the main results and policy implications are discussed in the concluding section.

2. Innovation systems and business innovation modes: a key relation

The innovation system refers to a set of organizations that, through intense and mutual interactions, contribute to the development and diffusion of new technologies and the innovation capacity of firms, particularly small firms that do not have enough resources to invest in R&D and highly qualified human capital (Cooke, 2001). For this reason, innovation scholars studied and identified specific patterns of innovation systems at the national (Lundvall, 2007; Nelson, 1993), regional (Cooke, 2001; Asheim and Gertler, 2005), technological and sectoral level (Carlsson et al., 1994; Breschi and Malerba, 1997). Challenging the more linear approach to innovation of neoclassical economics (for a review see Greunz, 2005), this strand of research emphasizes the existence of regional specificities of innovation in which the firms find incentives and/or constraints based upon localized and interactive technological and institutional settings (Cooke, 2001; Asheim et al., 2011; Boschma, 2015). This argument is recognized in recent works on regional innovation pathways (Camagni and Capello, 2013; Isaksen and Trippl, 2017; Coenen et al., 2017).

In this study, we stress the relevance of the interactive approach to innovation taken by leading scholars (Von Hippel, 1988; Chesbrough, 2003; Asheim and Gertler, 2005; Laursen and Salter, 2006; Lundvall, 2007; Vega-Jurado et al., 2008; Isaksen and Trippl, 2017). Within our study, the regional specificity of innovation is analyzed in relation to a well-known typology of innovative regions identified through the Regional Innovation Scoreboard –RIS- of the EU-PROINNO research team (Hollanders and Es-Sadki, 2014) that –based on four types of capabilities such as i) framework conditions, ii) investments, iii) innovation activities and iv) economic impact (see the end of this Section 2) - helps to determine whether this level of analysis devises relevant modes of innovation that go beyond the micro/firm level. The RIS classification is multifaceted, as it is based on regions that upgrade and downgrade their position across four types of innovative regions (leaders, strong, moderate and modest innovators) depending on their efforts and results over the four set of drivers.[1]

Our work takes the study of innovation systems and their impact on firms a step further, by studying the impact of innovation modes in different regional contexts. In recent years an increasing literature on business innovation modes has arisen as part of the debate on the most effective innovation systems. In this respect, our work differs from the strand of the literature on innovation management that focuses on identifying critical aspects of innovation at the firm level, (i.e. breadth and depth of collaborations for innovation, Laursen and Salter, 2006), or industry level (Tether and Tajar, 2008; Vega-Jurado et al., 2008; Trott and Simms, 2017). In this case, we work at the (regional) innovation system level by identifying peculiar innovation capabilities and outputs of specific regional innovation systems. This work is naturally embedded within this strand of literature on STI and DUI innovation modes, although it has not been analyzed by other scholars who have mostly discussed the differentiated impact of these modes across individual countries, industries, and business networks.

In this new strand of the literature, the first groundbreaking work was developed by Jensen et al. (2007), who clarified that such business innovation modes were strongly anchored in innovation systems that were characterized by a peculiar culture and strategy of knowledge management and innovation. They identified specific modes that are rooted in an intensive application of R&D expenditure and scientific human capital (Science and Technology-based Innovation –STI mode) or in the intensive use of experience and interaction through learning-by-doing, by-using and by-interacting (DUI mode). They also identified a third combined mode (STI&DUI) which, in the specific context of Denmark, delivered the highest innovation output. The novelty of this work was twofold. First, it provided evidence on the importance of this second innovation mode (DUI), which is justified in the case of systems with traditional SME-based industries (Tether and Tajar, 2008; Vega-Jurado et al., 2008; Trott and Simms, 2017). Second, this work discovered the importance of combining these different modes in a superior one, which may create additional capabilities for business innovation.

Subsequently, several studies followed up and refined the initial analysis through country applications (Amara et al., 2008, on Canada; Isaksen and Karlsen, 2010, Aslesen et al., 2012, Fitjar and Rodriguez-Pose, 2013, and Haus-Reve et al., 2019, on Norway; Chen et al., 2011, on China; Trippl, 2011, on Austria; Isaksen and Nilsson, 2013, on Sweden; Parrilli and Elola, 2012, Gonzalez et al., 2015, and Parrilli and Alcalde, 2016, on Spain; Nunes and Lopes, 2015, on Portugal; Apanasovich et al., 2016 and 2017 on Belarus; Thoma, 2017, and Thoma and Zimmermann, 2019 on Germany; Trott and Simms, 2017; and Lee and Miozzo, 2019 on the UK). All these studies entail a number of peculiar methodological and empirical variations that contribute to the thorough understanding of this area of research, although also raise new research questions.

Whilst most of these studies have either taken a micro or an industry-specific approach to business innovation modes, only two have

[1] Regions are divided among four categories that depend on their innovation index in relation to the EU average: beyond 120% of the EU average for leaders, 90% − 120% for strong innovators, 50% − 90% for moderate innovators, and below 50% for modest innovators (Hollanders and Es-Sadki, 2014).

considered the geography of innovation modes. Fitjar and Rodriguez-Pose (2011, 2013) emphasized the importance of geography for innovation (in Norway). They focused on the differentiated weight of regional vs global relationships in the application of business innovation modes and found that the DUI mode applied through global supply chain interactions is the most effective innovation mode, even more than the global STI innovation mode based on interactions with global leaders of innovation (e.g. leading multinational companies or universities). To a certain extent, these scholars downplayed the importance of regional interactions vis-à-vis global interactions, particularly in the case of the DUI innovation mode. In the Spanish-Basque regional context, Parrilli and Alcalde (2016) anticipated the importance of region-specific nuances in innovation. They found that in the Basque context, global and local STI and DUI collaborations have a different importance vis-à-vis the Norwegian case.

These studies helped to emphasize the importance of geography for the innovation modes embraced by businesses. However, other gaps are open to research so as to clarify the options available to firms and their regional territories. A meta-study stressed the importance of country specificities in business innovation modes and their performance (Parrilli et al., 2016). These scholars hypothesize the relevance of absorptive capacity as a means to raise the capacity to combine effectively the two archetypical modes (DUI & STI). However, these studies do not theorize the precise impact of the regional context; they purport hypotheses for further research. In this study, we make a further step in this analysis. In particular, we conceive a differentiated approach to innovation modes and outputs across regions with different technological and institutional characteristics; simultaneously, we compare a number of heterogeneous regions grouped in specific clusters across the European space, and verify whether our overall argument and hypotheses hold.

In this respect, the Regional Innovation Scoreboard (Hollanders and Es-Sadki, 2014) helps as it pulls together distinct groups of regions with their own characteristics in terms of innovation drivers and economic output. These groups represent specific technological endowments and capabilities, and implicitly also social and institutional contexts (the "social, institutional, cognitive, and organizational nature of proximity and knowledge networks" of Boschma, 2005; Howells, 2012), which are likely to characterize distinctive types of innovation system (Asheim and Gertler, 2005; Camagni and Capello, 2013; Isaksen an Trippl, 2017).[2] In the RIS 2014 used in this study, regions are grouped in four categories called innovation leaders, strong, moderate and modest innovators. This taxonomy offers a relevant ground to apply our theoretical approach for which regional technological and institutional capabilities influence the firms' innovation modes, and their impact on innovation outputs.

The taxonomy of regions based on the RIS has weaknesses (e.g. the heterogeneity of drivers criticized in Camagni and Capello, 2013). However, the purpose of our study is not to suggest a new taxonomy of regions, as it would require a different theoretical discussion and empirical analysis (e.g. a principal component analysis). The aim of this study is to use the existing (RIS) taxonomy of regions -which has been published by the European Commission since 2009– as a means to show the diverse innovation capacity of regions and the innovation mode typically used by their firms.

Next, we move to the discussion of the innovation modes taken by businesses within the selected categories of regions.

[2] These innovative regions are identified through the use of 27 indicators that focus on framework conditions (e.g. human capital; infrastructure), investment (e.g. public and private R&D), innovation activities (e.g. collaborations; intellectual assets), and economic impacts (e.g. employment, business performance).

3. Regional specificities and the nature of innovation output

3.1. Regional specificities

The arguments of previous studies are adopted in this study, which queries: 1) the likelihood of significant regional variations in firms' approach to business innovation, alongside 2) the relevance of the relation between innovation modes and the nature of innovation output. European regions represent heterogeneous systems in terms of technological infrastructures, institutional and political conditions, and economic and social development. In these contexts, it is to be expected the application of varying business innovation modes (Asheim and Gertler, 2005; Boschma, 2005; Rodriguez-Pose, 2013; Isaksen and Trippl, 2017). Based on previous studies in Scandinavian and Northern European countries, a significant proportion of their firms are capable of combining the two separate modes in an effective STI&DUI mode (Jensen et al., 2007; Isaksen and Karlsen, 2010; Isaksen and Nilsson, 2013, for Denmark, Norway and Sweden; Trippl, 2011, and Thoma, 2017 for Austria and Germany). In contrast, a very recent study implemented in Norway, and based only on external STI and DUI collaborations, shows a different outcome as the two innovation modes displace one another (Haus-Reve et al., 2019). The aforementioned studies focus on countries that rank at the highest level of international development with the highest absorptive capacity, i.e. educational attainment (UNDP, 2017). In countries that attain a lower development level and a lower educational attainment (e.g. Southern European countries), there may be a lower business capacity to combine the two modes effectively. Studies produced in these contexts show less consistent results. For instance, in the Spanish-Basque region, the STI mode was the most effective across small and medium-sized firms (Parrilli and Elola, 2012); whereas in Portuguese regions, the cluster of firms that introduces STI drivers, beside the use of traditional DUI drivers, represents the most effective group in terms of innovation output (Nunes and Lopes, 2015). Instead, research carried out in China shows that the innovation mode applied successfully depends on the industry. Traditional industries (e.g. footwear, furniture) work effectively through DUI drivers alone, while high technology industries (e.g. automotive and telecoms) prove a higher capacity to combine the two modes effectively (Chen et al., 2011). This latter outcome aligns well with the innovation management studies that identify industry-specific innovation collaborations across firms (e.g. the Spanish case studied by Vega-Jurado et al., 2008; the European study by Tether and Tajar, 2008; and the UK food industry studied by Trott and Simms, 2017).

