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Performance effects of complementarity between environmental management systems and environmental technologies

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This paper analyzes whether the performance effects of environmental management systems (EMS) and environmental technologies (ET) can be enhanced by the complementarity between them. Our complementarity hypotheses are theoretically grounded in the asset complementarity argument of the resource-based theory of the firm. We examine two distinct types of ET: externality-reducing technologies (ERT) that focus on reducing emission and pollution, and efficiency-increasing technologies (EIT) that emphasize reduction of material and energy consumption. Results based on a sample of 36,645 firms from eight countries show that three-way complementarity-in-performance exist, in that firms that adopted EMS and the two types of ET achieved higher turnover growth compared to those firms that adopted either EMS, ERT or EIT singularly, or none of them.

Keywords: Environmental management systems; Environmental technologies; Complementarity analysis; Firm performance.

1. Introduction

An increasingly number of firms such as Toyota, GM, DuPont and Siemens have recently adopted a variety of pollution abatement practices[1], namely, environmental management systems (EMS) and/or environmental technologies (ET) in order to minimize the negative impact of their operations upon the natural environment (Klassen and McLaughlin, 1996). For example, in addition to ISO 14001, Toyota and GM have invested in "renewable technologies" by generation of electricity through landfill gas, wind and solar energy to reduce oil dependency in their plants (Nunes and Bennett, 2010). Given the importance of a portfolio approach to environmental management (Nath and Ramanathan, 2016), managers need to know which combination of pollution abatement practices to adopt; and, more importantly, whether investments in multiple pollution abatement practices generate complementarities. This calls for theories that explain and test if complementarity (Furlan et al, 2011; Resende et al., 2014) between EMS and ET can improve business performance.

To understand complementarity between EMS and ET, it is important to recognize the differences between EMS and ET, the former emphasizes organizational systems (Darnall et al., 2008) whilst the latter focuses on material, production and delivery technologies (Klassen and Whybark, 1999). Prior research points out the existence of positive performance effects of in-house EMS and externally certified EMS (e.g. ISO14001) (Klassen and Whybark, 1999; King and Lenox 2002). EMS improve business performance by providing formalized structures, procedures and processes that enable firms to manage their impact upon the environment (Curkovic and Sroufe, 2011; Lo et al., 2012; Su et al., 2015). Yet, some scholars also indicate that ISO14001 might lead to poorer lead-time (Melnyk et al., 2003) and might not always improve environmental performance (Ammenberg and Hjelm, 2002). With regards to ET, previous findings are also mixed. Some studies underline the adverse performance effects of environmental technologies due to the high costs of emission reduction technologies (Ghisetti and Rennings, 2014; Montabon et al., 2007), whilst others unravel their positive effects upon performance due to efficiency gains (Rexhäuser and Rammer, 2014).

In this paper, we argue that the lack of consensus with regards to the impact of EMS and ET upon business performance is due to two reasons: firstly, we contend that there are different types of pollution abatement technologies with diverse impact upon business performance (Rexhäuser and Rammer, 2014). While some abatement technologies may reduce environmental externalities without necessarily providing positive performance benefits (e.g. installation of carbon capture filters), others may generate business benefits by altering the production process and increasing material or energy

[1] Using energy-efficiency technologies (e.g. process optimization, fuel switch), DuPont saved approximately 36,880 metric tonnes of CO_2 and more than $11 million per year in North America. With a strong focus on ET such as renewable technologies, Siemens has reduced its direct Green House Gas emissions by 6% in 2015, while Toyota UK achieved 70-80% reduction in waste and usage of energy and water in 2015 compared to 1994 (Toyotauk.com/environment).

efficiency (e.g. emission via catalytic converters on automobile tailpipes). Secondly, we propose that oftentimes firms adopt multiple pollution abatement practices with the hope that they might generate complementarity-in-performance benefits (Ferrón-Vílchez and Darnall, 2016). Research on complementarities indicates that whilst adoption of a single practice might be costly or generate marginal performance benefits, the combination of different practices may create higher performance benefits (Milgrom and Roberts, 1990, 1995).

By explaining and testing complementarity effects of multiple pollution abatement practices, this paper provides theoretical and empirical contributions to the field of production economics. The contribution of this research to the literature is threefold: Firstly, we conceptualize pollution abatement technologies according to their expected economic outcomes. Following Rexhäuser and Rammer (2014) we divide pollution abatement technologies into Efficiency Increasing Technologies (EIT) and Externality Reducing Technologies (ERT). Both technologies benefit the environment as they reduce environmental impacts; yet, their economic outcomes and effects on production systems differ significantly. EIT bring about substantial changes in the production systems by reducing material and/or energy use per unit of output. Hence, they improve business performance by increasing efficiency. In contrast, ERT reduce externalities by controlling pollution rather than by modifying the production systems. In other words, ERT do not generate cost savings in the way that EIT do, thus, are perceived by firms as a financial burden.

Secondly, this paper contributes to the production economics literature by providing theoretical insights that explain how and when adoption of a single versus multiple pollution abatement practices is more beneficial for business performance and by empirically testing whether complementarity exists between EMS, ERT and EIT. Our theoretical framework differentiates complementarity-in-use from complementarity-in-performance (Ballot et al., 2015). Complementarity-in-use exists when adoption of one practice (EMS or ET) entails the use of another mutual supportive activity, whereas complementarity-in-performance occurs when the performance effect of combining different practices exceeds the performance effect of adopting them separately (cf. Ballot et al., 2015). For example, Gerstlberger et al. (2016) have shown that firms that implement EMS are more likely to adopt energy-efficient technologies. Yet, this occurrence of complementarity-in-use might not necessarily lead to complementarity-in-performance. Building on the resource-based view (Barney, 1991) and asset complementarity theory (Teece, 1986), we argue that the adoption of EMS creates tacit capabilities and routines that facilitate the adoption of ET (i.e. complementarity-in-use). Embedding such unique and inimitable capabilities and routines within the organization enhances a firm's competitive advantage in terms of access of new markets or the reduction of energy and/or material costs (i.e. complementarity-in-performance) (Klassen and Whybark, 1999; Klassen and McLaughlin, 1996).

The final contribution of this research is related to the introduction of a novel methodological approach, which allows us to formally test the existence of complementarity-in-performance in the context of pollution abatement practices. Based on the use of interaction effects or factoring/clustering methods (Battisti and Stoneman, 2010), prior research has tended to conclude that complementarity may exist between two practices. However, such methods may not be suitable for testing complementarity between more than two practices. This is because incorporating all possible interaction terms into a regression may lead to severe multicollinearity (Ballot et al., 2015). Cluster or factor analysis that provides evidence of only complementarity-in-use is often misinterpreted as complementarity-in-performance. More importantly, these methods assume linearity among the various activities whilst "it is the non-linear interactions that are at the heart of the concept of complementarity" (Ballot et al., 2015, 219). In this paper, we build upon the work of Milgrom and Roberts (1990), Mohnen and Röller (2005) and Cassiman and Veugelers (2006) and introduce a methodological approach to formally test complementarity-in-performance of three pollution abatement practices (EMS, ERT and EIT). Specifically, we first examine the pair-wise complementarities between two practices holding the third one constant. If all mutually exclusive pairs are complementary-in-performance this implies that the performance function is supermodular, i.e. a three-way complementarity exists among EMS, EIT, and ERT.

