STI and DUI innovation modes in micro, small, medium and large-sized firms: Distinctive patterns across Europe and the US

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Abstract

A growing literature discusses the effectiveness of business innovation modes on innovation performance. In particular, the innovation mode based on the application of science and technology drivers -STI- (e.g. R&D; collaboration with universities) is analysed and compared to the mode based on learning-by-doing, by-using and by-interacting -DUI- (e.g. teamwork, collaboration with suppliers and clients). These modes express the archetypical strategies firms use to innovate. The literature has long identified specificities of small and medium-sized enterprises (SMEs). However, in this study we segment this group of enterprises further and inquire the peculiar innovation modes adopted by these firms as we expect SMEs to be less homogeneous than typically expected. In this work, we distinguish between internal STI and DUI drivers, and external STI and DUI drivers as we expect firms of different sizes to compete through different combinations of these drivers. Complementarily, we investigate the impact of these drivers on innovation output across these different types of firms. The results show the effective adoption of internal STI drivers across micro/small firms, and the well-rounded approach taken by medium-sized firms. Large firms show a more limited effectiveness of external STI and DUI drivers, which seems to be linked to a selective approach to innovation.

Keywords:

Innovation; STI and DUI innovation modes; SMEs; Large firms; Europe, US.

1. Introduction

Economic growth means overcoming financial crises, more opportunities for society, and potentially more for everyone from the ever-bigger pie, if divided accordingly (Acs et al., 2017). This growth can be guaranteed only when a sizable number of firms join the market in a competitive position. In the current globalised market where competition has become extremely fierce, only the firms that can offer a unique value proposition (Love and Roper, 2015) or engage successfully with new technological and managerial challenges (Linton and Solomon, 2017) are likely to prosper. This unique capacity is bolstered by the capacity of firms and other agents of the innovation system to generate knowledge and to transform it into unique products, processes, organizational and commercial strategies (i.e. innovations), which generate sales of innovative goods and services, and broader economic performance (Acs et al., 2017; Cooke, 2005; Etkowitz, 2012).

In this study we focus on the innovation modes adopted by firms. This refers to resources, capabilities and strategies that firms adopt as a means to develop innovations that give them a competitive edge in the market (Jensen et al., 2007). In particular, it refers to a debate that has arisen over the past ten years on the innovation modes, whether based on science and technology (STI mode), or on learning-by-doing, by-using or by-interacting (DUI mode) (Fitjar and Rodriguez-Pose, 2013; Isaksen and Karlsen, 2010; Jensen et al., 2007; Parrilli and Alcalde, 2016; Thoma, 2017).

Within this strand of the literature on innovation, recent contributions focused on a wide set of innovations that include both the typical OECD-based (2005) technological innovation (product and process-based), and non-technological innovation (organizational and marketing/commercial-based, Parrilli and Alcalde, 2016; Thoma, 2017). This wider approach to innovation gives a more complete representation of the approach and capacity of firms to innovate and compete in the open economy. Taking into account this wider innovation framework, we aim at providing a deeper understanding of innovation activities and outcomes.

Within the literature on business innovation modes, the novelty of this specific contribution is about measuring the most effective innovation mode in relation to firm size, and its impact on innovation output. In practice, we want to unearth the relation between STI and DUI innovation modes, and the different types of firms by size. We argue that size is an essential aspect of business innovation performance as it is connected to their organizational structure and their overall capacity to devote resources to (and develop competences in) innovation activities. This proposition has been discussed with mixed results from Schumpeter (1934; 1942) onwards. Following a Mark II approach, some scholars expect large firms to take a leading role in innovation due to their formal R&D departments and dedicated human capital (Rochina et al., 2010; Shefer and Frenkel, 2005), though others – supportive of Mark I – expect SMEs to be agile in converting novel knowledge produced within their innovation system into different types of innovations (Nieto and Santamaria, 2010; Radicic and Djalilov, 2019).

In broad terms, our conceptualization recognizes the importance of both Schumpeter's Mark I and Mark II arguments (1934; 1942) that complement each other under specific conditions (Revilla and Fernandez, 2012). In particular, we acknowledge the effectiveness of SMEs in innovation when they rely effectively upon the agents of the innovation system that realize targeted efforts to generate novel knowledge and help firms, especially SMEs, to convert it into product, process, organizational and commercial innovations (Amara et al., 2008; Cooke, 2001; Cooke et al., 2004; Nieto and Santamaria, 2010; Radicic et al., 2019). However, we go a step beyond and distinguish between internal and external STI and DUI drivers as some of these apply to the use of internal resources (e.g. R&D and scientific human capital in the STI mode, or teamwork and in-company training in the DUI mode), while others apply to the type of collaborations in place between the firm and its environment (e.g. university-industry collaborations in the STI mode, and supply chain collaborations in the DUI mode, see Fitjar and Rodriguez-Pose, 2013; Jensen et al., 2007; Parrilli and Alcalde, 2016); This distinction helps us identify whether – in addition to confirming/disconfirming SME effectiveness in innovation – these firms rely more on external or internal drivers, and – in the case of SMEs- whether their effectiveness comes more through external supply-chain (or cluster-based) drivers (DUI) as described in the literature on clusters and industrial districts (Becattini et al., 2009; Porter, 2008), or also benefit from STI type of interactions (e.g. with universities) within the wider regional innovation system taken as a system of interdependencies among different actors involved in innovation activities directly and in synergy with other entities and businesses as suggested by the literature on national and regional innovation systems (Asheim et al., 2019:3; 2017). Simultaneously, we perform a similar analysis for large firms, their effective strategies and innovation modes. These research questions are tested using the Innobarometer survey from 2014.

In the next section a specific exploration of the STI and DUI innovation modes literature is presented before moving to a section that highlights the novelty of this work. The methodology (section 4) and the empirical evidence (section 5) follow, and anticipate the final section of conclusions and policy implications.

2. The importance of business innovation modes

The literature on innovation has received a significant boost over the past twenty years when the low cost-based competition has been found no longer appropriate within highly developed economies (Porter, 2008). Innovation is based on knowledge generation processes that are developed by scientists within universities, private research centers, technology centers (and in R&D departments within large firms). However, these agents are mostly interested in knowledge, while firms focus on innovation, thus knowledge that produces specific economic returns (Cooke, 2005; Etkowitz, 2012). In recent years, a very dense literature on business innovation modes has arisen as part of the discussion on effective innovation systems, i.e. as a means to understand what strategies firms based in specific innovation systems adopt to transform knowledge into innovation and economic performance.