Based on these patterns, we pursue two objectives and contributions. The first is the regionalization of the analysis of innovation modes; the second is the study of relationships that exist between specific innovation modes and selected innovation outputs. For the first contribution, we move away from the individual country type of analysis to perform a cross-section analysis over a large number of European regions grouped in the four aforementioned categories. This helps us verify the regional specificity of business innovation modes based on a comprehensive and robust assessment across larger geographies. In particular, we expect regional heterogeneities that respond to regional technological and institutional factors/assets.

Regions with stronger technological capabilities -leaders and strong innovators (northern European regions and the most innovative regions in Italy and Czech Republic) – are expected to be very effective in the application of the STI innovation mode (Camagni and Capello, 2013; Isaksen and Trippl, 2017). These regions exhibit high levels of human capital, thus a high absorptive capacity that helps their businesses to reap the effects of their investment in R&D activities (Cohen and Levinthal, 1990). These are regions where these inputs are complemented by a rich and extended trajectory of investment in new industries (e.g. IT, biotech, energy) where competition takes place based on innovation rather than cost effectiveness (Porter, 2008). In these industries, product innovation is essential as most products are not consolidated, but undergo critical experimentations (e.g. new bio-drugs, new applications for IT systems). For these reasons, the application of the STI mode is expected to produce a large impact on product innovation (in goods) and innovation sales as a measure of commercial success of product innovation (Love et al., 2014). It is the case of the impact generated by R&D in new products such as smartphones for Apple, driverless-vehicles for Tesla, or most recently, a new COVID-19 vaccine for the company that will produce it.

These regions and their businesses tend to rely on clusters of firms (e.g. Medicon valley in Denmark/Sweden, biotech cluster in Cambridge) whose critical mass of enterprises generates opportunities for value chain coordination (Porter, 2008). Businesses in these regions are aware of the importance of managing effective supply chain-based collaborations for innovation (Fitjar and Rodriguez-Pose, 2013; Parrilli and Radicic, 2020). Based on their very high absorptive capacity (Parrilli et al., 2016), and the capacity to coordinate the contribution of all employees in the firm, and all firms in the chain, we also expect firms in these regions to be able to combine STI and DUI modes effectively. This is a type of outcome that is expected in "organizationally thick and diversified innovation systems" that are capable of using all agents and resources in a wide set of high technology industries and firms in order to open brand-new "path-renewal" and "path-creation" trajectories (Camagni and Capello, 2013; Isaksen and Trippl, 2017). Overall, we expect firms in these regions to produce the largest impact on different types of innovation output, but particularly in the application of the STI mode and the combined STI&DUI mode. Therefore, we set the following hypotheses:

H1a: Leaders and strong innovators use more effectively the STI mode compared to moderate and modest innovators.

H1b: Leaders and strong innovators use the DUI mode effectively.

H1c: Leaders and strong innovators combine effectively the two modes to reach higher outputs than by using the two modes in isolation, and in comparison to moderate and modest innovators.

In relation to moderate innovators (most regions in Italy, Spain, Portugal, Greece, and Eastern Europe), we expect a significant effort in terms of STI mode as a means to catch up with more advanced regions based on a significant investment in R&D activities and skilled human capital. It is the case of the Basque region (Parrilli and Elola, 2012), and most coastal regions of Portugal (Nunes and Lopes, 2015) where firms and their (regional) innovation systems are producing effective industry growth. However, due to their lower absorptive capacity (UNDP, 2017), and the related difficulty to transform external inputs (e.g. patents, external R&D) into innovation output, they are likely to produce a smaller impact on innovation outputs, particularly on product innovation and the corresponding innovation sales. These regions are likely to be associated with strong user-producer interactions along the local supply chain as they have traditionally based their production capacity on such relations (Lundvall, 1992; Becattini et al., 2009). As a consequence, their DUI mode is likely to be at least as effective as in the leading regions (Camagni and Capello, 2013; Isaksen and Trippl, 2017). This argument is also supported by the innovation management literature, and specific studies in the context of medium and-low technology manufacturing (Vega-Jurado et al., 2008; Tether and Tajar, 2008; Trott and Simms, 2017). In these regions, the business capacity to combine STI and DUI innovation modes is likely to be positive, although lower than in the former category as the overall absorptive capacity (i.e. human capital) is usually lower than in the first group of regions.

Overall, this pattern is representative of "path-extension" prospects typical of "organizationally thick and specialized innovation systems" that try to catch up with the former group of innovators by means of R&D efforts within specialized industries (Camagni and Capello, 2013; Coenen et al., 2015; Isaksen and Trippl, 2017). As a result, we formulate the following hypotheses:

H2a: Moderate innovators extract positive innovation outputs from the application of the STI mode, although this impact is lower compared to leaders and strong innovators.

H2b: Moderate innovators extract positive and large impact from the application of the DUI mode (to a similar extent as for leaders and strong innovators).

H2c: Moderate innovators generate positive impact on innovation outputs through the combination of STI and DUI modes.

In the case of modest innovators (e.g. most Polish, Bulgarian, Greek and Romanian regions, laggard regions in Italy and Spain), their technological capabilities are limited, and any effort made is less likely to be effective. As shown in a study on China (Chen et al., 2011), the innovation pattern of most firms, which are engaged in traditional industries, is very likely to be linked to the intensity of supply chain collaborations (see also Tether and Tajar, 2008; Trott and Simms, 2017), thus these regions should be able to produce an effective application of the DUI mode (Chen et al., 2011). In contrast, due to their limited absorptive capacity, they are likely to combine the two innovation modes less effectively, thus generating lower innovation outputs.

This limitation might be explained, in part, by reduced human capital and technological capabilities; and in part by the limited resources invested in R&D activities that require reaching a critical mass to work effectively (Chen et al., 2011; Radicic et al., 2016). In this respect, and according to recent research, modest innovators represent the so-called "organizationally thin innovation systems" in which a small number of knowledge-related organizations operate and produce a limited applied research output for the benefit of their regional production system (Camagni and Capello, 2013; Isaksen and Trippl, 2017). This prospected outcome would match findings by Thoma (2017), Tether and Tajar (2008), and Trott and Simms (2017) on SMEs that mostly rely on DUI drivers. Therefore, we posit the following hypotheses:

H3a: Modest innovators do not make an effective use of the STI mode for innovation outputs.

H3b: Modest innovators are likely to effectively exploit the DUI mode.

H3c: In modest innovators, the combined effect of STI and DUI generates lower innovation outputs compared to other types of regions.

3.2. The nature of innovation outputs

Now, we turn to our second objective and analyze business innovation modes in relation to the nature of innovation output. This implies studying – from a firm perspective - the impact of different innovation modes on innovation outputs (i.e. product, process, marketing and organizational innovations), and economic performance (i.e. innovation sales). In this way, we have the opportunity to revisit some of the most recent results on business innovation modes and present an overall model of interlinkages between STI and DUI innovation modes and innovation outputs. For instance, we can test whether the combined STI&DUI mode is more effective than the individual modes alone or not (as recently suggested by Haus-Reve et al., 2019). We can also verify whether product and process innovation maintain similar (Parrilli and Alcalde, 2016) or dissimilar patterns (Vega-Jurado et al., 2008; Radicic et al., 2019) in relation to the application of STI and DUI modes. In this case we move away from the argument that product and process innovation follow a similar pattern. This is based on the consideration that, in general, process innovation relies upon interactive learning-by-doing and learning-by-using rather than on R&D activities (Lundvall, 2007). In spite of divergences in the literature on innovation modes (Parrilli and Alcalde, 2016), this has been earlier established in the literature on innovation management (Tether and Tajar, 2008; Vega-Jurado et al., 2008; Trott and Simms, 2017).

Moreover, we introduce service innovation, which has only been very recently studied in this literature (Lee and Miozzo, 2019). Previous studies related service innovation to lighter methods, i.e. changing routines rather than investing in R&D (Tether and Tajar, 2008; Abreu et al., 2010). Lee and Miozzo (2019) found that knowledge-intensive business services (KIBS) were heterogeneous. In spite of a segment of R&D services (STI-oriented), there is a larger segment of DUI-oriented firms (e.g. recruitment companies, marketing firms, IP protection consultancies). These are less focused on scientific knowledge and more on service customization for which they rely on close interactions with their clients and on facilitating their commercial knowledge. Therefore, we expect service innovation to show a different nature vis-à-vis innovation in goods, as services require softer type of skills (e.g. co-design and teamwork) that benefit from user-producer interactions (Tether and Tajar, 2008). Similarly, organizational and commercial innovation are more likely to benefit from the application of DUI drivers (e.g. collective engagement and tacit knowledge flows) rather than from STI drivers (Parrilli and Alcalde, 2016; Apanasovich et al., 2016). This argument is supported by the wider innovation management literature that stresses the positive impact of user-producer interactions and employee contribution in these innovation outputs (Von Hippel, 1988; Lam, 2005; Tether and Tajar, 2008). On these bases we hypothesize the following relations:

H.4a: The impact of the STI mode on product innovation in goods – and the related innovation sales – is larger than the impact of the DUI mode.

