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Full Research Article

Drivers and barriers of process innovation in the EU manufacturing food processing industry: exploring the role of energy policies

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Abstract. This paper investigates the driving forces that can promote or impede process innovation adoption in the European food manufacturing industry. The study uses a logit model applied to Community Innovation Survey (CIS) data containing information on innovation at the industry level for 15 EU Member States. Results suggest the relevance of many factors, internal and external to the enterprise, such as size and organization of business practices on one hand, and networking activities and cooperation agreements within the supply chain on the other hand. We also focus on energy policy variables as process innovation determinants. Energy policies implementation, energy price and the availability of public funds, show a significant impact on process innovation adoption in the European food processing industry.

Keywords. Environmental Regulation, Energy policy, Innovation, Cooperation activities, Food manufacturing industry, EU.

JEL codes. L66, O3, Q4, Q16.

1. Introduction

In October 2014 the European Council agreed on a new 2030 Framework for climate and energy, including EU-wide targets and policy objectives. This strategy aims to help the EU achieve a more competitive, secure and sustainable energy system and to meet its long-term 2050 greenhouse gas reductions target. The figures for renewables and energy efficiency have subsequently been increased in the Targets for 2030 context including, among others, a 40% cut in greenhouse gas emissions compared to 1990 levels and an indicative target for an improvement of at least 32.5% energy efficiency at EU level.

The food processing industry makes a significant and increasing contribution to the overall energy consumption and GHGs emitted in the food chain (OECD, 2017). Eurostat considers the total energy consumed by the food processing industry (including bever-

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ages and tobacco) to be 29178.5 Mtoe in 2015. This amount represents 28% of the energy embedded in the food chain (Monforti- Ferrario *et al.* 2015), 2.7% of the average final energy consumption and the 10% of the average energy consumption in the manufacturing industry, with Denmark and Croatia having the larger shares. Although the European food processing and beverage sector has gradually improved its energy efficiency – measured as the ratio value added/energy consumption - gaining competitiveness and reducing GHGs emissions in the last decades, still it has a strong potential for decreasing energy consumption both as a result of process optimization and plant system improvements (OECD, 2017; Ladha-Sabur et al, 2019). Technical potential energy savings have been estimated to be 22% (compared to 2004) by 2030 (Altmann et al, 2010; ICF, 2015). Energy use reduction and energy recovery from waste are two important methods to reduce production costs in the food processing industry (OECD, 2017; Altmann *et al.* 2010; Monforti- Ferrario *et al.* 2015). Kaminski and Leduc (2010) have identified the most important systems and processes where significant energy-efficiency improvements can be achieved in the EU's food industry: steam, motor and pump, compressed air systems, process cooling and refrigeration, and buildings heating and lighting.

The EU Lisbon Strategy considers innovation as one of the most important factors to enhance productivity, competitiveness, and sustainability in the economy. Literature, starting from Schumpeter's studies (1934, 1942) has tried to understand what the internal and external factors influencing process innovation are (Cohen, 1996; Galende and de la Fuente, 2003). Many factors determine the firm's capacity to innovate, ranging from technical capabilities, financial structure, market needs, network relationships, regulations, and subsidies. Enterprises, however, can also be deterred from engaging in innovation or fail to bring in new processes or products because existing barriers. Recognizing the nature of these barriers is important both from a policy and a management point of view (D'Este *et al.* 2012).

Literature on innovation has focused mainly been on high tech industries and only a few studies have considered low-tech traditional sectors such as the food processing industry.

Some specificity characterizes innovation in the food processing industry. Firstly, food firms are mainly process innovation oriented (Minarelli *et al.*, 2014). Secondly, the production of new technologies is usually developed by upstream industries and R&D expenditure is low compared to other sectors (Garcia-Martinez and Briz, 2000; Triguero *et al.*, 2013). Thirdly, most innovations are incremental rather than radical (Garcia-Martinez and Briz, 2000). Fourthly, product typologies and process phases are extremely differentiated and difficult to uniform (Capitanio *et al.*, 2010). Finally, SMEs are characteristically prevalent in the agri-food sector. Literature shows that SMEs behave differently with respect to large enterprises relative to innovation adoption, with larger firms being more innovative than smaller ones (Galizzi and Venturini, 1996). This distinction has important policy implications for policy design. Recent research (Minarelli *et al.*, 2014) indicates that, in the EU, SMEs are a very heterogeneous group regarding their innovation profile, particularly in the food sector. The relation between size and innovation is not straightforward, as other factors influence firms' behaviour as workforce in-house capabilities and the engagement in R&D activities (Avermaete *et al.* 2004). The small average size is considered one of the main barriers to innovation in Southern European countries (Garcia-

Martinez and Briz, 2000; Capitanio *et al.* 2010).

Nevertheless, the food processing industry is becoming more technologically intensive to maintain better process control, exploit economies of scale and guarantee food safety and quality, facing market competition through new products and processes development.

Capitanio *et al.* (2009) analysing the driving factors of innovation in the Italian food processing industry conclude that the determinants can be found both in internal and external factors. Among the first, there is the human capital qualification, a clearer orientation to quality products, organizational changes, and relation capacity development. On the external side, factors such as the increasing competition and demand have a relevant role in shaping the innovation process. Different determinants emerge when analysing process and products innovation separately. In the first case, the of human capital and market relationships qualities are the most important drivers, while in the of process innovation case, the firm's financial structure and capital intensity are the most relevant. The firm's location, meaning socioeconomic context relevance, has a positive and significant impact on process or product innovation adoption. With regard to Spain, research has underlined the machinery and equipment suppliers contribution to innovation diffusion (Garcia Martinez and Briz, 2000), together with significant path dependence (Triguero *et al.*, 2013). Environmental and market factors role seems higher in the food processing industry compared to other manufacturing industries. Cleaner technologies[1] can improve the production process efficiency by reducing materials and energy consumption, improving firm's productivity and competitiveness (Del Rio, 2005; Frondel *et al.*, 2007; Arimura *et al.*, 2007). Regarding the adoption of cleaner processes in the Spanish food industry, such as material recycling and water management processes, Cuerva *et al.* (2014) find that firm organizational capabilities - i.e. the implementation of an environmental management system - are an important driver, while no significant relationship with public support is found. The same result is confirmed in other studies on France and Germany (Belin et. al. 2011) and for the EU-27 (Triguero *et al.* 2013).