2. Theoretical framework and hypotheses development

2.1 EMS and Business Performance

Based on the resource-based view (Barney, 1991), we regard EMS as a unique resource that enhances a firm's competitive advantage over competitors (Darnall and Edwards, 2006). EMS provides "a formal system of articulating goals, making choices, gathering information, measuring progress, and improving performance" with respect to resource use, throughput and emissions (Florida and Davison, 2001: 64). By adopting EMS, firms learn to apply 'Plan, Do, Check, Act (PDCA)' model into environmental management. These steps make sure firms identify and minimize the potentially negative environmental effect of their operations, comply with existing laws and continually improve in this direction. EMS such as ISO 14001 is a flexible tool because it does not impose environmental performance requirements (Khanna and Damon, 1999; Alberini and Segerson, 2002) and is applicable to a variety of firms with distinct environmental concerns. According to the ISO survey[2], the number of ISO14001 certifications in 2015 was 319,324 in 171 countries worldwide.

Although the impact of EMS upon environmental performance has evoked criticisms[3], prior environmental management literature has granted significant importance to the EMS with regards to

[2] Available online at www.iso.org

[3] The study by Ammenberg and Hjelm (2002) shows that EMS, such as ISO14001, do not guarantee good environmental performance. This is because such standards do not distinguish between a company that has

its relation with business performance (Melnyk et al., 2003; King and Lenox, 2002; Wagner and Schaltegger, 2004). For example, Ammenberg and Hjelm (2003) conducted a case-study for 26 SMEs in the Hackefors industrial district in Sweden. Their findings indicate that 96% of the environmental co-ordinators of these SMEs considered that ISO14001 generated positive commercial effects. Recent evidence also shows that the adoption of EMS may be positively associated with business performance, e.g., facilitating cost-reductions, improving returns on assets, labour productivity, reputation, and turnover growth (Su et al. 2015, Wakke et al., 2016; Ozusaglam et al., 2017). The positive association between EMS adoption and business performance may be related to positive work attitude among the employees owing to the sustainable brand image (Delmas and Pekovic, 2013), increased external legitimacy with key stakeholders (González-Benito and González-Benito, 2008;), good reputation amongst regulators and insurers (Ambec and Lanoie, 2008) and the possibility of receiving contracts for the sale of products and services (Ammenberg and Hjelm, 2003).

In addition, firms can reap cost advantages through internal efficiency (Ferrón-Vilchez and Darnall, 2016) because EMS require firms to undertake internal assessments that incorporate source reduction into product design, thus institutionalizing pollution prevention programs and extending them throughout the organization (Qi et al., 2012; Takahashi and Nakamura, 2010). These activities reduce environmental impact and eliminate unnecessary materials, including substituting costly toxic inputs for environmentally friendly ones (Christmann, 2000; Sroufe, 2003; Qi et al., 2012), energy consumption, and the use of toxic product inputs (Hart and Ahuja, 1996). Cost-savings can lead to more competitive pricing. It is also possible to generate additional turnover especially when cost advantage is combined with a better reputation owing to EMS adoption. In sum, properly designed EMS can support both environmental and economic objectives. Accordingly, in line with the extant literature we propose Hypothesis 1.

Hypothesis 1: *EMS is expected to exert a positive effect on firms' business performance.*

2.2. Environmental Technologies and Business Performance

Pollution abatement or environmental technologies (ET) have become an integrative part of a firm's environmental management programs (EMPs) (Carrillo-Hermosilla et al., 2010; Dangelico and Pujari, 2010). EMPs are generally classified into operational, tactical and strategic practices all of which can be improved by adopting an appropriate environmental technology portfolio (ETP) (Klassen and Whybark, 1999a, 1999b; Sarkis and Cordeiro, 2001; Montabon et al., 2007; Thoumy and Vachon, 2012; Vachon, 2007). Environmental Technologies (ET) in general refer to new or modified processes and products that enable companies to reduce environmental damages compared to relevant alternatives (Kanda et al., 2016). There are different definitions of ET in the academic and public

improved a single environmental aspect and a company that has integrated environmental issues into core business strategies and has thereby been able to reduce its overall environmental impact.

domains and a variety of terms are used synonymously with or related to ET such as “eco-innovation”, “environmentally sound technology”, “clean technology”, “green technology”, and “low carbon technology” (see Guziana, 2011). This broad terminology of ET reflects the fact that there are different types of ET with different objectives, determinants and specific attributes (Carrilo-Hermosilla et al. 2010; Christensen, 2011; Damanpour et al., 2009) such that their potential environmental and economic benefits vary. This raises the important issue of further classifying ET to better understand their specific characteristics as well as their potential benefits for environmental and business performance.

Environmental management literature have classified pollution prevention and pollution control technologies as components of ETP (Klassen, 2000; Klassen and Whybark, 1999a, b). This classification reflects how managers in the past viewed pollution abatement strategies, either to control or to prevent pollution. However, the most recent developments in measuring different environmental technologies suggests that managers not only view ETP from an externality reduction perspective but also from an efficiency increasing perspective (Jones and Klassen 2001; Rexhäuser and Rammer 2014; Ghisetti and Rennings 2014; Hottenrott et al. 2016). Accordingly, in this paper, we introduce two types of ET, which are inherently different in terms of their impacts on business performance.

Firstly, efficiency-increasing technologies (EIT) refer to the adoption of new production methods and/or modification of existing methods that reduce input or energy usage (Cheng and Shiu, 2012). EIT prevent pollution by increasing operational efficiency. The adoption of EIT requires changes in the basic product or material acquisition, production and delivery processes (Klassen and Whybark, 1999). EIT reduce costs by achieving resource efficiency i.e. they reduce the consumption of resources (energy or fossil fuels and materials) per unit of output. As such, EIT often involve structural changes to critical components of a product or process (Smith and Melnyk, 1996; Klassen and Whybark, 1999). The use of renewable energy technologies and/or adoption of less energy-intensive technologies are examples of EIT. We argue that adoption of EIT allows firms to build unique resources and capabilities (Barney, 1991), which may differentiate a plant from others in terms of resource efficiency and pollution abatement. In turn, efficiency improvements increase firm competitiveness and turnover (either via competitive prices or superior profit margins). Prior literature suggests that investments in EIT have a significant positive effect on firms’ profitability (Ghisetti and Rennings, 2014; Rexhäuser and Rammer, 2014) and turnover (Ambec and Lanoie, 2008). For example, Klassen and Whybark (1999) showed that allocation of resources to EIT relates to better manufacturing performance. Based on the above discussion we argue that environmental technologies that alter the production process so as to increase material or energy efficiency improve business performance. Accordingly, we propose Hypothesis 2:

Hypothesis 2: EIT are *expected to exert a positive effect on firms' business performance*

Secondly, externality-reducing technologies (ERT) predominantly reduce pollution created by a firm's production (Rexhäuser and Rammer, 2014). ERT often involve structural investment to control pollution[4] at the final stage of the production process by reducing carbon emission, soil, water, and air pollution (Demirel and Kesidou, 2011; Klassen and Whybark, 1999) or by replacing materials with less polluting or hazardous substitutes (Rexhäuser and Rammer, 2014). Investments in ERT often offer short-term quick fix solutions that leave the original product and production process essentially unaltered since by definition they only fulfil primarily environmental protection tasks. Hence, ERT are found to be associated with lower business performance (Thoumy and Vachon, 2007; Rexhäuser and Rammer, 2014). Cleff and Rennings (1999) showed that the adoption of ERT is particularly related to compliance with environmental regulations rather than economic motivations. In the same vein, Ghisetti and Rennings (2014) showed that ERT significantly reduces firms' profitability in terms of operating margins. Based on the above discussion, we argue that quick fix solutions such as investment in ERT may reduce environmental externalities without necessarily providing positive performance benefits. Accordingly, we propose Hypothesis 3:

Hypothesis 3: ERT are *expected to exert a negative effect on firms' business performance*.

