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ABSTRACT: The energy industry is facing substantial challenges that require innovation to be fostered. Nevertheless, levels of R&D investment and innovation remain quite low in comparison with other sectors. In this paper we analyse the main drivers of R&D investment and obstacles to innovation in the energy industry. We examine, firstly, whether the stated R&D objectives pursued by firms play a role in their R&D effort. Secondly, we analyse the effects of financial, knowledge and market barriers on the innovation outcomes of the firms. We rely on data from the Technological Innovation Panel (PITEC) for Spanish firms for the period 2003-2010. We use a structural model with three equations corresponding to the decision to carry out R&D or not, the R&D effort and the production of innovations. The results of the econometric estimations show, first, that R&D intensity is positively related to process innovation. Second, the main barriers that hamper innovation in the energy industry are related to market factors while financial and knowledge obstacles are not significant.

JEL Codes: Q40, O31

Keywords: R&D, innovation, energy, barriers, regulation.

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1. INTRODUCTION

The energy sector is facing major challenges in most of its activities and segments. The main challenges are related to the mitigation of climate change, increasing efficiency and to guaranteeing energy security. Many recent reports and papers (Anadon et al. 2011; Nakicenovic and Nordhaus, 2011; OECD, 2011; Anadon, 2012; IEA, 2012) have stressed that fostering innovation is crucial to meeting these challenges. Nevertheless, the level of R&D investment and innovation in the energy industry remains quite low in comparison with other sectors (GEA, 2012).

Many papers have analysed the R&D determinants and the barriers that firms face in the manufacturing sector (Griffith et al., 2006; Savignac, 2008; Cohen, 2010). In addition some recent papers have examined the effects of the liberalisation and restructuring of the electricity markets on R&D investments (Jamasb and Pollit, 2008; Sanyal and Cohen, 2009; Kim et al., 2012).

Nevertheless, our knowledge of the reasons that explain R&D and innovation in this sector remains scant. The lack of data on R&D activities in the energy industry has made R&D determinants and innovative behaviour in this sector difficult to analyse (Jamasb and Pollit, 2008; European Commission, 2009a; Anadon et al., 2011; Gallagher et al., 2012). Therefore, very few papers have examined the R&D drivers for the energy industry (Salies, 2010; Kim et al., 2012; Sterlacchini, 2012) and, to our knowledge, the effect of the whole set of obstacles to innovation in the energy industry has not been empirically analysed.

The analysis is carried out for energy supply utilities and distinguishes on the one hand those factors influencing the decision about whether to do R&D or not, and on the other, those that affect the relative amount of resources devoted to R&D. In addition, the effects of financial barriers and other obstacles to innovation are examined. In particular, we analyse how the existence of dominant incumbents is affecting innovation. Therefore, the main research questions of this paper are to examine why R&D investment and innovation levels in the energy industry are so low in comparison with other sectors and in what way the peculiarities of the energy industry may be influencing its innovative behaviour.

Innovation in the energy industry may be driven by some specific forces and face specific barriers related to the characteristics of the innovation activities in this industry. Some of the characteristics that may affect the innovative behaviour of the firms and the low level of R&D investment in this sector are the large scale of the R&D projects, the dominance of existing technologies, preference for incremental innovations or the greater size of the firms in this sector that may allow them to overcome financial barriers more easily than firms in other sectors. The identification of the R&D drivers and the factors that hamper innovation in the energy industry has significant policy implications that are important for the design of adequate instruments to incentivize R&D investment in this sector.

The analysis of the drivers that explain business investments in R&D and the obstacles to innovation in the energy industry is carried out taking into account the current competitive situation after the liberalisation reforms. Recent literature shows that there has been a significant reduction in the R&D expenditure of energy firms and that the R&D strategies of firms are more oriented towards increasing efficiency and to short-term objectives (Sterlacchini, 2012). Competition compels firms to provide electricity fulfilling quality and efficiency requirements and the R&D and the innovation effort is related to the realisation of profits and oriented to market objectives.

After this introduction, the paper is organized as follows. The next section provides a brief discussion of the main characteristics and peculiarities of R&D and innovation activities in the energy industry. The third section describes the database, presents the specification of the model and explains the variables used. The fourth section discusses the econometric estimation and presents the estimation results. The paper ends with a concluding section which also presents policy implications and proposals for future research.

2. R&D AND INNOVATION IN THE ENERGY INDUSTRY

The energy industry, despite its importance in the economy, has traditionally shown a low level of expenditure on R&D. Moreover, with the liberalisation process started in the early 1990s there has been a decrease in R&D investments, both in the United States and in the majority of European countries. In addition, this process has brought with it profound changes in the energy industry that have affected the drivers of R&D and the barriers to innovation and, therefore, the R&D investment decisions of firms. The liberalization process in the energy sector was designed to create a new institutional framework to benefit consumers and foster welfare. In a competitive environment, energy is offered in conditions of cost and quality efficiency and these attributes are transferred to the consumer through prices. As Joskow (2008) argues, these benefits can be realized by relying on competitive wholesale markets for power to provide better incentives for controlling the construction and operating costs of new and existing generating capacity, to encourage innovation in power supply technologies and to provide incentives for network operators to deliver appropriate levels of service quality. With retail competition, suppliers are expected to offer an enhanced array of retail service products, risk management, demand management, and new opportunities for service quality differentiation to better match individual consumer preferences.

Under competitive market conditions utilities should reduce costs and adapt to demand. In such a framework, energy firms adopt new competitive strategies focused on efficiency in processes to reduce costs and increase margins, on the one hand, and on differentiation in contracts, on the other, given that energy is a homogenous product (Jamasb and Pollit, 2008). Apparently the only effective competitive differentiation strategies are those based on the type of contract, whether it is on the wholesale market or on the retail market (Salies, 2010). The R&D and innovation projects that take a long time to mature are displaced by those with rapid implementation and returns. In addition, the low growth rate of demand for electricity in OECD countries (IEA, 2012) also forces utilities to give up long-term projects (Jamasb and Pollit, 2008; Salies, 2010). This change in R&D partially explains the lower volumes of investment in the energy sector under competition (Jamasb and Pollit, 2008, Starlacchini, 2012). More importantly, the liberalisation process may have modified the structure of incentives faced by energy firms. Consequently, the level and composition of their R&D expenditures may have been changed both as a response to the new market conditions and to the increased uncertainties imposed by greater competitive pressure.