Small food firms contribute substantially to the food processing industry economic performance and are considered to play a key role in achieving sustainable economic growth in local economies.

In the EU, the food and drink sector turnover, in 2017 was 1,192 billion with 294,000 firms. The food processing industry is dealing with several challenges related to the sustainability productive processes, being a large surface water and energy user. However, as previously mentioned, it has a strong potential of decreasing energy consumption both a result of process optimization and plant system improvements (OECD, 2017; Ladha-Sabur et al, 2019).

On the same vein, we focus on the food processing industry investigating for factors that can statistically be associated with the firm's innovation process. We study the adoption of process innovation in the food processing industry in the EU, considering the role of energy prices and policies[2] role. According to the CIS 9 survey, 30% of firms in the

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[1] Process innovations are usually grouped in clean technologies and end-of-pipe technologies (Kemp and Volpi 2008; Rave et al, 2011).

[2] The main limitation of this study concerns the fact that it does not exploit the endogeneity issues; the panel is too short and the use a lagged variable may overfit the endogenous lagged dependent variable-

F&B industry that have innovated have reduced their energy consumption while 20% have contributed to reduce energy use or the CO2 "footprint" during the consumption or use of a good or service by the end-users.

Financial measures count for half of the policies addressing energy efficiency in industry. The Odyssee- MURE project shows that in many countries the policies in place include a broad mix such as co-operative measures (e.g. agreements among enterprises on energy efficiency), cross-cutting measures with sector-specific characteristics (e.g. industry eco-tax with reduced rates); fiscal/tariff measures (e.g. tax deduction for energy saving investments in businesses); information/education/training (e.g. advice programs for industry, energy management systems); legislative/informative (e.g. Mandatory execution of energy audits in large enterprises); legislative/normative (for e.g. CO2 emission fee for large emitters; new market-based instruments. About 10% of overall measures have been introduced under the Energy Efficiency Directive (2012/27/EU), especially measures introduced under Article 7 (energy efficiency obligations and/or alternative measures), mandatory audits (Article 8) and new certification/qualification schemes. Nevertheless, most energy measures are not EU-related but national measures, particularly those rated with a high impact (Odyssee-Mure, 2015).

The main questions addressed in this paper are: i) Are networking and cooperation activities between research institutions and food companies relevant in generating and promoting process innovation? ii) Is the high energy price a driver for boosting process innovation? iii) Does environmental regulation together with policy stringency stimulate the process innovation introduction? iv) If yes, what is the most effective driver?

The paper is structured as follows. Section 2 presents the hypothesis that will be tested in the model. Section 3 introduces the dataset mainly based on the Eurostat Community Innovation Survey and the empirical model. Section 4 reports the econometric estimates. Section 5 shows the main conclusions.

2. Conceptual background and hypotheses

The empirical literature on the determinants of innovations focuses on four groups of factors impacting production and innovation adoption: technological capabilities, organizational capabilities, market pull and external influences related to the regulatory push/pull and potential existence of networks (Cuerva *et al.*, 2014, Horbach, 2008, Wagner, 2009). Technological capabilities refer to knowledge resources, human skills and access to internal or external funds and are common drivers for all kinds of innovation. Organizational capabilities have a strong impact on green innovations; for example, the quality management systems adoption is often linked to the implementation of environmental management systems (Mazzanti *et al.* 2008). Market pull factors relate to consumers' preferences or customers' requirements for new products as well as the search for new niche markets. Among external innovation sources, literature considers the regulatory push/pull effect as very relevant (Rennings, 2000). Regulations have been found to be significantly more important for environmental innovation compared to other innovation (Horbach *et al.* 2012).

At the same time, government policies play a role in inducing the creation of new cleaner technologies and also in the adoption of already existing technologies by firms

(Veugelers, 2012). The EU growth strategy Europe-2020 seeks to booster innovation and collaboration across actors in the supply and innovation chains and private companies, and to strengthen cooperation among research institutions and firms, in addition to promoting more effective and efficient public financial support for innovation activities. Furthermore, the EC Green Deal Communication notes the role of new technologies in providing additional benefits in the transition to a sustainable economy.

A recent OECD (2017) study on energy efficiency in the agri-food sector identifies four broad groups of barriers: structural, behavioral, availability and policy. Structural barriers encompass issues such as limited know-how on implementing energy-efficiency measures, or fragmented and under-developed supply chains. Such barriers prevent an end-user from adopting an energy-efficient technology or practice: for example, low educational attainment and ageing farmers impede the adoption of new potentially energy-efficient technologies. Behavioral barriers include situations in which limited awareness or end-user inertia inhibit an opportunity pursuit. Inertia represents the resistance to change and risk, and the more radical the change, the higher the barrier will be (Sorrel *et al.* 2000). It can lead to preferring interventions with quick and low investments and returns, thus slightly modifying the production system with short pay-back criteria may be explained by risk aversion (Jaffe and Stavins, 1994). An unfavorable perception or treatment of risks can inflate energy-efficiency projects costs or lead to the underestimation of risks associated with changes in energy prices. Uncertainty about energy prices can also limit energy efficiency measures because of higher perceived risks. Risks management associated with energy costs and availability in agri-food businesses are largely determined by business size, with larger businesses being more likely to be proactive in managing risks from volatility in energy and commodity prices (OECD, 2017).

Availability barriers include situations in which the decision-maker is interested in and willing to innovate, but barriers, for example, a lack of capital access might prevent an upgrade to a new heating system or the availability and diffusion of technology and innovations (OECD, 2017).

Policy barriers are policy-induced market distortions which result in market conditions hindering energy efficiency. For example, energy subsidies can crowd-out public spending and private investment, encourage excessive energy consumption, reduce incentives for investment in renewable energy, and accelerate the depletion of natural resources (McKinsey and Company, 2010) i.e. encouraging more fossil fuels or energy usage intensive production .

Cagno *et al.* (2013) find that the major perceived barrier for Italian manufacturing SMEs in the food processing industry, regarding the adoption of energy efficiency technologies, is represented by high investment costs. Same or also insufficient profitability and low capital availability.