H.4b: The impact of the DUI mode on process and service innovations is larger than the impact of the STI mode.

H.4c: The impact of the DUI mode on organizational and marketing innovation is larger than the impact of the STI mode.

H4d: For any type of innovation outputs, the combined application of STI and DUI innovation modes produces a higher impact than the application of either the STI or the DUI mode in isolation.

4. Methodology

4.1. Context and data

As mentioned above, we adopt the typology developed by the European Commission for the RIS-2014 (Hollanders and Es-Sadki, 2014). It is a classification based on the innovation attainment of European regions that entails a set of technological and institutional features, such as their absorptive capacity and overall institutional drive to innovation. It is a relevant typology for the purpose of our research as it offers a recognized taxonomy to understand and interpret divergent innovation trends across different regional contexts.

The empirical analysis in this paper is based on data from the Community Innovation Survey (CIS), which have been used extensively in the innovation literature (Cassiman and Veugelers, 2002; Ballot et al., 2015). CIS data cover all major sectors of economic activities and collect information on different types of innovation output. Overall, the quality of CIS2014 data is of a high standard with systematic data quality checks conducted at the national and enterprise level. Countries follow a harmonized CIS2014 questionnaire and methodological recommendations provided by the Eurostat (CIS Quality Report, 2014).[3] The high response rate has been recognized as one of the main strengths of the CIS2014. The response rate varies across national surveys (from 100% in Cyprus to 51.8% in Denmark), but for most of the countries is above 80%.

According to classification in the RIS, countries belong to several categories as some regions are more advanced than others. CIS2014 covers regions from Germany and Ile de France in France (innovation leaders), Belgium, some region in France, Italy and Luxembourg (strong innovators), Hungary, Italy, France, Lithuania, Malta, Slovakia and Cyprus (moderate innovators), and Bulgaria, Italy, Romania, Hungary and Latvia (modest innovators).

The use of a harmonized CIS survey including multiple countries is pertinent in many empirical studies. As Stojcic et al. (2020:7) note about the CIS survey "it is the most comprehensive cross-country dataset on the innovation behavior of European firms." Stojcic et al. (2020) used the same wave of the CIS data (2014) as we do, but their dataset is at the country level, while ours is regional. They explored how effective was public procurement of innovation compared to supply-side innovation policy measures. They estimated their model in eight Central and Eastern European countries. Hashi and Stojcic (2013), used the CIS4 wave, conducted in 2004 to estimate the Crépon et al. (CDM) model in Central, Eastern and Western European countries. Hölzl and Janger (2014) used the CIS4 and CIS6 datasets for 18 countries to explore differences in the perception of innovation barriers between innovative and non-innovative firms. Mate-Sanchez-Val-and Harris (2014) use CIS4 data for the UK and Spain. They explored the role of national differences derived from structural country characteristics, and how these impact on firms' innovation performance.

The only difference between these studies and our study is that the aforementioned studies analyze CIS data at country level, while our study analyzes CIS data at the regional level. This is one of our contributions, thanks to the introduction of regional data in the CIS survey in 2014. Furthermore, we have used the same model specification for each regional category, similar to aforementioned studies which use the same model specification for different countries or groups of countries.

4.2. Empirical strategy

Our empirical strategy encompasses the use of propensity score estimation for multiple treatments, which is motivated by the endogeneity of the STI and DUI modes given the nature of their components, e.g. internal and external R&D activities (Duso et al., 2014), and the potential reverse causality between cooperation for innovation and innovation performance (Pippel and Seefeld, 2016; Haus-Reve et al., 2019). Consequently, the effect of STI and DUI innovation modes on innovation performance should be estimated as a treatment assignment (i.e. average treatment on the treated effect, ATT).

Previous studies looking at complementarity between different innovation activities or policies treated those activities/policies as exogenous. In particular, whether complementarity is investigated through interaction terms and their marginal effects, like in Haus-Reve et al. (2019), or by applying the supermodularity function, the variable(s) of interest are treated as exogenous, although the theory suggests that they are endogenous. With respect to the latter, Love et al. (2014) investigated potential complementarity between different innovation activities (R&D and external linkages). The authors discuss the issue of endogeneity of variables of interest in great detail as the supermodularity approach does not address this issue. They note that the instrumental variable approach is one way of dealing with endogeneity of innovation activities, but it requires valid instruments, which are difficult to find, particularly in innovation studies.

To sum up, in addressing the endogeneity of DUI and STI innovation modes, whichever methods have been used in previous studies did not address this issue because a valid instrument is not available. The only solution would be to use a dynamic panel analysis, i.e. the GMM

[3] However, some difference between countries do exist in relation to the survey type, collection method and response rate. Mostly a combination of sample survey and business census is used to target a population; with the exception of Lithuania which only uses a sample survey, and Bulgaria and Malta that exclusively use census. Regarding the collection method, the countries mainly collect data electronically via a web questionnaire, while some countries combine electronic survey with either postal or phone survey, use only postal survey or conduct face-to-face interviews. Belgium, Bulgaria, Germany, Spain, France, Latvia, Portugal, Romania, Serbia, Slovakia collect data electronically and also additionally send a questionnaire by post. In order to increase the response rate some countries use a postal service (Austria, Germany, Sweden and the Netherlands) or establish contact by phone (Belgium, Germany, Greece, and United Kingdom). Czech Republic, Macedonia, Malta, Slovenia and United Kingdom use a postal service only and Cyprus conducts face-to-face interviews.

estimator. However, the lack of longitudinal data (in the CIS data) is a common problem in innovation studies. If researchers are bound to use a cross-section data, STI and DUI modes can either be treated as exogenous (like in previous studies) or as endogenous (as we have done here), but with the caveat that complementarity cannot be fully explored. Namely, we can estimate and compare the joint effects of both modes versus individual modes, but not within a traditional definition of complementarity - an increase in a marginal effect of one mode increases the effect of another mode-. In other words, we can explore an additive effect, but not a multiplicative joint effect (Haus-Reve et al., 2019).

Matching estimators, whether in the framework of one or more treatments, have few advantages over other cross-section empirical strategies. Compared to the Instrumental Variable (IV) approach, matching does neither require valid instruments for the treatment variables nor makes any assumptions about the functional form of the outcome equation (Czarnitzki et al., 2007). However, the main disadvantage of matching estimators is the assumption of unconfoundedness or selection of observables. Namely, matching estimators control for endogeneity arising from a selection bias under the assumption that there is no unobserved heterogeneity.

Given that firms might simultaneously engage in STI and DUI modes, we estimate treatment effects in the multiple treatment contexts through the matching approach with multiple treatments introduced by Lechner (2001). We have $M + 1$ treatments, whereby treatment = 0 denotes the non-engagement with STI and DUI. The average treatment effect on the treated (ATT) effect is then calculated as:

$$ATT = E(Y^m|T = m) - E(Y^l|T = m) \quad (1)$$

where m denotes the treatment level, l represents the comparison group (the treatment level to which m is compared, termed matched controls by Czarnitzki et al., 2007), and Y^m and Y^l denote outcomes in states m and l respectively. We employ the inverse probability of treatment weighting regression adjustment (IPWRA) estimator.

The IPWRA estimator belongs to a group of matching estimators that have the double-robust property. Double robustness implies that either the treatment model or the outcome model (or both) have to be correctly specified for the estimator to produce consistent treatment effects (Hirano et al., 2003). The use of the IPWRA estimator requires three steps. First, for each firm in the sample, the treatment model estimates the propensity score, which is the probability for each firm of engagement in STI only, DUI only or both (i.e. treatment assignment). Given that we evaluate multiple treatment effects, the propensity scores are estimated by a multinomial logit model, incorporating all four treatment levels: neither STI nor DUI; only DUI; only STI; and both.[4] The choice of the model is motivated by the nature of our treatment variable, which has more than two outcomes with no natural ordering. The propensity scores enable firms to be matched within each treatment level. Second, regressions are estimated by the logit model, because the outcome variables are binary indicators, in which the inverse of the estimated propensity scores are used as weights on covariates X and our treatment dummies. Third, from each of these regressions, the ATT effect is computed as the difference in the weighted averages of the predicted outcomes (for technical details, see Wooldridge, 2010). This three-step approach provides consistent estimates given the underlying assumption of the independence of the treatment from the predicted outcomes once covariates are modelled in steps 1 and 2.[5]

[4] Due to a large number of models we have estimated, results from multinomial logit models are not reported but are available upon request.

[5] We report valid standard errors (of the Huber/White/sandwich type) which take into account that the estimates are computed in a three-step approach (Emsley et al., 2008).

