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The relationship between R&D subsidy and R&D cooperation in eco-innovative companies. An analysis taking a complementarity approach

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ABSTRACT

We analyze whether eco-innovation has a positive or negative influence on the business performance of companies and, through the complementarity approach, whether the joint implementation of R&D subsidy and R&D cooperation increases or decreases the sum of their respective individual impacts on the business performance. If the joint implementation is substitutive, business performance will be lower than potentially possible, so granting R&D subsidies under the condition of establishing R&D cooperation would not be an adequate policy to promote eco-innovation. The analyses were performed using data from the Technological Innovation Panel (PITEC) of 2013 for Spanish manufacturing companies. Our findings indicate that an eco-innovation-oriented strategy positively affects the labor productivity of companies and that receiving public aid as a consequence of establishing R&D cooperation agreements has a lower effect on labor productivity (non-eco-innovative companies), or the same effect (eco-innovative companies), compared to the sum of the individual impacts of R&D cooperation and R&D subsidy. Consequently, in non-eco-innovative companies the use of subsidized R&D cooperation is inadvisable, while their use in eco-innovative companies is neutral.

1. Introduction

Two of the main differences between companies that implement strategies oriented to eco-innovation and those that implement strategies oriented to conventional innovation involve a dilemma and an old debate. This dilemma and debate have led to an abundant and flourishing literature, with important implications for academics, practitioners and political decision makers.

The dilemma has been posed in the following terms (Mazzi, Toniolo, Manzardo, Ren & Scipioni, 2016): is the impact of eco-innovation on business performance positive or negative?

In the field of conventional innovation there is no such dilemma, since for a long time the economic literature has assumed that highly innovative companies perform better than less innovative ones (*e.g.*, Shakina and Barajas 2020; Wolfe 1994), however, the same is not true in the field of eco-innovation, where there are two opposing conceptions and approaches to this issue. In this regard, it is often argued that there is a conflict between environmental protection and business performance (Ambec, Cohen, Elgie & Lanoie, 2013; Eiadat, Kelly, Roche & Eyadat, 2008), insofar as environmental improvement efforts increase the costs of companies and erode their competitive advantage and business performance (Eiadat et al., 2008; Feichtinger, Hartl, Kort & Veliov, 2003; Konar & Cohen, 2001; Waddock & Graves, 1997; Walley & Whitehead, 1994). From this perspective, it could be noted that environmental commitment is a luxury (Pearce & Palmer, 2001).

In contrast to the previous conception, the seminal work of Porter and Van der Linde (1995) argues that eco-innovation would simultaneously be beneficial for the environment and for business performance and competitive advantage (Walker & Wan, 2012), since eco-innovation facilitates a reduction in the use of energy and/or materials. Similarly, Porter (1991) pointed out that companies which have to comply with demanding environmental regulations also have greater incentives to implement innovations that more than offset the corresponding compliance costs (Burnett, Hansen & Quintana, 2007). Along the same lines, there are also authors who point out that the existence of strict environmental regulations encourages the replacement of underperforming

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assets, which contributes to an increase in the productivity of companies and an improvement in business performance (Stoll, 2011). In other words, the design and implementation of an environmental innovation strategy can bring both economic benefits to companies and environmental benefits to society; that is, it is a win-win solution ((Ambec & Lanoie, 2008) Amores-Salvadó, Martin de Castro & Navas-López, 2015; De Marchi, 2012).

On the other hand, the old debate to which we have referred is related to spillovers and their impact on investments in R&D and the establishment of cooperation agreements in R&D. In this sense, the literature on conventional innovation indicates that the existence of spillovers allows a large number of competing companies to take advantage of the R&D efforts of other companies without having to bear the corresponding costs. This means that private companies rarely make private R&D investments with high social returns, which leads to underinvestment in R&D from the social point of view. Consequently, the level of economic development in those countries does not achieve its potential, which hampers improvements in the welfare and wealth of citizens, since, as recognised in the economic literature, innovation is the causal key that allows the efficient transformation of inputs into outputs, which makes it the most significant factor in improving productivity, quality, and competitiveness (Dahlman, 2007).

In accordance with the above, one of the main objectives of governments is to create the appropriate conditions so that the maximum possible level of innovation flourishes in their corresponding countries. That policy seeks to favor the emergence and development of competitive companies that facilitate citizens to enjoy high levels of well-being and wealth, and therefore, this underinvestment in R&D justifies policymakers in granting direct subsidies to private companies so as to undertake R&D investments (Aerts & Czarnitzki, 2006). But policymakers are also interested in the rapid dissemination of R&D knowledge derived from these investments (Grossman & Helpman, 1991), as this increases the number of competitive domestic firms. In other words, unlike private companies, policymakers are interested in having as many spillovers as possible. In terms of spillovers, therefore, private companies and governments pursue antagonistic objectives.

Initially, granting direct subsidies to undertake R&D investments promotes the development of innovation, but only in beneficiary private companies, which means distorting the performance of the invisible hand of the market and, consequently, also the efficient allocation of scarce resources. There may be better justification for this distortion, however, if there are more beneficiary companies. The objective of promoting the dissemination of advanced knowledge among a greater number of companies can be achieved by promoting so-called subsidised R&D cooperation agreements (Broekel & Graf, 2012; Czarnitzki, Ebersberger & Fier, 2007; Fornahl, Broekel, & Boschma, 2011; Guisado-González, González-Blanco, Coca-Pérez & Guisado-Tato, 2018; Katz & Ordover, 1990). With this kind of cooperation agreement, companies obtain subsidies for innovation and a certain degree of control over spillovers, since they partially manage to internalize them (Cassiman & Veugelers, 2002; Martin, 2002). On the other hand, governments ensure that R&D investments are made, which without the granted subsidies would not be carried out, and that the knowledge generated simultaneously benefits a greater number of companies. Subsidised R&D cooperation agreements mean that private companies and governments do not achieve their highest goals, but there is no doubt that both achieve reasonable levels.

Ultimately, innovation generates new knowledge, but as a consequence of spillovers, many companies cannot appropriate all of the potential benefits that their innovations generate. This determines that the market, without the intervention of public administrations, will provide a lower level of innovation than is potentially possible and socially desirable.

As an activity that generates new knowledge, eco-innovation must also support the classic problems of incomplete appropriability, so that public powers also intervene by granting R&D subsidies under the condition that cooperative agreements are established between the recipient firms. It must be taken into account, however, that eco-innovation involves an additional externality (Rennings, 2000), since it generates goods and services with a lower environmental impact than its non-eco-innovative competitors. This is because non-eco-innovative companies have lower private production costs than those of eco-innovative companies, since the latter internalize a large part of the costs due to reducing the environmental impact, which conventional innovative companies do not do. If governments do not subsidize eco-innovation activities to a greater extent than conventional innovative activities, therefore, the level of eco-innovation will still be lower than that of conventional innovation, which leads to underinvestment in eco-innovation from the point of view of environmental sustainability. Consequently, a greater level of public subsidy and a greater proportion of R&D cooperation agreements between environmentally innovative firms should be expected (De Marchi & Grandinetti, 2013).

This study pursues two central objectives in relation to eco-innovation. The first is to verify whether eco-innovation has a positive or negative influence on the business performance of companies, thus helping to expand the empirical research in this field. In this sense, it must be taken into account that analysis of the relationship between eco-innovation and business performance is still fully valid (Mazzi et al., 2016), since companies show great interest in obtaining information on the economic consequences that the acquisition of a greater environmental commitment entails.

Secondly, the literature on environmental innovation has verified that R&D subsidies and R&D cooperation have a positive effect on the business performance of companies (*e.g.*, Del Río, Peñasco and Romero-Jordán 2015; Triguero, Moreno-Mondéjar and Davia 2013), however, no empirical studies in the environmental field have analysed the impact that the interaction of these two variables has on the business performance of companies. The impact of the joint implementation of these variables on business performance might be greater than the sum of their respective impacts separately (complementarity), or less (substitutability). If the interaction is substitutive, business performance will be lower than potentially possible, so granting R&D subsidies under the condition of establishing R&D cooperation would not be an adequate policy to promote eco-innovation.

We are not aware of any previous research on this interaction in the field of eco-innovation. This paper tries to fill the gap by providing empirical evidence on this issue. We took a complementarity approach (Milgrom & Roberts, 1990) to check the existence of complementarity or substitutability between R&D subsidy and R&D cooperation, an approach that has recently been used in empirical studies of innovation (*e.g.*, Ballot, Fakhfakh, Galia and Salter, 2015; González-Blanco, Vila-Alonso and Guisado-González, 2019; Guisado-González, González-Blanco and Coca-Pérez, 2017).

To respond to the two proposed objectives, this paper is divided into the following sections. In the next section, we establish the theoretical framework and propose the corresponding hypotheses. Next, we describe the source of the data used, define the variables, and detail the methodology employed. In the subsequent sections, we discuss the results and present the conclusions.