The identification of barriers to innovation is crucial for effective policy design. According to the Eurobarometer survey of SMEs in the EU (Eurobarometer, 2016), most common barriers are represented by uncertain market demand and returns. Other causes are the lack of funds or qualified personnel and in general, low technological capabilities. This barriers typology is expected to be more pervasive for SMEs, particularly in sectors with non–energy-intensive production processes (Fleiter *et al.*, 2012, Trianni *et al.*, 2013) such as the food processing industry.

Hence, we explore the following research hypotheses:

H1a) Networking and cooperation activities between research institutions and food companies are positively associated with process innovation.

Research shows that networking and cooperation effects are unclear, indeed some SMEs benefit from positive effects from cooperation to achieve innovations (De Jong and Vermeulen 2006; Van Gils and Zwart, 2004; Batterink *et al.*, 2010; Omta, 2002); while others experience problems (Hoffmann and Schlosser, 2001; Caputo *et al.* 2002; Kaufmann and Todtling, 2002). The importance of cooperation has risen steadily alongside the complexity, risk and cost of innovation activities. Innovation cooperation influences innovation activities through the pattern of collaborative relationships and partner type involved (Vinding 2002). This relationship is mutually reinforcing - external linkages facilitate innovation, and at the same time innovative outputs attract further collaborative ties (Powell and Grodal 2005). Companies that continuously cooperate with different external subjects such as suppliers, customers, competitors, and research organization improve both knowledge sharing and market knowledge acquisition by the firms, resulting in expansion of the firm's existing knowledge base, which in turn advances a firm's innovation capability (Zhou & Li, 2012). Such collaboration has been identified in literature as one of the most important external predictors of innovations (Alexiev *et al.*, 2016; Clauss and Kesting, 2017; Heirati *et al.*, 2016). In addition, a company may establish collaboration with other business partners, such as technology providers and researchers (Bigliardi and Galati, 2013). In fact, through networking, a company can extend its range of skills by an effective contractual arrangement (Martino and Polinori, 2011). Vertical cooperation offers more possibilities for innovation SMEs because cooperation is often used to acquire external know-how, in particular where firms have neither R&D employees nor the special technical requirements necessary to engage in R&D activities (Gellynck *et al.*, 2007; Gellynck and Khüne, 2010; Laperche and Liu, 2013). Collaborative innovation networks are defined when members participate in new product development and innovation processes (Alexiev *et al.*, 2016; Möller & Halinen, 2017). The role of firm network relationships and internationalization has been investigated by Cainelli *et al.* (2011) for Italian firms, finding to have a strong effect on the environmental innovations adoption by internationalized firms while being less clear for locally oriented firms.

Yet, scholars show that when firms cooperate with universities or research institutes, the overall effects on innovation capacity is positive (Hájek and Stejskal, 2018). Research also demonstrates that participating in cooperation networks makes companies more prone to undertaking sustainable oriented innovation (Melano-Levado, 2020; Klewitz and Hansen, 2013). Resorting to cooperation agreements (e.g. Cainelli *et al.* 2012; DeMarchi 2012; Del Río *et al.* 2013) and external knowledge sourcing (e.g. Del Río *et al.* 2013; Ghisetti *et al.* 2015) are thus particularly important and "complement" investments made in organizational and technological capabilities (e.g. Horbach 2008; Demirel and Kesidou 2011; Horbach *et al.* 2012).

H1b) Information is positively associated with a process innovation.

This hypothesis follows the previous one. Even in this case, several studies reveal that access to information facilitates the use of scientific knowledge, enhancing innovation and increasing the food processing industry competitiveness (Ciliberti *et al.* 2016). However, firm size matters in this regard, where small companies rely on universities or research institutes while larger enterprises might have the capabilities needed to put new ideas into practice (King et al, 2003; Ciliberti *et al.* 2016). Lasagni (2012) suggested that innovation performance in SMEs can be higher when they strongly collaborated with users, customers and suppliers. His results also showed that SMEs can be more successful in product development when they closely work with research institutes. This suggests that there can be specific types of partners preferred by SMEs. Gomez et al (2016) examine a panel of manufacturing firms in Spain to verify the extent to which the use of internal and external sources of information generate product and process innovation. Their results show that, although internal sources are influential, external sources of information are key to achieve innovation performance. Furthermore, the importance of external sources of information varies depending on the type of innovation (product or process) considered. To generate process innovation, firms mainly rely on suppliers while, to generate product innovation, the main contribution is from customers.

H2a) The higher energy price stimulates process innovation.

A relatively higher energy price in a country, as a result of country's energetic structure and energy taxation, will induce a technological change heading to higher energy efficiency. Ghisetti and Rennings (2014) found that innovation leading toward reductions in the use of energy or materials per unit output positively affect the firm's competitiveness, while externality-reducing innovations hamper the firm's competitiveness. Cainelli & Mazzanti (2013) find that policies targeting the manufacturing sector are likely to induce innovation adoption in the services sector, especially when considering innovation practices aimed at abating CO_2 emissions and improving energy efficiency. Yet, the study of Popp (2002), on the standard inducement mechanism, confirms that both energy prices and the quality of knowledge exert a significant and positive effect on patenting.

H2b) Environmental Policy Measures stimulate firms' process innovation adoption.

The relevant contribution of Porter and Van der Linde (1995b) has paid attention to "Porter hypothesis", according to which a good environmental innovation can lead to an increase in firms' performance, for instance through a reduction in energy or materials use. However, since firms are not always aware of the opportunities from eco-innovation, a strict and effective environmental regulation is required in increasing this awareness. Therefore, environmental policy seems to be an important eco-innovation driver and deserves specific attention.