2.3. Complementarity between EMS and Environmental Technologies

The ways in which EMS, EIT, and ERT fit with and complement each other can be explained by drawing on the theory of asset complementarity (Teece, 1986). Complementary assets are defined as the resources that are required to capture the benefits associated with a strategy, technology, or innovation (Christmann, 2000). Prior literature on complementarity research identifies two types of complementarity; complementarity-in-use and complementarity-in-performance (Ballot et al., 2015). Complementarity-in-use refers to relatedness in the use of different practices – such approach seeks to investigate whether there is a good fit between practices. Complementarity-in-performance explores the effects of the combination of different practices upon business performance. As purported by the theory of supermodularity (Milgrom and Roberts, 1990, 1995), complementarity is not simply about associations between two factors. Complementarity-in-performance exists when "the total economic value added by combining two or more complementary factors [resources] in a production system therefore exceeds the value that would be generated by applying these production factors [resources] in isolation" (Ennen and Richter, 2010: 2008). In this research we seek to understand the circumstances under which a mix of pollution abatement practices contribute to business performance

[4] For example organizations invest in end-of-pipe scrubber technology in order to lower SO_2 emissions.

(complementarity-in-performance) rather than simply asking whether adoption of one practice is associated with one another (complementarity-in-use).

To understand complementarity-in-performance between environmental technologies - ERT and EIT, we integrate the resource-based view of the firm (Barney, 1991) with the notion of asset complementarity (Teece, 1986). We argue that the adoption of ERT creates tacit and complex capabilities and routines that facilitate the development of routines that are required for the adoption of EIT (Florida, 1996; King and Lenox, 2001). For instance, ERT for reducing carbon emissions allows firms to develop tacit capabilities and to establish technical skills and teams (King and Lenox, 2001; Darnall et al., 2008). In turn, these complex capabilities and routines could be redeployed and enhanced when firms adopt EIT seeking to reduce energy use per unit of output (e.g., using smart meters). Accordingly, we posit that firms that simultaneously adopt these two inherently different technologies can improve their business performance by embedding deep such unique tacit capabilities and routines within the organization (Ferrón-Vílchez and Darnall, 2016), and, in turn creating competitive advantage (Barney, 1991). In line with this argument, we propose Hypothesis 4:

Hypothesis 4: Combining EIT and ERT would exert greater impact on business performance than applying these technologies in isolation.

Secondly, complementarities could also occur when combining environmental technologies with environmental organizational systems (e.g. EMS) such that they enhance each other in an optimal fashion. Recent research shows that complementarities between technological and organizational innovations in general explain differences in the business performance and competitiveness (Battisti and Stoneman, 2010). Bloom et al. (2010) found that better managed firms use energy inputs more efficiently, which help them increase profitability and productivity. Prior research also shows that EMS can generate performance benefits when combined with other management practices such as quality management system (Ferrón-Vílchez and Darnall, 2016). Similarly, King and Lenox (2001) demonstrate that ISO 14001 certification is associated with ISO 9001 certification and Theyel (2000) find that the adoption of multiple management practices (e.g., total quality management, certification of suppliers, R&D, employee involvement in innovation and training) complements environmental management initiatives. Yet, with few exceptions (Hottenrott et al., 2016) it is unclear whether complementarities between ET and EMS exist.

To achieve more benefits from ET, we argue that firms need to synchronize their organizational units and reorganize their organizational processes; EMS is a structured approach to achieve this (Post and Altman, 1992). EMS requires firms to document their operations in detail and helps them to identify specific technologies so as to achieve their environmental objectives. Moreover, adoption of EMS generally helps firms to develop routines and technical and/or practical know-how, which may allow them to capture the benefits associated with a technology. Accordingly, at the plant level, the presence of strategic resources accrued through adoption of EMS is particularly important for determining the type of environmental technologies to be implemented. By implication, firms that adopt EMS might opt in adopting efficiency increasing technologies (EIT), externality reducing technologies (ERT) or a combination of both (Aragón-Correa, 1998). Even though, adoption of EMS is not a necessary or sufficient condition for the implementation of ET; EMS, as a complementary asset, may facilitate and/or shorten the time required to introduce new ET (Lopez-Gamero et al., 2008). In addition, if firms invest in new ET as a response to environmental regulations, adoption of EMS could offset the cost of technology adoption by increasing internal organizational efficiencies. In sum, firms seeking to achieve higher level of environmental and business performance would ideally implement a combination of EMS and ET (such as EMS & EIT & ERT), whereas firms with low-level of commitment would focus more on adoption of a single environmental practice that would help them to obtain legitimacy (such as ERT or EMS). Accordingly, it is expected that firms that are determined to achieve better environmental performance would invest in more comprehensive portfolio of environmental practices (Nath and Ramanathan, 2016), and subsequently achieve better business performance. In contrast, firms that embrace the compliance strategy will invest on single environmental practice without prior expectations of better business performance. Finally, we propose Hypotheses 5, 6 and 7:

Hypothesis 5: Combining EMS with ERT would exert greater impact on business performance than applying these technologies in isolation

Hypothesis 6: Combining EMS with EIT would exert greater impact on business performance than applying these technologies in isolation

Hypothesis 7: Combining EMS with EIT and ERT would exert greater impact on business performance than pairwise application of these technologies

3. Methodology

3.1. Measuring Complementarities

We use a methodology based on the supermodularity theory to test for complementarity among the three pollution abatement practices (see Milgrom and Roberts, 1990, 1995; Topkis, 1998 for detailed explanations of lattice theory). As discussed in Ballot et al. (2015) the primary problem with empirical analysis of complementarity is related with the divisibility requirement of the choice variables. However, oftentimes such variables are discrete, for example capturing organizational decisions to adopt or not an EMS and/or an ET. This problem is overcome with the application of lattice or order theory, which does not require continuity (Milgrom and Roberts, 1990). In other words, if the set of combinations of choice variables is defined over a sub-lattice, the concept of supermodularity works for binary choice variables, which is our case.