This literature derives from the literature on innovation system which focuses on the impact that specific cultural, institutional, social and even organizational contexts produce on the innovation modes adopted by businesses (Asheim and Gertler, 2005; Boschma, 2005; Cooke et al. 2004; Isaksen and Trippl, 2016; Zukauskaite et al., 2017). This might be approached from both national and regional perspectives, as for a few economies the country perspective is quite comprehensive (i.e. smaller and homogeneous countries), while in others the regional heterogeneity is significant and needs to be taken directly into account (e.g. Italy, Spain, France, the US). For instance, business systems where individuals have a strong entrepreneurial drive will tend to reach out to universities directly (e.g. the Anglo-Saxon market-coordinated system), while systems where institutions and public organizations take the lead are likely to expect public-private intermediary organizations to support university-industry collaborations towards higher innovation outputs (Asheim et al., 2019; Cooke, 2004).

Within this new strand of the literature on business innovation modes, the first seminal work was developed by Jensen, Johnson, Lorenz and Lundvall (2007), who argued that such business innovation modes are typically anchored to their innovation systems that are characterized by a peculiar culture and style of producing innovation. In practice, they identified specific modes that are rooted either in an intensive investment in R&D expenditure and qualified/scientific human capital (the Science and Technology-based Innovation – STI) that tends to exploit specific knowledge bases (analytical), or in an intensive use of experience and interaction through learning-by-doing, by-using and by-interacting (DUI mode), and that often exploit synthetic knowledge bases (Asheim and Coenen, 2006). In the selected context of Denmark, they also identified a third combined mode (STI+DUI) that delivered the highest outcome in terms of more radical innovations.

From then onwards, a number of studies focused on this research question with the attempt of refining the first and seminal analysis through various country applications (Amara et al., 2008, on Canada; Chen et al., 2011, on China; Isaksen and Karlsen, 2010; Fitjar and Rodriguez-Pose, 2013, and Haus-Reve et al., 2019, on Norway; Trippl, 2011, on Austria; Isaksen and Nilsson, 2013, on Sweden; Parrilli and Elola, 2012, and Parrilli and Alcalde, 2016, on Spain; Nunes and Lopez, 2015, on Portugal; Apanasovich et al., 2016 and 2017, on Belarus; Thoma, 2017, on Germany; Trott and Simms, 2017; and Lee and Miozzo, 2019, on the UK). All these studies identified a number of peculiar research objectives, and methodological strategies that contributed to a more thorough understanding of this research area.

Most of these studies focused on product and process innovation (Amara et al., 2008; Chen et al., 2011; Fitjar and Rodriguez-Pose, 2013; Jensen et al., 2007; Nunes and Lopez, 2015; Parrilli and Elola, 2012). Only recently, a new wave of studies addressed a wider innovation spectrum, which includes commercial and organizational innovations (Apanasovich et al., 2016; Parrilli and Alcalde, 2016; Thoma, 2017), and service-based innovations (Lee and Miozzo, 2019). More specifically, in the context of Spain, Parrilli and Alcalde (2016) identified the importance of technological and cultural nuances of innovation. In practice, product and process innovations rely very much on STI drivers, whereas commercial and organizational innovations rely more on DUI drivers. This result was expected in the case of commercial and organizational innovation, while it is more debated for process innovation that is traditionally linked to user-producer interactions and the role of suppliers across effective production processes (Lundvall, 2007).

One crucial gap in this research field refers to the size of firms and their innovation modes. The aforementioned studies were focused on large country-based datasets or qualitative studies that delivered information about the broad innovation patterns adopted by undifferentiated set of firms. Not much emphasis has been given to the importance of different firm sizes for different types of innovation drivers and modes (i.e. internal and external STI and DUI). Only studies on Canada (Amara et al., 2008), Germany (Thoma, 2017), Spain (Parrilli and Elola, 2012) reported results about the relevance of a specific innovation mode across smaller firms -as an homogeneous group-, and yet delivered contrasting outcomes. Yet, several questions are still open, such as whether these findings can be verified and systematized across several country settings, whether internal and external DUI and STI drivers equally matter for any firm size, and what is their effectiveness in generating all types of innovation. As part of an ongoing debate (Nieto and Santamaria, 2010, vs. Damanpour, 2010; Thoma, 2017), we consider that firms of different size are likely to show distinct behavior and performance. Moreover, the results might be different from the typically expected direction (i.e. SMEs relying on the DUI mode). This is analyzed in the next section.

3. Firm size and innovation modes

Since Schumpeter's Mark II (1942), there is an expectation that large firms lead innovation through their superior capacity to invest in R&D activities and develop innovations (Rochina et al., 2010; Shefer and Frenkel, 2005). Nevertheless, also small firms are able to benefit from R&D activities (Love and Roper, 2015; Revilla and Fernandez, 2012), and yet they are not endowed with such resources to a significant extent (Cowling, 2016). This situation leaves this opportunity to a reduced proportion of SMEs, usually those involved in high-technology industries, such as biotechnology, information technology and software (Linton and Solomon, 2017; Revilla and Fernandez, 2012).

A set of activities are thought to be leading to a growing innovation capacity, such as human capital, R&D expenditure, design capacity, access to finance, and intellectual property protection (Love and Roper, 2015). These factors are more accessible to large firms than to SMEs, thus a question arises about the drivers that bolster SME innovation output. Since small firms engage in R&D activities to a lesser extent than larger firms, they are more likely to rely on other drivers, such as the close interaction with supply chain partners, i.e. clients and suppliers (Becattini et al., 2009; Jensen et al., 2007; Love and Roper, 2015; Radicic et al., 2019) and with the broader system of innovation (Asheim et al., 2011; Cooke, 2001; 2004; Lundvall, 2007).

This argument and related discussion has generated the growing literature on STI and DUI innovation modes. The general understanding is that, based on the aforementioned constraints, SMEs mostly adopt the DUI innovation mode (Amara et al., 2008; Thoma, 2017; Trott and Simms, 2017). However, this may happen in spite of the potentially low innovation output produced by such a traditional mode of innovation (Parrilli and Elola, 2012). The literature on innovation modes has not measured the most effective innovation mode in relation to firm size categories, and its effective impact on innovation output. Additionally, the strand of literature on innovation modes has not focused on assessing the effectiveness of internal and external drivers of STI and DUI innovation modes within different types of firm. As a consequence, there is a gap that deserves further study as it may help scholars to provide a valuable assessment of the innovation modes adopted by SMEs. It would also help policy-makers to draw relevant policy implications to set up programs that bolster SME innovation capacity.

This task is particularly relevant for SMEs, which represent the majority of firms in any country, but that are hardly considered leaders of innovation and development in any context. The ancient industrial policy oriented to promote "national champions" is still alive (Falck et al., 2011). This situation grants additional instruments to large firms, while neglecting smaller firms. As a matter of fact, the very large majority of firms are micro and small enterprises. Data in Table 1 justify the concern about the role of SMEs, and justify studies on their contribution to innovation and competitiveness within national and global markets.