According to Porter and van der Linde (1995a), environmental standards can foster innovation but under three well established conditions. Firstly, they must create maximum opportunities for eco-innovation, letting the industry choose its own approach to innovation. Secondly, regulation should foster continuous improvement in any technology. Thirdly, the regulatory process should not leave uncertainty at every stage of implementation. The type of regulation or policy and the way in which it is implemented is important. It could lead firms to effectively address environmental problems. The stringency of the policy and the terms in which it is defined are equally important, since uncertainty depends on these factors. Several empirical studies (ZEW, 2001; Rehfeld at al. 2006; Reid *et al.* 2008; Belin at al. 2009) find a positive correlation between innovation and regulations. Porter and van der Linde, (1995a/b), Kemp *et al.* (2001) and Jänicke *et al.* (2002) show that strict environmental regulations stimulate innovation in several ways, such as advantages created by the development of "green" technologies. However, firms are not able to recognize the environmental innovation cost saving potentials as in the case of energy or materials savings (Horbach and Rennings, 2007). This leads many of them to believe that an environmentally virtuous behavior is a burden rather than an asset (Kemp and Andersen, 2004). Therefore, regulations and policies can be a catalyst and help them to understand the potential benefits of environmental innovations. Popp (2009) argues that in general, market-based policies are thought to provide greater incentives for innovation, as they provide rewards for continuous improvement in environmental quality. Conversely, command-and-control policies penalize polluters who do not meet the standard, but do not reward those who do better than mandated as the command-and-control regulations direct a specific level of performance.

3. Dataset, Variable and estimation methods

3.1 Data

The dataset used in the analysis is based on the biennial CIS surveys carried out from 2010 to 2014 (CIS 8 and CIS 9). The CIS questionnaire addresses several elements of firms such as size, i.e. firm's size, turnover, employees, cooperation activities, source of information, public financial supports, innovation expenditures, and innovation activities.

The CIS survey provides information on sectors innovativeness, different types of innovations and various aspects of innovation development. The survey allows to distinguish firms that can easily be categorized into innovating and non-innovating.

Table 1 reports data on process innovation implemented by enterprises across the EU-28 between 2012 and 2014. The highest proportion of enterprises that have developed process innovation is observed for Belgium (46,8%), Netherlands (33,4%), Portugal (37,2%) and Lithuania (42,3%) in 2012/2014, while rates are lower for Bulgaria, Hungary, Romania and Slovakia , ranging from 5% to 9%.

Our panel (CIS 8 and CIS 9) includes all the in the firms belonging to the food manufacturing industry (NACE Code C10-12). For data availability reasons, we have restricted the analysis to the following EU countries: Bulgaria, Cyprus, Croatia, Czech Republic, Germany, Estonia, Hungary, Italy, Lithuania, Portugal, Spain, Romania, Slovenia, Slovakia and Norway. After removing missing value, the sample contains 4618 observations which are used in the analysis.

Data on energy policy come from the MURE project (Mesures d'Utilisation Rationnelle de l'Energie)[3] which provides information on energy efficiency policies and their impact assessment in EU countries.

The score classifies the EU member states based on scoring energy efficiency policies and trends. It aims to provide comparison indicators and comparable characteristics helping countries to understand whether their policies are comparable or better than in

[3] https://www.odyssee-mure.eu

Table 1. Enterprises in the food processing industry that have introduced process innovation.

	2010/2012	2012/2014		2010/2012	2012/2014
Belgium	35.5	46.8	Lithuania*	18.4	42.3
Bulgaria*	9.6	9.2	Luxembourg	43.8	22.6
Czechia*	27.2	25.3	Hungary*	6.1	7.4
Denmark	26.8	19.0	Malta	:	29.8
Germany*	22.3	17.4	Netherlands	27.0	33.4
Estonia*	37.3	21.9	Austria	20.0	26.0
Ireland	:	51.7	Poland	8.1	8.5
Greece	29.0	30.3	Portugal*	35.8	37.2
Spain*	20.0	18.5	Romania*	5.1	5.1
France	25.0	26.3	Slovenia*	23.1	28.7
Croatia*	15.2	21.8	Slovakia*	9.1	17.3
Italy*	32.6	31.7	Finland	38.4	30.1
Cyprus*	26.9	:	United Kingdom	17.0	23.6
Latvia	21.2	14.3			

The * symbol is indicating the countries used in the analysis.
Source: Eurostat, Community Innovation Survey

other countries or whether they can learn from other countries to improve their policies. It ranges between 0 and 5, with 0 meaning "*worst*" and 5 "*best*". Countries with a lower score are Cyprus, Hungary and Croatia; conversely, Spain, Norway and Slovenia reported the highest score.

The energy price yearly data come from Eurostat database available at the following link: "https://ec.europa.eu/eurostat/web/energy/data/database". Prices are provided without taxes, with VAT and with all taxes included.

A detailed explanation of the variables definition and measurement is reported in appendix (Table A.1).

3.2 Model and estimation

The choice to adopt a process innovation is represented by a binary logit model where the dependent variable (process innovation adoption hereafter *proc_inno_adop*) is a binary variable (yes=1/no=0) based on the response – at the firm level - on the introduction of innovations in the previous three years.

Let y the dependent variable observed and the latent variable satisfying the single index model

$$y_j^* = x_j'\beta + \varepsilon_j \tag{1}$$

Even if is not observed, we do observe

$$y_j = \begin{cases} 1 \; if \; y_j^* > 0 \\ 0 \; if \; y_j^* \leq 0 \end{cases} \tag{2}$$

(0 for non-innovative firms and 1 for the otherwise). From 1 and 2 we have:

$$\begin{aligned} \Pr(y_j = 1) &= \Pr(x_j'\beta + \varepsilon_j > 0) \\ &= \Pr(-\varepsilon_j < x_j'\beta) \\ &= \mathrm{F}(x_j'\beta) \end{aligned} \tag{3}$$

Where $F(x'\beta)$ is the cumulative distribution function of $-\varepsilon_j$. The logit model specifies that cumulative standard logistic is:

$$\Pr(y = 1|x) = \frac{e^{x'_j\beta}}{1+e^{x'_j\beta}} = \frac{1}{1+e^{-x'_j\beta}} = \Lambda(x_j'\beta) \tag{4}$$

and the marginal effect is:

$$\frac{\partial p}{\partial x} = \Lambda(x_j'\beta)\{1 - \Lambda(x_j'\beta)\}\beta \tag{5}$$

Thus, we estimate the following equation:

$$proc\_inn\_adop_{it} = \alpha + \beta_1 \ln(turnover_{it}) + \beta_2 funds_{it} + \beta_3 lmarket_{it} + \beta_4 rmac_{it} + \beta_5 gnewmkt_{it} + \beta_6 orgbup_{it} + \beta_7 co_{it} + \beta_8 int\_info\_sources_{it} + \beta_9 other\_info\_sources_{it} + \beta_{10} policy\_m_{it} + \beta_{11} ep_{it} + fe_i + fe_t + \varepsilon_{it} \tag{6}$$

where *i* denotes countries, t = 2010, 2012 and fe_i and fe_t represent country and time fixed effects respectively.