2. Theoretical framework and hypotheses

There is increasing pressure from governments for companies to implement policies that have less environmental impact. To this end, the instrument most often used by governments are so-called environmental regulations. Obviously, these regulations are not neutral, since they oblige companies to make significant environmental investments, either through their own technological developments or through the purchase of technology incorporated in machinery and equipment. These environmental investments create significant expenses that affect the profitability and competitive advantage of companies (Ambec et al., 2013). The academic literature demonstrates that this effect is ambiguous, since different empirical investigations have obtained contradictory results (Rexhäuser & Rammer, 2014). The prevailing belief among economists, however, is that environmental quality is a luxury good (Kristrom & Riera, 1996), and as such has a negative effect on different measures of business performance. Results in the empirical literature support this belief. Some authors have found evidence that of a negative relationship between environmental regulation and productivity (*e.g.*, Christainsen and Haveman 1981; Gollop and Roberts 1983; Gray 1987; Gray and Shadbegian 2003; Greenstone 2002; Shadbegian and Gray 2005). and empirical studies have also reported a negative relationship between environmental innovation and economic performance (*e.g.*, Boons and Wagner 2009; Cordeiro and Sarkis 1997; Filbeck and Gorman 2004; Quan Zhang and Hung Chen 2017; Wagner, Phu, Azomahou and Wehrmeyer, 2002).

Porter and Van der Linde (1995) have pointed out that government regulations not only lead to the achievement of social benefits (improvement of the environment), but also to the achievement of private benefits (improvement of business performance and competitiveness of companies). In this sense, Rexhäuser and Rammer (2014) point out that government regulations reduce environmental externalities and the profits of firms, but, on the other hand, they also contribute to an increase in the productivity of companies through two different routes: (a) increasing the efficiency energy and material consumption per unit of output; and (b) facilitating the creation of new higher quality products. These new products will have an impact on the achievement of a higher level of sales, and/or on the ability to charge higher prices, as a result of the differentiation in quality that these new products entail, thereby facilitating the achievement of greater economic performance. Studies confirm this relationship between environmental product innovation, performance (*e.g.*, Pujari 2006), and competitive advantages (*e.g.*, Chang 2011). These productivity improvements overcompensate for the costs of introducing environmental innovations, and thus increase economic performance.

In short, according to Porter and Van der Linde (1995), the implementation of strict environmental regulations can induce the irruption of innovations that help reduce the environmental impact and, simultaneously, also contribute to the improvement of business performance. They constitute what Jaffe and Palmer (1997) called the weak version and the strong version of Porter's hypothesis, referring to the effect that government regulations have on environmental innovations, on the one hand, and business performance, on the other. In general, most empirical studies have corroborated the weak hypothesis, but few studies corroborate the strong hypothesis (see Ambec et al. (2013) and Van Leeuwen and Mohnen (2017). It should be noted that there are two studies that show a positive and significant relationship between resource-saving eco-innovations (mainly in terms of material and energy consumption) and business performance (Rexhäuser & Rammer, 2014; Van Leeuwen & Mohnen, 2017).

This paper is focused on the Spanish manufacturing sector. It has a predominance of small and medium-sized companies with low R&D expenditures and a concentration of traditional low technology sectors (Guisado-González et al., 2017). The productivity and technological level of most firms in Spain is consequently lower than that of its international competitors (Molero & Buesa, 1996; Roxburgh, Labaye, Thompson, Tacke & Kauffman, 2012). This characterises the Spanish manufacturing industry as a technological follower and moderate innovator (Hollanders & Es-Sadki, 2013). Furthemore, environmental regulations in Spain are not stringent, and Spanish customers have a low awareness of paying extra for environmental sustainability (Jové-Llopis & Segarra-Blasco, 2018). Under these conditions, the main concern of most Spanish companies is to achieve a level of economic profitability that ensures their survival (González-Blanco, Coca-Pérez & Guisado-González, 2018). We thus intuit that these companies will try to avoid environmental innovations that aim to reduce the negative environmental externalities generated by their activity, since this undermines their economic performance, but they will gladly accept, even with enthusiasm, all those innovations that lead to increased efficiency in the consumption of energy and materials, since that greater efficiency increases economic profitability. We thus propose the following hypothesis:

Hypothesis 1: Eco-innovation-oriented strategies have a positive and significant effect on the labor productivity of innovative companies in the Spanish manufacturing sector.

In relation to spillovers, private companies and policymakers pursue different objectives: Policymakers are interested in the existence of a high level of spillovers, since they facilitate a rapid and extensive dissemination of knowledge, resulting in a large number of companies possessing advanced knowledge (Grossman & Helpman, 1991), and thus with the ability to support high wages and contribute to an increase in the population's standard of living; however, private companies do not seek to generate any kind of spillovers, since they try to prevent their competitors from taking advantage of their R&D efforts at virtually no cost. This is why, in many cases, some companies stop undertaking advanced R&D projects that would be socially desirable (Chatterjee, Chattopadhyay & Kabiraj, 2018; d'Aspremont & Jacquemin, 1988; Kamien, Muller & Zang, 1992; Katz, 1986; Suzumura, 1992).

Political decision-makers tend to subsidize some R&D activities in private companies, in order to promote socially desirable investments (Aerts & Czarnitzki, 2006) in sectors considered strategic (Broekel, Schimke & Brenner, 2011), and also in order to ensure that advanced knowledge in R&D reaches the largest number of national companies possible. Policymakers thus expect that public subsidies will stimulate private R&D investments, but in many cases, political decision-makers do not achieve their objectives, since many private companies renounce making those investments in R&D that have high appropriability problems, and therefore do not request public subsidies, since they do not want rival companies to reinforce their competitive position without any cost or risk (Guisado-González et al., 2018). In situations of this nature, political decision-makers and private companies find themselves at a difficult and controversial crossroads.

There is an instrument that helps private companies and policy makers to achieve their particular objectives, albeit not fully. It involves subsidised R&D cooperation agreements, that is, the granting of R&D subsidies conditioned on the establishment of cooperation agreements between different companies (Broekel & Graf, 2012; Czarnitzki et al., 2007; Fornahl, Broekel, & Boschma, 2011). In this way, policymakers get private companies to invest in socially desirable R&D projects and ensure that the new knowledge generated is shared by the different cooperating companies. These companies receive public subsidies that reduce their investment risk in R&D and normalize the flow of spillovers between cooperating partners. The use of subsidised R&D cooperation agreements does not allow private companies to totally eliminate spillovers, nor allow policymakers to achieve the maximum dissemination of the new knowledge generated by the projects they subsidize, but there is no doubt that both agents achieve a significant number of their objectives. Subsidised R&D cooperation agreements ensure that incentives to promote R&D achieve their objectives, while preventing market competition from being seriously damaged (López, 2008). In short, as long as there are poor appropriability conditions (high spillovers), subsidizing R&D cooperation agreements is more effective in increasing socially desirable investments than subsidizing non-cooperating firms (Gussoni & Mangani, 2009).

The European Union has designed policies to promote innovation (Framework Programs) that grant public aid for R&D on the condition of establishing cooperation agreements between different companies and public research institutions (Hottenrott & Lopes-Bento, 2014; Scherngell & Barber, 2011), thereby trying to stimulate private investment in R&D and disseminate the new knowledge generated to a certain degree (European Commission, 1995).

The relationship between the R&D cooperation and R&D subsidy variables is expected to be complementary in relation to the labor productivity of companies, since the joint implementation of both variables facilitates the achievement of public aid for R&D and thus the ability to develop innovative projects that increase the productivity of companies. However, it is also possible that the R&D subsidies received are insufficient to offset the additional costs involved in managing a cooperation agreement, or that the benefits derived from the cooperation agreements cannot be adequately exploited due to insufficient absorption capacity of the company.[1] Sometimes many companies establish R&D cooperation agreements for the sole purpose of obtaining public aid (Broekel et al., 2011). Under these conditions, it can be expected that the R&D subsidy and R&D cooperation variables are substitutes, that is, that their joint implementation generates a productivity lower than the sum of the productivities of their respective individual implementations.

This study is focused on innovative companies in the Spanish manufacturing sector. In general, Spain is considered a moderate innovator country (Hollanders & Es-Sadki, 2013), with a predominance of small and medium-sized companies with low R&D intensity (Molero & Buesa, 1996). Spanish manufacturing companies show, on average, a low absorption capacity (Harris, Krenza & Moffata, 2019; Segarra-Blasco & Arauzo-Carod, 2008), so it is expected that the relationship between R&D subsidy and R&D cooperation does not meet the objectives pursued by public support programs for R&D. Accordingly, we propose the following hypothesis:

Hypothesis 2: The relationship between R&D cooperation and R&D subsidy is substitutive in relation to the labor productivity among innovative companies in the Spanish manufacturing sector that do not have an eco-innovative strategy implemented.

Compared to companies that only implement conventional innovation, eco-innovative companies have to bear an additional environmental positive externality (Rennings, 2000), which means that firms investing in cleaner technologies must bear higher costs than polluting competitors. In other words, in these cases, society ends up appropriating part of the value created by eco-innovative companies, since it is this class of companies that mainly bear the costs generated by reducing environmental damage. Eco-innovative companies thus face greater disincentives when it comes to undertaking socially desirable innovation projects (Jaffe, Newell & Stavins, 2005; Rennings, 2000), so it is expected that eco-innovative companies will receive greater public subsidies than conventional innovative firms (Rennings, 2000).