However, there are some forces that may also foster R&D. Sanyal and Cohen (2009) list the following. First, R&D expenditure increases the firm's absorptive capacity, hence contributing to more efficient R&D projects in the future and to the ability to enjoy benefits from spillovers derived from R&D expenditure by competing firms and even firms in other sectors. Second, firms may conduct research on several technology options and thus increase the research budget. Third, R&D could be a substitute for ordinary investment if it places the firm in a position to invest more rapidly in new technology once the optimal investment strategy is revealed. Finally, in a competitive environment firms will face a situation of relatively more elastic demand, in which the firm knows that a small technological success –and a small price decrease- can represent a large number of new customers.

The market-based model implemented necessarily leads to short-term objectives. In a context in which the new regulatory framework does not allow the recovery of the total costs of long-term R&D; firms will change their objectives and reduce the volume of investment (Sterlacchini, 2012). In competitive conditions utilities try to maximise their profits and increase their market value at the expense of investments with sunk costs or with very long-term returns, such as R&D. Sanyal and Ghosh (2012) calculate that the negative impact of competition on innovation more than compensates for the positive impact derived from the appropriability effect.

Technology and innovation in the energy sector show some peculiarities that make them different vis-à-vis other sectors in the economy. Market failures related with R&D activities are more intense in the energy sector. Indivisibility, spillovers and uncertainty affect energy R&D in a significant way (Jamasb and Pollit, 2008). Salies (2010) argues that the main cause of the decline of R&D in the sector is increased uncertainty that mostly affects investment decisions, an argument raised previously by Dooley (1998). Similarly, the close relationship with the environment explains why investments in R&D in the energy sector produce greater positive externalities than other activities. The existence of spillovers creates problems of appropriability and reduces private incentives for investment (Salies and Nesta, 2010, Salies, 2010; Kim et al., 2012).

The characteristics of competitive energy industries have effects on R&D investments. First, the process of total or partial privatisation has meant the practical disappearance of the old public monopolies. Part of the literature argues that the model of ownership is a significant variable in understanding the causes of the fall in R&D. Sterlacchini (2012) states that in a competitive environment public ownership maintains higher expenditure on R&D since privately owned firms are not able to charge higher prices to recoup their R&D investments. However, Kim et al. (2012) argue that private ownership does not by itself explain the fall in R&D. According to these authors, only when private ownership operates in a liberalised market does privatisation have negative effects on R&D. This supposed interaction between liberalisation and privatisation leads the authors to an implicit defence of private monopolies and the debateable benefits for R&D of the appropriation of monopoly rents. On the contrary it can be argued that public ownership, and especially under monopoly conditions, could provide inefficient R&D financing. The Netherlands Bureau for Economic Policy Analysis (CPB) questions the interpretation of the literature on the evolution of R&D pointing out that, before reform, investment in innovation was inefficient and enjoyed an abundance of resources that were not justified by the objectives achieved. Less R&D is not necessarily the same as a lower degree of dynamic efficiency (Mulder et al., 2006).

Second, the average size of firms is now smaller. This reduction in size is due to unbundling and to the inclusion, in competitive conditions, of new entrants into the wholesale and retail markets. Moreover, the adoption of new technologies for generation has reduced the average size of businesses. Theory generally shows that size is a barrier to entry for R&D (Cohen, 2010). In the case of the energy sector this barrier is more evident as the structure of the market is still very concentrated (Acs and Audretsch, 1987). Sanyal (2007), Sanyal and Cohen (2009), Salies (2010) and Kim et al. (2012) argue that the size of energy firms affects decisions on R&D and the objectives of the projects and find support for the Schumpeterian hypothesis, demonstrating that size positively affects R&D expenditure. In the literature, the only exception is Sterlacchini (2012), who does not obtain significant results for the size variable. Scale appears generally to be associated with the availability of funds for the financing of R&D projects. Bigger firms have greater resources available and make more investments in R&D (Sanyal, 2007), even if this association is not maintained when intensity is considered.

The entry of new agents into the energy industries, characterised by the use of low-emission technologies, has furthered a change in the composition and volume of R&D. This change is mainly associated with the technology mix, which in turn depends heavily on energy policies. Hydraulic energy is related to the development of innovation and the R&D of renewable energies whereas nuclear and fossil energies act as barriers to entry for radical innovations (Markard and Truffer, 2006; Salies, 2010). In other words, the technology mix can deter entry when incumbent utilities concentrate their portfolio on nuclear and fossil technologies. A competitive environment can, thus, have asymmetric effects on innovation by incentivising projects based on renewable and environment-friendly energy while penalising nuclear and fossil energies (Salies and Nesta, 2010). In such a context, incumbents will concentrate their R&D efforts on patenting previous innovations, or alternatively innovation will be targeted towards applications and existing assets (Jamasb and Pollit, 2008).

Faced with the threat of competition, firms adopt new strategies according to the portfolio of the generation mix and the inherent characteristics of the networks. These activities demand a high level of investment in very specific assets with long-term amortisation. Generally, the strategies adopted by firms with regard to their investment projects are determined by the interaction between market failures and their internal resources (Jalivand and Harris, 1984). In this respect, Jalivand and Kim (2012) find, from a sample of US firms in the period 1999-2011, that investment in innovation and R&D is not considered by utilities to be a strategic investment –not even before reform-, in contrast to those in technology-intensive sectors. On the other hand, utilities are characterised by their extensive commitment to capital expenditure investment. Slack resources have been invested in specific assets –generation technologies and networks-, in improvements in the efficiency of functioning technology and in increases in productivity. Results by Jalivand and Kim (2012) suggest a trade-off between investment in specific assets and investment in R&D and that the firm takes into account the opportunity cost of investment in R&D. With the exception of these authors, no other contribution offers significant results in attempting to explain the possible effects of the financing variable on R&D. Wilder and Stansell (1974) observe, previous to reform, that an increase in regulated income did not lead to more investment in R&D, in accordance with the Modigiani-Miller theorem. Salies (2010) and Sterlacchini (2012) obtain similar results. The volume of profits does not have a significant effect on the investment in R&D carried out by utility firms. On the other hand Sanyal (2007) argues that financing does have explanatory power, related to the size of the firm. The availability of financial resources is greater in large firms, more inclined to finance projects internally whereas small and medium-sized firms tend to resort to external financing (Salies, 2010).