4.3. Variables

4.3.1. Dependent variables: innovation outputs

Previous studies on innovation modes focus on technological innovation, primarily product and process innovation (Jensen et al., 2007; Chen et al., 2011; Fitjar and Rodriguez-Pose, 2011; 2013). More recent studies also consider non-technological innovation, i.e. marketing and organizational (Parrilli and Alcalde, 2016; Thoma, 2017). This paper is even more inclusive in that we focus on most types of innovation output described in the Oslo Manual (OECD, 2005). Six innovation types are considered: product (goods and services) and process innovation (Fitjar and Rodriguez-Pose, 2011; 2013); marketing and organizational (Parrilli and Alcalde, 2016; Apanasovich et al., 2016). Moreover, as the firm final objective is a survival and/or growth, a measure of economic performance based on innovation is considered; i.e. innovation sales (defined as sales from new products).

For the purpose of our analysis, product innovation is a binary variable coded one (1) if the firm has introduced new or significantly improved products (i.e. goods or services) during 2012–2014; otherwise it takes value zero (0). A successful product innovation contributes to firms' profitability by increasing sales. Process innovation is also binary and results from the combination of three variables (introduction of new/significantly improved methods of producing goods/services; logistics, delivery or distribution methods; and support activities for its processes). As a consequence, it contributes to firms' productivity by reducing production costs. If the firm has introduced at least one of these process innovations during the last three years this variable is coded one (1); otherwise it takes value zero (0). Organizational innovation is a binary variable equal to one (1) if at least one of the following innovations was adopted: workplace innovation; knowledge management innovation; or external relations-based innovation; otherwise it equals zero (0). Organizational innovation encompasses changes in the routines of firms that will contribute to efficiency, productivity and/or profitability. This type of innovation is either a prerequisite for successful products or process innovations, or a necessary adaptation for the introduction of new technologies. In the CIS survey, the definition of organizational innovation includes these different aspects. Marketing innovation is a binary variable taking value of one (1) if at least one of the following four marketing Ps innovations was adopted: product design or packaging; product placement; product promotion or pricing; otherwise it equals zero (0).

4.3.2. Treatment variables

As posited earlier, STI and DUI innovation modes imply different types of interactions, both within the firm and with its external environment (Jensen et al., 2007; Chen et al., 2011; Fitjar and Rodriguez-Pose, 2013). Here, we follow the CIS and the classification developed by Jensen et al. (2007). The advantage is that, unlike many studies that measure STI and DUI mostly based on different types of collaboration (Chen et al., 2011; Fitjar and Rodriguez-Pose, 2013; Parrilli and Alcalde, 2016; Haus-Reve et al., 2019), our investigation also considers firms' internal activities associated with STI or DUI innovation modes. STI is equal to 1 if firms either undertake (internal and/or external) R&D activities or cooperate with higher education institutions and government research centers, and zero otherwise. Instead, DUI drivers include in-house activities (i.e. in-company training, design, and market introduction of innovations) and cooperation with suppliers, customers, competitors and consultants. This driver takes value of 1 if any of these activities or types of cooperation occurs, and zero otherwise.

To estimate the individual and joint effects of STI and DUI, we create treatment variables with the following values:

- treatment = 0 if a firm adopted neither STI nor DUI innovation modes (52% of the firms);
- treatment = 1 if a firm only adopted the STI mode (11% of the firms);

– treatment = 2 if a firm only adopted the DUI mode (11% of firms);
– treatment = 3 if a firm adopted the combined mode STI + DUI (26% of firms).

4.3.3. Control (matching) variables

In the analysis of the full sample, as well as of country group samples, the following set of variables is included in the estimation of the propensity score. One group of variables considers firm characteristics such as firm size and financial performance. Previous empirical literature found close correlation between firm size and innovation output (Cassiman and Veugelers, 2002). Furthermore, the literature suggests that large firms utilize a combination of several R&D sources, while small firms organize simpler innovation strategies, e.g. training (Cassiman and Veugelers, 2002). We controlled for firm size by using a log of employment (Chen et al., 2011; Ballot et al., 2015). Moreover, based on studies that show that exporters produce higher innovation output, we controlled for the exporting activity of the firm (Ballot et al., 2015).

As in other studies, sectoral effects were controlled by including dummies based on the Eurostat classification of manufacturing and service sectors at NACE 2-digit level according to technological intensity: i.e. high-tech, medium-high, medium-low and low-tech, knowledge-intensive services, less knowledge-intensive services, and other sectors (Chen et al., 2011; Ballot et al., 2015). Finally, following the RIS2014 (Hollanders and Es-Sadki, 2014), dummies for different regional groups based on innovation performance (i.e. leaders/strong, moderate and modest innovators) have been included.

5. Empirical evidence

5.1. Regional variations

We recognize that in any country there are different regional production systems, some of which are more innovative than others (e.g. Piedmont vs Sardinia in Italy, Navarre vs Extremadura in Spain). For this reason, we decided to focus on European regions to spot different innovation patterns and capabilities. Table 1 provides descriptive statistics on innovation activities and business innovation modes aggregated in three regional categories: 1) innovation leaders & strong innovators (pulled together due to sample size limitation); 2) moderate innovators, and 3) modest innovators.

Now, we turn to Tables 2, 3 and 4 for the empirical results from propensity score estimation for multiple treatments.[6] Column 1 and 6 across Tables 2, 3 and 4 show that H1a is partly supported as leaders& strong innovators show the positive and higher impact of STI drivers in relation to innovation in goods and innovation sales vis-à-vis moderate and modest innovators. Marketing and organizational innovation instead do not show significant difference across regions. In leaders and strong innovators, the STI mode has a significant and large impact on all innovation outputs including marketing and organizational innovation. This result proves the strong capabilities of leaders and strong innovators and their businesses in R&D activities and in collaborations with scientific partners as a means to boost their innovation capacity (Tether and Tajar, 2008; nuanced in Vega-Jurado et al., 2008, that stress the importance of internal R&D for product innovation). This STI impact is maintained in other categories (e.g. moderate innovators); however, for leaders&strong innovators the strength of the correlation is particularly high for innovation sales. The coefficient for this group of regions is significantly higher than across moderate (for product innovation and innovation sales) and modest innovators (for all types of innovation). This outcome shows that these regions provide firms with a much higher capacity to develop (radical) product innovations that lead directly to higher innovation sales, thus higher economic performance.

Column 2 in Table 2 shows that the application of the DUI mode produces significant and large impact on all types of innovation output (Fitjar and Rodriguez-Pose, 2013), and even more strongly in the case of service, process, marketing and organizational innovation. This outcome supports H1b. In relation to the combined STI&DUI mode (H1c), the evidence (see column 3 in Table 2) confirms Jensen's et al. (2007) work that recognizes the additive value of combining the innovation modes to obtain a superior innovation output. In the context of these most innovative regions, the STI and DUI modes produce a higher output than by using each mode in isolation – see columns 4 and 5 in Table 2- (Jensen et al., 2007; Parrilli and Alcalde, 2016; Thoma, 2017). This is different from the recent results produced by Haus-Reve et al. in Norway (2019) due to two methodological decisions. Firstly, their study is based on external collaborations, while we also consider internal drivers; secondly, our study shows the additive impact of the two modes whilst Haus-Reve et al.' work shows their multiplicative impact. In relation to the second part of H1c, the evidence shows that leaders&strong innovators do not produce a higher impact on innovation outputs than moderate innovators (apart from innovation sales), although they do in relation to modest innovators for all innovation outputs (see column 3 across Tables 2, 3 and 4).

Moderate innovators follow a similar pattern to leaders&strong innovators in relation to the application of both STI and DUI mode as well as for the impact of the combined STI&DUI mode (see columns 1, 2 and 3 in Table 3). This indicates that this group of regions is on an intense catching-up trajectory (Parrilli and Elola, 2012; Nunes and Lopes, 2015). However, a significant difference is visible between these groups, which relates to the way the STI drivers influence innovation sales in these regions. In particular, innovation sales respond more softly to STI drivers in this group of regions vis-a-vis leaders & strong innovators (column 1 in Tables 2 and 3). This difference reveals a divergent nature of innovation across different regional contexts as, across leaders&strong regions it is often the commercialization of very radical/innovative products, while in the case of moderate innovators, their capacity to innovate and sell such innovations successfully in the market is significant, but notably smaller (Vega-Jurado et al., 2009, for manufacturing firms in Spain). Overall, hypothesis H2a is supported. The DUI mode has a positive and significant impact on all types of innovation output in a similar way to leaders&strong innovators. This outcome fully supports H2b (see column 2 in Table 3). Interestingly, moderate innovators are also good at combining STI and DUI modes and produce higher output across all range of innovations (columns 3, 4 and 5 in Table 3). As a result, H2c is fully supported. These general results show the intense effort of these regions to catch-up with the most innovative regions, and yet the more reduced capacity to exploit the two modes in the market (i.e. innovation sales).

The third typology of regions is significantly different from the others. These are the modest innovators. Here the STI drivers matter, but only for product and service innovation (see column 1 in Table 4). Instead, it does not produce effective results in process, marketing, organizational innovation and innovation sales. This outcome leads to a partial acceptance of H3a. In contrast, modest innovators mostly rely on the DUI mode of innovation (column 2 in Table 4) and the related capabilities as firms in these regions benefit a lot from user-producer interactions along the supply chain. This evidence provides support for H3b. This finding can be interpreted in terms of a group of regions (modest innovators) that are not yet capable of fully exploiting the potential of STI drivers. Here the firms mostly rely on the exploitation of DUI drivers for all types of innovation output. Interestingly, the combined STI&DUI innovation mode is additive in innovation output terms, thus H3c is supported. In all outputs the combination STI&DUI produces a positive impact which is higher than the application of the

[6] The estimated ATTs in the full sample are shown in Table A2 in Appendix. We do not comment on these results, given that our focus is on the comparisons between different regional groups, following the formulated hypotheses in Section 3.

two modes in isolation (see columns 4 and 5 in Table 4). This impact on innovation outputs is lower than in the former regions, apart from service and organizational innovation where no significant differences appear (compare column 3 across Tables 2, 3 and 4). Overall, this outcome is relevant in policy terms, because it justifies private investments in R&D and/or scientific collaborations also in less dynamic regional contexts, more as a means to develop higher regional absorptive capacity (Cohen and Levinthal, 1990; Zahra and George, 2002).