On the other hand, as technology becomes increasingly complex, the life cycle of products shortens, the degree of globalization of markets intensifies and competition at all levels becomes more acute, investments in technology are becoming more expensive, and the uncertainties that accompany them are also growing and becoming more apparent. Similarly, to a greater degree than in the past, technological investments tend to increase the proportion of fixed expenses over the variable expenses, causing the need to shorten recovery times for the corresponding investments in order to control risk (Bower & Hout, 1988; Yip, 1992).

The potential sources of knowledge for companies are increasingly complex and are of highly variable territorial and sectoral origin, which means that a large number of companies cannot use their own internal R&D to access all the technological knowledge that they require for the development of their innovation activities in competitive terms (Coombs, Harvey & Tether, 2003; Park, Mezias & Song, 2004). Moreover, the knowledge that companies need is often not available on the market. There are thus situations in which the internal generation of knowledge or its acquisition through the market is not feasible for companies. When this happens, many companies are committed to the implementation of cooperation agreements, since this constitutes the only practicable alternative for obtaining the resources and capacities they need (Das & Teng, 2000; Eisenhardt & Schoonhoven, 1996; Markides & Williamson, 1996; Park et al., 2004). In addition, as Teece (1986) points out, the diversity of technological resources and capacities that companies will probably need in order to compete successfully has been very high and also increasing for the last 20 years, which makes it difficult, if not impossible, for a single company to be up-to-date and to possess all the technologies it needs by itself. Cooperation agreements are therefore very effective when the objective is to appropriate the tacit knowledge of other companies (Hennart, 1988; Inkpen, 1998; Jorde & Teece, 1990; Khanna, 1998; Teece, 1981). Companies therefore use cooperation agreements as a means to obtain complementary resources and capacities, in order to be in a position to build competitive advantages.

On the other hand, the literature on innovation also suggests that companies cooperate in innovative activities because such cooperation facilitates a reduction in transaction costs (Mistri & Solari, 2001; Monteverde & Teece, 1982; Williamson, 1985), a better control of uncertainty (Das & Teng, 2001; Lui & Ngo, 2004; Luo, 2002) and the joint exploitation of complementary resources of the cooperating companies (Belderbos, Carree & Lokshin, 2004b, 2004a; Tether, 2002). Cooperation agreements in R&D have increased significantly since the 1980s (Caloghirou, Ioannides & Vonortas, 2003; Hagedoorn, 2002), as the evolution of technology has entered a path of greater complexity and acceleration. This is because cooperation in R&D allows companies quick access to the resources and capacities of other companies, and thereby facilitates and accelerates their corresponding learning processes (Becker & Dietz, 2004).

In general, all the characteristics outlined above, which push companies to establish cooperation agreements in R&D, are present to a greater extent in environmental innovation than in conventional innovation. On average, investments in environmental innovation are thus more costly and risky than conventional innovations. The greater the risk of environmental innovations is related to the relatively longer payback period, the lower the maturity of green markets and the appropriability problems generated by the double externality indicated by Rennings (2000). The development of environmental innovation also requires greater financial commitment, and the achievement of positive returns has a longer term than in conventional innovation (Berrone, Fosfuri, Gelabert & Gomez-Mejia, 2013; Ghisetti, Mancinelli, Mazzanti & Zoli, 2017). On the other hand, many environmental innovations tend to operate in the realm of strict novelty, forcing eco-innovative companies to undertake radical innovations and introduce and use resources and capabilities beyond their core competencies. In short, many of the new environmental innovations are highly complex, so their development requires the assistance of different experts, which pushes eco-innovative companies to establish cooperation agreements (Cainelli, De Marchi & Grandinetti, 2015; De Marchi, 2012; Horbach, 2008; 2013; Miotti & Sachwald, 2003).

According to the literature reviewed, it is expected that innovative environmental firms will cooperate in innovation with external

[1] Benefits from R&D cooperation depend on the absorptive capacity of the firm (Cohen & Levinthal, 1989). Frequently, R&D intensity is used as a measure of the absorptive capacity of the firm (*e.g.*, Belderbos, Carree, Diederen, Lokshin, & Veugelers, 2004; Cassiman & Veugelers, 2002; Cohen & Levinthal, 1990). However, the R&D intensity of companies can be very different, so the absorption capacity differs from company to company (Graevenittz, 2004). Therefore, companies with low levels of R&D will exhibit low absorption capacity, will not be adequately equipped to select the appropriate partner (Mayer & Salomon, 2006) and will manage the knowledge flows between the partners much worse (Mooty & Kedia, 2014). All of this prevents them from properly taking advantage of all the potential benefit that they could derive from R&D cooperation agreements.

partners to a greater extent than conventional innovative firms (De Marchi, 2012). In fact, there is abundant evidence of the growing role played by cooperation agreements in the development of environmental innovations (Collins, Lawrence, Pavlovich & Ryan, 2007; Horbach, 2008; Mazzanti & Zoboli, 2009; Posch, 2010).

It is expected that eco-innovative companies will receive more public subsidies for R&D development and establish more R&D cooperation agreements than conventional innovation companies. Taking into account that policymakers tend to force the companies they grant subsidies to establish cooperation agreements with each other, so that environmental innovations reach as many companies as possible, it is expected that R&D cooperation and R&D subsidy will be complementary; that is, that the impact on the business performance of the joint implementation of these variables is greater than the sum of their respective impacts separately, since eco-innovative companies receive more public aid and, on average, they are more R&D intensive than conventional innovation companies. In accordance with all of the above, we propose the following hypothesis:

Hypothesis 3: The relationship between R&D cooperation and R&D subsidy is complementary in relation to the labor productivity among innovative companies in the Spanish manufacturing sector that have implemented an eco-innovative strategy.

3. Data, variables and methodology

3.1. Data

The data used for the analysis is from the Panel de Innovación Tecnológica 2013 (PITEC – name in Spanish). PITEC is a panel survey based on the Community Innovation Survey (CIS) and was set up by the Fundación Española para la Ciencia y la Tecnología (FECYT – name in Spanish) and the Instituto Nacional de Estadística (INE – name in Spanish). PITEC is a firm-level panel database on the innovative activities of Spanish firms. We selected manufacturing companies from these databases, as the study focuses on this kind of business. After removing observations with missing values, we obtained a database with 4543 companies that operate in the manufacturing sector, of which 3024 are in innovative manufacturing.

3.2. Variables

In order to apply the complementarity approach, it is necessary to use a measure of company performance as a dependent variable (Cassiman & Veugelers 2006). We have used labor productivity as a measure of performance, which has been used in many studies analysing the relationship between R&D and productivity (Hall, Mairesse & Mohnen, 2010). Using the complementarity approach (Milgrom & Roberts, 1990) requires that the variables whose complementarity is to be evaluated have to be defined in binary mode (0,1). The R&D subsidy, R&D cooperation and eco-innovation oriented strategy variables are thus defined in this mode (0,1).

PITEC directly provides binary responses (0,1) for the R&D subsidy and R&D cooperation variables, however, the same is not true for the eco-innovation oriented strategy variable, whose construction must be carried out. PITEC asks firms what objectives they were pursuing when they introduced innovations. There are three objectives that can be closely linked to the eco-innovation oriented strategy of a firm: the decrease in materials consumption per unit produced, the decrease in energy consumption per unit produced and lower environmental impact. Similarly, PITEC and the CIS have already been used in other eco-innovation studies (De Marchi, 2012; Del Río, Romero-Jordán & Peñasco, 2017; Horbach, 2008; Jové–Llopis & Segarra–Blasco, 2018; Sáez-Martínez, Díaz-García & Gonzalez-Moreno, 2016). The companies were asked to evaluate the importance of these three objectives on a Likert scale of 1 to 4: 1 represents high importance, 2 represents intermediate importance, 3 represents low importance and 4 means not relevant. Based on the responses to these three objectives, the eco-innovation oriented strategy variable takes a value equal to 1 if one or more of these three objectives has a high importance. In all other cases, the variable takes the value 0.

We have also introduced a number of control variables, according to their potential effect on the productivity of the company. Relying on the evidence in the economic literature, we incorporated the following variables: group, export intensity, R&D intensity and size. Finally, and in order to implement the Heckman correction (Heckman, 1979) we also incorporate the innovator variable and a series of obstacles to innovation (lack of internal funds, lack of external funds, high innovation costs, lack of qualified personnel, lack of information on technology, lack of market information, lack of partners with whom to cooperate, market dominated by established companies and uncertain demand).

A precise definition of how the variables were constructed, and their basic descriptive statistics, can be found in Table 1.

3.3. Methodology

The theory of supermodular games, based on the mathematical model developed by Topkis (1978), allows the necessary conditions to understand the relationship of complementarity/substitutability between two variables to be precisely formalised. Milgrom and Roberts (1990) were the first to implement the complementarity approach in the field of management.

Formally, a pair of innovation activities is complementary if the sum of the benefits to do only one or the other is no greater than the benefit of doing both together.