More precisely, let **f** be a function of three alternative activities A_1, A_2 and A_3, and in this case A_1 = efficiency-increasing technologies (EIT), A_2 = externality-reducing technologies (ERT), and A_3 = EMS. Each activity can be performed by the firm ($A_j = 1$) or not ($A_j = 0$) and $j \in \{1, 2, 3\}$. There are 2^3 possible combinations of these three activities, C $\{A_1A_2A_3\}$ = [{000}, {001}, {010}, {100}, {011}, {110}, {101}, {111}], where {000} refers to non-adoption of any activity and {111} refers to adoption of all the three activities. The theory posits that the function **f** is supermodular only if the co-occurrence of two activities provides higher increasing returns on performance than occurrence of the activities in isolation, irrespective of whether the third activity is being adopted. Thus, the following inequalities are formulated for examining complementarity between activities A_1 and A_2 (1), A_1 and A_3 (2), and A_2 and A_3 (3):

$$f(\alpha_{11k}, Z) + f(\alpha_{00k}, Z) \geq f(\alpha_{10k}, Z) + f(\alpha_{01k}, Z) \tag{1}$$

$$f(\alpha_{1k1}, Z) + f(\alpha_{0k0}, Z) \geq f(\alpha_{1k0}, Z) + f(\alpha_{0k1}, Z) \tag{2}$$

$$f(\alpha_{k11}, Z) + f(\alpha_{k00}, Z) \geq f(\alpha_{k10}, Z) + f(\alpha_{k01}, Z) \tag{3}$$

Where $k = \{0, 1\}$, α are the coefficients of a firm's activities, Z is the exogenous control variables affecting performance. If all these three inequalities (1, 2, 3) hold we can claim that the function **f** is supermodular in those arguments and, therefore, there is a three-way complementarity.

3.2. Assessing Complementarity-in-Use

The complementarity-in-use or adoption approach examines the conditional (on other factors) correlation of two activities. However, Athey and Stern (1998) state that indirect correlation between two activities does not necessarily indicate complementarity; correlation between activities may be obscured due to the influence of a common set of exogenous factors. Cassiman and Veugelers (2006) argue that unobserved heterogeneity between different observations could bias the estimation results and yield evidence in support of complementarity while no complementarity exists, or vice versa. This implies that it is practically impossible to distinguish complementarity from correlation due to unobserved common factors that determine joint adoption (Miravete and Pernías, 2010) and complementarity-in-use is neither sufficient nor necessary condition for the presence of complementarity.

3.3. Assessing Complementarity-in-Performance

The complementarity-in-performance approach examines the combined impact of different activities upon performance where a measure of firm performance is regressed on a set of drivers and exclusive combination of activities (Love et al., 2014). Accordingly, the complementarity-in-performance approach is directly related to the supermodularity theory. Following the framework proposed by Mohnen and Röller (2005) and Cassiman and Veugelers (2006), we define the following production function:

$$\mathrm{Per}_i = \alpha_{000}(\{000\}_i) + \alpha_{100}(\{100\}_i) + \alpha_{010}(\{010\}_i) + \alpha_{001}(\{001\}_i) + \alpha_{110}(\{110\}_i) + \alpha_{101}(\{101\}_i) + \alpha_{011}(\{011\}_i) + \alpha_{111}(\{111\}_i) + \gamma_i Z_i + v_i \quad (4)$$

Where Per_i is a measure of a firm *i's* performance proxied here by the growth of turnover (Growth). Z_i is the exogenous control variables affecting the firm performance, α_i are coefficients of the activities, γ_i are coefficients of the control variables, and v_i represents the error terms.

Robustness of the performance approach is tested by obtaining the consistent estimates of the coefficients corresponding to each activity and their combinations. We first estimate a production function (equation 4) using the Ordinary Least Square (OLS) method to examine whether complementarity affects performance. However, OLS estimation may not be robust when data is censored (Wooldridge, 2002). In this study, the dependent variable is right-censored (e.g. turnover growth rate has a maximum of 200%). OLS will produce inconsistent estimates of the parameters i.e. the coefficients from the econometric analysis will not approach the "true" population parameters. To correct this, we employed a Tobit estimation method. Tobit produces a consistent estimator (Amemiya, 1984) as it considers the right-censored nature of the data. Finally, the data used in this research provides information only for firms that had engaged in some form of innovation during the past two years. Accordingly, this selection bias can affect the results, if not accounted for. To address this issue, we employ a two-step Maximum Likelihood Heckman model. Specifically, we first estimate a selection equation, and subsequently the outcome equation correcting for selection bias (Greene, 2003).

4. Data and Descriptive Statistics

We use micro-aggregated data drawn from the European Community Innovation Survey (CIS) 2006-2008, which includes a special module on environmental management and environmental technologies. The CIS relies on a harmonized questionnaire based on the second (1997) and third edition (2005) of the Oslo Manual. To ensure comparability across countries, Eurostat, in close cooperation with the countries, has developed a standard core questionnaire starting with the CIS3 data collection. The micro-aggregated data provides firm-level information on, among others, the main economic activity, location, turnover, implementation of environmental management systems, environmental benefits from innovation, expenditure in intramural and extramural R&D, innovation collaboration, and knowledge sources in 14 European countries. However, due to country specific differences in regard to coverage of the core sections and special section on environmental innovation we use data pertaining to eight countries: Germany, Portugal, Czech Republic, Hungary, Slovakia, Estonia, Lithuania and Cyprus.

The data are collected by the countries statistical offices via mail or online surveys; and, in many countries there are enforceable penalties to ensure that firms fill in the questionnaire. Accordingly, around 70% - 85% of the firms in Estonia, Slovakia Portugal, Hungary and Czech Republic have responded the questionnaire. The response rate is almost 100% in Cyprus and Latvia while only about 20% of the German firms have completed the survey since in Germany participation is voluntary. As in the previous waves of the CIS survey, the reference period for most questions was from the beginning of 2006 to the end of 2008. The indicators on innovation expenditures were based on the calendar year 2008, while the turnover and employment of enterprises were requested for the two years. Accordingly, our representative sample of 36,445 firms was collected, all of which had a minimum of 10 employees.

4.1. Dependent variable

According to our hypotheses, turnover growth and cost reduction are potential business performance improvements due to complementarity between EMS and ET. Turnover growth due to e.g., increased reputation, cost efficiency or product sales is a more stringent performance indicator than operational cost-reduction (King and Lenox, 2001; Melnyk et al., 2003) and is deemed more relevant for our research. In the CIS, turnover is defined as the market sales of goods and services. Specifically, the CIS questionnaire requests the respondents to declare the firm’s total turnover in 2006 and 2008 i.e. *what was your enterprise’s total turnover for 2006 and 2008? Turnover is defined as the market sales* of goods and services (Include all taxes except VAT). As adoption of EMS and ET are prime examples of medium term investments - they require time to affect the firm’s performance. Thus, our dependent variable business performance is measured with turnover growth (Growth) in terms of the percentage change in previous year’s total turnover.

4.2. Independent Variables

In the CIS survey respondents were asked to indicate whether they had introduced management procedures to regularly identify and reduce the firm’s environmental impact e.g. ISO 14001 certification. Accordingly, we measure the adoption of Environmental Management Systems (EMS) with a binary variable that takes the value of 1 if the firm adopted an EMS during the period 2006-2008, and 0 otherwise.

There are several alternatives to measure environmental technologies (ET) such as contamination control and prevention (Zeng et al., 2011), environmental practices (Zhu and Sarkis, 2004), and innovation (Christmann, 2000). However, the literature does not propose an established scale to measure them. In absence of a unified scale to measure ET, this research, in line with previous literature (Rexhäuser and Rammer 2014; Ghisetti and Rennings 2014; Hottenrott et al. 2016), measures the adoption of Efficiency-increasing technologies (EIT) and Externality-reducing technologies (ERT) based on the CIS survey question "During the three years 2006 to 2008, did your enterprise introduce innovations with any of the following environmental benefits?".