The literature distinguishes two types of objectives and projects in energy R&D. The first type of R&D and innovation projects is targeted at immediate applications and short-term returns and is the most frequently carried out by firms. These projects seek to improve the efficiency of the industrial process through incremental innovation or enable innovative technological complementarities that in turn may demand new organisational strategies and the expansion of markets. R&D in smart grids, smart metering and wind and solar energies brings efficiency, greater profitability and short-term competitive reinforcement. R&D in capturing carbon dioxide emitted by thermal power plants also shows the same characteristics as it reinforces the competitiveness of a conventional technology. Salies (2010) also includes hybrid or electric vehicles in this type of R&D. These innovations are incremental and their effectiveness is measured in terms of the improvements in profits within a foreseeable period. In competitive conditions, utilities have reoriented their R&D projects with the objective of consolidating their competitive position in relation to rival firms (Defeuilly and Furtado, 2000).

In contrast, another type of projects is one that requires long periods of research and that contributes potential disruptive innovations directly focused on climate change mitigation –such as fuel cell batteries, tidal turbine systems, storage, and biomass gasification (Salies, 2010)-. Some of these projects require large amounts of resources, scientific knowledge and the transmission of information between the different phases of the industrial process, including the manufacturing of technology. These projects are normally classified as scientific applications and are of a non-commercial nature, even as precompetitive technology. They require public policy for their implementation and public-private partnerships for their development (Newell, 2010; Henderson and Newell, 2011). Hence, in a competitive energy market public support is crucial for R&D projects focused on climate change mitigation given that they have no possibility of being developed privately.

3. DATA AND MODEL SPECIFICATION

The empirical analysis is carried out using the Spanish Technological Innovation Panel (PITEC) for the period from 2003 to 2010. PITEC is the result of collaboration between the Spanish National Statistics Institute and the COTEC foundation aimed at providing data from the Community Innovation Survey (CIS) that is carried out annually following the guidelines of the OECD's Oslo Manual. The PITEC offers comprehensive and detailed information on the characteristics of Spanish firms and their innovative activities. While the CIS dataset offers a cross section, the Spanish PITEC overcomes this drawback by providing panel data. The dataset provides exhaustive information for more than 12,000 firms for the period 2003-2010 and has been frequently used to carry out empirical analyses on innovation (Barge-Gil, 2010; De Marchi, 2012).

Although the PITEC has notable advantages it has some limitations as well. One limitation is that the level of industry disaggregation is at two digits, making it impossible to accurately identify the specific activity of energy companies within the whole group of utilities. In Spain, all the gas and electricity companies are privately owned whereas almost all water companies are public. Hence, to improve the accuracy of the results we have removed firms that were publicly owned from the sample of utilities included in PITEC thus restricting the analysis to the private energy sector. After this filtering process 462 observations are available for energy companies forming an unbalanced panel for the period 2003-2010.

The main characteristics of the firms in the Spanish energy industry (see Table 1 for descriptive statistics) show that they are, with an average size of more than 600 employees, much larger than firms in general. More than half the energy companies (59.1%) reported performing R&D activities and the mean R&D effort is 1.8%. Although process innovation is much more frequent (65.6%) a substantial proportion of firms (39%) has also introduced product innovations. These data show in the same way as recent reports on innovation in the energy industry in Spain (Molero, 2012; Economics for Energy, 2013) that R&D and innovation levels are, similarly to

European countries, low for the size and importance of this sector in the Spanish economy.

TABLE 1

The Spanish energy industry is similar to other European countries. When comparing the wholesale market position of European countries, Spain is close to the average in terms of the number of companies with more than 5% share of generation capacity and the share of the three biggest companies. This is also the case when analysing structural business indicators such as the firms’ turnover and gross value added per employee or the share of personnel costs in production (%) or the investment rates (European Commission, 2009b). In addition, the Spanish electric and gas regulations are totally harmonised with the European norm. The process of liberalisation and the transposition of European energy directives started in 1997. Today, all the transpositions have been completed, and this process has been accompanied by the corresponding modifications in the domestic laws. Unbundling imposes the absolute separation of ownership of the TSO (Transmission System Operator) from the rest of the operators, enforces TPA (third party access) to the networks, and establishes competition criteria between all the participants (with separation of activities) both in wholesale and retail markets. The liberalisation process has reduced the sector's concentration to levels below the EU-27 average and only transport and distribution networks maintain regulated returns, as the European norm establishes.

The model used for the estimation of the determinants of investment in R&D by energy companies is based on the structural model proposed by Crepon et al. (1998). This model, known as CDM, has been used in numerous empirical analyses (Griffith et al., 2006). Specifically, we use the first three equations which model the business decisions relating to R&D and the knowledge produced as a result of this investment. The first equation concerns the firm's dichotomous decision to spend on R&D or not while the second corresponds to the intensity of the total R&D effort or R&D investment function. Finally, the third equation corresponds to the innovation or knowledge production function. Formally:

$$D_{it} = \begin{cases} 1 \; if \; \delta Z_{it} + \varphi_i + \varepsilon_{1it} > 0 \\ 0 \; if \; \delta Z_{it} + \varphi_i + \varepsilon_{1it} < 0 \end{cases} \quad (1)$$

$$R\&D_{it} = \begin{cases} \beta X_{it} + \alpha_i + \varepsilon_{2it} \; if \; D_{it} = 1 \\ 0 \; if \; D_{it} = 0 \end{cases} \quad (2)$$

$$INN_{it} = \gamma R\&D_{it} + \beta W_{it} + \mu_{it} \quad (3)$$

Equations (1) and (2), that are estimated jointly, model the decision to spend on R&D or not and the R&D effort according to a set of explanatory variables -(Z_{it}) and (X_{it}) respectively- which are detailed below. Previous empirical analyses modelling R&D spending in utilities have also considered that research expenditure decisions are a two-step process (Sanyal and Cohen, 2009). Although there is no general consensus in the literature on how to measure either decisions it is considered that the selection equation (1) is a strategic, longer term, to be or not an innovative company, while the second (2) is more focused on the short term, in setting annual or multi-annual budgets to be spent on R&D (Artés, 2009).

In both equations (1) and (2) we include size, age and public funds as explanatory variables. First, firm size is a key variable in any analysis of the determinants of investment in R&D or innovation in general (Cohen, 2010). The expected sign of this variable is positive, since according to the literature for the sector, larger companies are most likely to invest in R&D (Jamasb and Pollitt, 2008; Sanyal and Cohen, 2009; Salies, 2010), despite the competitive pressures that market liberalization has introduced and that would largely relax the Shumpeterian hypotheses. Second, the inclusion of age in the models of determinants of R&D is relatively recent, although the literature has emphasized the importance of new entrants for innovation and economic growth (Baumol et al., 2007). The reason for its omission was the lack of information about age in innovation surveys, which however PITEC does offer. Third, numerous studies have examined the effects of subsidies on the R&D decisions of firms and, in particular, on the possible additionality of public support on private R&D (David et al., 2004). Some papers (Callejón and García-Quevedo, 2005) show that the sectoral reaction to R&D subsidies is not uniform and that while in some cases a significant additional effect occurs, in others the effect is very limited.