Overall, these findings support the hypothesis of regional specificities of innovation, and confirm previous exploratory studies (Parrilli and Alcalde, 2016; Parrilli et al., 2016), although on a much wider basis, i.e. large sample of European regions. In addition, this study draws more conclusive characterizations of these distinctive groups of regions.

5.2. The nature of innovation outputs

In Tables 2, 3, and 4 the following findings can be observed. First, technological boundaries matter (i.e. product innovation versus other types of innovation). In fact, there are findings that hold beyond the type of region considered in the analysis. As mentioned above, the combined STI&DUI innovation mode shows significantly higher impact vis-à-vis the individual modes when the three modes are compared to the case of no adoption of innovation modes (column 3 versus columns 1 and 2). This is confirmed in columns 4 and 5 in Tables 2, 3 and 4, in which the combined mode is compared with the two individual modes (STI in column 4 and DUI in column 5). This finding confirms the results of previous works applied to different contexts (Jensen et al., 2007; Trippl, 2011; Nunes et al., 2015; Parrilli and Alcalde, 2016). This proves a general and important argument based on the nature of innovation as a complex process and output. When firms – in all settings and regions – add STI and DUI drivers, they are very likely to produce significantly higher innovation outputs than firms that maintain either a more traditional DUI approach to innovation, or develop an approach mainly focused on strong investments in R&D and STI collaborations. Process innovation is an exception here as it only responds to DUI drivers (Table A2 column 5). This shows an additive effect between the two modes of innovation that needs to be exploited by firms. On these bases, hypothesis H4d is accepted.

A second type of finding on the nature of innovation is revealed in Figs. 1, 2 and 3. They show the relative importance of STI and DUI drivers. STI drivers show higher impact on product innovation (red dot above blue dot for innovation in goods, vs blue dot over red dot for all other innovation outputs), as expected from previous studies in this specific literature (Fitjar and Rodriguez-Pose, 2013; Parrilli and Alcalde, 2016), as well as in the wider literature on innovation management (Tether and Tajar, 2008; Vega-Jurado et al., 2008). This result is complemented by the outcome on innovation sales, which are usually associated with advanced product innovation. These are also mainly influenced by STI drivers. As a result, H4a is accepted.

A novel finding – within the innovation modes literature - refers to process innovation. Across all firms, this output is explained by the DUI mode alone, while the combined STI& DUI does not add up (see Figs. 1 and 2, and Table A2 column 5 in appendix). This result implies that the DUI mode represents the effective driver of process innovation. Work in teams and collaboration between users and producers are keys to promote process upgrading (Lundvall, 2007; Tether and Tajar, 2008; Trott and Simms, 2017). It is a relevant result as it shows a divergent pattern within technological innovation (i.e. product and process innovation). Taken individually, process innovation does not respond to STI drivers – contrarily to previous studies (Parrilli and Alcalde, 2016), where product and process were lumped together and showed an overall STI drive. In the case of service innovation, innovation output responds to both STI and DUI drivers, but with emphasis on the latter in accordance with previous literature on the innovation modes literature (Lee and Miozzo, 2019) and the general innovation management literature (Tether and Tajar, 2008). Therefore H4b is also accepted.

Organizational and marketing innovations also respond eminently to the DUI mode, although as for the case of service innovation, also benefit from the additive role of STI drivers. On these bases, hypothesis H4c is supported as in previous studies in this literature (Parrilli and Alcalde, 2016; Thoma, 2017).

Overall, these results imply that the application of DUI drivers is essential in any case (and regional economy) since they work together with STI drivers towards more effective outputs. In practice, even in the most advanced European regions, innovation cannot be left to scientists alone; rather, innovation benefits from the joint work performed by scientists, managers, administrators, and technicians, and from the application of a practice-based approach along the convincing arguments of innovation system scholars (Lundvall, 2007; Jensen et al., 2007; Isaksen and Karlsen, 2010, among others), and innovation management scholars (Von Hippel, 1988; Laursen and Salter, 2006; Tether and Tajar, 2008; Vega-Jurado et al., 2008; Trott and Simms, 2017). This important across-the-board collaborative perspective is particularly important in "process industries, where development activities take place within production lines or plant environments rather than in R&D centers". Innovation takes place through collaborative interactions through which "the plant is run and outputs tested"[7] (see also Trott and Simms, 2017).

6. Conclusions

6.1. Contributions to the literature

This study conducts a broad analysis of business innovation modes across EU regions. The access to the unique Eurostat regional database represents a critical aspect to go beyond the individual country studies that have been performed over the past ten years and that tend to be country-specific and dependent on specific methodologies.

This is a study in which regional variations are considered within wider technological patterns. The main findings support our view that regional specificities matter. The EU regions, divided among three groups of innovative regions (based on the RIS taxonomy, Hollanders and Es-Sadki, 2014), show differentiated patterns of innovation. In particular, leaders&strong innovators prove an effective capacity to use all set of drivers with the highest impact. Moderate innovators show an important catching-up trajectory in which they also use both drivers successfully. The difference between them refers to the highest capacity of the former to make the STI drivers work not only for innovation output, but also to the largest extent for economic performance (i.e. innovation sales). This outcome supports and extends the findings of earlier studies on innovation systems developed by Isaksen and Trippl (2017), Coenen et al. (2015), and Camagni and Capello (2013) on "organizationally thick and diversified innovation systems" vs "organizationally thick and specialized innovation systems". The case of modest innovators shows that they lag behind; however, they have also undertaken a positive innovation trajectory, which is mostly based on the successful application of DUI drivers, but that starts to benefit from the combined application of STI and DUI modes. To some extent, their case represents the "organizationally thin innovation systems" of Isaksen and Trippl (2017). However, our study shows the novelty of the intrinsic vitality that permeates also these laggard regions. The overall picture illustrated here is quite complex and shows that in all regions a number of drivers and the related innovation modes are positively impacting on innovation. This outcome also suggests that there is a process of convergence across Europe for which all regions are making their effort to catch up, and in addition have good resources to succeed (e.g. human resources). Yet, differences exist and need to be recognized as modest innovators are not very effective in the adoption of STI drivers, and moderate innovators are catching up, but yet need to enhance their capabilities to produce radical innovations that directly support business economic performance (i.e. innovation sales). These different innovation

[7] We want to thank an anonymous reviewer who highlighted the innovation peculiarities of process industries (e.g. machinery industries, food industries).

Table 1
Descriptive statistics for regional groups (leader and strong innovators, moderate innovators, and modest innovators).

Variables	Variable description	Leader and strong innovators Mean (standard deviation)	Moderate innovators Mean (standard deviation)	Modest innovators Mean (standard deviation)
Treatment	A categorical variable defined as: Neither STI nor DUI innovation modes (treatment = 0); only the STI mode (treatment = 1); only the DUI mode (treatment = 2); the combined mode STI + DUI (treatment = 3)	1.511 (1.346)	1.247 (1.302)	1.063 (1.156)
Outcome variables				
Product innovation in goods	Dummy variable (DV) = 1 if a firm introduced new or significantly improved goods in the period 2012–2014; zero otherwise	0.396 (0.489)	0.328 (0.470)	0.390 (0.488)
Product innovation in service	DV = 1 if a firm introduced new or significantly improved services in the period 2012–2014; zero otherwise	0.288 (0.453)	0.233 (0.423)	0.210 (0.407)
Process innovation	DV = 1 if a firm introduced a new process in the period 2012–2014; zero otherwise	0.478 (0.500)	0.439 (0.496)	0.515 (0.500)
Organisational innovation	DV = 1 if a firm introduced organizational innovation in the period 2012–2014; zero otherwise	0.460 (0.498)	0.369 (0.483)	0.326 (0.469)
Marketing innovation	DV = 1 if a firm introduced marketing innovation in the period 2012–2014; zero otherwise	0.377 (0.485)	0.358 (0.479)	0.329 (0.470)
Innovative sale	The percent of total turnover from (a) New or significantly improved products that were new to market and/or (b) New or significantly improved products that were only new to enterprise	7.412 (19.539)	0.770 (6.228)	0.157 (0.283)
Matching (control) variables				
Exports	DV = 1 if a firm sold goods and/or services to countries other than the home country in the period 2012–2014; zero otherwise	0.557 (0.495)	0.551 (0.493)	0.421 (0.496)
Turnover	The market sales of goods and services (includes all taxes except VAT) (in natural logarithm)	15.556 (2.257)	15.096 (1.794)	14.088 (1.780)
Employment	Average number of employees (in natural logarithm)	4.113 (1.560)	3.631 (1.200)	3.664 (1.151)
High_tech	DV = 1 if a firm belongs to a high-tech sector according to NACE2 classification in the period 2012–2014; zero otherwise	0.027 (0.162)	0.013 (0.115)	0.014 (0.116)
Medium_high_tech	DV = 1 if a firm belongs to a medium high-tech sector according to NACE2 classification in the period 2012–2014; zero otherwise	0.093 (0.291)	0.068 (0.251)	0.063 (0.242)
Medium_ low	DV = 1 if a firm belongs to a medium low-tech sector according to NACE2 classification in the period 2012–2014; zero otherwise	0.121 (0.326)	0.125 (0.330)	0.114 (0.317)
Low tech	DV = 1 if a firm belongs to a low-tech sector according to NACE2 classification in the period 2012–2014; zero otherwise	0.136 (0.343)	0.173 (0.378)	0.261 (0.439)
Knowledge intensive services (KIS)	DV = 1 if a firm belongs to a knowledge-intensive service (KIS) sector according to NACE2 classification in the period 2012–2014; zero otherwise	0.233 (0.423)	0.150 (0.357)	0.126 (0.332)
Other sectors	DV = 1 if a firm belongs to other sectors according to NACE2 classification in the period 2012–2014; zero otherwise	0.059 (0.237)	0.124 (0.329)	0.055 (0.229)

Table 2
Estimated average treatment effects on the treated (ATTs) for innovation leaders and strong innovators (Followers).
Source: Own elaboration based on Eurostat data, April 2017.