As shown in Table 1, this question contains five dimensions that are directly related to a firm`s operations and production systems. Recent research has used these dimensions to separate environmental innovations from conventional innovations (Doran and Ryan 2012; Ghisetti et al. 2015). Answers to this question reflect environmental process innovations instead of product innovations (Horbach et al., 2012). Moreover, recently Rexhäuser and Rammer (2014), Ghisetti and Rennings (2014) and Hottenrott et al. (2016) have shown that, in particular, environmental process innovations can be further classified as EIT and ERT using these dimensions as follow:

- The first two dimensions indicate whether a new technology provides better operational efficiency by i) reducing material use per unit of output and ii) reducing energy use per unit of output. Technologies with these two distinct dimensions bring about substantial changes in the production system. Also, they improve business performance by increasing operational efficiency. Hence, these two dimensions deemed relevant to EIT.
- The remaining three dimensions indicate whether a new technology focuses on i) reducing total CO_2 production, ii) replacing materials with less polluting or hazardous substitutes, and iii) replacing soil, water, noise, or air pollution within firm. These three dimensions emphasize merely the reduction of environmental pollution, oftentimes through end-of-pipe solutions so as to comply with regulations; they are thus related to ERT.

Our classification of EIT and ERT based on the above environmental dimensions, which is in line with prior research (Rexhäuser and Rammer, 2014; Ghisetti and Rennings, 2014; Hottenrott et al., 2016), considers the environmental benefits inherent in the technology as well as the economic benefits that they may provide. Unlike EIT, ERT sought to reduce externalities by controlling pollution rather than modifying the production system. Hence, ERT do not generate cost savings in the way that EIT do. Moreover, we use binary variables for measuring EIT and ERT because they represent discrete managerial choices, and they (compared to continuous variables) allow a rigorous examination of complementarity-in-performance based on the concept of supermodularity (Milgrom and Roberts, 1990) by considering non-linearity and circumventing multi-collinearity. Accordingly, we measure Efficiency-increasing technologies (EIT) with a binary variable, which takes the value of

1 if firm's experienced environmental benefits related to the first and/or second dimension during the period 2006-2008, and 0 otherwise. Externality-reducing technologies (ERT) are measured with a binary variable that takes the value of 1 if firm's experienced environmental benefits related to the third, and/or fourth and/or fifth dimensions during the period 2006-2008, and 0 otherwise[5].

Table 1. Typology of Environmental Technologies (ET)

Survey question "environmental benefits from the production of goods or services within your enterprise"	Environmental Technologies	
	Efficiency-increasing (EIT)	Externality-reducing (ERT)
Reduced material use per unit of output	√	
Reduced energy use per unit of output	√	
Reduced CO_2 'footprint' (total CO_2 production)		√
Replaced materials with less polluting or hazardous substitutes		√
Reduced soil, water, noise, or air pollution (within firm)		√

Our approach to classify ET into EIT and ERT works, as shown in Table 2. Table 2 shows the frequency with which firms introduce the exclusive sets of pollution abatement practices, including frequency with which firms introduce none of the three practices ({100}), a single practice (i.e., {100}, {010}, and {001}), and combinations of these activities (i.e., {110}, {011}, {101}, and {111}). These descriptive statistics assist us to identify joint occurrences of different practices and, in turn, to infer about potential complementarity between these practices. For example, if one environmental practice is adopted more often together with another, rather than separately, we may interpret this in favor of complementarity-in-use between the two practices.

The statistics indicate that 55% of the firms in our sample do not introduce any environmental practice. 10% of the firms adopt both EIT and ERT ({110}), which is more frequent compared to the adoption of these practices in isolation. Only 4.4% of firms adopt either EIT ({100}) or ERT ({010}). This may suggest some degree of complementarity-in-use between EIT and ERT. The statistics suggest that there might be a weak complementarity between the ERT and EMS ({011}), and EIT and EMS ({101}) since only 3.4% and 1.9% of the firms adopt these practices, respectively; whereas EMS ({001}) is adopted by 10.3% of the firms in the sample. Finally, it appears that the data contains some evidence in favor of three-way complementarity. The simultaneous adoption of EIT, ERT and EMS ({111}) is the most frequent (10.6%) category compared to all other pair-wise combinations of environmental practices.

[5] The bivariate correlation matrix of the three environmental activities EIT, ERT and EMS is presented in the Appendix A.

Table 2. Frequency of Environmental activities and Firm Performance

C	Combination of Environmental activities [a]	Frequency	(%)
{000}	None	19,204	(55.14%)
{100}	Efficiency-increasing technologies	1,522	(4.4%)
{010}	Externality-reducing technologies	1,532	(4.4%)
{001}	EMS	3.596	(10.3%)
{110}	Efficiency-increasing technologies & externality-reducing technologies	3,442	(9.9%)
{011}	Externality-reducing technologies & EMS	1,173	(3.4%)
{101}	Efficiency-increasing technologies & EMS	655	(1.9%)
{111}	Efficiency-increasing technologies & externality-reducing technologies & EMS	3,702	(10.6%)
Total	Total number of observations	34,826[b]	(100%)

Note: C = {Efficiency-increasing technologies, Externality-reducing technologies, EMS}
[a] Exclusive categories of environmental activities
[b]1,619 missing observations

4.3. Control Variables

Table 3 presents control variables that may influence the decision of the firm to adopt two or all three environmental practices. Firm size is examined because large firms attract increasing attention from customers and regulatory authorities and receive more pressure for environmental performance improvement (Simpson et al., 2012; Murillo-Luna et al., 2008). Ownership structure is examined because it may shape environmental strategy (Gedajlovic, 1993; Darnall and Edwards, 2006). It could indicate a firm's proximity to financial resources.

External pressures can drive adoption of environmental practices (Simpson et al., 2012). We also included two dummy variables indicating whether a firm is active in international or national market, while the local markets set is used as the baseline. External pressures become more prevalent especially in international markets. We also examined the role of customers by including a binary variable indicating that a firm has adopted an environmental activity in response to current or future market demand.

We included continuous R&D because knowledge and experience obtained during R&D is of great importance for the adoption of environmental technologies (Horbach, 2008). Following Laursen and Salter (2006), we included an ordered variable that controls for a firm's openness for the adoption of environmental activities. In order to identify the effects of cooperation, we further included two binary variables, as in Robin and Schubert (2013). The first indicates scientific cooperation (i.e., cooperation with either universities and higher education institutions or government/public research institutes) and the second indicates cooperation with other partners.