In the intensity equation (2), we have also considered foreign capital, cooperation with other firms and institutions and particularly the variables related to the objectives of innovation. Firms may engage in innovation and devote resources to R&D for a number of different reasons. With the inclusion of these variables we are able to examine the relationship between the different forces that drive innovation activity and R&D intensity.

In Technological Innovation Surveys and also in the PITEC, innovative firms are asked to report the relevance and the degree of importance of innovation objectives. Specifically, objectives oriented to product innovation (expansion of the range of goods and services, greater market share) and to process innovation (to increase production capacity, reduction of costs per unit of output) are considered. There are also other innovation objectives considered in the survey that in the energy sector may become relevant. On one hand, those R&D projects aimed at reducing the environmental impact of the activity and on the other hand, R&D projects designed to meet environmental health and safety regulations. In the estimation of equation (2) each of these objectives is measured by a dummy variable indicating whether the firm considers each specific factor to be of high importance.

In the third equation, the knowledge production function, we consider total innovation (process or product) but we also distinguish between these two different kinds of innovation outcome. In the estimations we exclude firms that meet the three following conditions: they have not innovated, they do not perceive any obstacle and state that they do no need to innovate. With this procedure we follow recent literature on barriers and innovation and we consider only firms that are potential innovators, avoiding problems of sample selection (Savignac, 2008; D'Este et al., 2012; Blanchard et al., 2012). The estimations are carried out for the period 2004-2010, instead of 2003-2010, because there is no information for the year 2003 on obstacles to innovation in the survey.

In these estimations we include the obstacles to innovation in the vector of explanatory variables (W_{it}) with the purpose of examining what type of barriers that may hamper innovation are relevant for the energy industry. We control also for the size of the firms and we consider whether the firms belong to a group because this may help them to overcome financial barriers more easily in comparison to an independent firm. In addition and following the proposal of Griffith et al. (2006) we include the predicted value for R&D effort estimated from equation (2). By using this value ($R\&D_{it}$), as explained later, we instrument the R&D effort and take care of possible endogeneity problems.

The main barriers considered in the literature are cost, knowledge and market factors. The first of these, financial constraints, are related to the characteristics of innovation projects like the high degree of uncertainty or the existence of information asymmetries. These market failures may explain the existence of financial barriers and particularly difficulties in obtaining external funding (Hall, 2002). Other factors, more related with a systemic view of innovation, such as the lack of qualified personnel or the lack of demand for innovations may also hamper innovation activity (OECD, 2005; D'Este et al., 2012; Blanchard et al., 2012). The specific characteristics of R&D activities in the energy industry such as the large scale of the projects or incumbent inertia with the dominance of existing technologies (Anadon et al., 2011; OECD, 2011) may explain the influence of specific factors on the decision to innovate or on the expected results of innovation activities.

All the firms, innovative or not, are asked in the PITEC, as in most technological innovation surveys, to report the relevance and the degree of importance of some specific factors that have hampered innovation activities or influenced the decision not to innovate (OECD, 2005). In the estimations we have considered six different factors: cost, knowledge, market dominated by established firms, uncertain demand, no need to innovate due to prior innovations and no need to innovate because of a lack of demand for innovations. Each of these barriers is measured by a dummy variable indicating whether the firm considers the specific factor to be of high importance.

In addition to the explanatory variables, in the equations we take into account time-invariant and unobservable specific firm characteristics and time effects in order to control for possible shocks arising from changes in the volatile economic cycle covered in the analysis and regulatory changes that have occurred in the sector and that may have had an effect on the R&D and innovation behaviour of energy companies as well.

4. ESTIMATION, RESULTS AND DISCUSSION

Most of the empirical work on the estimation of the impact of innovation on productivity has relied on the CDM model explained schematically in the previous section. This model is essentially a recursive system in which a first block explains both the probability of doing R&D and the intensity of the R&D undertaken; and a second block analyses the probability of being innovative, and the extent of product and/or process innovation. Finally, a third block (not estimated in this paper), uses the innovation output and other explanatory variables in order to estimate a productivity equation.

Generally, the model is static and unidirectional (productivity does not affect R&D or innovation) and it is estimated using cross-section data. These characteristics reflect the limitations of the innovation surveys in the majority of countries, where a new sample is drawn for each wave, hindering the possibility of any panel data analysis. Notwithstanding, this model deals with the endogeneity of R&D in the innovation equation and the possible selection bias of the R&D performers. In the original model, all equations were estimated jointly by asymptotic least squares, but most subsequent studies have relied on a sequential estimation, where the predicted value of the endogenous variable in the outcome equation enters as an explanatory variable in the following block (equation 3). In this respect, Musolesi and Huiban (2010) show that differences in the results derived from sequential instrumental variable estimation and maximum likelihood estimation are not important. Hence, the results are rather more robust in the estimation method if endogeneity and selection bias are taken into account (Mohnen and Hall, 2013).

However, as explained in the previous section as well, we do have a panel of firms. In this case, efficiency gains in the estimation are expected since it is possible to take into account differences between firms that may be related to variables not included in the empirical model. Generally speaking, not controlling for these frequently unobserved factors can lead to biased estimates. A standard solution for this problem is the estimation of fixed or random effects models for panel data, and it is the approach we follow in the estimation.

The main challenge in estimating the CDM model relies in the complexity of the first block, because of the possible selection bias of R&D performers. Until very recently, the estimation of sample selection models with panel data was restricted to static or partially dynamic frameworks or relied on semiparametric estimators (Arellano and Honoré, 2001; Gayle and Viauroux, 2007). However, Raymond et al. (2007; 2010) have proposed a full parametric random-effects dynamic panel data sample selection estimator in order to overcome the main difficulties that arise in such a setting, namely the presence of unobserved individual effects and the treatment of initial conditions. Unfortunately, the small sample of energy firms included in the PITEC and used in this paper impedes a full dynamic consideration of the model. In a static framework, the initial conditions problem is not an issue and we will not tackle it here. Fortunately, the model is flexible enough to nest several different specifications (with or without dynamics or sample selection), yet allowing for a more efficient joint estimation of parameters.