The dependent variable (*proc_inn_adop*) is a dummy that has been built using three indicators of the CIS: a) INPSD which considers the introduction onto the market of a new or significantly improved production method ; b) INPSLG which considers a new or significantly improved logistic, delivery or distribution system; c) INPSSU that considers the introduction onto the market of a new or significantly improved supporting activities. It takes a value of 1 if a new or significantly improved method of process or distribution has been introduced, 0 otherwise.

We have included the following control variables chosen on the basis of their relevance for firm characteristics and strategies:

- *lnturnover*, measured as the natural logarithm of the turnover. Literature has found that size affects the propensity to innovate, emphasizing the difficulties for small and medium enterprises. Indeed, the small average size is considered one of the main barriers to innovation in Southern European countries (Garcia-Martinez and Briz, 2000; Capitanio *et al.* 2010). Yet, scholars find that farm size has a positive, albeit small, effect on innovation, which is in line with the general innovation adoption literature (Lapple *et al.*, 2015; Feder *et al.*, 1985; Sauer and Zilberman, 2012). Moreover, as highlighted in the Diederen *et al.* (2003) study, agricultural farm size explains differences in adoption. Similarly, the work of Hashi and Stojcic (2012) show that larger firms are more likely to embark, to invest on innovation activities but with decreasing innovation output depending on the firm's size;

- *funds* reflecting the availability of public support to innovation. It takes a value of 1 if enterprises have benefited from public (Regional, National, European) support to innovation and 0 otherwise. Marzucchi and Montresor (2017) note that public funding for innovation generally increases the innovation adoption and environmental innovation particularly. Hyytinen and Toivanen (2003) analyze the effects of public policy, measured by government funding, on the behavior of privately owned, small and medium sized enterprises (SMEs) in Finland. Their findings pointed out that government funding disproportionately helps innovation and growth of firms in industries that are dependent on external finance;
- *lmarket* representing firm's prevalent market. It is a dummy variable equal to 1 if firms operate in the EU/international market and 0 for national/regional market. Regarding the access to foreign markets, literature has pointed out that international has been associated with successful innovation development (Oliveira and Carvalho, 2010; Salavisa *et al.*, 2012; de Faria *et al.*, 2010; Romijn and Albaladejo, 2002);
- *orgbup* representing organizational practices. It includes new business practices or new method of organizing work responsibilities and external relationships. A part of the literature supports the view that having a structured organization is important in achieving innovation. Laursen and Foss (2003), find that interdisciplinary teams, quality circles[4], employees' proposals collection system, planned job rotation, delegation of responsibility, integration of functions and performance related significantly lead to innovation. O'Connor and DeMartino (2006) agree that organizational structure and incentive systems are key elements in the innovation success. Prester and Bozac (2012) in analyzing companies over 20 employees on the European Manufacturing Innovation Survey (EMIS) in Croatia report findings similar to Laursen and Foss (2003). Therefore, organizational practices have impact in achieving innovation.

We test our hypothesis by considering the following variables:

- *co* is the variable cooperation agreements which includes active participation among companies or institutions on innovation activities. The aim of any cooperation agreement is that of introducing external knowledge to the firms. Studies show an uncleared networking and cooperation effect. Some SMEs benefit from positive cooperation effects to achieve innovations (De Jong and Vermeulen 2006; Van Gils and Zwart, 2004; Batterink *et al.*, 2010; Omta, 2002); while others experience problems (Hoffmann and Schlosser, 2001; Caputo *et al.* 2002; Kaufmann and Todtling, 2002);
- *int_info_sources* considers the internal sources of information; it is equal to 1 if its CIS score is more than 2 and 0 otherwise. Scholars find that innovations are developed by using knowledge from a diverse set of internal and external sources of information

[4] Jones *et al.* (2008) define quality circles in a following manner: "The company uses quality circles, defined as regular meetings between employees where they discuss issues related to immediate job tasks and make suggestions to improve production processes".

(Gomez *et al.*, 2016; Amara and Landry, 2005). Furthermore, the influence of each source is different depending on the innovation type. Internal sources and suppliers are the main contributors in the case of process innovation (Gomez *et al.* 2016);

- *other_info_sources* takes into account external sources of information. It considers information from suppliers, competitors, consultant or from other sources as scientific journal, which allows firms to generate new ideas and developing innovations by merging this kind of information with their internal ones (Lefebvre *et al.*, 2015; Lee *et al.*, 2010). This variable considers all the information sources other than internal one. It takes a value of 1 if all the information sources report a CIS score more than 2 and 0 otherwise;
- *policy_m* represents the score attributed to policies and measures at national level in terms of success in achieving energy efficiency in the industry end-use sectors (see data description). Regulations and policies can be a catalyst and help firms to understand the potential benefits of environmental innovations.
- *ep* refers to yearly energy price data. Energy prices are considered together with the policy measures. We include prices with taxes in the model. A relatively higher energy price in a country will induce a technological change in favor of higher energy efficiency. (Ghisetti and Rennings, 2014; Cainelli & Mazzanti, 2013; Popp, 2002).

Descriptive statistics on selected variables used in the estimated model are shown in appendix (Table A.2).

About 64% of the considered firms have introduced process innovations. Data show the importance of internal sources of information (68%) and the machinery and equipment acquisition (52%). At the same time, most of the enterprises in the sample operate in the EU markets (89%). Only 26% of the firms in the sample are engaged in cooperation activities or received public funds for innovation (26%). Energy price (with tax) has high variability in the EU countries ranging from a minimum value of 0.07 and a maximum value of 0.25. Finally, the successful policies in energy saving show high variability ranging between 0 and 4.38.

The correlation matrix is reported in table 2. Correlations are moderate implying that there is a low collinearity risk issues and redundancies in this set of variables. All the control variables are positively correlated with the dependent variable except for "other information sources" and "energy price".