Table 3. Definitions and Summary Statistics of Variables

Variables	*Construction*	*Mean (std)*
Turnover 2006	Total turnover in 2006 (Continuous).	0.68 *(7.57)*
Turnover 2008	Total turnover in 2008 (Continuous).	0.82 *(8.38)*
Growth	Growth of total turnover between 2006 and 2008 (Continuous).	0.29 *(0.51)*
Size 2006	Categorical variable indicating whether a firm is characterized as small, medium and large size in 2006	0.6 *(0.71)*
Size 2008	Categorical variable indicating whether a firm is characterized as small, medium and large size in 2008, (0-2).	0.62 *(0.72)*
Group	Binary variable indicating whether a firm is a part of an enterprise group in 2008, (0/1).	0.34 *(0.47)*
International market	Binary variable indicating whether a firm is active in international markets, (0/1).	0.51 *(0.5)*
National market	Binary variable indicating whether a firm is active in national markets, (0/1).	0.76 *(0.42)*
Local market	Binary variable indicating whether a firm is active in local markets, (0/1).	0.7 *(0.45)*
Market demand	Binary variable indicating whether a firm has introduced an environmental innovation in response to current or expected market demand from your customers for environmental innovations, (0-1).	0.14 *(0.35)*
Continuous R&D	Binary variable indicating whether a firm has permanent R&D staff in-house and engages in continuous R&D during 2006-2008, (0/1).	0.14 *(0.34)*
Openness	Ordered variable ranging from 0 to 8 where the highest score eight indicates that a firm is using all the internal and external sources of information and the lowest score is zero indicates that firm does not use any of the information sources, (0-8).	5.4 *(2.7)*
Scientific cooperation	Binary variable indicating whether a firm cooperates with scientific partners to develop innovation, (0/1).	0.1 *(0.27)*
Cooperation with others	Binary variable indicating whether a firm cooperates with other non-scientific partners to develop innovation, (0/1).	0.18 *(0.38)*
Voluntary	Binary variable indicating whether a firm introduced an environmental innovation in response to voluntary codes or agreements for environmental good practice within the sector, (0/1).	0.21 *(0.4)*
Regulation	Binary variable indicating whether a firm introduced an environmental innovation in response to existing and future environmental regulations, (0/1).	0.27 *(0.44)*

Environmental regulation and public funding on R&D may drive the adoption of environmental practices (Kesidou and Demirel, 2012). Hence, we control for environmental regulations with a binary variable. We also control for firms' voluntary engagement in adopting environmental initiatives with a binary variable. Finally, to capture the technological conditions in different industries and among various European countries, we included two-digit NAC[6] codes along with country dummies (see Appendix B).

5. Analysis and Results

5.1. Results from the Complementarity-in-Use Approach

Following the complementarity-in-use or adoption approach, we estimated a Probit model estimating the probability of adopting each (non-exclusive) environmental practice, which allowed us to examine the non-parametric correlation (Kendall τ_b) of the residuals resulting from each model.

Table 4. Non-parametric correlation Kendall tau_b of the residuals[α]

	R_EIT	R_ERT	R_EMS
R_EIT	1		
R_ERT	0.81***	1	
R_EMS	0.53***	0.54***	1

[α] The residuals are obtained after estimating the Probit models (4), (5) and (6).
*** All coefficients are significant at 1%; N= 17,449

Table 4 summarizes the bivariate correlation results. It shows that there is strong and positive correlation between the residuals obtained from the Probit models. The Kendall τ_b for correlation coefficients of the adoption of EIT and EMS, ERT and EMS and ERT and EIT are 0.53, 0.54 and 0.81, respectively, and they are statistically significant at 1% level. Statistically the high correlation between ERT and EIT points out that firms often adopt complementary mixed solutions to environmental problems based on underlying environmental targets, technology options, and related cost (Frondel et al. 2007). In sum, the high correlation between all pairs of environmental practices provides preliminary evidence for complementarity-in-use.

5.2. Results from the Complementarity-in-performance Approach

By adopting the complementarity-in-performance approach, we examined if complementarity amongst the three practices affects business performance in terms of turnover growth. As shown in Table 5, we regress the measure of performance on the exclusive combinations of activities (equation

[6] Nomenclature statistique des Activités économiques dans la Communauté Européenne, Statistical Classification of Economic Activities in the European Community in English.

4), together with other control variables, industry and country dummies (see Table 3). Most control variables such as firm size, R&D engagement, openness, cooperation and exposure to international markets appear influential.

As explained earlier, Tobit regressions are used to address right-censored bias and Heckman corrections are for addressing sample selection bias. The coefficients of the key parameters from the three estimation models - OLS, Tobit and Heckman - are quite similar. The results indicate that EMS (001) exerts a positive statistically significant effect on firms' turnover growth, which supports Hypothesis 1. This finding is in line with prior literature indicating that EMS improves business performance as they may enable firms to reduce operational costs through better environmental risk management (Ambec and Lanoie, 2008).

The results point out that adoption of EIT (100) boost growth confirming Hypothesis 2. In contrast, the variable ERT ({010}) has a negative sign indicating that adoption of ERT in isolation exerts a negative impact upon business performance supporting Hypothesis 3. These results provide new evidence, which aligns with a few prior studies, asserting that pollution abatement technologies affect business performance in distinct ways (Rexhauser and Rammer, 2014; Klassen and Whybark, 1999). On one hand, EIT may stimulate firm performance as this type of technology alters a firms` production process enabling the firm to not only reduce pollution but also to reduce resource/energy use (Rexhauser and Rammer, 2014). On the other hand, ERT (e.g. end-of-pipe technologies) oftentimes affect negatively business performance as this type of technology fulfills primarily environmental protection targets without generating efficiency gains (Frondel et al, 2007).

It is worth noting that the statistical significance of the coefficients representing the joint adoption of environmental practices [i.e. ({110}), ({101}), and ({011})] do not indicate whether the performance function is complementary per se (Mohnen and Röller 2005). Complementarity-in-performance amongst pair-wise combinations of exclusive EIT, ERT, and EMS exist only if the inequalities (i.e., 1, 2 and 3) hold.

Table 5: Performance Regressions

Dependent variable	Growth		
	OLS	**Tobit**	**Heckman**
Medium-size	-0.019**	-0.02**	-0.03***
	(0.009)	(0.009)	(0.01)
Large-size	-0.054***	-0.056***	-0.062***
	(0.012)	(0.013)	(0.013)
Group	0.036***	0.038***	0.039***
	(0.008)	(0.009)	(0.009)
Engagement in continuous R&D	-0.001	-0.0008	-0.002
	(0.01)	(0.01)	(0.01)
Openness	0.008***	0.007***	0.005**
	(0.001)	(0.001)	(0.002)
Scientific cooperation	-0.025**	-0.026**	-0.021*
	(0.012)	(0.012)	(0.012)
Cooperation with others	0.021**	0.022**	0.02**
	(0.01)	(0.01)	(0.01)
Active in international market	0.02**	0.02**	0.02**
	(0.01)	(0.01)	(0.01)
Active in national market	0.006	0.005	-0.003
	(0.01)	(0.011)	(0.012)
Market demand	0.03***	0.03***	0.025**
	(0.01)	(0.01)	(0.01)
{000}	0.26***	0.26***	0.28***
	(0.017)	(0.018)	(0.019)
{100}	0.26***	0.26***	0.28***
	(0.022)	(0.022)	(0.024)
{010}	-0.036**	-0.38**	-0.004***
	(0.015)	(0.015)	(0.016)
{001}	0.24***	0.24***	0.26***
	(0.022)	(0.023)	(0.025)
{110}	0.24***	0.24***	0.26***
	(0.02)	(0.02)	(0.022)
{011}	0.21***	0.21***	0.24***
	(0.024)	(0.025)	(0.026)
{101}	0.17***	0.17***	0.19***
	(0.027)	(0.028)	(0.029)
{111}	0.22***	0.22***	0.24***
	(0.02)	(0.021)	(0.022)
Model	F(47, 16217)= 140.8***	F(47, 16217)= 133.4***	Wald χ^2 (47) = 5786.1 Wald test (rho = 0): χ^2 (1)=9.35***
Observations	16264	16264 Right censored: 491 Uncensored: 15773	16461 Censored: 1472 Uncensored: 14989