4.1 Estimation procedure

In order to efficiently estimate the first block of the CDM model, the proposed econometric procedure is estimated by Maximum Likelihood and solves the two main difficulties referred to before, which are the presence of individual effects and the consideration of the initial conditions in a dynamic setting. The method proposes the use of random effects, since fixed effects in this case are subject to many shortcomings, especially when the panel consists of a large number of individuals (firms) and a small number of time observations. For instance, even if a conditional maximum likelihood estimator could be used –hence solving the inconsistency problem of estimating a potentially large number of dummy variables for individual effects by maximum likelihood when the number of periods is small-, this is restrictive in the sense that it is normally not possible to concentrate the likelihood with respect to the individual effects and, when possible, it works only under the assumption of the strict exogeneity of the explanatory variables, ruling out the inclusion of lagged dependent variables as explanatory variables (Neyman and Scott, 1948) .

More specifically, the first block of the CDM model outlined in the previous section consist of equations (1) and (2). Equation (1) is the selection equation that determines whether individual i is included in the sample on which the estimation of the equation of interest (equation 2) is based, at period t. It is a function of strictly exogenous explanatory variables ($\boldsymbol{Z}_{it}$), time-invariant unobserved individual effects (φ_i), and other time-variant unobserved variables (ϵ_{1it}). In a dynamic specification, we could also include the past selection outcome ($D_{i,t-1}$). The vector δ' captures the effects of the explanatory variables on the current selection process, and is to be estimated. The equation of interest depends on strictly exogenous explanatory variables ($\boldsymbol{X}_{it}$), time-invariant unobserved individual effects (α_i), and other time-variant unobserved variables (ϵ_{2it}), and is observed only when D_{it} is positive. As in the previous case, in a dynamic setting we would include its past outcome ($R\&D_{i,t-1}$). The vector β' captures the effects of explanatory variables on current outcome, and is to be estimated as well. In this case, since a fully parametric approach is designed for the estimation of this first block of the CDM model, there is no need for exclusion restrictions in the vector of strictly exogenous explanatory variables, making it possible that $\boldsymbol{Z}_{it}$ and $\boldsymbol{X}_{it}$ are the same, totally different or that they have common explanatory variables.

For the purpose of estimation, the individual effects are assumed, in every period, to be linear in the strictly exogenous explanatory variables (and in the initial conditions in the case of dynamic specifications), i.e.

$$\varphi_i = b_0^s + b_1^s D_{i0} + \mathbf{b}_2'^s \boldsymbol{Z}_i + a_{1i}$$
$$\alpha_i = b_0^r + b_1^r R\&D_{i0} + \mathbf{b}_2'^r \boldsymbol{X}_i + a_{2i}$$

where $\boldsymbol{Z}_i' = (\boldsymbol{Z}_{i1}', \dots, \boldsymbol{Z}_{iT}')$, $\boldsymbol{X}_i' = (\boldsymbol{X}_{i1}', \dots, \boldsymbol{X}_{iT}')$, b_0^s, b_1^s, $\mathbf{b}_2'^s$, b_0^r, b_1^r, $\mathbf{b}_2'^r$ are to be estimated, and a_{1i} and a_{2i} are independent of $(D_{i0}, \boldsymbol{Z}_i)$ and $(R\&D_{i0}, \boldsymbol{X}_i)$ respectively. The scalars b_1^s and b_1^r capture the dependence of the individual effects on the initial conditions. The vectors $(\epsilon_{1it}, \epsilon_{2it})'$ and $(a_{1i}, a_{2i})'$ are assumed to be independent of each other, and independently and identically distributed over time and across individuals following a normal distribution with mean zero and covariance matrices

$$\Omega_{\epsilon_1\epsilon_2} = \begin{pmatrix} \sigma_{\epsilon_1}^2 & \rho_{\epsilon_1\epsilon_2}\sigma_{\epsilon_1}\sigma_{\epsilon_2} \\ \rho_{\epsilon_1\epsilon_2}\sigma_{\epsilon_1}\sigma_{\epsilon_2} & \sigma_{\epsilon_2}^2 \end{pmatrix} \quad \text{and} \quad \Omega_{a_1a_2} = \begin{pmatrix} \sigma_{a_1}^2 & \rho_{a_1a_2}\sigma_{a_1}\sigma_{a_2} \\ \rho_{a_1a_2}\sigma_{a_1}\sigma_{a_2} & \sigma_{a_2}^2 \end{pmatrix}$$

respectively. The parameters of the covariance matrices are also to be estimated. Hence, the likelihood function of individual *i*, starting from *t*=1 and conditional on the regressors and the initial conditions, is written as

$$L_i = \iint_{-\infty}^{\infty} \prod_{t=1}^{T} L_{it}\left(D_{it}, R\&D_{it} \middle| D_{i0}, D_{i,t-1}, \boldsymbol{Z}_i, R\&D_{i0}, R\&D_{i,t-1}, \boldsymbol{X}_i, a_{1i}, a_{2i}\right) g(a_{1i}, a_{2i}) da_{1i} da_{2i} \quad (4)$$

where $\prod_{t=1}^{T} L_{it}\left(D_{it}, R\&D_{it} \middle| D_{i0}, D_{i,t-1}, \boldsymbol{Z}_i, R\&D_{i0}, R\&D_{i,t-1}, \boldsymbol{X}_i, a_{1i}, a_{2i}\right)$ and $g(a_{1i}, a_{2i})$ denote respectively the likelihood function of individual *i* conditional on the individual effects, and the bivariate normal density function of (a_{1i}, a_{2i}). With some transformations (please refer to Raymond et al., 2007 for details), the double integral in equation (4) can be approximated by a "two-step" Gauss-Hermite quadrature so that the random effects individual likelihood function of the type 2 tobit model becomes a function of the weights and abscissas of the first and second step of the numerical approximation of the likelihood function. Hence, the product over *i* of the resultant approximate likelihood function can be maximised using standard numerical procedures to obtain the desired estimates of the parameters of the model (see Raymond et al. 2007 and 2010 for technical details about the procedure).

To summarize, the proposed model assumes that the individual effects are, in every period, linear in the strictly exogenous explanatory variables (and the initial conditions in the case of a dynamic specification). Hence, the likelihood function of a given individual starting at the initial period and conditional on the regressors (and the initial conditions if taking into account dynamics) is a function of the likelihood function of that individual conditional on the individual effects and a bivariate normal density function of cross-equation individual effects. Hence, the individual effects are "integrated-out" with respect to their joint normal distribution. The resulting likelihood function covers a wide range of likelihood functions of panel data models whose estimation can be done by simply making restriction assumptions on the parameters of the dynamic panel data sample selection model just described and can be tested using standard likelihood ratio or Wald tests. For instance, in our model, since the limited sample of energy firms included in the PITEC database does not allow us to specify a fully dynamic model (the algorithm simply does not converge) we restrict the analysis to the static case, but we take into account both sample selection and individual effects in the estimates.