4. Results and Discussion

We have run three different models with the scope of investigating the energy policy variables effect on process innovation, (Table 3). The first one considers the main innovation process drivers and barriers and the successful policy measures (*policy_m*); the second one takes into account the effect of energy policy variables (*ep)*; while the third one considers the two policy variables effects (*ep* and *policy_m*). Most of the hypotheses are confirmed by the results with models 1, 2 and 3, satisfying all the tests.

The discussion below concerns model 3 in table 3. The variable *lnturnover* displays a positive and significant coefficient (+0.1288). This result is different from the study of Garcia-Martinez and Briz (2000) or Capitanio *et al.*, (2010), where the small average size hamper innovation. As regards to the other control variables we find a positive and sig-

Table 2. Correlation Matrix.

	Process innovation adoption (inno_proc_adop)	Internal information sources (int_info_ss)	Other information sources (other_info_ss)	Acquisition machinary (rmac)	Funds	Cooperation (co)	Business organization (orgbup)	Turnover (lnturnover)	Policy measures (pm)	Energy price (ep)
Process innovation adoption (inno_proc_adop)	1									
Internal information sources (int_info_ss)	0.1375*	1								
Other information sources (other_info_ss)	-0.1363*	0.2417*	1							
Acquisition machinary (rmac)	0.3102*	0.0928*	-0.0484*	1						
Funds	0.1677*	0.0789*	-0.0158	0.1284*	1					
Cooperation (co)	0.1841*	0.1931*	0.0424*	0.1005*	0.2466*	1				
Business organization (orgbup)	0.2585*	0.1557*	-0.0265*	0.1369*	0.1021*	0.1996*	1			
Turnover (lnturnover)	0.2036*	0.0746*	-0.2040*	0.0357*	0.1269*	0.2678*	0.2134*	1		
Policy measures (pm)	0.1119*	0.0151	-0.0185	-0.2215*	0.0085	-0.0124	0.0583*	0.0639*	1	
Energy price (ep)	-0.1534*	-0.0479*	0.2090*	-0.0901*	0.0188	-0.0639*	-0.0354*	0.0380*	-0.0541*	1

nificant influence in fostering process innovation adoption for machinery acquisition (rmac), business practices organization (orgbup) and public funds (funds). As regards to the machinery acquisition (rmac +1.8995), our result is in line with the main literature which shows that machinery acquisition foster process innovation adoption. (Ciliberti et al 2016). Business practices organization reports a positive and statistically significant coefficient (orgbup +0.8891). This result is supported by the following studies Laursen and Foss (2003); O'Connor and DeMartino (2006); Prester and Bozac (2012); while Silva *et al.* (2008) find a negative relationship between the propensity to innovate and the organizational rigidities. Public financial support for innovation seems to be a process innovation driver (+0.2613) with a positive and statistically significant coefficient. The opening of new markets (*gomkt*) and market localization (*lmarket*) report insignificant coefficient.

Focusing the discussion on the first two hypothesis, results reveal that the presence of cooperation agreements (co +0.3929) and networking activities are positively associated with innovation process. As literature points out, these activities facilitate learning about new opportunities and can improve market access and economies of scale and scope (de Faria *et al.* 2010; Cassiman and Veugelers, 2002; Lopez, 2008). Quantitative empirical studies on external knowledge sourcing provide evidence that involving a large number of external sources of knowledge in innovation is a promising choice for large firms (Lakhani *et al.* 2006; Laursen and Salter 2006).

Information sources reveal a different pathway depending on their nature. Our analysis suggests a relevant role for the internal sources (*int_info_sources +0.2622*); while the others (*other_info_sources -0.5494*) are negatively correlated with the process innovation. The impact of various information sources is not straightforward as their use can be public and private – universities, journals, conferences and suppliers among many others - which may generate costs that must be considered. In some cases, the over-search of external sources may take too much time and slow down the innovation process. Additionally, excessive reliance on external information sources can increase coordination and monitoring costs and could affect the creation of knowledge stocks within the firm. Comparing results with existing literature, we find that the information sources affect the generation process innovation as in Ciliberti et al 2016. However, this finding is dissimilar to other empirical evidence which shows that firms should always look for external information which can then be embodied into innovation (Köhler *et al.* 2012; Costa *et al.* 2015). In some cases in acquiring external information, companies demonstrate openness and ability to scan the market and identify opportunities which allow them to be more efficient in implementing innovation and decrease the risk of product failure (Stewart-Knox and Mitchell 2003; Avermaete *et al.* 2004; Wei and Wang 2011). As underlines by Tether and Tajar 2008; Lee *et al.* 2010, diverse information sources (from suppliers, competitors, consultants) are complementary and, if merged with the existing knowledge, allow to create new knowledge useful for innovation.

The third and fourth hypothesis have tested through the impact of the implementation at the country level of energy saving policy measures *(policy_m*). The positive and statistically significant coefficient of *policy_m* (+3.3934) indicates that energy policies adopted by EU countries boost innovation. Firms innovated, i.e. adopting new or making changes to the organization of the productive process. Very similar is the energy price effect (*ep +7.8284*), which clearly shows that a high energy price is an incentive to modify

Table 3. Logit regression result from panel data.

	(1) Proc_inn_adoption	(2) Proc_inn_adoption	(3) Proc_inn_adoption
Proc_inn_adoption			
lnturnover	0.1274***	0.1288***	0.1288***
	(0.0243)	(0.0244)	(0.0244)
funds	0.2605**	0.2613**	0.2613**
	(0.0994)	(0.0992)	(0.0992)
lmarket	-0.0088	-0.0087	-0.0087
	(0.0865)	(0.0865)	(0.0865)
rmac	1.8986***	1.8995***	1.8995***
	(0.0903)	(0.0903)	(0.0903)
gnewmkt	0.0599	0.0517	0.0517
	(0.0376)	(0.0381)	(0.0381)
co	0.3934***	0.3929***	0.3929***
	(0.1073)	(0.1073)	(0.1073)
orgbup	0.8888***	0.8891***	0.8891***
	(0.0919)	(0.0918)	(0.0918)
Inte_info_sources	0.2620**	0.2622**	0.2622**
	(0.0896)	(0.0896)	(0.0896)
Other_info_sources	-0.5122***	-0.5494***	-0.5494***
	(0.1208)	(0.1237)	(0.1237)
policy_m	1.9569**		3.2951**
	(0.8876)		(1.133)
ep		7.8284*	7.8284*
		(4.5457)	(4.5457)
N	4645	4645	4645
adj. R^2	0.41	0.40	0.40
chi2	1191.8519	1196.1113	1196.1113
BIC	4559.1268	4564.8505	4564.8505
VIF	1.20	1.21	1.21