In relation to the complementarity approach (Milgrom & Roberts 1990), suppose that there are two activities Xi and Xj, and Z is a vector of exogenous variables in an objective function F(Xi,Xj,Z). Assume that Xi and Xj are dichotomous choices that take the value 1 if they are adopted by the firm and the value 0 if they are not. The complementarity approach regresses an objective on exclusive combinations of innovation activities and the vector of exogenous variables:

$$F(X_i, X_j, Z) = \beta_{00}(1 - X_i)(1 - X_j) + \beta_{10}X_i(1 - X_j) + \beta_{01}(1 - X_i)X_j + \beta_{11}X_iX_j + \beta_z Z + e$$

Where,

β_{11} measures the partial cross return of choosing Xi and Xj jointly.

β_{10} measures the return of only choosing Xi.

β_{01} measures the return of only choosing Xj.

β_{00} measures the return derived from not choosing either of the two activities.

Then, the objective function $F(X_i,X_j,Z)$ is supermodular and X_i and X_j are complementary if:

$$\beta_{11} + \beta_{00} - \beta_{10} - \beta_{01} > 0$$

Conversely, the objective function $F(X_i,X_j,Z)$ is submodular and X_i and X_j are substitutes if:

$$\beta_{11} + \beta_{00} - \beta_{10} - \beta_{01} < 0$$

In the complementarity approach two different methods are used to test the hypotheses: Mohnen and Röller (2005) use H0: $R\beta > r$ as a null hypothesis, and H1: $R\beta \leq r$ as alternative hypothesis. Belderbos et al. (2006) use H0: $R\beta = r$ vs H1: $R\beta \geq r$.

Ballot et al. (2015) point out that the first test often offers abundant inconclusive results, while the second test offers more information, which is mainly important when analysing the

Table 1
Definition of variables and descriptive statistics.

name of variable	variable construction	mean / stand. deviation
labor productivity	relationship between sales and number of employees	243,663/411,749
RD Subsidy	The firm receives R&D subsidies from one or more of the following programs: Spanish regions, Spanish state, European Union, and Framework program (0,1)	0.2435/0.4292
RD Cooperation	The company cooperates in R&D with other companies or institutions (0,1)	0.2756/0.4468
Eco-innovation oriented strategy	The variable takes the value 1 when the company considers high (four possible categories: high, intermediate, low and not relevant) the importance of one or more of the following objectives of technological innovation: fewer materials per unit produced, less energy per unit produced and less environmental impact. Otherwise, it takes value 0	0.2661/0.4419
Group	The company belongs to a group (0,1)	0.4200/0.4940
Export intensity	Percentage of exports in total sales.	0.3260/0.3269
RD Intensity	Relationship between internal R&D expenditure and total sales of the company.	0.0231/0.0939
Size	Logarithm of the number of employees.	1.6826/0.6354
Innovator	If the company introduces one or more of the following innovations: product innovation, process innovation, organization innovation and marketing innovation (0,1)	0.6656/0.4718
Lack of internal funds	It is a measure of the importance of the lack of funds in the company or group as an obstacle of the innovative process (valued between 0, not relevant, and 3, very relevant).	1,8400/1.1060
Lack of external funds	It is a measure of the importance of the lack of external financing as an obstacle of the innovative process (valued between 0, not relevant, and 3, very relevant).	1.7600/1.1340
High innovation costs	It is a measure of the importance of the existence of high innovation costs as an obstacle to the innovative process (valued between 0, not relevant, and 3, very relevant).	1.7900/1.1000
Lack of qualified personnel	It is a measure of the importance of the lack of qualified personnel as an obstacle to the innovative process (valued between 0, not relevant, and 3, very relevant).	1.1700/0.9210
Lack of information on technology	It is a measure of the importance of the lack of information on technology as an obstacle for the innovative process (valued between 0, not relevant, and 3, very relevant).	1.1100/0.8730
Lack of market information	It is a measure of the importance of the lack of market information as an obstacle for the innovative process (valued between 0, not relevant, and 3, very relevant).	1.1300/0.8940
Lack of partners to cooperate	It is a measure of the importance of the difficulty of finding partners to cooperate as an obstacle for the innovative process (valued between 0, not relevant, and 3, very relevant).	1.0700/1.0100
Market dominated by established companies	It is a measure of the importance of the existence of a market dominated by established companies as an obstacle to the innovative process (valued between 0, not relevant, and 3, very relevant).	1.4200/1.0470
Uncertain demand	It is a measure of the importance of the existence of an uncertain demand for innovative goods or services as an obstacle to the innovative process (valued between 0, not relevant, and 3, very relevant).	1.6100/1.0660

complementarity of more than two variables. In this paper we thus focus on the second test.

We analyze the complementarity/substitutability relationships between the R&D subsidy, R&D cooperation, and eco-innovation oriented strategy variables. Using the complementarity approach, the relationship between variables is tested pairwise. For example, if we want to test the complementarity between R&D subsidy and R&D cooperation, we have to test the two following non-trivial inequalities:

$$\beta_{110} + \beta_{000} - \beta_{100} - \beta_{010} > 0 (\textit{test carried out among non} - \textit{eco} - \textit{oriented strategy firms})$$

$$\beta_{111} + \beta_{001} - \beta_{101} - \beta_{011} > 0 (\textit{test carried out among eco} - \textit{oriented strategy firms})$$

Our analysis focused on innovative manufacturing companies (3024), selected from the set of manufacturing companies (4543), which means the sample is not random and, there may be sample selection bias. To correct this bias, the Heckman correction method is used (Heckman, 1979). This methodology is based on a two-step procedure. The first stage consists of a binary selection equation, using all available observations (4543) and considering as a dependent variable whether or not the firm carries out innovation activities (Innovator). The selection equation is estimated at this stage, and the inverse Mills ratio is calculated. In the second stage, the outcome equation is estimated, to which the inverse Mills ratio calculated in the first stage is incorporated. The sample selection bias is corrected using the inverse Mills ratio. In this second stage, we only considered innovative firms, that is, 3024 observations.

We use two models in this study. The outcome equation of Model I incorporates R&D subsidy, R&D cooperation and eco-innovation oriented strategy as central variables. Using the coefficient of this last variable, we analyze the effect of the eco-innovation oriented strategy on the labor productivity of companies (Hypothesis 1). In addition to these three central variables, the outcome equation of Model I incorporates different independent variables, such as group, export intensity, R&D intensity and size. The variables are similar to those used in other studies exploring the effect of different strategies or types of innovation on some measure of performance (Ballot et al., 2015; Cassiman & Veugelers, 2006). The independent variables in the outcome equation must be a strict subset of the independent variables of the selection equation (Wooldridge, 1995). The selection equation therefore has the same independent variables as the outcome equation, plus a set of representative variables of different barriers to innovation: lack of internal funds, lack of external funds, high innovation costs, lack of qualified personnel, lack of information on technology, lack of market information, lack of partners to cooperate, market dominated by established companies and uncertain demand.

In the outcome and selection equations of Model II we substitute the R&D subsidy, R&D cooperation and eco-innovation oriented strategy variables with eight exclusive profiles of these three variables. For example, the variable (0 1 0) represents the unique combination of companies that cooperate in R&D, but they do not receive public subsidies or have an eco-innovation oriented strategy implemented. In order to implement complementarity tests it is necessary to estimate the coefficients of the eight exclusive profiles, but the presence of the eight exclusive variables in Model II generates perfect multicollinearity, so the model collapses and can't be estimated. To avoid this perfect multicollinearity, it is therefore necessary to eliminate the constant of the model. The coefficients of the eight exclusive variables will be used to contrast Hypotheses 2 and 3.

Table 2
Eco-oriented strategy and non-eco-oriented strategy (mean values, and standard deviation in brackets).

		Eco-innovation oriented strategy		Non-Eco-innovation oriented strategy	
Variable	Nature of the variable	Innovator	Non-innovator	Innovator	Non-innovator
Laboral productivity	Continuous	284,812 (293,361)	245,314 (228,887)	242,843 (369,742)	212,382 (531,969)
RD Subsidy	Binary (0 1)	0.4206 (0.4939)	0.4024 (0.4934)	0.2752 (0.4467)	0.0536 (0.2253)
RD Cooperation	Binary (0 1)	0.5084 (0.5002)	0.3171 (0.4682)	0.3184 (0.4660)	0.0341 (0.1816)
Group	Binary (0 1)	0.5700 (0.4950)	0.3700 (0.4850)	0.4500 (0.4970)	0.2700 (0.4450)
Export Intensity	Continuous	0.4014 (0.3243)	0.3681 (0.3535)	0.3501 (0.3258)	0.2325 (0.3071)
RD Intensity	Continuos	0.0354 (0.1195)	0.0672 (0.2379)	0.0285 (0.0960	0.0043 (0,0274)
Size	Continuous	267 (712)	130 (229)	131 (271)	75 (221)
Observations		1127	82	1897	1437

Table 3
Results of the regression of the outcome equation of models I and II.