In our case, equations (1) and (2) –the first block of the CDM model where we analyse the drivers of R&D (characteristics of the firms and reasons to engage in innovation)-, are jointly estimated using this relatively novel estimator to control for selection bias and unobserved heterogeneity. In these estimations we include the main characteristics such as size, age, public support, cooperation and foreign capital that, following the literature, are related to the decision to do R&D and to the effort. We also include the variables that capture the reasons to innovate or objectives (oriented to product innovation, oriented to process innovation, reducing environmental impact and to meet regulations).

The third equation, where we examine the effect of the different obstacles to innovation, -the second block of the CDM model- is estimated using a random effects probit model defined as follows:

$$INN_{it}^{*} = \gamma R\&D_{it} + \beta W_{it} + u_{it}$$

$$INN_{it} = \begin{cases} 1 \; if \; INN_{it}^{*} > 0 \\ 0 \; otherwise \end{cases}$$

where INN_{it}^{*} is the unobservable variable, INN_{it} is the observed outcome, $R\&D_{it}$ is the predicted value of the outcome equation (2), $\boldsymbol{W}_{it}$ is the observed vector of exogenous characteristics which influence INN_{it}^{*}, γ and β are parameters to be estimated. Furthermore, we can decompose the error term into two parts:

$$u_{it} = \alpha_i + \epsilon_{it}$$

here the $\alpha's$ denote individual specific unobservable effects, assuming that α_i ~ $\mathrm{N}(0, \sigma_{\alpha}^{2})$ and ϵ_{it} is the iid N(0,1) random error. From this specification we know that

$$Var(u_{it}) = 1 + \sigma_{\alpha}^{2}$$

The common error component α_i means that, within individuals, the u_{it} will be correlated by a magnitude

$$\rho = \frac{\sigma_\alpha^2}{1 + \sigma_\alpha^2}$$

Since the realizations of INN_{it} are correlated, the common α_i mean that the Ti observations on individual i are distributed according to a T-variate normal distribution, making the likelihood function really complicated. However, Butler and Moffitt (1982) showed that, because the dependence in the u_{it} is completely due to the common variation in the $\alpha_i's$, we can eliminate the higher order integrals by conditioning on the α_i, and integrate them out of the likelihood. This approach limits us to evaluating one-dimensional integrals, again by means of the Gauss-Hermite quadrature approximation.

In this specification, and in order to avoid some potential endogeneity problems, the vector of exogenous characteristics includes the predicted value for the firms' R&D effort taken from the previous estimations. We also include the size of the firms and the barriers that may hamper innovation. We consider barriers related to costs, knowledge, market and reasons for not innovating.

4.2 Results and discussion

With the estimation for the R&D equations with the use of a sample selection model we examine the effects of the explanatory variables on the decision to engage or not in R&D and on the amount of R&D expenditure. The results (Table 2) show, first, that size is a determining factor for performing R&D but not for R&D intensity. Once they carry out R&D activities, smaller companies devote more resources to R&D (in relative terms). The empirical analyses of electric utilities have shown that there is a positive and significant effect of the size of the firms on R&D expenditure (Jamasb and Pollit, 2008). In particular, the econometric estimations that have taken into account the existence of sample selection (Sanyal and Cohen, 2009; Salies, 2010, Kim et al., 2012) have always found a positive and significant relationship between size and engaging in R&D. Our results point out in the same direction showing that there is a critical scale to obtain profits from R&D investments in the energy industry. However, the results on the elasticity of R&D expenditure with respect to size vary significantly in the empirical analyses from values greater than 1 to values less than 1, or even not significant (Sterlacchini, 2102).

Second, younger firms are more likely to devote more resources to R&D activities, although they do not necessarily engage more than older firms in the long-run decision to perform R&D. Competition has implied more entry either thorough unbundling or by new entrants and younger firms are among the more intense R&D performers. Third, public support has a positive influence on the decision to perform R&D but not on the intensity.

Finally, the energy firms that claim that process innovation is of great importance are those that devote resources to technological activities with greater intensity. The other innovation objectives have no impact on R&D intensity. These results are consistent with several contributions discussed in section 2. In a liberalised energy market, competition forces firms to search for higher margins by means of enhanced productive efficiency, thus embracing process innovations. Competition results in a reorientation of research investment towards short-term objectives and focuses on applied R&D with the aim of increasing efficiency and profit margins (Defeuilly and Furtado, 2000; Jamasb and Pollit, 2008; Salies, 2010).

TABLE 2

The estimations for the innovation equation (Table 3) show, as expected, that the main control variables –size and the estimated R&D intensity (resulting from the estimated parameters of the model in Table 2)- have positive and highly significant effects on the probability of introducing innovations. The results for the energy industry also show that financial and knowledge obstacles are not important barriers hampering innovation, in contrast to the analyses carried out for firms in general (Mohnen et al., 2008; Savignac, 2008; Blanchard et al., 2012). While empirical evidence has stressed that firms face financial obstacles to innovation activities (Hall, 2002; Blanchard et al., 2012; Popp and Newell, 2012), our results suggest, in the same way as Salies (2010), that firms in the energy industry seem not to be subject, even after the liberalisation reforms, to financial constraints in carrying out their innovative projects.

TABLE 3

Firms in the energy sector that perceive that the market is dominated by established firms have a lower probability of introducing innovations. The estimations show that the parameter is negative and significant confirming the dominance of existing technologies and the incumbent inertia of the energy system. Despite the liberalisation reforms and the current competitive situation, our results show that incumbents and existing technologies in the industry are hampering innovative projects with alternative technologies. These results suggest, as pointed out in section two, that the technology mix of the country may be an entry barrier when incumbent firms concentrate their portfolio on traditional energy technologies.

For the other market obstacle, the uncertainty of the demand, the parameter is significant and positive. Nevertheless, this only holds for product and not for process innovation. Therefore there is a positive relationship between the firms that state that demand uncertainty is a significant obstacle and the most innovative firms, in terms of new products, showing that although they face this obstacle, it does not hamper their innovation activities. These kinds of innovation are mainly related to the liberalisation process and increasing competition in the retail energy markets, where suppliers are offering more innovative goods, and particularly services, to consumers. In liberalised markets, characterised by the existence of greater uncertainties than in monopoly conditions, new players have entered. The supplier companies, with more freedom to design products and prices, are developing a variety of new, more customer oriented, energy services (Markard and Truffer, 2006). Competition in the residential electricity markets tends to be initiated by a few smaller players who offer innovation and over time incumbent firms, that present quite considerable initial resistance, also deliver more innovative services to customers (Littlechild, 2006; Markard and Truffer, 2006).