Time dummies and country dummies are included in the model. Standard errors in parentheses. Variable statistically significant at * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ respectively.

the productive process. Our results are also consistent with what is found in Rennings and Rammer (2009) revealing that process innovations are more strongly aimed at cost reduction, since increasing energy and/or material efficiency are associated with lower costs per unit. On the same vein, Popp (2002) exposes the strong and positive impact energy prices on new innovations. Similarly, Rennings *et al.* (2008), Del Rio Gonzalez (2005) find that regulation pressure and corporate image are the main drivers for adopting green technologies in the Spanish pulp and paper industry.

Table 4 merges the results of the model with the underlying hypothesis, showing that the model performs reasonably well, with energy policy, cooperation activities, financial public supports, and technical capabilities play an important role in creating a favourable environment for processes innovation.

Table 4. Merging Hypothesis and results.

Hypothesis	Results
H1a) Networks and cooperation activities promote process innovation	**YES** ⇒ + and significant
H1b) Sources of information stimulate process innovation	**Internal** ⇒ **YES** ⇒ + and significant **Other** ⇒ **YES** ⇒ - and significant
H2a) Successful policies measures stimulates firm to introduce process innovation	**YES** ⇒ + and significant
H2b) Energy price is positively associated with process innovation	**YES** ⇒ + and significant

4.1 Robustness Check

In order to test the robustness of our results, further elaborations are provided (Table 5). Results were confirmed when we ran the logit model considering the original variables of the CIS survey instead of the transformed variables used in section 3. Again, cooperation, information sources, policy variables and energy price, are positively associated with process innovation. Results were also confirmed when we used variables acting as barriers instead of drivers.

The estimated models are consistent; indeed, the impact of most explanatory variables is statistically significant and different from zero. Results of the confusion matrix[5], which describes how many actual and predicted values exist for different classes predicted by the model, indicate that the model fit quite well with both estimation techniques having a percentage of corrected classified value about 78% (Table A.3 in appendix).

Results from VIF test suggest that variables are uncorrelated with each other. Tolerance is different from zero and the variance inflation is low.

Evidence of good fit is reflected in a ROC curve (figure 1 in appendix), the area under the ROC curve is equal to 0.83 meaning that 83% of the observations are correctly classified.

5. Conclusions

The food processing industry is a sector mainly constituted by SMEs, with a low propensity to adopt process innovation. It represents one of the four sectors that consumes more energy in Europe although, at a large extent, it is not considered energy intensive and therefore covered by the EU Emissions Trading System (ETS); it also is considered to have a high energy saving potential. A major barrier that literature finds is the low importance attributed to energy consumption in non-energy intensive industries as in the case

[5] A confusion matrix is a table used to describe the performance of a classification model on a set of test data for which the true values are known. It tells us how many actual values and predicted values exist for different classes predicted by the model.

Table 5. Robustness Logit estimation.

	(1) Proc_inn_adoption	(2) Proc_inn_adoption	(3) Proc_inn_adoption
Proc_inn_adoption			
lnturnover	0.1163***	0.1100***	0.1052***
	(0.0248)	(0.0255)	(0.0259)
funds	0.0878	0.0881	0.0902
	(0.0992)	(0.0996)	(0.0996)
lmarket	-0.0453	-0.0343	-0.0449
	(0.0885)	(0.0889)	(0.0893)
rmac	1.5594***	1.5537***	1.5553***
	(0.0914)	(0.092)	(0.092)
gnewmkt	-0.0017	0.0011	-0.0001
	(0.039)	(0.0393)	(0.0392)
orgbup	0.7801***	0.7812***	0.7771***
	(0.0929)	(0.0936)	(0.0937)
ssup	0.3931***	0.3991***	0.3996***
	(0.0431)	(0.0433)	(0.0433)
scom	-0.0871	-0.0888	-0.089
	(0.0452)	(0.0456)	(0.0456)
sins	0.1445**	0.1416**	0.1395**
	(0.0478)	(0.0479)	(0.048)
co	0.2694*	0.2749*	0.2677*
	(0.1071)	(0.1078)	(0.1079)
policy_m	4.8399***	4.5146**	4.4198**
	(1.2369)	(1.3724)	(1.3801)
ep	15.4363**	15.3776**	15.0575**
	(4.8897)	(4.8956)	(4.9124)
obsprs		0.0219	0.0241
		(0.0455)	(0.0454)
obsfin		-0.0441	-0.0429
		(0.0384)	(0.0384)
empedu			0.1113
			(0.1003)
N	4425	4398	4398
adj. R-sq	0.346	0.34	0.34
chi2	998.4058	994.3702	999.5503
BIC	4358.8634	4345.35	4352.528

Time dummies and country dummies are included in the model. Standard errors in parentheses. Variable statistically significant at $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$ respectively.

of food processing industry. Another barrier is the lack of high expected returns ad short payback times. Furthermore, SMEs have limited access to information, low energy share on their expenditures, too high transaction costs for fund searching, cost disadvantages in obtaining or developing innovation. All these problems need to be specifically addressed by policy measures. In particular, small food firms contribute substantially to the food processing industry economic performance and are considered to play a role in achieving sustainable economic growth in local economies. Nevertheless, the small size of the industries and their less energy intensive use clarifies why it is difficult to apply energy policy measures and, why the optimization process is often not a priority for company managers.

Being among the largest users of surface water and energy among the manufacturing sectors, the food processing industry needs to reduce its energy consumption and improve its energy efficiency. However, changes in energy efficiency are often difficult because they depend on several factors such as the energy used technical performance, the importance of energy trans-formations, climate conditions, the structure of each economic sector that uses energy (MEDENER, 2013).