INSERT TABLE 1 HERE

The size of these enterprises implies peculiar dynamics that need to be assessed and interpreted. According to the literature, SMEs are disadvantaged in relation to their access to finance and the possibility of investing resources in R&D departments, infrastructures and human capital (Cowling, 2016; Love and Roper, 2015; Radicic and Pugh, 2017). However, they tend to benefit from embedding in local economies as they know most local agents and develop interactive innovation practices along the supply chain (Amara et al. 2008; Cooke, 2001; Nieto and Santamaria, 2010). On these bases, we make a set of considerations on the most effective innovation modes that are applied by different firm size categories.

In particular, we separate the analysis of micro and small firms from medium-sized firms because we argue that medium-sized firms have changed their nature and competitiveness over the past decades and have become less homogeneous vis-à-vis smaller firms (Coltorti et al., 2013). They have become more autonomous companies with a size that allows them to invest in R&D resources, and to extract relevant innovation output. Based on this argument, we formulate different hypotheses for these groups of firms.

Micro and small enterprises can be more homogeneous among themselves, and yet are quite an heterogeneous segment. Some are traditional retail shops or service providers (e.g.

hairdressers) or typical manufacturing companies (e.g. small component suppliers for larger firms in the automotive industry), others are knowledge-intensive business services (e.g. advertising and logistics services), while some are also high-technology-based (e.g. university spinoffs in biotech and ICT industries). In the first two cases, they are not much involved in innovation activities - apart from having one or few people dedicated to design activities, to test new specifications sent by their clients (Radicic et al., 2018; Spithoven et al., 2010). This situation changes for the second group of firms that operate in high-technology industries or KIBS that are more likely to invest resources in R&D and human capital (Love and Roper, 2015; Revilla and Fernandez, 2012). In these cases, they can benefit from a STI approach that is focused on elaborating innovative products (e.g. software and drugs) for large lead companies (e.g. pharmas). However, it is fair to say that the latter are likely to still represent a reduced proportion of micro and small firms that populate the European and US geography (although in the most advanced countries/regions this proportion is becoming highly significant). For the purpose of this study, focused on broad trends across firm sizes in Europe and the US, the large majority of micro and small firms is expected to come from the first group of (more traditional) enterprises.

More commonly, SMEs produce incremental innovations that respond to technical specifications requested by their main clients (Radicic and Djalilov, 2019; Radicic et al., 2018). For this they benefit from collaborations with other firms in the supply chain as well as through learning from internal practice, i.e. learning-by-doing (Amara et al., 2008; Jensen et al., 2007; Thoma, 2017). The limited resources they devote to R&D activities are likely to produce a smaller impact on innovation. In relation to the use of external STI drivers, as the theory on innovation systems suggests, there is certainly a potential for collaboration with universities and other science-based -organizations (Cooke, 2001; Isaksen and Karlsen, 2010; Lundvall, 2007). However, in practice, there are significant reasons that imply a less than satisfactory relationships between micro/small firms and science and technology agents that is explained by clashing objectives in terms of confidentiality of innovation, duration of the collaboration, financial budget, among other issues (see Bennat and Sternberg, 2020: 329-330). For these reasons, we formulate the following hypotheses:

H1a: Micro and small firms (MSEs) benefit from the application of the DUI innovation mode through the use of both internal (i.e. joint contribution of employees and managers) and external drivers (i.e. collaborations with clients and suppliers).

H1b: On average, micro and small firms do neither benefit from the application of internal STI drivers (R&D expenditure), nor from collaboration with external STI sources (e.g. universities). No positive impact is expected on innovation outputs.

We purport a different perspective for *medium-sized enterprises* as their specific dynamic has changed over time. Medium-sized firms are different from most micro and small enterprises as they have become firms with more complex structures and dynamics. In the past decade or so, these firms have built up resources to set up their own R&D facilities with specialized personnel (Coltorti et al., 2013; Prajogo et al., 2013). The case of the Sassuolo ceramic tile district is an example of this changing pattern (Russo, 2004). They are also likely to work with specialized agents of the innovation system to acquire ideas and advanced technological knowledge for innovation (Cooke, 2001; Lundvall, 2007; Russo, 2004). These firms are often first or second-tier suppliers within global and national value chains, and benefit from effective supply chain coordination (external DUI driver) and a wider set of internal DUI drivers, such as training and development that also bolster their innovation capacity (Amara et al., 2008; Becattini et al., 2009; Thoma, 2017). To a certain extent, we argue that these firms have undergone a structural transformation from the 1970s/1980s homogeneous SMEs of industrial districts (Becattini et al., 2009), and have become more autonomously competitive firms that acquired several features which are typical of large firms. Overall, because of their size, resources and capabilities, medium-sized firms are the kind of enterprise that can benefit most from the application of STI and DUI innovation modes, both internally and externally. For these reasons, we develop the following hypotheses:

H2a: Medium-sized firms adopt effectively the STI innovation mode based on both internal and external drivers, thus having a positive impact on innovation outputs.

H2b: In medium-sized firms, the application of the DUI innovation mode based on both internal and external drivers produces a positive impact on innovation outputs.

Large firms represent a completely different type of companies. They have hundreds or thousands of employees, several plants in a country and across countries, and have the capacity to organize work through divisions that are specialized in specific operations, processes, components and products. Over time, they have been able to apply lean production practices (e.g. JIT, TQM), which are likely to help them to exploit both internal and external DUI drivers, e.g. team work, supply chain collaborations (Dore and Sako, 2012). Yet, large firms operate in both traditional sectors (e.g. retailing, traditional manufacturing), and medium/high technology industries (e.g. automotive, energy, aircraft, and pharma). Their investment in science and technology varies depending on the sector and it is clearly more proactive and pervasive in the second segment of industries. In general, we would expect an emphasis on internal drivers for product innovation, and for process and organizational innovation (Audretsch and Vivarelli, 1996; Love and Roper, 2015). In medium/high technology industries, large firms are likely to invest significant resources in the creation of global innovation networks that effectively contribute to their innovation output (Cooke, 2013; Parrilli, Nadvi and Yeung, 2013), although these tend to include mostly other lead firms rather than universities and technology centres from their own regions and countries. For this reason, we would expect a lower engagement and impact of university-industry (STI) collaborations within their national/regional innovation system. For these reasons, we establish the following hypotheses:

> *H3a: Large firms apply effectively internal STI drivers (R&D activities), while the application of external STI drivers (e.g. collaborations with universities and technology centres) produces no impact on innovation outputs.*
>
> *H3b: Large firms are expected to exploit internal and external DUI drivers effectively, thus producing a positive impact on innovation outputs.*

The above arguments are synthesized in Table 2 below.