Notes: {$A_1A_2A_3$} where A_1 = efficiency-increasing technologies; A_2 = externality-reducing technologies; A_3 = *EMS; α:* Standard errors are in parenthesis below each coefficient; b: The hypothesis of sample selection is accepted at 1% significance level indicating that the selection bias would affect OLS estimation results; *** p<1%; ** P<5%; * p< 10%

Table 6: Complementarity Tests

	OLS	Tobit	Heckman
(1) EIT & ERT			
1st condition (k=0): $110+000 \geq 100+010$	F (1, 16217) = 80.6***	F (1, 16217) = 79.4***	chi2 (1) = 87.8***
2nd condition (k=1): $111+001 \geq 101+001$	F (1, 16217) = 6.6**	F (1, 16217) = 6.26**	chi2 (1) = 6.2**
(2) EIT & EMS			
1st condition (k=0): $101+000 \geq 100+001$	F (1, 16217) = 6**	F (1, 16217) = 5.56**	chi2 (1) = 4.8**
2nd condition (k=1): $111+010 \geq 110+011$	F (1, 16217) = 78.7***	F (1, 16217) = 77.3***	chi2 (1) = 85.6***
(3) ERT & EMS			
1st condition (k=0): $011+000 \geq 010+001$	F (1, 16217) = 81.9***	F (1, 16217) = 38.8***	chi2 (1) = 86.12***
2nd condition (k=1): $111+100 \geq 110+101$	F (1, 16217) = 6.44**	F (1, 16217) = 6**	chi2 (1) = 6**

Notes: *** p<1%; ** P<5%; * p< 10%

Accordingly, we focus on the results of the complementarity tests, which are presented in Table 6. The 2nd, 3rd and 4th columns include the complementarity tests of both inequality conditions for the different sets of environmental practices that are generated after estimating turnover growth in Table 5. Here we examine whether complementarity-in-performance between two exclusive activities exists, regardless of whether the third activity is being adopted. That means the conditions of supermodularity hold when the third activity is being adopted (k=1) or not (k=0). The significance of the χ^2 and the F statistics indicate if such conditions are met. The results of the complementarity tests in Table 6 show that both conditions used to test complementarity-in-performance between exclusive combinations of EIT and ERT, EMS and ERT, and EMS and EIT are met, respectively, at the 1% level of significance. These results indicate that there is pair-wise complementarity-in-performance between EIT and ERT (Hypothesis 4), EMS and ERT (Hypothesis 5), and between EMS and EIT (Hypothesis 6). The results in Table 6 point out that all pairs of environmental practices are complementary, thus, this implies that the performance function is supermodular in its components confirming the three-way complementarity and Hypothesis 7.

6. Discussion and Conclusion

Over the years firms have been constantly searching for new ways to minimize any negative impact of their products and operations on the natural environment without hampering their business performance. Subsequently, firms with distinct environmental concerns have invested in multiple pollution abatement practices. Nevertheless, the relationships between the EMS, ET and business performance remain unclear in spite of the significant body of empirical studies that have focused on them (Melnyk et al., 2003; King and Lenox 2002; Darnall and Edwards, 2006; Su et al., 2015; Wakke et al., 2016).

The results of this paper call scholars to view with caution past findings focusing on the negative impact of pollution abatements practices (e.g. ERT in our case) upon business performance, without first examining possible complementarities arising from adoption of multiple pollution abatement practices. The synergy with EMS and ERT is particularly important when adopting technologies that purely reduce externalities. Our results underline that ERT negatively affects firms' business performance when adopted in isolation, but not when adopted in conjunction with EIT or EMS. Similarly, the complementarity between ERT and EIT supports the notion that replacing materials with less polluting or hazardous substitutes (ERT) helps generate tacit knowledge that could be used along with technologies that change the production process to reduce material use per unit of output (EIT) (Christmann 2000).

Additionally, the findings of this research illustrate that a three-way complementarity-in-performance exist, in that firms that adopted EMS and the two types of ET achieved higher turnover growth compared to those firms that adopted either EMS, ERT or EIT singularly, or none of them. This implies that firms with a portfolio of EMS, EIT and ERT that emphasizes resource and operational efficiency through better use of energy inputs and reduced carbon footprint supported by a formal EMS outperform those firms that have adopted a single or a pair of pollution abatement practices (Potoski and Prakash, 2005; Ferrón Vílchez and Darnall, 2016). Complementary assets accrued through adoption of EMS seem to have promoted the development of distinctive skills in organizational management (Lopez-Gamero et al., 2008) that helped our sample firms to form the necessary information basis for the development of ET, as purported by our novel three-way complementary assets theory.

The first contribution of this article concerns to the distinction between ERT and EIT and the individual performance effects of EMS, ERT and EIT. This paper adds new knowledge about the distinct performance effects of ET by dividing them into two distinct categories; externality reducing technologies (ERT) and efficiency increasing technologies (EIT). Our results show that ERT are related to negative turnover growth as a key dimension of business performance, while EIT has a positive effect on growth in turnover (Ambec and Lanoine, 2008; Ghisetti and Rennings, 2014). These results reinforce the argument that ERT are forms of emission reduction technologies that add costs but no economic benefits (Ghisetti and Rennings, 2014; Montabon et al., 2007), even though they are necessary for complying with regulations and/or generating legitimacy. In contrast, EIT are forms of resource/energy efficiency technologies that alter the production system, thus, enhancing a firm's price competitiveness.

The second contribution of this study lies in the integration of asset complementarity theory and resource-based-view of the firm in the context of pollution abatement practices. Whilst the original resource-based view and complementary assets theories (Barney, 1991; Teece, 1986) can explain how the adoption of either EMS or ET creates socially complex resources, our contribution to theory is about explaining how and when the adoption of one pollution abatement practice acts as a complementary asset that facilitates the adoption of one another practice (complementarity-in-use).

Regarding how, our theoretical framework provides a new perspective that untangles the intricate inter-relationships between EMS, ERT and EIT. By doing so, we clarify the argument by Albertini (2013) and Wagner (2008) that EMS do not operate in isolation and that their existence must be understood in connection with firm's environmental resources and capabilities. More precisely, our results show that EMS are not only an important environmental practice but also an important organisational asset. EMS provide necessary structure to a process that emphasize the use of PDCA. By adopting EMS, firms need to formally define environmental goals, making choices, gathering information, measuring progress with regards to environmental performance improvement (Florida and Davison, 2001). EMS implementation helps develop internal routines and technical and/or practical know-how related to environmental management. In turn, this allows firms to introduce new ET into the production process more efficiently.