	Model I		Model II	
Dependent variable: Labor productivity	Coefficient	Standard error	Coefficient	Standard error
R&D Subsidy	42,499.2***	15,016.9	–	–
R&D Cooperation	125,246***	14,886	–	–
Eco-innovation oriented strategy	130,523.3***	13,705.4	–	–
Group	71,718.8***	14,347.8	71,372***	14,350.3
Export intensity	94,761.8***	18,785.8	85,991.8***	18,804.9
R&D Intensity	−75,118.3	62,644	−101,738.1	62,574.4
Size	114,864.9***	12,141.4	112,713.1***	12,163.6
(0 0 0)	–	–	284,086.8***	19,671.5
(1 1 1)	–	–	−40,836.9	31,704.6
(1 0 0)	–	–	113,030.6***	31,547.7
(0 1 0)	–	–	−34,266.1	29,845.9
(0 0 1)	–	–	−49,047.9*	26,554.2
(1 1 0)	–	–	−64,671.7**	29,348.5
(1 0 1)	–	–	−65,034.1*	35,778.6
(0 1 1)	–	–	−6846.2	332,248.2
Constant	259,974.3***	19,350.1	–	–
Model	Wald chi2 (7)= 821.3***		Wald chi2(12)= 1195.4***	

Statistical significance of the coefficients: 1% ***, 5% ** and 10% *.

4. Results and discussion

Table 2 shows the basic descriptive statistics of the variables that are part of the outcome equation, differentiating between the companies that have implemented an eco-oriented strategy and those that have not. Similarly, we differentiate between innovative and non-innovative companies within each group.

The sample used in the econometric analysis includes 4543 Spanish firms, of which 1209 (26.6%) have implemented an eco-oriented strategy and 3334 (73.4%) have not. Within the group of companies that have implemented an eco-oriented strategy, 1127 firms are innovative and 82 firms are not. Among the companies that have not implemented an eco-oriented strategy, 1897 are innovative companies and 1437 are not.

Most research into the relationship between eco-innovation and performance is focused on the manufacturing industry (Munodawafa & Johl, 2019). The literature on Spanish eco-innovative manufacturing firms suggests that compared to conventional innovative firms, the eco-innovative firms are more intensive in R&D, cooperate to a greater extent, exhibit greater membership in groups of companies, are more active in international markets and are larger (Jové-Llopis & Segarra-Blasco, 2017). Similar behaviours were found by Pons, Bikfalvi and Llach (2018) for a pool of companies from Spain, France and Portugal. In line with these studies, Table 2 shows that eco-innovative manufacturing companies achieve higher values than non-eco-innovative companies in all the variables under analysis (labor productivity, R&D subsidy, R&D cooperation, group, export intensity, R&D intensity and size).

Table 3 shows the results of the regression of the labor productivity variable on the set of independent variables in Models I and II. In relation to the control variables, it verifies that in both models all the variables have a positive and statistically significant effect, except for the R&D intensity variable, the effect of which is negative and not significant. This last characteristic is a probable indication of the heterogeneous and low level of R&D intensity demonstrated by Spanish companies, on average, in relation to their European counterparts.

Model I shows that the eco-innovation oriented strategy variable has a positive and fully significant effect on the labor productivity of companies. Hypotheses 1 is therefore supported. Our result is in line with studies that have also confirmed a positive relationship between proactive environmental strategy and business performance (*e.g.*, Cheng, Yang and Sheu 2014; Christmann 2000; Klassen and Whybark 1999; Marcus and Geffen 1998; Zhang and Walton 2016).

Finally, Table 4 shows the results of the complementarity tests performed from the estimated coefficients of the eight exclusive variables (Model II). Complementarity is explored between R&D subsidy and R&D cooperation. This relationship is tested in two different scenarios, depending on whether or not the eco-innovation oriented strategy is present in each test.

The complementarity test carried out between companies that do not implement an eco-innovation-oriented strategy indicates that the relationship between R&D cooperation and R&D subsidies is substitutive. Hypothesis 2 is thus supported.

As we have previously indicated, the relationship between R&D subsidy and R&D cooperation is expected to be complementary, since both variables positively affect the productivity of companies and, furthermore, both tend to reinforce each other. The European Union has thus designed and implemented innovation policies aimed at promoting subsidised R&D cooperation agreements (Broekel, 2015; Scherngell & Barber, 2011), since the development of new knowledge

Table 4
Complementary tests.

		Chi2	P-value
R&D Subsidy – R&D Cooperation	Eco-innovation oriented strategy = 0		
	T1: $\beta_{110}+\beta_{000}-\beta_{010}-\beta_{100}=0$	26,65	0.0000
	T2: $\beta_{110}+\beta_{000}-\beta_{010}-\beta_{100}\leq 0$		0.9999
	Complementary / Substitutability / No relation	**Substitutive**	
	Eco-innovation oriented strategy = 1		
	T1: $\beta_{111}+\beta_{001}-\beta_{011}-\beta_{101}=0$	0,15	0.6950
	T2: $\beta_{111}+\beta_{001}-\beta_{011}-\beta_{101}\leq 0$		
	Complementary / Substitutability / No relation	**No relation**	

is stimulated and diffused through this kind of agreement (Hottenrott & Lopes-Bento, 2014). There is empirical evidence to suggest that the interaction between R&D cooperation and R&D subsidies has a positive effect on firm performance (*e.g.* Broekel et al. 2011; Czarnitzki et al. 2007; Sakakibara 2001), however, this evidence has been obtained using data from advanced European countries, so it should not be inferred that the interaction of both variables leads to identical results in Spain, since the absorption capacity of Spanish companies is clearly lower than that of companies in more advanced European countries. In this regard, it must be taken into account that absorption capacity has a determining effect on the costs and benefits of R&D cooperation (Edler, 2008). It is thus expected that, on average, Spanish companies are not able to take full advantage of knowledge spillovers generated by R&D cooperation agreements, since they have a notable lack of internal ability to leverage the expertise that partners bring. The costs associated with cooperation may thus be higher in many Spanish companies than the additional revenue reported. The substitutability between R&D subsidy and R&D cooperation is expected in the context of Spanish manufacturing companies that do not implement an eco-innovation-oriented strategy Although empirical studies have addressed this issue, our finding coincides with the results of Guisado-González et al. (2018) for all Spanish manufacturing companies (eco-innovative companies and non-eco-innovative companies).

The findings of our research provide evidence that the interaction between R&D subsidy and R&D cooperation is substitutive among Spanish manufacturing companies which do not implement an eco-innovation-oriented strategy. Our research therefore expands the current literature, providing a clearer understanding of how the subsidised R&D cooperation agreements do not always have a positive impact on the performance of companies, and that the widespread implementation of these kinds of policies does not always seem convenient. The design and implementation of subsidised R&D cooperation agreements must take into account the internal R&D capabilities of companies.

Among the companies that implement an eco-innovation-oriented strategy, however, the test indicates that R&D subsidy and R&D cooperation are not complementary or substitutive; in other words, they are independent variables, since their interaction is not statistically significant in relation to the corresponding labor productivity. Hypothesis 3 is therefore not supported. In this case, however, it is clear that the impact of the interaction between R&D subsidy and R&D cooperation has helped to improve the performance of companies, since the interaction of both variables is not substitutive. The different behavior of the interaction analysed between companies that implement an eco-innovation-oriented strategy and those that do not is likely to be due to the differences in size and internal R&D capabilities of both groups of companies. Descriptive statistics (Table 2) show that, on average, companies that have implemented an eco-innovation-oriented strategy are larger and have superior internal R&D capabilities. On the other hand, the literature on innovation emphasises that size and internal capacities in R&D are variables that determine the absorptive capacity of companies and their propensity to cooperate with other companies (*e.g.*, Ebersberger and Herstad 2013; Faems, de Visser, Andries and Van Looy 2010; López 2008; Rammer, Czarnitzki and Spielkamp 2009). It can thus be expected that as soon as Spanish eco-innovative companies increase their size and internal capacities in R&D, the interaction between the R&D subsidy and R&D cooperation variables will become complementary. Under these conditions, the promotion of subsidised R&D cooperation agreements may be a reasonable policy with which to increase and spread environmental innovations in the context of the Spanish manufacturing sector.

5. Conclusions

The literature on innovation has highlighted the importance of implementing an eco-innovation-oriented strategy for improving the environment, as well as the role played by public subsidies and the establishment of R&D cooperation agreements in promoting eco-innovation. For companies to commit to the development of environmentally friendly policies, it is necessary that the implementation of these policies does not deteriorate the business performance of companies, since doing so would jeopardize their future viability (González-Blanco et al., 2018). In the field of innovation literature there thus is a broad interest in analysing the impact of eco-innovation strategies, granted R&D subsidies and the establishment of R&D cooperation agreements on business performance.