INSERT TABLE 2

4. Methodology

4.1 Data

On the afore-mentioned bases and splitting firms into three main categories (micro/small, medium, and large firms), we develop an argument of what we would expect in terms of their innovation mode/strategy. In this case, we need to distinguish clearly between descriptive statistics and inferential statistics for the following reasons. In previous studies, the significance of certain drivers was confirmed, e.g. STI drivers (Parrilli and Elola, 2012) or supply chain relationships for SMEs (Amara et al., 2008; Nieto and Santamaria, 2010). However, the significance might be based on few successful cases (e.g. university spinoffs, biotech or KIBS companies) that are in the position to access to and benefit from unique resources (i.e. R&D, scientific human capital). Yet, most small firms find it difficult to access those resources, whereas they find it easier to keep practicing an interactive (e.g. user-producer) and experience-based mode of innovation that is aligned with the application of DUI drivers. This second type of information is delivered by descriptive statistics (see Table 3).

We use the Flash Eurobarometer 394 - “The role of public support in the commercialisation of innovations” survey, which includes firms from 28 EU Member States, Switzerland and the United States (European Commission, 2014) and covers the period from January 2011 to February 2014. In our analysis, we have included US firms together with European firms. The survey was requested by the Directorate-General for Enterprise and Industry (for methodological details see European Commission, 2014). The sample was selected from an international business database and stratified by size, sector, and country.[1] Different Eurobarometer surveys have been explored in Radicic (2019), who used this same dataset, and Ghisetti (2017), who used Innobarometer 2015 data.

In total, 12,108 firms were interviewed. However, our analysis includes only firms that were innovators. Following Aschhoff and Sofka (2009), in order to mitigate potential selection bias arising from a non-random selection of firms in the sample, we excluded non-innovating firms (defined as “firms that introduce neither technological nor non-technological innovations”), so the final sample amounted to 7,670 innovative firms. In this study, micro-sized firms are defined as those with fewer than 10 employees, small firms with more than 10 and fewer than 50 employees and medium-sized firms with more than 50 and fewer than 250 employees. This definition is also consistent with the new European Commission (2008) guidelines. In our study the first two categories are pulled together based on our arguments and hypotheses (yet for the purpose of full transparency micro and small firms’ empirical evidence is presented separately).

The definition of innovation adopted in the survey is as follows. “Innovation occurs when a company introduces a new or significantly improved good, service, process, marketing strategy or organisational method. A company can develop the innovation itself or acquire it

[1] The database is publicly available at https://www.gesis.org/en/home/.

from other companies or organizations" This broad definition of innovation alignes with the *Oslo Manual* (OECD, 2005), thus encompassing product, process, organizational and marketing innovation.

4.2 Empirical strategy

Our empirical strategy encompasses the use of propensity score estimation, which is motivated by the endogeneity of the STI and DUI modes given the nature of their components, i.e. 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 STI and DUI innovation modes treated those activities as exogenous (Haus-Reve et al., 2019; Love et al., 2014). The former discuss the issue of endogeneity of variables in great detail. 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 in quantitative research. The only solution in this case would be to use a dynamic panel analysis, i.e. the GMM estimator. However, the lack of longitudinal data (see CIS data) is a common problem in innovation studies. If a researcher is bound to use cross-section data, then STI and DUI modes can either be treated as exogenous (see previous studies) or as endogenous (our study).

Matching estimators are based on two identifying assumptions. The first assumption is the conditional independence assumption (CIA) or selection on observables, which posits that the outcome in case of no treatment (Y_0) is independent of treatment assignment, conditional on covariates X (Imbens and Wooldridge 2009). That is,

$$Y_0 \coprod D | X \tag{1}$$

where X represents a vector of covariates and D is the treatment assignment.

The second assumption is associated with the overlap or common support condition, where the estimated propensity scores take values between zero and one (see Equation 2) (Heckman and Vytilacil, 2007). The overlap condition thus implies that both treated and non-treated firms have a positive probability (P) of receiving a treatment (D=1) or not receiving a treatment (D=0).

$$0 < P(D = 1|X) < 1 \tag{2}$$

The treatment of interest is the Average Treatment Effect on the Treated (ATT), which indicates the difference in outcomes of the treated firms with and without treatment and can be written as:

$$ATT = E[Y_1|D = 1] - E[Y_0|D = 1] \tag{3}$$

The first term on the right-hand side of Eq. (3), $E[Y_1|D = 1]$, is the expected outcome for the treated firms conditional on their receipt of a treatment, while the second term $E[Y_0|D = 1]$ is the expected outcome had treated firms not received a treatment. This second term refers to a counterfactual outcome that is not observed but estimated.

Concerning the choice of covariates X, the literature suggests that all observed variables that simultaneously affect treatment assignment and the outcome should be included (Caliendo and Kopeinig, 2008; Steiner et al., 2010). After the selection of matching variables, the next step in the matching protocol is the estimation of the propensity score model either using probit or logit models (Caliendo and Kopeinig, 2008).

Next, we select the matching algorithm. We utilize the Inverse Probability Weighing Regression Adjustment (IPWRA) estimator. The main advantage of the IPWRA estimator is its double robust property. If either the propensity score model (the outcome model) or the treatment model is correctly specified, this estimator will yield treatment effects with a lower bias than will other estimators that are not characterized by the double robustness property. The estimator consists of three steps: first, the propensity score model - the treatment model- is estimated. The dependent variable is the treatment variable and the independent variables are the control (matching) variables, which are explained in detail in next section. As we have five treatment variables, we estimated five propensity score models.[2] Second, the inverse of the estimated propensity scores (probabilities of receiving a certain level of treatment) are used as

[2] The results are not reported but are available upon request.

weights in the regression analysis. Third, for each outcome variable (types of innovation), the ATT is computed as the difference in the weighted averages of the predicted outcomes in treated and untreated firms (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. We report valid standard errors (of the Huber/White/sandwich variety) which take into account that the estimates are computed in a three-step approach (Emsley et al. 2008).

4.3 *Model specification*

Our models include the following binary treatment variables: 1) R&D activity, which represents our internal STI driver[3]; 2) employees and managers contribution to innovation as our internal DUI driver; 3) customers and 4) other firms (suppliers, competitors) as our external DUI drivers; and 5) Higher Education Institutions (HEIs), which represent our external STI drivers. The outcome variables are binary indicators for a range of innovation output indicators – product innovation; process innovation; organizational innovation; and marketing innovation (see Table 3 for variable description and descriptive statistics).