The question of when is answered by our three-way complementarity analysis. This shows that firms achieve higher level of business performance when they combine resources generated by EMS and ET (such as EMS & EIT & ERT). Other firms with low-level of commitment focus more on adoption of a single environmental practice to purely obtain legitimacy (such as ERT or EMS) and they are less likely to achieve significant turnover growth. Even though the results imply that the adoption of both EMS and ET generates additional returns to business performance, such as turnover growth, that exceed what they would have achieved had they been adopted in isolation (complementarity-in-performance), the decision to adopt EMS in conjunction with ET may be driven by firm`s organisational strategy as well as other external factors. This is to say, choosing only a subset of these environmental practices could be based on firm`s internal motivations as well as other situational factors such as isomorphic pressures from within the industry, clients or regulatory authorities. This suggests the importance of being open and cooperation with others, as well as exposure to international markets where competition is higher.

The third contribution of this research comes from our novel methodological approach that allows three-way complementarity analysis. The pair-wise complementarity analysis introduced to the production economics literature (Furlan et al, 2011; Resende et al., 2014) relies in the fulfillment of just one condition. In this paper, we formalize a method for assessing a three-way complementarity by adding an additional condition to ensure that a pair-wise complementarity exists regardless of the existence of the third activity. Moreover, this is the first study we know of that assessed complementarity-in-use and complementarity-in-performance between EMS, EIT and EIT using rigorous estimation methods (e.g. OLS, Tobit and Heckman selection models), which control for selection bias and right-censored nature of our dependent variable.

In terms of practical implications, managers are increasingly concerned with how to simultaneously reduce their environmental impact and increase competitiveness. They are facing different choices: adopting technologies that predominantly reduce environmental externalities; adopting technologies that tend to increase resource efficiency; adopting an EMS. The results of this study show that a large number of firms (over 19 thousands firms) from eight European countries have not adopted any pollution abatement practice. The findings of this research would recommend such firms to adopt a combination of EMS and ET because, more importantly, investments in multiple pollution abatement practices generate complementarities. Our results reinforce the argument that "…without the organizational and skill infrastructure, technology alone is not enough…" (Caroli and Van Reenen 2001: 1450). We would, then, recommend managers to first re-orient their organizational strategy towards the adoption of an EMS as it can assist them in adopting/developing both externality-reducing (ERT) and efficiency-increasing technologies (EIT). Managers may find it difficult to justify an investment in especially EMS or ERT, yet, this study shows that such investments produce additional turnover growth. Moreover, managers that favor EIT over ERT ought to consider implementing both technologies in conjunction.

Since environmental issues are complex and hard to tackle, further research is required to reveal how problems related to the synchronization of organizational units and environmental initiatives can be resolved to enable adoption of multiple pollution abatement practices (Post and Altman, 1992). Our findings also suggest that policy makers should consider assisting firms that have adopted a single environmental practice so that they can reap additional business benefits by adopting two or more pollution abatement practices.

The paper has some limitations that derive from the nature of the CIS survey data. We encounter three problems when using such survey data. First, selection bias arises because few firms innovate while most of the subsections of the CIS survey are relevant to innovative firms. Therefore, only a subset of the total population of firms answers these questions. We addressed this issue by employing a Heckman selection model, which accounts for selection bias pertinent to use of such datasets.

Second, the categorisation of Environmental Technologies (ET) into EIT and ERT is theoretically based, as both types of technologies reduce environmental impact, yet, their impact upon business performance differs (Rennings and Rammer, 2009; Rexhäuser and Rammer, 2014). However, the operationalization of EIT and ERT based on the CIS has shortcomings as we cannot unambiguously identify whether each dimension of environmental impact corresponds to EIT or ERT. This is because the question has not been asked independently for each dimension of environmental impact, which makes the classification of EIT and ERT based on these dimensions cumbersome. One possibility to overcome this caveat is to use country specific CIS survey data in conjunction with other databases. However, our research relies on a micro-anonymised large CIS data comprising eight European countries, which eliminates this possibility. Also, future research could measure EIT and ERT using small and self-administered surveys that are more detailed and insightful in their measurement of the concepts. Yet, the small sample might raise issues of selection bias and common method bias, which may affect the reliability of the findings.

Third, endogeneity may arise due to various causes but the most relevant reason relating to this study is the fact that firms' strategic decisions are oftentimes co-determined (Mairesse and Mohnen, 2010). For example, it is likely that a firm's decision to pursue continuous R&D and to innovate is strictly correlated to each and jointly dependent on third factors as well. Since the dataset does not provide sufficient information about the potential 'third' factors determining the causality between, for example, continuous R&D and innovation could be difficult. Such a problem could be tackled by using the instrumental variable (IV) approach or by constructing a panel dataset. However, the dataset used in this research is not rich in exogenous variables that can serve as relevant and valid instruments. In addition, as the CIS 2008 is the only wave of the CIS surveys that comprises a special section on ET it is impossible to construct a panel of data. Thus, we cannot attenuate all the endogeneity issues in this study. Future research is required to examine the relevance of complementarities amongst similar or other environmental activities.

Appendix A: Kendall tau_b non-parametric correlation of the non-exclusive environmental practices

	Number of firms; N=36,445	1. (EIT)	2. (ERT)	3. (EMS)
1. Efficiency-increasing technologies (EIT)	9,550 (26.2%)	1.00		
2. Externality-reducing technologies (ERT)	10,080 (27.6%)	0.65***	1.00	
3. Environmental management systems (EMS)	9,126 (26.2%)	0.28***	0.33***	1.00

Notes: Non-exclusive environmental practices; * All coefficients are significant at 1%.

Appendix B: NACE Industry and Country Dummies

Industry and Country dummies		Observations
Industries and NACE codes	B - Mining and Quarrying	1,038
	C10-C12 - Manufacture of Food, Beverages and Tobacco	6,080
	C13-C15 - Manufacture of Textiles, Wearing Apparel and Leather	7,855
	C16-C18 - Manufacture of Wood, Paper and Printing	4,400
	C19-C23 - Manufacture of Coke, Chemicals and Chemical Products	6,331
	C24-C25 - Manufacture of Basic Metals and Fabricated Metal Products	5,344
	C26-C30 - Manufacture of Computer, Electronic and Machinery	6,711
	C31-C33 - Manufacture of Furniture and, Repair and Installation of Machinery	4,598
	D - Electricity, Gas, Steam and Air Conditioning Supply	1,224
	E - Water Supply	2,259
	F – Construction	2,202
	G - Wholesale and Retail Trade	13,815
	H49-H51 - Land, Water Transport and Air Transport	4,748
	H52-H53 - Warehousing and Support Activities for Transportation and Postal Activities	1,856
	I - Accommodation and Food Service Activities	164
	J58-J60 - Publishing, Broadcasting and Video Production Activities	1,119
	J61-J63 - Telecommunications, Computer Programming, Consultancy and Information Service Activities	3,160
	K - Financial and Insurance Activities	2,534
	L - Real estate activities	75
	M69-M70 - Legal and Accounting Activities and, Activities of Head Offices	450
	M71-M73 - Architectural, Engineering, Advertising, Market Research and Scientific R&D Activities	3,070
	M74-M75 - Other professional, Scientific, Technical and Veterinary activities	112
	N - Administrative and Support Service Activities	827
Country dummies	Germany	6,026
	Portugal	6,512
	Czech Republic	6,804
	Hungary	5,390
	Slovakia	4,592
	Estonia	3,986
	Lithuania	2,111
	Cyprus	1024

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