This study pursued a double objective. The first objective was to determine whether eco-innovation has a positive or negative effect on the business performance of companies. In this way, we contribute to expanding information on the economic consequences for companies that derive from a greater environmental commitment. This information is especially relevant for economies with a mediocre innovation propensity and which are not overly enthusiastic about the green economy. This analysis is very relevant for managers, since there is continuing controversy regarding eco-innovation: some authors argue that environmental commitment is a luxury, since the reduction of environmental damage entails significant increases in costs that erode their competitive advantage and business performance (Pearce & Palmer, 2001); conversely, other authors confirm that eco-innovation benefits the environment and companies simultaneously, since eco-innovation facilitates a reduction in the use of energy and/or materials, and stimulates the replacement of underperforming assets (Porter & van der Linde, 1995). The results of our research suggest that an eco-innovation-oriented strategy positively affects the labor productivity of companies. This is especially applicable and encouraging, since it has been obtained from data from the Spanish economy, which is characterised by a moderate innovative profile and consumers unlikely to pay more for products that contribute to environmental sustainability

Second, we analysed the way in which the joint implementation of R&D subsidy and R&D cooperation increases or decreases their respective individual impacts on productivity. We used the complementarity approach (Milgrom & Roberts 1990) to develop this second objective. The literature on eco-innovation has found that R&D

subsidy and R&D cooperation have a positive effect on the business performance of companies (*e.g.*, Del Río et al. 2015; Triguero et al. 2013), but, as far as we know, it has not analysed the impact derived from their joint implementation. In other words, there has been no analysis, in the field of eco-innovation, of whether the variables are complementary or substitutive in relation to the labor productivity of companies. The findings of our empirical analysis indicate that, among companies that do not implement an eco-innovation-oriented strategy, the interaction of R&D subsidy and R&D cooperation is substitutive; and that there is no relationship between the variables when it comes to eco-innovative companies. The results of the two complementarity tests thus suggest that receiving public aid as a consequence of establishing R&D cooperation agreements has a lower effect on labor productivity (non-eco-innovative companies), or the same effect (eco-innovative companies), compared to the sum of the individual impacts of R&D cooperation and R&D subsidy. This information is extremely important, both for managers and for policy makers.

Our findings suggest that the managers of non-eco-innovative companies in the Spanish manufacturing sector should not be interested in requesting public subsidies for innovation that entail an obligation to cooperate with other companies, since the interaction of R&D subsidy and R&D cooperation is substitutive, which ultimately impairs the potential productivity of companies. This is true because these companies probably have a low absorption capacity, and therefore a manifest inability to extract all the potential benefits offered by cooperation agreements. The R&D subsidies that these companies receive are insufficient to offset the costs they incur for their mandatory participation in R&D cooperation agreements. It is more profitable for these companies to request subsidies for innovation that are not conditional on the establishment of cooperation agreements.

On the other hand, to the managers of eco-innovative companies can agree to participate in subsidised R&D cooperation agreements, since the interaction between R&D subsidy and R&D cooperation is neither substitute nor complementary in this class of companies; that is, the joint implementation of both variables does not increase or decrease the labor productivity of companies. They do, however, benefit from their respective individual positive effects on productivity. From the perspective of labor productivity, therefore, eco-innovative companies can resort to more public aid for innovation (R&D subsidies without cooperation conditionality and subsidised R&D cooperation agreements) than non-eco-innovative companies. This is probably because eco-innovative companies are larger and have greater absorption capacity than non-eco-innovative companies.

These findings can also be an important guide for policymakers in designing innovation promotion policies that make use of public aid for the development of R&D activities, and especially those related to improving the environment. Public administrations tend to grant much of the aid for innovation on the condition that beneficiary companies establish cooperation agreements between them (Broekel & Graf 2012; Czarnitzki et al., 2007; Guisado-González et al., 2018). The results suggest that a generalised application of this policy is not appropriate in the context of the Spanish productive fabric. It is clearly unjustified for companies that carry out traditional innovation activities, as these companies are, on average, small and have an inadequate absorption capacity, and therefore demonstrate a manifest inability to take advantage of all the benefits that R&D cooperation agreements report. It seems logical that before forcing them to cooperate, public policies should be designed that push companies to increase their size and their corresponding absorption capacity. The results suggest that subsidised R&D cooperation agreements can be used among eco-innovative companies, since these types of companies are larger and have greater absorption capacity than non-eco-innovative companies (Jové-Llopis & Segarra-Blasco, 2017). This absorption capacity is also insufficient to take advantage of all the potential benefits generated by subsidised R&D cooperation agreements (the relationship between R&D subsidy and R&D cooperation is not complementary), however, so the implementation of public policies aimed at increasing the size and the absorption capacity of eco-innovative companies is also desirable.

References

Aerts, K., & Czarnitzki, D. (2006). *The impact of public R&D-funding in flanders*. Brussels, Belgium: IWT Study No. 54.

Ambec, S., Cohen, M., Elgie, S., & Lanoie, P. (2013). The porter hypothesis at 20: Can environmental regulation enhance innovation and competitiveness? *Review of Environmental Economics and Policy*, *7*, 2–22.

Amores-Salvadó, J., Martin de Castro, G., & Navas-López, J. E. (2015). The importance of the complementarity between environmental management systems and environmental innovation capabilities: A firm level approach to environmental and business performance benefits. *Technological Forecasting & Social Change*, *96*, 288–297.

Ballot, G., Fakhfakh, F., Galia, F., & Salter, A. (2015). The fateful triangle. Complementarities between product, process and organizational innovation in the UK and France. *Research Policy*, *44*, 217–232.

Becker, W., & Dietz, J. (2004). R&D cooperation and innovation activities of firms - evidence for the German manufacturing industry. *Research Policy*, *33*, 209–223.

Belderbos, R., Carree, M., & Lokshin, B. (2006). Complementarity in R&D cooperation strategies. *Review of Industrial Organization*, *28*, 401–426.

Belderbos, R., Carree, M. A., Diederen, B., Lokshin, B., & Veugelers, R. (2004a). Heterogeneity in R&D cooperation strategies. *International Journal of Industrial Organanization*, *22*, 1137–1263.

Belderbos, R., Carree, M. A., & Lokshin, B. (2004b). Cooperative R&D and firm performance. *Research Policy*, *33*, 1477–1492.

Berrone, P., Fosfuri, A., Gelabert, L., & Gomez-Mejia, L. R. (2013). Necessity as the mother of 'green' inventions: Institutional pressures and environmental innovations. *Strategic Management Journal*, *34*, 891–909.

Boons, F., & Wagner, M. (2009). Assessing the relationship between economic and ecological performance: Distinguishing system levels and the role of Innovation. *Ecological Economics*, *68*, 1908–1914.

Bower, J. L., & Hout, T. M. (1988). Fast cycle capability for competitive power. *Harvard Business Review*, *66*, 110–118.

Broekel, T. (2015). Do cooperative research and development (R&D) subsidies stimulate regional innovation efficiency? Evidence from Germany. *Regional Studies*, *49*, 1087–1110.

Broekel, T., & Graf, H. (2012). Public research intensity and the structure of German R&D networks: A comparison of 10 technologies. *Economics of Innovation and New Technology*, *21*, 345–372.

Broekel, T., Schimke, A., & Brenner, T. (2011). *The effects of cooperative R&D subsidies and subsidized cooperation on employment growth.*Working Paper Series in Economics, No. 34.

Burnett, R., Hansen, D., & Quintana, O. (2007). Eco-efficiency: Achieving productivity improvements through environmental cost management. *Accounting and the Public Interest*, *7*, 66–92.

Cainelli, G., De Marchi, V., & Grandinetti, R. (2015). Does the development of environmental innovation require different resources? Evidence from Spanish manufacturing firms. *Journal of Cleaner Production*, *94*, 211–220.

Caloghirou, Y., Ioannides, S., & Vonortas, N. (2003). Research joint ventures. *Journal of Economic Surveys*, *17*, 541–570.

Cassiman, B., & Veugelers, R. (2002). R&D co-operation and spillovers: Some empirical evidence from Belgium. *American Economic Review*, *92*, 1169–1184.

Cassiman, B., & Veugelers, R. (2006). In search of complementarity in innovation strategy: Internal R&D and external knowledge acquisition. *Management Science*, *52*, 68–82.

Chang, C. H. (2011). The influence of corporate environmental ethics on competitive advantage: The mediation role of Green innovation. *Journal of Business Ethics*, *104*, 361–370.

Chatterjee, R., Chattopadhyay, S., & Kabiraj, T. (2018). Spillovers and R&D incentive under incomplete information. *Studies in Microeconomics*, *6*, 50–65.

Cheng, C. C. J., Yang, C. L., & Sheu, C. (2014). The link between eco-innovation and business performance: A Taiwanese industry context. *Journal of Cleaner Production*, *64*, 81–90.

Christainsen, G. B., & Haveman, R. H. (1981). The contribution of environmental regulation to the slowdown in productivity growth. *Journal of Environmental Economics and Management*, *8*, 381–390.

Christmann, P. (2000). Effects of best practices of environmental management on cost advantage: The role of complementary assets. *Academy of Management Journal*, *43*, 663–680.

Cohen, W. M., & Levinthal, D. A. (1989). Innovation and learning: The two faces of R&D. *Economic Journal*, *99*, 569–596.

Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly*, *35*, 128–152.

Collins, E., Lawrence, S., Pavlovich, K., & Ryan, C. (2007). Business networks and the uptake of sustainability practices: The case of New Zealand. *Journal of Cleaner Production*, *15*, 729–740.

Coombs, R., Harvey, M., & Tether, B. S. (2003). Analysing distributed processes of provision and innovation. *Industrial and Corporate Change*, *12*, 1125–1155.

Cordeiro, J. J., & Sarkis, J. (1997). Environmental proactivism and firm performance: Evidence from security analyst earnings forecasts. *Business Strategy and the Environment*, *6*, 104–114.