Finally, the parameter corresponding to no need to innovate due to prior innovations is also significant reinforcing the conclusion that the dominance of existing technologies is hampering innovation in the energy industry, specifically in the case of process innovations. Even if liberalisation has brought about more competition and this in turn has transformed the structure of the energy sector by altering the number and average size of participating firms, by renewing the technologies for generation as well as introducing increased rivalry in retail, the main barriers hindering innovation in the sector are related to the perception of incumbent dominance in the energy market.

For the estimations of the innovation production functions, we have performed some robustness checks to take into account some discussions on the literature on R&D and innovation. Firstly, R&D investments may require some time to have an effect on innovation in processes and products. Therefore, we switched the predicted R&D effort from the first block, that considers a contemporaneous correlation between R&D effort and innovation outcomes, to the corresponding lagged value (t-2). In this case, the results are consistent with the previous ones. Secondly, in order to account for possible systematic correlations between decisions to perform product and process innovations (Martínez-Ros and Labeaga, 2009), we estimate a bivariate probit model with binary equations for each outcome. In this case, the only possibility of carrying out the estimations is to use pooled data. Hence we are not able to control for individual effects in these estimations. The results from our first estimation are also confirmed and show the relevance of market obstacles to innovation and the differences regarding process or product innovation. The estimate for the cross equation correlation is positive, indicating complementarities between the two decisions.

TABLES 4 and 5

5. CONCLUSIONS

There is a broad consensus on the convenience of the energy industry devoting more resources to R&D and innovation. To meet the challenge related to climate change requires a significant increase in energy innovation. Nevertheless, the levels of R&D and innovation of the energy sector after the liberalisation reforms started in the 1990s, and currently, remain quite low in comparison with the importance of this sector in the economy.

The objective of this paper has been to improve our understanding of the reasons that explain R&D investment and innovation in the energy sector. Putting together two strands of the literature on the determinants of innovation, we have analysed the influence of the characteristics of the firms and the objectives of innovation on R&D decisions and effort and, particularly, what barriers are hampering innovation in this sector.

The econometric analysis has been carried using panel data for the period 2003-2010 and the main conclusions from the estimations regarding R&D drivers and obstacles to innovation in the energy industry are the following ones. Firstly, our joint estimations for the decision to spend on R&D or not and the R&D effort show, consistently with the literature, that size is a barrier to entry for R&D in the energy sector. Nevertheless, there is not a positive relationship between size and R&D intensity. Once they carry out R&D, smaller companies make a greater effort in R&D, measured in relative terms with respect to sales. Secondly, R&D intensity is particularly related to innovation objectives oriented to process innovation likely to increase efficiency through a reduction of costs or to an increase in production capacity. For the rest of the innovation objectives, including the reduction of environmental impact, none of the parameters are significant.

The estimations of the innovation production function provide the main conclusions of the paper regarding the obstacles to innovation. Firstly, our results show that the main barrier hampering innovation activities in the energy industry is the market dominance of established firms. This conclusion is reinforced by the estimates that show that there is a prevalence of dominant technologies that have a negative effect on the decision to innovate in new processes and therefore hamper the introduction of new energy technologies. Secondly, the estimations for product innovations show that although the most innovative firms state that they are facing an uncertain demand for innovative goods and particularly services, this obstacle is not hampering their innovative activities. Thirdly, and in contrast to the results of the literature for other industries, financial constraints are not a significant obstacle to innovation in the energy industry.

The analysis of R&D drivers and obstacles to innovation has been carried out for the energy supply industry. However, other industries, such as component suppliers, the machinery industry or transport equipment, also play an important role in energy innovation. To include these sectors in the analysis would require further research and enough information to be able to differentiate their R&D and innovative activities related with energy from those not related to this sector. In the analysis carried out it should be also taken into account that the available information does not allow differentiation between the firms that perform their activity in the absolutely liberalised segments of the energy market from those in segments where some regulation exists. To distinguish between these types of firms would allow an analysis of whether there are some differences in their R&D and innovative behaviour.

Finally, the results have some policy implications regarding how to increase R&D efforts and innovation in the energy sector. The general rationale for policy support to R&D and innovation is the existence of market failures. Together with this justification for policy action, our results show there are important barriers particular to the energy industry related to the dominance of established firms in the market and the existing technologies that hamper innovation efforts significantly. To confront this situation it would be convenient to introduce changes in the regulation of the sector in order to foster innovation projects and to increase public efforts oriented towards long-term goals.

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Table 1. Descriptive statistics

Variable	Description	N	Mean	Std. Dev.	Min	Max
R&D decision	Dummy = 1 if the firm has performed R&D activities	462	0.591	0.492	0	1
R&D effort	R&D expenditure over sales	462	1.8	7.7	0	88.0
R&D effort estimated	R&D effort estimated with results from model in table 1	462	0.794	1.6	0	22.0
Size	Number of employees	462	612.0	1090.8	1	7900
Age	Years the firm has been operating in the market	362	30.8	33.2	0	110
Public funds	Dummy = 1 if the firm received an R&D subsidy	416	0.413	0.493	0	1
Foreign capital	Dummy = 1 if the firm is partially owned by foreign investors	462	0.154	0.361	0	1
Cooperation	Dummy = 1 if the firm cooperates in innovation	380	0.574	0.495	0	1
Group	Dummy = 1 if the firm belongs to a group of firms	410	0.654	0.476	0	1
Objective: Product	Dummy = 1 if the firm considers the objective of high importance	334	0.189	0.392	0	1
Objective: Process	Dummy = 1 if the firm considers the objective of high importance	334	0.204	0.403	0	1
Objective: Environment	Dummy = 1 if the firm considers the objective of high importance	334	0.380	0.486	0	1
Objective: Norms	Dummy = 1 if the firm considers the objective of high importance	334	0.308	0.463	0	1
Total innovation	Dummy = 1 if the firm has performed either product or process innovation	410	0.739	0.440	0	1
Process innovation	Dummy = 1 if the firm has performed process innovation	410	0.656	0.476	0	1
Product innovation	Dummy = 1 if the firm has performed product innovation	410	0.390	0.488	0	1
Cost barriers	Dummy = 1 if the firm considers the barrier to be of high importance	410	0.066	0.248	0	1
Knowledge barriers	Dummy = 1 if the firm considers the barrier to be of high importance	410	0.005	0.070	0	1
Market: Incumbents	Dummy = 1 if the firm considers the barrier to be of high importance	410	0.095	0.294	0	1
Market: Demand uncertainty	Dummy = 1 if the firm considers the barrier to be of high importance	410	0.090	0.287	0	1