Outcome variable	STI vs 0 Column 1	DUI vs 0 Column 2	STI&DUI vs 0 Column 3	BOTH vs STI Column 4	BOTH vs DUI Column 5	DUI vs STI Column 6	No of obs. Column 7
Product innovation in goods	0.382***	0.262***	0.550***	0.184***	0.307***	−0.108***	11,629
	(0.018)	(0.021)	(0.014)	(0.016)	(0.020)	(0.023)	
	[0.347, 0.418]	[0.220, 0.304]	[0.523, 0.577]	[0.152, 0.216]	[0.268, 0.346]	[−0.153, −0.064]	
Product innovation in services	0.180***	0.255***	0.315***	0.145***	0.055***	0.069***	11,629
	(0.016)	(0.020)	(0.013)	(0.015)	(0.020)	(0.023)	
	[0.149, 0.211]	[0.216, 0.295]	[0.289, 0.340]	[0.115, 0.175]	[0.015, 0.094]	[0.024, 0.115]	
Process innovation	0.262***	0.416***	0.410***	0.148***	−0.007	0.135***	11,670
	(0.021)	(0.022)	(0.017)	(0.017)	(0.018)	(0.024)	
	[0.221, 0.303]	[0.372, 0.460]	[0.376, 0.443]	[0.115, 0.180]	[−0.043, 0.029]	[0.088, 0.181]	
Organisational innovation	0.085***	0.276***	0.317***	0.234***	0.035	0.150***	11,634
	(0.020)	(0.024)	(0.017)	(0.017)	(0.022)	(0.024)	
	[0.045, 0.125]	[0.230, 0.323]	[0.285, 0.350]	[0.201, 0.267]	[−0.008,0.077]	[0.103, 0.196]	
Marketing innovation	0.084***	0.209***	0.334***	0.257***	0.107***	0.125***	11,638
	(0.019)	(0.023)	(0.016)	(0.016)	(0.021)	(0.023)	
	[0.047, 0.122]	[0.165, 0.254]	[0.303, 0.365]	[0.225, 0.289]	[0.066, 0.147]	[0.079, 0.170]	
Innovation sales	7.140***	2.150***	11.444***	4.963***	9.686***	−3.394***	11,629
	(0.690)	(0.560)	(0.523)	(0.735)	(0.615)	(0.790)	
	[5.788, 8.493]	[1.051, 3.248]	[10.419, 12.469]	[3.521, 6.404]	[8.481, 10.891]	[−4.941, −1.846]	

Notes: Robust standard errors in parentheses; 95% confidence intervals in square brackets.
*$p < 0.10$.
**$p < 0.05$.
***$p < 0.01$.

Table 3
Estimated average treatment effects on the treated (ATTs) for Moderate Innovators.
Source: Own elaboration based on Eurostat data, April 2017.

Outcome variable	STI vs 0 Column 1	DUI vs 0 Column 2	STI&DUI vs 0 Column 3	BOTHvs STI Column 4	BOTHvs DUI Column 5	DUIvs STI Column 6	No of obs. Column 7
Product innovation in goods	0.356***	0.264***	0.497***	0.140***	0.228***	−0.059***	26,729
	(0.011)	(0.011)	(0.008)	(0.011)	(0.011)	(0.013)	
	[0.334, 0.378]	[0.243, 0.285]	[0.480, 0.513]	[0.118, 0.162]	[0.207, 0.250]	[−0.084, −0.033]	
Product innovation in services	0.134***	0.224***	0.292***	0.154***	0.071***	0.115***	26,729
	(0.009)	(0.009)	(0.008)	(0.010)	(0.010)	(0.012)	
	[0.116, 0.153]	[0.205, 0.242]	[0.272, 0.306]	[0.134, 0.174]	[0.050, 0.091]	[0.092, 0.139]	
Process innovation	0.271***	0.421***	0.422***	0.153***	0.006	0.121***	26,729
	(0.012)	(0.011)	(0.010)	(0.011)	(0.010)	(0.013)	
	[0.246, 0.295]	[0.400, 0.442]	[0.404, 0.440]	[0.131, 0.175]	[−0.014,0.026]	[0.095, 0.147]	
Organisational innovation	0.101***	0.257***	0.331***	0.220***	0.067***	0.180***	26,727
	(0.012)	(0.012)	(0.009)	(0.011)	(0.011)	(0.013)	
	[0.078, 0.124]	[0.234, 0.280]	[0.313, 0.349]	[0.198, 0.243]	[0.045, 0.089]	[0.153, 0.205]	
Marketing innovation	0.108(0.011)	0.239***	0.344***	0.235***	0.096***	0.148***	26,727
	[0.086, 0.130]	(0.011)	(0.009)	(0.011)	(0.011)	(0.013)	
		[0.217, 0.261]	[0.327, 0.361]	[0.212, 0.257]	[0.074, 0.118]	[0.122, 0.174]	
Innovation sales	0.742***	0.231***	1.765***	1.008***	1.433***	−0.365**	26,729
	(0.142)	(0.084)	(0.136)	(0.169)	(0.142)	(0.155)	
	[0.463, 1.021]	[0.066, 0.395]	[1.499, 2.031]	[0.677, 1.339]	[1.155, 1.711]	[−0.669, −0.060]	

Notes: Robust standard errors in parentheses; 95% confidence intervals in square brackets.
*$p<0.10$.
***$p<0.01$.
**$p<0.05$.

Table 4
Estimated average treatment effects on the treated (ATTs) for Modest Innovators.
Source: Own elaboration based on Eurostat data, April 2017.

Outcome variable	STI vs 0 Column 1	DUI vs 0 Column 2	STI&DUI vs 0 Column 3	BOTHvs STI Column 4	BOTH vs DUI Column 5	DUI vs STI Column 6	No of obs. Column 7
Product innovation in goods	0.177***	0.172***	0.298***	0.119***	0.124***	0.029	4622
	(0.025)	(0.021)	(0.023)	(0.028)	(0.024)	(0.031)	
	[0.127, 0.226]	[0.130, 0.214]	[0.252, 0.344]	[0.064, 0.175]	[0.077, 0.171]	[−0.031, 0.089]	
Product innovation in services	0.045**	0.229***	0.306***	0.251***	0.087***	0.135***	4622
	(0.023)	(0.022)	(0.024)	(0.026)	(0.024)	(0.024)	
	[0.001, 0.090]	[0187, 0.271]	[0.258, 0.354]	[0.199, 0.302]	[0.040, 0.134]	[0.089, 0.182]	
Process innovation	0.025	0.159***	0.255***	0.236***	0.092***	0.117***	4622
	(0.029)	(0.024)	(0.026)	(0.030)	(0.023)	(0.032)	
	[−0.031, 0.082]	[0.111, 0.207]	[0.204, 0.305]	[0.178, 0.294]	[0.047,0.137]	[0.054, 0.179]	
Organisational innovation	−0.009	0.209***	0.347***	0.351***	0.109***	0.206***	4622
	(0.026)	(0.024)	(0.026)	(0.028)	(0.025)	(0.028)	
	[−0.095, 0.041]	[0.162, 0.257]	[0.297, 0.398]	[0.295,0.406]	[0.059,0.159]	[0.151, 0.261]	
Marketing innovation	0.028	0.206***	0.331***	0.285***	0.108***	0.190***	4622
	(0.026)	(0.024)	(0.026)	(0.029)	(0.026)	(0.028)	
	[−0.022, 0.078]	[0.157, 0.253]	[0.280, 0.382]	[0.228,0.342]	[0.057,0.159]	[0.134, 0.245]	
Innovative sale	0.014	0.069***	0.138***	0.135***	0.074***	0.068***	4622
	(0.017)	(0.014)	(0.017)	(0.016)	(0.015)	(0.016)	
	[−0.019, 0.047]	[0.041, 0.097]	[0.105, 0.170]	[0.103, 0.168]	[0.045, 0.103]	[0.038, 0.099]	

Notes: Robust standard errors in parentheses; 95% confidence intervals in square brackets.
*$p<0.10$.
***$p<0.01$.
**$p<0.05$.

profiles of regions cannot be pursued with a blanket-type of intervention, but need very detailed and specific applications (Todtling and Trippl, 2005; Uyarra and Flanagan, 2010; Asheim et al., 2011; Rodriguez-Pose, 2013; Boschma, 2015). This research outcome and the related policy reflections are confirmed by the literature on innovation management that tackled this research question from the individual business perspective and the industry-specific approach (Tether and Tajar, 2008; Vega-Jurado et al., 2008; Trott and Simms, 2017).