INSERT TABLE 3 HERE

To account for firm and market characteristics, we include the following control (matching) variables.[4] Firms' exporting activities (variable *Exports*) are measured as a percentage of firms' total revenues that come from sales in foreign markets (Aschhoff and Sofka, 2009; Guerzoni and Raiteri, 2015). We also specify a binary indicator for firms that belong to an enterprise group (Czarnitzki and Lopes-Bento, 2014). The variable *Young* is equal to 1 if a firm was established after January 2008, and zero otherwise. This variable is included to control for business experience, which may affect the innovation endeavour of SMEs (Reis and Cabral, 2015). We also control for firms' patent application (a binary indicator *Patents*

[3] For each treatment variable, the treated firms have the value of treatment equal to 1, while untreated firms have the value of zero (see Table 2 for variable description).
[4] These control (matching) variables are used in the estimation of the propensity score, which is the first step of matching estimator (see Section 4.3 below).

equal to 1 if a firm applied for one or more patents or trademarks since January 2013, and zero otherwise). Patents are regarded as an intermediate innovation outcome.

Country effects are captured by four dummies for "Innovation leaders" country group, "Innovation followers", "Moderate innovators", and "Modest innovators" ("Moderate innovators" are the base category) according to the European Innovation Scoreboard (European Commission 2014) (see Table 2 for the list of countries in each group).[5] To control for industry effects, we utilized the already-created variable in the dataset dividing industries into four categories: manufacturing (NACE category C); retail (NACE categories G); services (NACE categories H, I, J, K, L, M, N, and R); and industry (NACE categories D, E, and F). The base category is manufacturing.

Models that evaluate the impact of sources of ideas for innovation other than R&D activity include *R&D activity* as an additional matching variable. Czarnitzki and Lopes-Bento (2014) and Radicic and Pugh (2016) note that the inclusion of the innovation input indicator, such as R&D expenditures, enables the matching algorithm to find suitable matches between firms at different treatment levels, but with the same level of investment in R&D.

5. Empirical results and discussion

5.1 Main Findings

The descriptive statistics illustrate the relation between the adoption of innovation practices and firm size. Large firms show the highest percentage in all STI and DUI drivers apart from collaboration with customers. In the latter, the relation is inverted as the microenterprises are those that manifest the highest use of customer collaboration. In relation to innovation output, large firms show higher values that depend on higher investment in the aforementioned set of drivers.

In the following part, we investigate segmented data about micro, small, medium and large firms in order to identify the impact on innovation produced by internal and externally-based STI and DUI drivers.

INSERT TABLE 4 HERE

[5] The European Innovation Scoreboard publishes the average innovation performance based on a composite indicator, encompassing 25 individual indicators. Innovation performance of each Member State is then compared to the average innovation performance of 28 EU Member States.

The upper panel in Table 4 shows interesting findings about the impact of innovation modes on innovation performance among *micro and small enterprises (MSEs)*. Here, all types of internal and external innovation drivers deliver positive impact on most innovation outputs. However, some nuances shall be made on the impact of HEI collaborations, particularly across micro enterprises. These results are important as they show the capacity of MSEs to take a wide approach to innovation. In terms of individual drivers, the internal DUI and STI drivers are the most impactful. This indicates the importance of internal resources for innovation across MSEs. The traditional emphasis given to clustering and network divisions of labour across SMEs needs to be combined with the critical role of internal resources and capabilities, which define the innovation capacity of these firms. Surprisingly, the impact generated by internal STI drivers (R&D activity) is significant across MSEs. This is a confirmation of the effectiveness of smaller firms not only in production, but also in innovation (Chen et al., 2011; Nunes and Lopes, 2015; Parrilli and Elola, 2012). However, this is not an indication that most small firms use R&D. Instead, it means that those MSE that use such factors effectively innovate. This finding sets a relevant indication for the innovation strategy that many other MSE can implement in the future.

As expected from the literature on industrial districts (Becattini et al. 2009), the supply chain-based drivers matter for MSEs, as both customers and suppliers show a positive and significant impact on all types of innovation. Instead, collaboration with higher education institutions (HEIs) is more nuanced, as it generates positive impact on some types of innovation, but no significant impact on product, organizational and marketing innovation in microenterprises, and process and marketing innovation across small firms. This finding indicates significant margins of improvement in the collaboration of MSE with agents of the innovation system (Fritsch and Slavtchev, 2011; Isaksen and Trippl, 2016; Parrilli et al., 2010). Based on these results hypothesis H1a is confirmed to a large extent, while H1b is not supported.

Medium-sized firms show an innovation pattern that improves even further the successful approach adopted by MSEs, in particular in relation to the collaboration with science and technology organizations which is generally successful. Also in this case there is a clear prominence of internal STI and DUI drivers, while external STI and DUI drivers are also positively and significantly correlated. This outcome generally supports hypotheses H2a and H2b, and justifies the view that medium-sized firms are the best performers in terms of the use of internal and external STI and DUI drivers. Specifically, the internal DUI drivers are the most impactful determinants of innovation outputs. The internal STI driver is also significant and shows the importance of investments and resources internally devoted to innovation activities (Colforti et al., 2013; Russo, 2004). In relation to external collaboration, medium-sized firms are able to exploit both DUI and STI drivers that generate a positive and significant impact on innovation outputs. This is not happening in process innovation, where only R&D activities and the contribution of all employees matter. This latter innovation takes place mostly within the firm, thus making medium-sized firms similar to large companies. Apart from this case, HEIs have a significant impact on all types of innovation. This indicates the structured nature of medium-sized firms and their capacity to interact with all agents -including the universities- as a means to bolster their innovation capacities (Asheim and Gertler, 2005; Cooke, 2001). They represent the type of firm that exploit the resources of the system to the highest extent, in addition to exploit their own resources.

The case of *large firms* is quite singular. The impact of external STI drivers is significantly less prominent than in the case of SMEs. The collaboration with HEIs works extremely well for organizational innovation. It may be related to the growing training programmes universities organize for large corporations. However, HEI do not produce impact on all the rest of innovation outputs (product, process, marketing and innovation sales). Instead, R&D activity matters for all types of innovation output (Love and Roper, 2015). In general, these results confirm hypothesis *H3a*. DUI drivers matter in a more selective form. The internal DUI drivers matter substantially for all types of innovation. The external DUI drivers matter in a varied form; suppliers matter in all cases apart from organizational innovation, while customers are relevant only for product and marketing innovations. In general, these findings broadly support hypothesis *H3b,* which is aligned with previous analyses focused on large corporations (Dore and Sako, 2012).

5.2 Overall discussion

The most general outcome of this study is the higher impact of internal STI and DUI drivers on innovation outputs. This seems to be working across all firm sizes. It is an insightful outcome as one could expect it for large, and perhaps also for medium-sized firms, but to a much lower extent for MSE as these have few resources to devote to impactful R&D activities, and in addition, depend a lot on the "sole entrepreneur" (and family) that often drives the company business in a top-down style (Keliher and Reinl, 2009). These findings add nuances to the literature on clustering that typically connects the strength of SMEs to their external supply chain-based or innovation system-based linkages and cooperation (Becattini et al., 2009; Piore and Sabel, 1984; among others).