Czarnitzki, D., Ebersberger, B., & Fier, A. (2007). The relationship between R&D collaboration, subsidies and patenting activity: Empirical evidence from Finland and Germany. *Journal of Applied Econometrics*, *22*, 1347–1366.

Dahlman, C. (2007). Technology, globalization, and international competitiveness: Challenges for developing countries. UnitedNations, *Industrial development for the 21st century: Sustainable development perspectives* UnitedNations. (pp. 29–83). New York: Department of Economic and Social Affairs, United Nations.

Das, T. K., & Teng, B. S. (2000). A resource-based theory of strategic alliances. *Journal of Management*, *26*, 31–61.

Das, T. K., & Teng, B. S. (2001). Trust, control, and risk in strategic alliances: An integrated framework. *Organization Studies*, *22*, 251–283.

d'Aspremont, C., & Jacquemin, A. (1988). Cooperative and noncooperative R&D in duopoly with spillovers. *American Economic Review*, *78*, 1133–1137.

De Marchi, V. (2012). Environmental innovation and R&D cooperation: Empirical evidence from Spanish manufacturing firms. *Research Policy*, *41*, 614–623.

De Marchi, V. D., & Grandinetti, R. (2013). Knowledge strategies for environmental innovations: The case of Italian manufacturing firms. *Journal of Knowledge Management*, *17*, 569–582.

Del Río, P., Peñasco, C., & Romero-Jordán, D. (2015). Distinctive features of environmental innovators: An econometric analysis. *Business Strategy and the Environment*, *24*, 361–385.

Del Río, P., Romero-Jordán, D., & Peñasco, C. (2017). Analysing firm-specific and type-specific determinants of eco-innovation. *Technological and Economic Development of Economy*, *23*, 270–295.

Ebersberger, B., & Herstad, S. (2013). The relationship between international innovation collaboration, intramural R&D and SMEs innovation performance: A quantile regression approach. *Applied Economic Letters*, *20*, 626–630.

Edler, J. (2008). Creative internationalization: Widening the perspectives on analysis and policy regarding international R&D activities. *Journal of Technology Transfer*, *33*, 337–352.

Eiadat, Y., Kelly, A., Roche, F., & Eyadat, H. (2008). Green and competitive? An empirical test of the mediating role of environmental innovation strategy. *Journal of World Business*, *43*, 131–145.

Eisenhardt, K. M., & Scoonhoven, C. B. (1996). Resource-based view of strategic alliances formation: Strategic and social effects in entrepreneurial firms. *Organization Science*, *7*, 136–150.

European Commission. (1995). *Green paper on innovation*. Luxembourg: Office for official publications of the european communities.

Faems, D., de Visser, M., Andries, P., & Van Looy, B. (2010). Technology alliance portfolios and financial performance: Value-enhancing and cost-increasing effects of open innovation. *Journal of Product Innovation Management*, *27*, 785–796.

Feichtinger, G., Hartl, R. F., Kort, P. M., & Veliov, V. M. (2003). Environmental policy, the Porter hypothesis and the composition of capital: Effects of learning and technological progress. *Journal of Environmental Economics and Management*, *50*, 434–446.

Filbeck, G., & Gorman, R. F. (2004). The Relationship between the environmental and financial performance of public utilities. *Environmental and Resource Economics*, *29*, 137–157.

Fornahl, D., Broekel, T., & Boschma, R. A. (2011). What drives patent performance of German biotech firms? The impact of R&D subsidies, knowledge networks and their location. *Papers in Regional Science*, *90*, 395–418.

Ghisetti, C., Mancinelli, S., Mazzanti, M., & Zoli, M. (2017). Financial barriers and environmental innovations: Evidence from EU manufacturing firms. *Climate Policy*, *17*, 131–147.

Gollop, F. M., & Roberts, M. J. (1983). Environmental regulation and productivity growth: The case of fossil-fueled electric power generation. *Journal of Political Economy*, *91*, 654–674.

González-Blanco, J., Coca-Pérez, J. L., & Guisado-González, M. (2018). The contribution of technological and non-technological innovation to environmental performance. An analysis with a complementary approach. *Sustainability*, *10*(11), 4014. doi:10.3390/su10114014.

González-Blanco, J., Vila-Alonso, M., & Guisado-González, M. (2019). Exploring the complementarity between foreign technology, embedded technology and increase of productive capacity. *Technological and Economic Development of Economy*, *25*, 39–58.

Graevenittz, G. (2004). *Spillovers reconsidered: How optimal R&D subsidies depend on the spillover process*. Mimeo: Department of Economics, University College London.

Gray, W. B. (1987). The cost of regulation: OSHA, EPA and the productivity slowdown. *American Economic Review*, *77*, 998–1006.

Gray, W. B., & Shadbegian, R. J. (2003). Plant vintage, technology, and environmental regulation. *Journal of Environmental Economics and Management*, *46*, 384–402.

Greenstone, M. (2002). The impacts of environmental regulations on industrial activity: Evidence from the 1970 and 1977 clean air act amendments and the census manufacturers. *Journal of Political Economy*, *110*, 1175–1219.

Grossman, G. M., & Helpman, E. (1991). *Innovation and growth in the global economy*. Cambridge, Massachusetts: MIT Press.

Guisado-González, M., González-Blanco, J., & Coca-Pérez, J. L. (2017). Analyzing the relationship between exploration, exploitation and organizational innovation. *Journal of Knowledge Management*, *21*, 1142–1162.

Guisado-González, M., González-Blanco, J., Coca-Pérez, J. L., & Guisado-Tato, M. (2018). Assessing the relationship between R&D subsidy, R&D cooperation and absorptive capacity: An investigation on the manufacturing Spanish case. *Journal of Technology Transfer*, *43*, 1647–1666.

Gussoni, M., & Mangani, A. (2009). *The impact of public funding for innovation on firms' R&D investments: Do R&D cooperation and appropriability matter?* Department of Economics, University of Pisa *Discussion papers, 90*.

Hagedoorn, J. (2002). Inter-firm R&D partnerships: An overview of major trends and patterns since 1960. *Research Policy*, *31*, 477–492.

Hall, B. H., Mairesse, J., & Mohnen, P. (2010). Measuring the returns to R&D. In B. H. Hall, & N. Rosenberg (Eds.), *Handbook of the economics of innovation* (pp. 1034–1076). Amsterdam and New York: Elsevier.

Harris, R., Krenza, A., & Moffata, J. (2019). The impacts of absorptive capacity in the European Union. Online: https://www.researchgate.net/publication/333388489

Heckman, J. J. (1979). Sample selection bias as a specification error. *Econometrica : journal of the Econometric Society*, *47*, 153–161.

Hennart, J. F. (1988). A transaction cost theory of equity joint ventures. *Strategic Management Journal*, *9*, 361–374.

Hollanders, H., & Es-Sadki, N. (2013). *Innovation union scoreboard 2013. Maastricht economic and social research institute on innovation and technology*. Maastricht, The Netherlands: UNU-MERIT.

Horbach, J. (2008). Determinants of environmental innovation-New evidence from German panel data sources. *Research Policy*, *37*, 163–173.

Horbach, J., Oltra, V., & Belin, J. (2013). Determinants and specificities of eco-innovations compared to other innovations-An econometric analysis for the French and German industry based on the community innovation survey. *Industry and Innovation*, *20*, 523–543.

Hottenrott, H., & Lopes-Bento, C. (2014). (International) R&D collaboration and SMEs: The effectiveness of targeted public R&D support schemes. *Research Policy*, *43*, 1055–1066.

Inkpen, A. C. (1998). Learning, knowledge acquisition and strategic alliances. *European Management Journal*, *16*, 223–229.

Jaffe, A., Newell, R., & Stavins, R. (2005). A tale of two market failures: Technology and environmental policy. *Ecological Economics*, *54*, 164–174.

Jaffe, A. B., & Palmer, K. (1997). Environmental regulation and innovation: A panel data study. *Review of Economics and Statistics*, *79*, 610–619.

Jorde, T. M., & Teece, D. J. (1990). Innovation and cooperation: Implications for competition and antitrust. *Journal of Economic Perspectives*, *4*, 75–96.

Jové-Llopis, E., & Segarra-Blasco, A. (2017). *Eco-innovation: Spanish service and manufacturing firms*. Spain: Universitat Rovira i Virgili *Document de treball, n.09*.

Jové-Llopis, E., & Segarra-Blasco, A. (2018). Eco-innovation strategies: A panel data analysis of Spanish manufacturing firms. *Business Strategy and the Environment*, *27*, 1209–1220.

Kamien, M. I., Muller, E., & Zang, I. (1992). Research joint ventures and R&D cartels. *American Economic Review*, *82*, 1293–1306.

Katz, M. L. (1986). An analysis of cooperative research and development. *RAND Journal of Economics*, *17*, 527–543.

Katz, M. L., & Ordover, J. A. (1990). R&D cooperation and competition. In M. N. Baily, & C. Winston (Eds.), *Brookings papers on economic activit: Microeconomics* (pp. 137–203). Washington, DC: Brookings Institution.

Khanna, T. (1998). The scope of alliances. *Organization Science*, *9*, 340–355.

Klassen, D., & Whybark, D. (1999). The impact of environmental technologies on manufacturing performance. *Academy of Management Journal*, *42*, 599–615.