The analysis of the nature of innovation shows interesting results. The main outcome of this work is the superiority of the combined STI& DUI mode in the promotion of business innovation in general. This result stands out across all typologies of innovative regions, and in almost all types of innovation output. This confirms the early seminal work of Jensen et al. (2007) on Denmark, later replicated in a wider set of country contexts (Isaksen and Karlsen, 2010; Isaksen and Nilsson, 2013; Nunes and Lopes, 2015; Parrilli and Alcalde, 2016; Apanasovich et al., 2016).[8]

[8] Our study cannot be directly compared to Haus-Reve et al. (2019), as the latter focuses on the interaction term between the two innovation modes, i.e. the effect of one innovation mode on the other, whilst in our case the focus is on the additive value of the combined strategy. Other relevant differences include the timeframe (they have three CIS waves for Norway), the country range (Norway vs a large selection of European regions), and the selected variables (external collaborations in their case vis-à-vis internal and external drivers in ours).

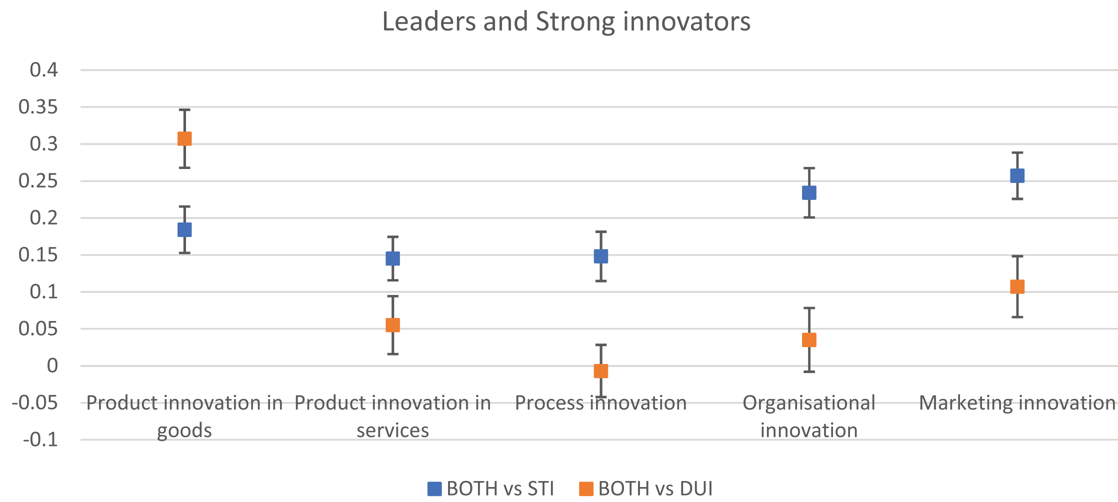

Fig. 1. Estimated ATTs with 95% confidence intervals in leaders&strong innovators.

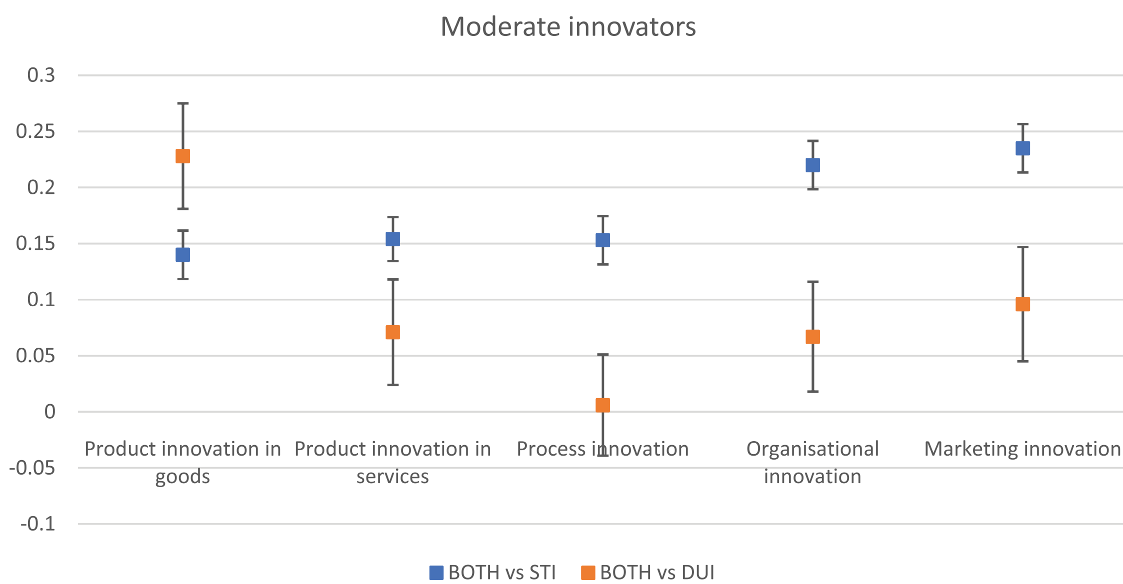

Fig. 2. Estimated ATTs with 95% confidence intervals in moderate innovators.

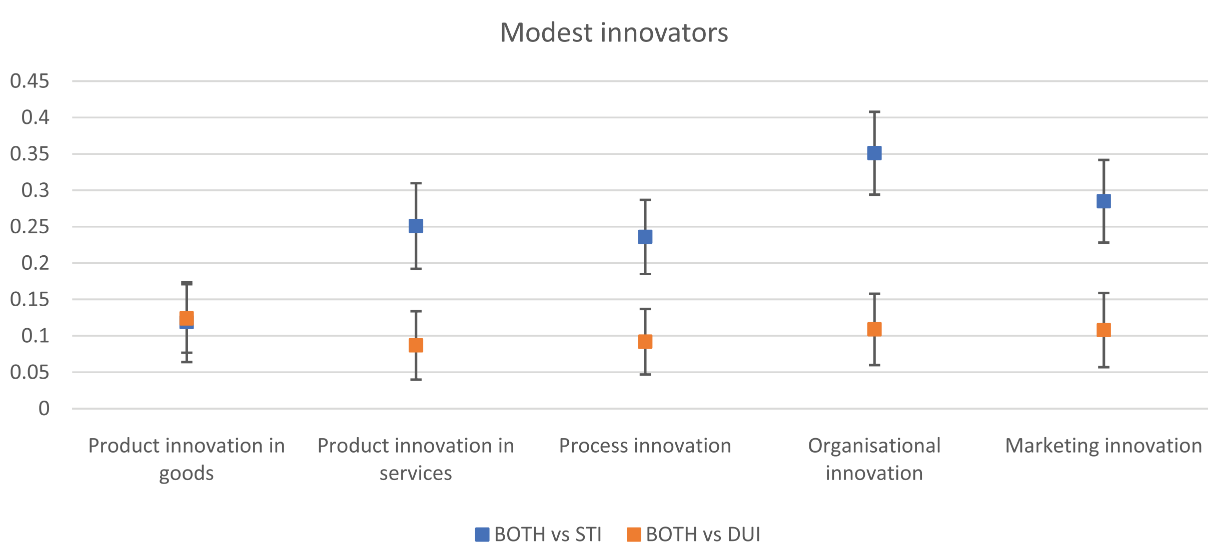

Fig. 3. Estimated ATTs with 95% confidence intervals in modest innovators.

One exception to the complementarity between STI and DUI drivers is process innovation, which depends on the exclusive application of the DUI mode (i.e. the STI mode does not add value in this case, see Table A2 column 5 in appendix). This outcome is aligned to the literature on innovation management that stresses the relevance of user-producer interactions for technological upgrading (Tether and Tajar, 2008; Trott and Simms, 2017). This result is important as product and process innovation exhibit divergent patterns and drivers. A completely different result stands out for product innovation and innovation sales in which the STI drivers take the lead, as seen in previous studies (Tether and Tajar, 2008; Vega-Jurado et al., 2008; Camagni and Capello, 2013; Parrilli and Alcalde, 2016). Overall, we could interpret that product and process innovations differ in the knowledge assets required for their implementation. Process innovation relies much more on tacit knowledge (Cohen and Klepper, 1996) whose nature is intangible, and more difficult to exchange (Weigelt, 2009). Therefore, it requires a focus on learning-by-doing, by-using and by-interacting.

In general, the STI mode is more significant for product innovation (i.e. goods) as well as for innovation sales. The DUI mode affects more directly all the other innovation outputs, including organization and commercial innovation as well as process and service innovation. For a large segment of firms, service innovation responds primarily to user-producer interactions, particularly clients who can signal key aspects that service providers respond to in a customized form (Trott and Simms, 2017; Lee and Miozzo, 2019).