In this study, we have addressed the following issues: a) the role of cooperation agreements between food processing industries and research institutes in promoting process innovation adoption; b) whether or not the high price of energy encourages process innovation adoption; c) whether or not the environmental regulation and the severity of the policies stimulate process innovation adoption; d) which of these two factors, energy price and successful policy measures, are the most effective tool in promoting process innovation adoption. Through our models, we have addressed the issues related to process innovation adoption in the EU food processing industry. As regards to the first two hypotheses, namely the role of cooperation and network activities, on the one hand (H1a) and the role of information (H1b), our study confirms that cooperation agreements encourage SMEs to adopt new process innovations. Networking activities in this regard are relevant because they allow SMEs to acquire all the knowledges that is unavailable within the firm. The role of different information sources is uncertain. Indeed, the internal sources availability seem to encourage the adoption of new processes innovation. External sources information availability shows a negative sign that could be due to the higher costs related to the acquisition of this kind of knowledge and the manager's or owners' attitudes.

Concerning the role energy policy, results confirm the key role of energy prices and energy policies, with the energy price coefficient having a higher weight.

Furthermore, results confirm the role and the relevance of drivers like financial resources availability at the enterprise level, the presence of new organizational methods, the positive role of R&D firms' engagement and cooperation activities. These are important findings, in particular, if we consider that SMEs have limited access to information, low energy share on their expenditures, too high transaction costs for fund searching, cost disadvantages in obtaining or developing innovation.

Our results support previous research in identifying the main areas for policy action. Process innovation adoption in the food processing industry could be enhanced by measures addressed to:

- information cost reduction in order to support informed choices. One example is the support energy auditing in SMEs as a tool to track energy consumption and costs throughout a facility and identify opportunities to reduce energy use, increasing entrepreneurs' awareness.
- Contrasting the low private investment in R&D in SMEs for process and energy saving innovations through public-funded R&D or promoting enterprises aggregation

in networks. This action can take several forms research public of financing activities that require partnership with the private sector including technology providers and or facilitating partnership agreements between sectoral entrepreneurs and technology providers.

- Promoting policy coherence in EU policies impacting on energy use and innovation i.e. CAP, EU Cohesion policies, Energy and Climate policies as well the Bioeconomy and the Circular economy Strategies.
- Reinforcing the role of partnership tools along the whole supply chain in the agri-food sector enhancing cooperation towards sustainable production, thus creating the necessary conditions by which green labels could deliver and increase the demand for sustainable products.
- Considering that policy instruments are located at different government levels (EU, MS, regional or local) when dealing with the appropriate policy mix, and increase policy coherence through the whole governance system in which policy tools operate (Borràs and Edquist 2013).

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APPENDIX

Table A.1. Variables' description.

Variable CIS	Description	Variable in the model	Re-coded Variable	Expected sign
INPSPD	Introduced onto the market a new or significantly improved method of production	Dependent Variable: process innovation adoption	dummy variable: 0=No; 1=Yes	
INPSLG	Introduced onto the market a new or significantly improved logistic, delivery or distribution system			
INPSSU	Introduced onto the market a new or significantly improved supporting activities			
TURN	Total turnover	Size	total turnover in euros	+
FUNDS	Public funding from local or regional authorities	External Financial capacity	dummy variable: 0=No; 1=Yes	+
MOTHER	Local/regional market (within country)	lmarket	dummy variable: 0=No; 1= Yes	+
RMAC	Acquisition of machinery	RMAC		+
GOMKT	Increase market share	GOMKT		+
ORGBUP	New business practices for organizing work or procedures	ORGBUP	dummy 0= No , 1=Yes	+
CO	Cooperation arrangements on innovation activities	Cooperation activities	dummy variable: 0=No; 1=Yes	+
SENTG	Sources from within the enterprise or enterprise group	Int_info_sources	dummy variable: 0=not important; 1=important	+
SSUP	Suorces from suppliers of equipment, materials etc	other_info_sources	dummy variable: 0=not important; 1=important	+
SCOM	Sources from Competitors and other enterprises of the same industry			
SINS	Sources from consultants, commercial labs or private R&D institutes			

Variable CIS	Description	Variable in the model	Re-coded Variable	Expected sign
SUNI	Sources from Universities or other higher education institutes			
SCLUP	Clients or customers from the public sector			
SCON	Sources from professional conferences, trade fairs, meetings			
SJOU	Sources from Scientific journals, trade/ scientific publications			
SPRO	Sources from Professional and industry associations			
Policy_m	Energy saving successful policy measures	Policies	0<score<4.389	+
ep	Energy price (including not-refundable taxation)		value of energy price Euros/kw	+

Source: CIS 2010 - 2012.

Table A.2. Descriptive statistics of the Panel sample.

Variable	Obs	Mean	Std. Dev	Min	Max
proc_inn_adop	4,651	0.641	0.480	0	1
lmarket	4,646	0.890	0.313	0	1
rmac	4,651	0.526	0.499	0	1
co	4,651	0.258	0.438	0	1
orgbup	4,651	0.344	0.475	0	1
gnewmkt	4,651	2.009	1.105	0	3
turnover	4,651	42400000	141000000	12645	3.10E+09
int_info_sources	4,651	0.697	0.459	0	1
others_info_sources	4,651	0.1163	0.320	0	1
funds	4,651	0.258	0.438	0	1
ep	4,651	0.118	0.036	0.07045	0.2504
policy_m	4,651	3.539	0.939	0	4.389
year	4,651	2010.722	0.961	2010	2012

Source: CIS 2010 - 2012.

Table A.3. Confusion Matrix.

Classified	True D	True ~D	Total
+	2726	730	3456
-	254	935	1189
Total	2980	1665	4645

Classified + if predicted Pr(D) >= .5
True D defined as dipend_1 != 0

Sensitivity	Pr(+| D) 91.48%
Specifity	Pr(-|~D) 56.16%
Positive predictive value	Pr(D| +) 78.88%
Negative predictive value	Pr(~D|-) 78.64%

False + rate for true ~D	Pr(+|~D) 43.84%
False - rate for true D	Pr (-| D) 8.52%
False + rate for classified +	Pr(~D|+) 21.12%
False - rate for classified -	Pr(D| -) 21.36%
Correctly classified	78.82%

Figure 1. ROC Curve.