When focusing on the core aspect of this work (firm size and innovation), we observe rather intriguing results on large firms. These indicate lower capacity of large firms to benefit from some STI or DUI drivers, especially external drivers (i.e. HEI contribution and customers). This implies ineffectiveness of large firms in working with supply chain agents (i.e. customers) and with innovation agents (e.g. universities). They mainly centre their efforts on their internal resources and capabilities, while pay less attention to synergies and coordination with external agents (apart from organizational innovation).

In contrast, the other very singular result is the high capacity of SMEs to exploit the adoption of STI and DUI drivers both internally and externally. Rather unexpectedly (see discussion related to hypothesis H1b), MSEs exhibit the capacity to extract significant value from their (limited) internal innovation efforts (R&D expenditure –Revilla and Fernandez, 2012, as well as managers' and employees' contribution to innovation) in which one would expect them to be weaker (Kehliher and Reinl, 2009). It is an original result that supports a proactive approach to private and public funding channels for internally- and externally-based R&D (Revilla and Fernandez, 2012; Cowling, 2016). Simultaneously, they show some margins for upgrading their collaboration with universities. This raises the issue of the efficiency of the innovation systems that are supposed to support SMEs' innovation capacity (Fritsch and Slavtchev, 2011).

Medium-sized firms are the most complete type of firms as they exhibit a well-rounded approach to innovation based on internal and external STI and DUI drivers applied effectively (Coltorti et al., 2013; Prajogo et al., 2013; Russo, 2004). This shows the transformation that medium-sized firms underwent vs their traditional homogenization within the SME category. They tend to upgrade and acquire higher capabilities relative to both smaller and larger companies. Overall, these findings show that SMEs are part of effective supply chains, and that the private sector works rather efficiently (Amara et al., 2008; Parrilli and Alcalde, 2016; Thoma, 2017). This represents a new lesson to learn and to incorporate in any policy plan for the promotion of SME innovation capacity.

This set of results is useful to understand that SMEs have their specific innovation patterns vis-à-vis large firms. They tend to rely much more on the wide supply chain agents as well as on agents of the innovation system (i.e. universities). This result is aligned with the literature on innovation systems that recognize the role of these systems as a critical means that SMEs use to innovate and compete in open markets (Asheim et al., 2011; Cooke, 2001; Lundvall, 2007). In stark contrast with this literature, the evidence suggests that SMEs are also extremely effective in the use of internal resources.

For long time, scholars have stressed the inefficient work of supply chains and innovation systems, while we find evidence that support the effectiveness of SMEs –and particularly of medium-sized firms- in these chains and systems. Overall, these findings show a convergence process in which SMEs grow and become reliable actors of economic development, and in the near future, strong partners of large firms for the expansion of economic systems in Europe and the US. Table 5 presents our key findings. The expected signs are respected in all cases apart from the two grey boxes that show the overachievement of micro/small firms in relation to internal STI drivers, and a certain underachievement in the use of external STI drivers.

INSERT TABLE 5 HERE

6. Conclusions

In this study we have investigated how effective STI and DUI innovation modes are in increasing innovation performance across firms of different characteristics, particularly firm size. This literature is focused on understanding whether science and technology-based (STI) drivers are as or more effective in generating innovation output than drivers based on learning-by-doing and by-interacting (DUI). We have added two novelties in this literature. On the one hand, we have considered whether this impact is different depending on firm size, in a query that includes questioning the traditional homogeneity of small and medium-sized firms. On the other, we have studied the importance of internal and external STI and DUI drivers as a means to understand whether these firms make an effective use of them.

Our results show that MSEs use effectively all innovation modes, with some nuance on external STI drivers, and a strong effectiveness in exploiting internal STI drivers (i.e. R&D and contribution from employees), which implies that they have enough absorptive capacity to make it work (Cohen and Levinthal, 1990). This outcome exhibits how these firms contribute to innovation based on their interactive and practice-based approach (Acs et al., 2017;

Becattini et al., 2009; Love and Roper, 2015), and to a lesser extent through their connection with regional innovation agents (Asheim et al., 2011; Cooke, 2001; Lundvall, 2007).

Medium-sized firms show a more complete approach to innovation in which they exploit both internal and external STI drivers. Simultaneously, they show a significant capacity to benefit from internal and external DUI drivers in a similar way to micro and small firms (Coltorti et al., 2013; Prajogo et al., 2013), and to a larger extent than large firms. These results are important because they query the traditional homogeneity of the SME segment of enterprises. Medium-sized firms are outstanding, and so represent a new potential leader of growth within regional and national economies (Russo, 2004).

Large firms look more selective, and perhaps more inefficient. In particular, they do not benefit much from external STI collaborations with HEIs. A preliminary interpretation points at their strong reliance on their internal resources, and perhaps on the rising trend of large companies investing in the formation of global innovation networks with other lead corporations (Cooke, 2013; Parrilli et al., 2013). Moreover, large firms benefit strongly from internal STI drivers (Audretsch and Vivarelli, 1996), internal DUI drivers, and external DUI/supply chain collaborations (Dore and Sako, 2012), although selectively as they work with suppliers, while being more selective vis-à-vis their customers.

These outcomes stress the set of policies that could be arranged to respond to the features of these firms, particularly SMEs. Those SMEs that apply internal STI drivers are rather effective in generating innovation, thus campaigns and training programmes could be organized so as to improve the absorptive capacity of a larger number of SMEs. Medium-sized firms can be the new leaders of local economic development, thus both local authorities and national policy-makers could design more thorough cluster-led and innovation system-led programmes focused on their role as supply chain leaders. This is a way to reaffirm a stronger focus on place-based development and innovation policies (Asheim et al., 2011; 2017; 2019; Isaksen and Trippl, 2016), with the added knowledge that this specific actor of local development can drive the competitiveness of locally-based supply chains supported by many MSEs.

Further research is required in this field so as to understand the opportunities for regional development offered by such proactive SMEs. More research is required to understand whether large firms can benefit from a deeper involvement with HEIs. They remain leaders of innovation also thanks to both their internal resources, and the exploitation of their new global innovation networks (Cooke, 2013; Parrilli et al., 2013), although they tend to disconnect from regional innovation agents, thus do not promote an effective collaboration with most SMEs and their regional economy. Further research on business innovation modes should be reconnected more explicitly to the wider literature on innovation systems from which it derives as a means to investigate the relevance of the spatial dimensions of knowledge sourcing (i.e. regional, national and global) acquired through their external STI and DUI drivers. In addition, based on a current debate on the complementarity or substitutability of STI and DUI modes (Jensen et al., 2007; Parrilli and Alcalde, 2016; Haus-Reve et al., 2019; Thoma and Zimmerman, 2019), future research could explore the use of a Qualitative Comparative Analysis (QCA) to infer which combination of STI and DUI innovation modes contributes most to firms' superior innovation performance.