6.2. Policy implications and future research agenda

In the current technological society, this research delivers an original outcome. Several drivers contribute to the effective innovation capacity of firms. The treatment effect helps to disentangle the different weight of STI and DUI modes. The latter is clearly shown as the one that generates the highest impact on service, process, organizational, and marketing innovation. As a result of the previous findings, and in a rather counterintuitive manner with regard to the Lisbon agenda and mainstream innovation policy applied over these many years, we argue that policies and businesses should develop a portfolio approach in which the STI mode and policies are developed in relation to product innovation and innovation sales. Simultaneously, the DUI mode regains prominence and requires the adoption of specific policies and actions that strengthen the capacity of firms and regions to attain service- and process-based innovations as well as organizational and commercial innovation. As a consequence, the DUI mode is not part of the past and of low technology industries and less innovative regional production systems (Pavitt, 1984; Vega-Jurado et al., 2008; Tether and Tajar, 2008; Trott and Simms, 2017). Instead, the DUI mode represents a critical set of drivers that promote the innovation capacity of all regions and firms. On these bases, specific DUI-type of actions could be recommended around the promotion of learning capabilities within the firm (e.g. on-the-job training, technical assistance, and teamwork that are useful for process and organizational innovation) and across firms (e.g. supply chain-based workshops to promote standardization and certification practices for product and process innovation).

Regional variations should be recognized by policy-makers, thus leading to plans that include the application of regional government efforts in the aforementioned DUI activities, particularly for modest and moderate innovators. This would guarantee a stronger and systematic basis for innovation output in these less innovative regions. The use of selective STI drivers should also start in a more gradual form across modest innovators in a way that minimizes business investment costs (e.g. external R&D contracted to technology centers). Thanks to their higher absorptive capacity, moderate innovators could deepen their investment in internal R&D as a means to catch up with leaders and strong innovators (Vega-Jurado et al., 2008). As a consequence, policy-makers could stir the banking system to provide adequate financial lines to support business R&D in these regions. In the case of leaders&strong innovators, not much can be added apart from carrying on with their dual approach to STI&DUI innovation while continuing their strong investments that strengthen the impact of the STI innovation mode on innovation sales.

A final comment is linked to future research lines. This study examines different innovation modes adopted in various groups of regions. Yet, it does not tell the way in which these innovation modes are successfully promoted, and in particular, how the capacity to combine STI and DUI modes is built up and extended across larger numbers of regions and firms. More reflections and research are needed on the characteristics and requirements of firms that can combine STI and DUI innovation drivers effectively. This is important also because there still are a significant proportion of firms that do not use any innovation mode or that only use one of the modes in isolation. Their specific upgrading process needs to be investigated and understood in more depth. From a regional perspective, it is also important to understand how moderate and, particularly, modest innovators can exploit STI drivers to a higher extent so as to reduce the gap with leaders&strong innovators. In both cases, qualitative research methodologies, and longitudinal empirical studies may provide in-depth understanding that is required to accomplish this task. Another line of inquiry would be to investigate a moderation effect from STI mode in moderate and modest regions. Namely, although STI mode might have a limited impact on innovation in these regions, it might positively moderate the relation between the use of DUI mode and innovation outputs.[9] Finally, the impact of STI and DUI innovation modes is likely to differ substantially in low- and medium-technology industries vs high-technology industries. The role of process, organizational and commercial innovations vis-à-vis product innovation changes very much in these cases, which need to be studied separately and then compared. Industry/sector-centered surveys could be run to study whether these regional and business specific impacts are moderated by the most representative regional industries, which to a certain extent has been anticipated by earlier studies on the economics of innovation (Pavitt, 1984), and innovation management (Tether and Tajar, 2008; Trott and Simms, 2017).

Credit author statement

The three authors actively contributed to the development of this paper. MDP is more involved in the theoretical discussion, formulation of hypotheses, and empirical interpretation, whilst DR and MB are more directly involved in the methodological settings of this work. DR was responsible for the technique to be used (ATT) and the empirical strategy pursued in the paper, while MB was directly involved in the collection of data and the empirical tests made in the Eurostat secure office in Luxembourg. The three have however intensely collaborated in all the parts of the work and have developed the current homogeneous work on the selected topic.

Declaration of Competing Interest

To the best of our knowledge, the three authors of this work do not face any conflict of interest in relation to their submission of the paper “Business innovation modes and their impact on innovation output: Regional variations and the nature of innovation matter across EU regions” to the journal Research Policy.

[9] We thank an anonymous reviewer for this suggestion.

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Appendix

Table A1
Description of the components of DUI and STI innovation modes.

Innovation activities comprising DUI mode	***Variable description***
Design	DV = 1 if a firm responded “Yes” to the question “During the three years 2012 to 2014, did your enterprise engage in the following innovation activities: Design”; zero otherwise
Market introduction of innovations	DV = 1 if a firm responded “Yes” to the question “During the three years 2012 to 2014, did your enterprise engage in the following innovation activities: Market introduction of innovations”; zero otherwise
Training	DV = 1 if a firm responded “Yes” to the question “During the three years 2012 to 2014, did your enterprise engage in the following innovation activities: Training for innovative activities”; zero otherwise
Info_suppliers	DV = 1 if a firm responded “High” or “Medium” to the question “During the three years 2012 to 2014, how important to your enterprise's innovation activities were each of the following information sources? Suppliers of equipment, materials, components, or software”; zero otherwise
Info_customers	DV = 1 if a firm responded “High” or “Medium” to the question “During the three years 2012 to 2014, how important to your enterprise's innovation activities were each of the following information sources? Clients or customers from the private or from the public sector”; zero otherwise
Info_competitors	DV = 1 if a firm responded “High” or “Medium” to the question “During the three years 2012 to 2014, how important to your enterprise's innovation activities were each of the following information sources? Competitors or other enterprises in your sector”; zero otherwise
Info_consultants	DV = 1 if a firm responded “High” or “Medium” to the question “During the three years 2012 to 2014, how important to your enterprise's innovation activities were each of the following information sources? Consultants or commercial labs”; zero otherwise
Coop_suppliers	DV = 1 if a firm responded “Yes” to the question “Please indicate the type of innovation co-operation partner: Suppliers of equipment, materials, components, or software”; zero otherwise
Coop_customers	DV = 1 if a firm responded “Yes” to the question “Please indicate the type of innovation co-operation partner: Clients or customers from the private or from the public sector”; zero otherwise
Coop_competitors	DV = 1 if a firm responded “Yes” to the question Please indicate the type of innovation co-operation partner: Competitors or other enterprises in your sector”; zero otherwise
Coop_consultants	DV = 1 if a firm responded “Yes” to the question Please indicate the type of innovation co-operation partner: Consultants or commercial labs”; zero otherwise
Innovation activities comprising STI mode	
Internal R&D	DV = 1 if a firm responded “Yes” to the question “During the three years 2012 to 2014, did your enterprise engage in the following innovation activities: In-house R&D”; zero otherwise
External R&D	DV = 1 if a firm responded “Yes” to the question “During the three years 2012 to 2014, did your enterprise engage in the following innovation activities: External R&D”; zero otherwise
Info_HEIs	DV = 1 if a firm responded “High” or “Medium” to the question “During the three years 2012 to 2014, how important to your enterprise's innovation activities were each of the following information sources? Universities or other higher education institutes”; zero otherwise
Info_government	DV = 1 if a firm responded “High” or “Medium” to the question “During the three years 2012 to 2014, how important to your enterprise's innovation activities were each of the following information sources? Government, public or private research institutes”; zero otherwise
Info_conferences	DV = 1 if a firm responded “High” or “Medium” to the question “During the three years 2012 to 2014, how important to your enterprise's innovation activities were each of the following information sources? Conferences, trade fairs, exhibitions”; zero otherwise
Info_publications	DV = 1 if a firm responded “High” or “Medium” to the question “During the three years 2012 to 2014, how important to your enterprise's innovation activities were each of the following information sources? Scientific journals and trade/technical publications”; zero otherwise
Info_associations	DV = 1 if a firm responded “High” or “Medium” to the question “During the three years 2012 to 2014, how important to your enterprise's innovation activities were each of the following information sources? Professional and industry associations”; zero otherwise
Coop_HEI	DV = 1 if a firm responded “Yes” to the question Please indicate the type of innovation co-operation partner: Universities or other higher education institutes”; zero otherwise
Coop_government	DV = 1 if a firm responded “Yes” to the question Please indicate the type of innovation co-operation partner: Government, public or private research institutes”; zero otherwise

Table A2
Estimated average treatment effects on treated (ATTs) in the full sample.

Outcome variable	STI vs 0	DUI vs 0	STI&DUI vs 0	BOTH vs STI	BOTH vs DUI	DUI vs STI
Product innovation in goods	0.287***	0.266***	0.475***	0.191***	0.228***	−0.003
	(0.006)	(0.007)	(0.005)	(0.006)	(0.008)	(0.007)
Product innovation in service	0.110***	0.236***	0.286***	0.170***	0.054***	0.145***
	(0.005)	(0.006)	(0.005)	(0.006)	(0.008)	(0.007)
Process innovation	0.208***	0.424***	0.410***	0.191***	−0.009	0.212***
	(0.007)	(0.007)	(0.006)	(0.007)	(0.008)	(0.008)
Organisational innovation	0.105***	0.249***	0.332***	0.224***	0.072***	0.144***
	(0.007)	(0.008)	(0.006)	(0.007)	(0.008)	(0.008)
Marketing innovation	0.127***	0.258***	0.353***	0.229***	0.094***	0.143***
	(0.006)	(0.007)	(0.005)	(0.006)	(0.008)	(0.008)
Innovative sale	0.916***	0.166*	1.476***	1.094***	2.476***	−0.568***
	(0.117)	(0.098)	(0.098)	(0.188)	(0.150)	(0.113)

Notes: ***$p < 0.01$.
..**$p < 0.05$.
*$p < 0.10$.

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