Motives: Previous innovations	Dummy = 1 if the firm considers the barrier to be of high importance	410	0.032	0.175	0	1
Motives: No demand for innovations	Dummy = 1 if the firm considers the barrier to be of high importance	410	0.110	0.313	0	1

Table 2. R&D equation (decision and intensity)

	R&D Intensity	R&D decision
Size	-0.780*** (0.123)	0.412** (0.202)
Age	-0.0116*** (0.00410)	-0.00164 (0.00505)
Public funds	0.214 (0.430)	2.739*** (0.582)
Foreign capital	-0.101 (0.341)	-0.956 (0.697)
Cooperation	-0.0418 (0.372)	
Objectives:		
Product innovation	-0.524 (0.449)	
Process innovation	1.392*** (0.387)	
Environmental impact	0.166 (0.408)	
Norms and regulations	0.214 (0.472)	
Constant	4.393*** (0.816)	-2.403** (1.003)
Observations	273	462

Tests of sample selection and individual effects:

$\rho_{a_1 a_2}$	0.179 (0.270)
$\rho_{\varepsilon_1 \varepsilon_2}$	-0.428 (0.384)
σ_{a_1}	-0.168 (0.373)
σ_{a_2}	0.415*** (0.112)
σ_{ϵ_2}	0.0560 (0.099)

Note: All regressions include time dummies to control for year-specific effects. Standard errors in parentheses and *** denotes significant at 1%, ** denotes significant at 5% and * denotes significant at 10%.

Table 3. Innovation production functions

	Innovation: Total	Process	Product
Size	0.554***	0.588***	0.244*
	(0.167)	(0.160)	(0.127)
R&D effort	1.396***	1.501***	0.512**
	(0.313)	(0.310)	(0.214)
Group	0.589	0.358	0.316
	(0.441)	(0.455)	(0.425)
Barriers:			
Cost	0.167	0.201	-0.324
	(0.516)	(0.513)	(0.432)
Knowledge	-0.649	0.133	1.110
	(2.847)	(2.490)	(1.501)
Market:			
Incumbents	-1.530**	-1.120*	-0.751
	(0.620)	(0.610)	(0.560)
Demand uncertainty	1.686**	0.615	1.557***
	(0.763)	(0.639)	(0.485)
Motives for not innovating:			
Previous innovations	-1.990**	-1.555*	-0.189
	(0.943)	(0.902)	(0.760)
No demand for innovation	-0.144	-0.192	-0.674
	(0.498)	(0.487)	(0.484)
Constant	-2.987***	-3.833***	-2.709***
	(0.895)	(0.927)	(0.767)
ρ	0.742*	0.757*	0.759*
	(0.095)	(0.079)	(0.066)
Log-likelihood	-140.6	-161.3	-199.0
chi2	31.68	35.81	24.66
Prob(chi2)	0.00711	0.00189	0.0547
Observations		410	

Note: All regressions include time dummies to control for year-specific effects. Standard errors in parentheses and *** denotes significant at 1%, ** denotes significant at 5% and * denotes significant at 10%.

Table 4. Robustness check for Innovation production functions–lag predicted R&D effort

	Innovation: Total	Process	Product
Size	0.426**	0.384**	0.384*
	(0.181)	(0.169)	(0.215)
Lagged R&D effort (t-2)	0.685**	0.743**	0.319
	(0.303)	(0.299)	(0.354)
Group	1.423**	1.051	0.224
	(0.682)	(0.650)	(0.735)
Barriers:			
Cost	-0.211	-0.416	-0.492
	(0.615)	(0.583)	(0.581)
Knowledge	1.119	1.117	3.496
	(4.331)	(3.675)	(2.250)
Market:			
Incumbents	-1.578**	-1.296*	-1.717*
	(0.749)	(0.733)	(0.893)
Demand uncertainty	0.605	0.429	1.566**
	(0.778)	(0.734)	(0.791)
Motives for not innovating:			
Previous innovations	-3.008*	-2.651*	-0.614
	(1.645)	(1.543)	(1.935)
No demand for innovation	-0.249	-0.141	-0.851
	(0.649)	(0.601)	(0.785)
Constant	-1.108	-1.134	-2.505**
	(0.968)	(0.922)	(1.177)
ρ	1.145**	1.146**	1.760***
	(0.527)	(0.480)	(0.463)
Log-likelihood	-88.02	-108.0	-133.3
chi2	21.94	23.58	20.32
Prob(chi2)	0.0799	0.0515	0.120
Observations	294	294	294

Note: All regressions include time dummies to control for year-specific effects. Standard errors in parentheses and *** denotes significant at 1%, ** denotes significant at 5% and * denotes significant at 10%.

Table 5. Robustness for Innovation production functions – bivariate probit

	Innovation:	
	Process	Product
Size	0.313***	0.0721
	(0.0526)	(0.0458)
R&D effort	1.000***	0.166
	(0.177)	(0.123)
Group	0.250	0.429***
	(0.177)	(0.163)
Barriers:	0.453	-0.0436
Cost	(0.356)	(0.297)
	-0.890	-0.176
Knowledge	(0.636)	(0.728)
Market:		
Incumbents	-0.896***	-0.574**
	(0.280)	(0.256)
Demand uncertainty	0.260	0.914***
	(0.295)	(0.267)
Motives for not innovating:		
Previous innovations	-0.756*	-0.552
	(0.438)	(0.469)
No demand for innovation	-0.300	-0.244
	(0.280)	(0.241)
Constant	-1.909***	-1.232***
	(0.366)	(0.337)
ρ	0.218**	
	(0.0985)	

Note: All regressions include time dummies to control for year-specific effects. Standard errors in parentheses and *** denotes significant at 1%, ** denotes significant at 5% and * denotes significant at 10%. In the bivariate probit (assuming normality of the error terms) the correlation parameter ρ provide information about the covariation of the error terms.

2011

2011/1, Oppedisano, V; Turati, G.: "What are the causes of educational inequalities and of their evolution over time in Europe? Evidence from PISA"
2011/2, Dahlberg, M; Edmark, K; Lundqvist, H.: "Ethnic diversity and preferences for redistribution "
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