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Table 1: Number of firms, employment and value added in Europe (2013)

	Micro firms	Small firms	Medium-sized firms	SMEs (Total)	Large firms	Total
No. Firms	18,783,480	1,349,730	222,628	20,355,839	43,454	20,399,291
%	92.1	6.6	1.1	99.8	0.2	100
Employment	37,494,458	26,704,352	22,615,906	86,814,717	43,787,013	130,601,730
%	28.7	20.5	17.3	66.5	33.5	100
Employment/firm	2	20	102	4	1018	6
Value added (Million €)	1,242,724	1,076,388	1,076,270	3,395,383	2,495,926	5,891,309
Value added (per firm)	66,160	797,483	4,834,387	166,801	57,438,348	288,799

Source: European Observatory of SMEs, 2013: 10.

Table 2: Innovation mode adoption and impact across different sizes of enterprises

	Innovation output in micro and small firm	Innovation output in medium firms	Innovation output in large firms
Internal STI drivers	=	+	+
External STI drivers	+	+	=
Internal DUI drivers	+	+	+
External DUI drivers	+	+	+

Source: own elaboration.

Table 3. Variable description and summary statistics.

Variables	Variable description	Micro firms	Small firms	Medium-sized firms	Large firms
		Mean (standard deviation)	Mean (standard deviation)	Mean (standard deviation)	Mean (standard deviation)
Treatment variables (STI and DUI innovation modes)					
R&D activity	DV = 1 if a firm carried out R&D either in-house or by subcontracting since January 2011; zero otherwise	0.176 (0.381)	0.273 (0.445)	0.383 (0.486)	0.559 (0.497)
Source-employees and managers	DV=1 if a firm responded that its employees or managers "Contributed a lot" or "Contributed a little" to the development of the ideas for the company's innovations since January 2011; zero otherwise	0.536 (0.499)	0.675 (0.468)	0.740 (0.438)	0.844 (0.363)
Source-other firms	DV=1 if a firm responded that other firms "Contributed a lot" or "Contributed a little" to the development of the ideas for the company's innovations since January 2011; zero otherwise	0.510 (0.500)	0.540 (0.499)	0.608 (0.488)	0.687 (0.464)
Source-HEIs	DV=1 if a firm responded that universities or research organisations "Contributed a lot" or "Contributed a little" to the development of the ideas for the company's innovations since January 2011; zero otherwise	0.137 (0.340)	0.189 (0.392)	0.283 (0.450)	0.487 (0.500)
Source-customers	DV=1 if a firm responded that individual customers "Contributed a lot" or "Contributed a little" to the development of the ideas for the company's innovations since January 2011; zero otherwise	0.478 (0.500)	0.413 (0.493)	0.339 (0.474)	0.395 (0.489)
Outcome variables					
Product innovation	DV =1 if a firm introduced new or significantly improved goods or services since January 2011; zero otherwise	0.483 (0.500)	0.577 (0.494)	0.611 (0.488)	0.740 (0.439)
Process innovation	DV =1 if a firm introduced new or significantly improved processes (e.g. production processes or distribution methods) since January 2011; zero otherwise	0.240 (0.427)	0.370 (0.483)	0.473 (0.499)	0.617 (0.486)
Organizational innovation	DV =1 if a firm introduced new or significantly improved organizational methods (e.g. knowledge management or the workplace organisation) since January 2011; zero otherwise	0.244 (0.429)	0.355 (0.478)	0.433 (0.496)	0.529 (0.500)
Marketing innovation	DV =1 if a firm introduced new or significantly improved marketing strategies since January 2011; zero otherwise	0.259 (0.438)	0.347 (0.476)	0.368 (0.482)	0.394 (0.489)
Innovative sales	=0 if a firm responded "0%" to the question: "Approximately what percentage of your company's turnover in 2013 was due to innovative goods	1.203 (0.878)	1.155 (0.769)	1.121 (0.645)	1.110 (0.580)

	or services that have been introduced since January 2011?"; = 1 if a firm responded "Between 1 and 25%"; =2 if a firm responded "Between 26 and 50%"; =3 if a firm responded "Between 51 and 75%"; =4 if a firm responded "Between 76 and 100%"				
Control (matching) variables					
Young	DV = 1 if a firm was founded after January 2008; zero otherwise	0.201 (0.401)	0.093 (0.290)	0.045 (0.207)	0.030 (0.171)
Export	Percentage of firms' total revenues from selling goods and services abroad in 2013	6.151 (19.089)	12.687 (26.261)	22.892 (33.450)	29.007 (37.792)
Patents	DV = 1 if a firm applied for one or more patents or trademarks since January 2011, zero otherwise	0.042 (0.201)	0.086 (0.280)	0.152 (0.359)	0.311 (0.463)
Leaders	DV=1 if a firm is located in Denmark, Finland, Germany, Sweden, Switzerland and USA; zero otherwise	0.219 (0.413)	0.211 (0.408)	0.213 (0.409)	0.277 (0.488)
Followers	DV=1 if a firm is located in Austria, Belgium, Cyprus, Estonia, France, Ireland, Luxembourg, Netherlands, Slovenia and United Kingdom; zero otherwise	0.299 (0.458)	0.320 (0.467)	0.331 (0.471)	0.305 (0.461)
Moderate innovators	DV=1 if a firm is located in Croatia, Czech Republic, Greece, Hungary, Italy, Lithuania, Malta, Poland, Portugal, Slovakia and Spain; zero otherwise	0.375 (0.484)	0.380 (0.485)	0.356 (0.479)	0.314 (0.465)
Modest innovators (base category)	DV=1 if a firm is located in Bulgaria, Latvia and Romania; zero otherwise	0.107 (0.309)	0.089 (0.285)	0.100 (0.301)	0.104 (0.305)
Manufacturing (base category)	DV=1 if a firm operates in the NACE category C; zero otherwise	0.136 (0.342)	0.238 (0.426)	0.347 (0.476)	0.374 (0.484)
Retail	DV=1 if a firm operates in the NACE category G; zero otherwise	0.285 (0.451)	0.248 (0.432)	0.173 (0.378)	0.140 (0.347)
Services	DV=1 if a firm operates in the NACE categories H, I, J, K, L, M, N, and R; zero otherwise	0.358 (0.480)	0.305 (0.461)	0.311 (0.463)	0.325 (0.469)
Industry	DV=1 if a firm operates in the NACE categories D, E, and F; zero otherwise	0.221 (0.415)	0.209 (0.407)	0.169 (0.375)	0.161 (0.368)