Konar, S., & Cohen, M. (2001). Does the market value environmental performance? *Review of Economics and Statistics*, *83*, 281–289.

Kristrom, B., & Riera, P. (1996). Is the income elasticity of environmental improvements less than one? *Environmental and Resource Economics*, *7*, 45–55.

López, A. (2008). Determinants of R&D cooperation: Evidence from Spanish manufacturing firms. *International Journal of Industrial Organization*, *26*, 113–136.

Lui, S. S., & Ngo, H. Y. (2004). The role of trust and contractual safeguards on cooperation in non-equity alliances. *Journal of Management*, *30*, 471–485.

Luo, Y. (2002). Contract, cooperation, and performance in international joint ventures. *Strategic Management Journal*, *23*, 903–919.

Marcus, A., & Geffen, D. (1998). The dialectics of competency acquisition: Pollution prevention in electric generation. *Strategic Management Journal*, *19*, 1145–1168.

Markides, C. C., & Williamson, P. J. (1996). *Corporate diversification and organizational structure: A resource-based view: 39* (pp. 340–367). Academy of Management Journal.

Martin, S. (2002). Spillovers, appropriability, and R&D. *Journal of Economics*, *75*, 1–32.

Mayer, K. J., & Salomon, R. M. (2006). Capabilities, contractual hazards, and governance: Integrating resource-based and transaction cost perspectives. *Academy of Management Journal*, *49*, 942–959.

Mazzanti, M., & Zoboli, R. (2009). Embedding environmental innovation in local production systems: SME strategies, networking and industrial relations: Evidence on innovation drivers in industrial districts. *International Review of Applied Economics*, *23*, 169–195.

Mazzi, A., Toniolo, S., Manzardo, A., Ren, J., & Scipioni, A. (2016). Exploring the direction on the environmental and business performance relationship at the firm level. Lessons from a literature review. *Sustainability*, *8*, 1–25.

Milgrom, P., & Roberts, J. (1990). The economics of modern manufacturing: Technology, strategy, and organization. *American Economic Review*, *80*, 511–528.

Miotti, L., & Sachwald, F. (2003). Co-operative R&D: Why and with whom? An integrated framework of analysis. *Research Policy*, *32*, 1481–1499.

Mistri, M., & Solari, S. (2001). Social networks and productive connectance: Modeling the organizational form of the industrial district. *Human System Management*, *20*, 223–236.

Mohnen, P., & Röller, L. (2005). Complementarities in innovation policy. *European Economic Review*, *49*, 1431–1450.

Molero, J., & Buesa, M. (1996). Patterns of technological change among Spanish innovative firms: The case of the Madrid region. *Research Policy*, *25*, 647–663.

Monteverde, K., & Teece, D. J. (1982). Appropriable rents and quasi-vertical integration. *Journal of Law and Economics*, *25*, 321–328.

Mooty, S., & Kedia, B. (2014). R&D partnership portfolio strategies for breakthrough innovation: Developing knowledge exchange capabilities. In R. Culpan (Ed.), *Open innovation through strategic alliances* (pp. 219–252). New York: Palgrave Macmillan.
Munodawafa, R. T., & Johl, S. K. (2019). A systematic review of eco-innovation and performance from the resource-based and stakeholder perspectives. *Sustainability*, *11*, 6067.
Park, N. K., Mezias, J. M., & Song, J. (2004). A resource-based view of strategic alliances and firm value in the electronic marketplace. *Journal of Management*, *30*, 7–27.
Pearce, D., & Palmer, C. (2001). Public and private spending for environmental protection: A cross-country policy analysis. *Fiscal Studies*, *22*, 403–456.
Pons, M., Bikfalvi, A., & Llach, J. (2018). Clustering product innovators: A comparison between conventional and green product innovators. *International Journal of Production Management and Engineering*, *6*, 37–46.
Porter, M. (1991). America's green strategy. *Scientific American*, *264*, 168.
Porter, M., & Van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives*, *9*, 97–118.
Posch, A. (2010). Industrial recycling networks as starting points for broader sustainability oriented cooperation? *Journal of Industrial Ecology*, *14*, 242–257.
Pujari, D. (2006). Eco-innovation and new product development: Understanding the influences on market performance. *Technovation*, *26*, 76–85.
Quan Zhang, K., & Hung Chen, H. (2017). Environmental performance and financing decisions impact on sustainable financial development of Chinese environmental protection enterprises. *Sustainability*, *9*, 2260.
Rammer, C., Czarnitzki, D., & Spielkamp, A. (2009). Innovation success of non-R&D-performers: Substituting technology by management in SMEs. *Small Business Economics*, *33*, 35–58.
Rennings, K. (2000). Redefining innovation - eco-innovation research and the contribution from ecological economics. *Ecological Economics*, *32*, 319–332.
Rexhäuser, S., & Rammer, C. (2014). Environmental innovations and firm profitability: Unmasking the Porter hypothesis. *Environmental and Resource Economics*, *57*, 145–167.
Roxburgh, C., Labaye, E., Thompson, F., Tacke, T., & Kauffman, D. (2012). *Investing in growth: Europe's next challenge*. McKinsey Global Institute. Available online: https://www.mckinsey.com/~/media/McKinsey/Featured%20Insights/Europe/Investing%20in%20growth/MGI_Europe_Investing_Executive_Summary_Dec2012.ashx.
Sáez-Martínez, F. J., Díaz-García, C., & Gonzalez-Moreno, A. (2016). Firm technological trajectory as a driver of eco-innovation in young small and medium-sized enterprises. *Journal of Cleaner Production*, *138*, 28–37.
Sakakibara, M. (2001). The diversity of R&D consortia and firm behavior: Evidence from Japanese data. *Journal of Industrial Economics*, *49*, 181–196.
Scherngell, T., & Barber, M. J. (2011). Distinct spatial characteristics of industrial and public research collaborations: Evidence from the fifth EU Framework Programme. *Annals of Regional Science*, *46*, 247–266.
Segarra-Blasco, A., & Arauzo-Carod, J. M. (2008). Sources of innovation and industry −university interaction: Evidence from Spanish firms. *Research Policy*, *37*, 1283–1295.
Shadbegian, R. J., & Gray, W. B. (2005). Pollution abatement expenditures and plant-level productivity: A production function approach. *Ecological Economics*, *54*, 196–208.
Shakina, E., & Barajas, A. (2020). Innovate or Perish?: Companies under crisis. *European Research on Management and Business Economics*, *26*, 145–154.
Stoll, M. L. (2011). Green chemistry meets green business: A match long overdue. *Journal of Business Ethics*, *99*, 23–28.
Suzumura, K. (1992). Cooperative and noncooperative R&D in an oligopoly with spillovers. *American Economic Review*, *82*, 1307–1320.
Teece, D. J. (1981). The Market for know-how and the efficient international transfer of technology. *Annals of the American Academy of Political and Social Science*, *458*, 81–96.
Teece, D. J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Research Policy*, *15*, 285–305.
Tether, B. S. (2002). Who co-operates for innovation, and why: An empirical analysis. *Research Policy*, *31*, 947–967.
Topkis, D. M. (1978). Minimizing a submodular function on a lattice. *Operations Research*, *26*(2), 305–321.
Triguero, A., Moreno-Mondéjar, L., & Davia, M. A. (2013). Drivers of different types of eco-innovation in European SMEs. *Ecological Economics*, *92*, 25–33.
Van Leeuwen, G., & Mohnen, P. (2017). Revisiting the porter hypothesis: An empirical analysis of Green innovation for the Netherlands. *Economics of Innovation and New Technology*, *26*, 63–77.
Waddock, S., & Graves, S. (1997). The corporate social performance-financial performance link. *Strategic Management Journal*, *18*, 303–319.
Wagner, M., Phu, N. V., Azomahou, T., & Wehrmeyer, W. (2002). The relationship between the environmental and economic performance of firms: An empirical analysis of the European paper industry. *Corporate Social Responsibility and Environmental Management*, *9*, 133–146.
Walker, K., & Wan, F. (2012). The harm of symbolic actions and greenwashing: Corporate actions and communications on environmental performance and their financial implications. *Journal of Business Ethics*, *109*, 227–239.
Walley, N., & Withehead, B. (1994). It's not easy being green. *Harvard Business Review*46–52 May -June.
Williamson, O. E. (1985). *The economic institutions of capitalism*. New York: Free Press.
Wolfe, R. A. (1994). Organizational innovation: Review, critique and suggested research directions. *Journal of Management Studies*, *31*, 405–431.
Wooldridge, J. M. (1995). Selection corrections for panel data models under conditional mean independence assumptions. *Journal of Econometrics*, *68*, 115–132.
Yip, G. (1992). *Total global strategy: Managing for worldwide competitive advantage*. Englewood Cliffs, NJ: Prentice-Hall.
Zhang, J. A., & Walton, S. (2016). Eco-innovation and business performance: The moderating effects of environmental orientation and resource commitment in green-oriented SMEs. *R&D Management*, *47*, 26–39.

Further reading

Ambec, S., & Lanoie, P. (2008). Does It Pay to be Green? A Systematic Overview. *Academy of Management Perspectives*, *22*, 45–62.