Table 4. The Average Treatment Effects on the Treated (ATTs) in micro, small, medium and large firms

Outcome variables	MICRO FIRMS					SMALL FIRMS				
	STI modes		DUI modes			STI modes		DUI modes		
	R&D activity	HEIs	Employees & managrs	Other firms	Customers	R&D activity	HEIs	Employees &managrs	Other firms	Customers
Product innovation	0.318*** (0.017) [0.284, 0.351]	0.033* (0.019) [-0.004, 0.070]	0.723*** (0.012) [0.700, 0.746]	0.067*** (0.014) [0.039, 0.095]	0.066*** (0.014) [0.038, 0.093]	0.267*** (0.018) [0.232, 0.302]	0.073*** (0.017) [0.041, 0.108]	0.723*** (0.015) [0.694, 0.752]	0.072*** (0.016) [0.040, 0.102]	0.045*** (0.016) [0.015, 0.077]
Process innovation	0.271*** (0.019) [0.233, 0.309]	0.088*** (0.028) [0.034, 0.142]	0.395*** (0.012) [0.373, 0.418]	0.063*** (0.019) [0.027, 0.099]	0.072*** (0.018) [0.036, 0.107]	0.231*** (0.020) [0.191, 0.271]	0.044* (0.027) [-0.009, 0.095]	0.490*** (0.013) [0.465, 0.515]	0.064*** (0.021) [0.026, 0.107]	0.061*** (0.021) [0.018, 0.099]
Org. innovation	0.188*** (0.019) [0.149, 0.225]	0.040 (0.027) [-0.015, 0.093]	0.368*** (0.013) [0.342, 0.394]	0.033* (0.019) [-0.004, 0.069]	0.081*** (0.018) [0.044, 0.115]	0.176*** (0.020) [0.136, 0.215]	0.067** (0.027) [0.014, 0.120]	0.467*** (0.013) [0.442, 0.493]	0.093*** (0.021) [0.050, 0.132]	0.099*** (0.021) [0.058, 0.140]
Marketing innovation	0.194*** (0.019) [0.156, 0.232]	0.047* (0.028) [-0.008, 0.101]	0.394*** (0.013) [0.369, 0.419]	0.082*** (0.019) [0.045, 0.118]	0.118*** (0.018) [0.082, 0.153]	0.186*** (0.020) [0.146, 0.225]	0.016 (0.027) [-0.037, 0.069]	0.456*** (0.013) [0.430, 0.481]	0.013 (0.021) [-0.025, 0.055]	0.123*** (0.021) [0.082, 0.163]
Innovative sales	0.561*** (0.040) [0.483, 0.640]	0.202*** (0.058) [0.089, 0.315]	0.854*** (0.023) [0.809, 0.898]	0.226*** (0.035) [0.158, 0.294]	0.119*** (0.034) [0.053, 0.186]	0.374*** (0.037) [0.300, 0.477]	0.149*** (0.047) [0.056, 0.241]	0.814*** (0.021) [0.773, 0.856]	0.144*** (0.036) [0.073, 0.214]	0.104*** (0.034) [0.036, 0.171]
Outcome variables	MEDIUM FIRMS					LARGE FIRMS				
	STI modes		DUI modes			STI modes		DUI modes		
	R&D activity	HEIs	Employees &managrs	Other firms	Customers	R&D activity	HEIs	Employees & managrs	Other firms	Customers
Product innovation	0.294*** (0.023) [0.249, 0.340]	0.075*** (0.019) [0.036, 0.112]	0.764*** (0.014) [0.737, 0.792]	0.052** (0.020) [0.012, 0.091]	0.092*** (0.020) [0.053, 0.131]	0.174*** (0.033) [0.109, 0.239]	0.026 (0.030) [-0.032, 0.082]	0.837*** (0.021) [0.804, 0.883]	0.112*** (0.035) [0.039, 0.179]	0.057** (0.028) [0.003, 0.111]
Process innovation	0.253*** (0.025) [0.203, 0.303]	0.038 (0.028) [-0.017, 0.092]	0.574*** (0.017) [0.540, 0.609]	0.044* (0.025) [-0.004, 0.094]	0.025 (0.026) [-0.025, 0.076]	0.168*** (0.044) [0.082, 0.254]	-0.001 (0.041) [-0.086, 0.075]	0.701*** (0.021) [0.684, 0.760]	0.092** (0.043) [0.009, 0.181]	0.042 (0.039) [-0.034, 0.118]
Org. innovation	0.168*** (0.027) [0.116, 0.220]	0.082*** (0.031) [0.023, 0.143]	0.540*** (0.015) [0.511, 0.569]	0.081*** (0.027) [0.029, 0.134]	0.101*** (0.027) [0.049, 0.153]	0.087* (0.050) [-0.010, 0.184]	0.135*** (0.050) [0.031, 0.240]	0.602*** (0.024) [0.575, 0.658]	0.071 (0.050) [-0.026, 0.658]	0.047 (0.043) [-0.037, 0.132]
Marketing innovation	0.133*** (0.026) [0.081, 0.184]	0.071** (0.031) [0.010, 0.131]	0.459*** (0.015) [0.430, 0.489]	0.067** (0.026) [0.015, 0.119]	0.181*** (0.027) [0.129, 0.233]	0.166*** (0.048) [0.073, 0.259]	0.077 (0.050) [-0.023, 0.177]	0.472*** (0.021) [0.426, 0.509]	0.103** (0.051) [-0.001, 0.201]	0.178*** (0.043) [0.093, 0.262]
Innovative sales	0.322*** (0.044) [0.235, 0.409]	0.170*** (0.044) [0.084, 0.255]	0.814*** (0.021) [0.774, 0.854]	0.120*** (0.038) [0.045, 0.195]	0.119*** (0.039) [0.043, 0.195]	0.210*** (0.073) [0.068, 0.353]	0.051 (0.074) [-0.094, 0.195]	0.853*** (0.031) [0.793, 0.914]	0.227*** (0.071) [0.087, 0.367]	0.066 (0.059) [-0.049, 0.181]

Notes: Robust standard errors in parentheses; ****p<0.01; **p<0.05; * p<0.10*.

Table 5: Innovation mode adoption and impact across different sizes of enterprises

	Innovation output in micro and small firm	**Innovation output in medium firms**	**Innovation output in large firms**
Internal STI drivers	+	+	+
External STI drivers	-/+	+	-
Internal DUI drivers	+	+	+
External DUI drivers	+	+	+

Source: own elaboration.