Schumpeter School of Business and Economics

SCHUMPETER DISCUSSION PAPERS

Energy and Material Efficiency Innovations: The Relevance of Innovation Strategies

Werner Bönte
Christian Dienes

The Schumpeter Discussion Papers are a publication of the Schumpeter School of Business and Economics, University of Wuppertal, Germany
For editorial correspondence please contact SSBEEditor@wiwi.uni-wuppertal.de

SDP 2012-001
ISSN 1867-5352

Impressum
Bergische Universität Wuppertal
Gaußstraße 20
42119 Wuppertal
www.uni-wuppertal.de

BERGISCHE UNIVERSITÄT WUPPERTAL

Energy and Material Efficiency Innovations: The Relevance of Innovation Strategies

Werner Bönte and Christian Dienes*

Schumpeter School of Business and Economics

University of Wuppertal, Wuppertal, Germany

Abstract: This study explores the relationship between energy and material efficiency innovations (EMEIs) and innovation strategies employed by manufacturing firms to develop their process innovations. Firms may mainly develop process innovations in-house, let them mainly develop by other enterprises or institutions, or they may develop them jointly with external partners. The empirical analysis is based on data of European manufacturing firms obtained from the fourth Community Innovation Survey. Our results suggest that EMEIs are related to process innovation strategies. Firms which let mainly develop their process innovations by other enterprises or institutions tend to be less likely to introduce EMEIs at all and these firms are also less likely to introduce EMEIs with stronger efficiency effects. Moreover, our results do not suggest that firms following the 'cooperation strategy' are more likely to introduce EMEIs and to reach a higher EMEI performance than firms following the 'in-house strategy'. Hence, our results do not confirm the results of previous research pointing to a positive relationship between environmental innovations and cooperation with external partners.

Keywords: energy and material efficiency, process innovations, innovation strategy

JEL-Classifications: D22, O32, O33, Q55

* E-Mail: boente@wiwi.uni-wuppertal.de; dienes@wiwi.uni-wuppertal.de

I. Introduction

Improving energy and material efficiency of production has become an important issue for top management in recent years. The economic growth of emerging economies is associated with an increase in the global demand for energy and resources resulting in higher prices of energy and materials. Furthermore, especially firms operating in energy- and material-intensive industries are challenged by increasingly restrictive environmental policies aiming at, for instance, the reduction of CO_2 emissions. In the short-run, the reduction of firms' energy and materials use is restricted by existing production technologies. In the medium- and long-run, however, firms may cope with increasing input prices and environmental regulations by introducing energy and material efficiency innovations (EMEIs). The effects of EMEIs may be twofold: firstly, innovating firms may gain competitive advantage since such innovations may reduce the costs of production. Secondly, they may result in a reduction of greenhouse gas emissions and could therefore improve ecological sustainability due to the introduction of less energy- and material-intensive production processes (Kjaerheim 2005; Frondel et al. 2007).

While environmental innovations have gained increased attention in academic research (Rennings 2000; Jaffe et al. 2002, 2005; Rennings et al. 2006; Horbach 2008), our knowledge about the relationship between environmental innovations and firms' innovation strategies is still limited. Recently, De Marchi (2011) argues that R&D cooperation with external partners could be especially important for the introduction of environmental innovations because firms are still inexperienced on the development of such innovations and empirical results reported by De Marchi (2011) confirm that environmentally innovative firms are more likely to cooperate with external partners than other innovative firms.

Our study contributes to the existing literature by investigating the relationship between firms' innovation strategies and energy and material efficiency innovations (EMEIs) which are considered as one important form of environmental innovations (Frondel et al. 2007). In doing so, we do not only focus on the relevance of firms' innovation strategies for the propensity to introduce EMEIs but also examine whether the extent of efficiency improvements induced by EMEIs is related to firms' innovation strategies. Moreover, we focus on firms' strategies with respect to the development of *process* innovations. In particular, we analyze three different process innovation strategies: Firstly, process innovations may be mainly developed within the firm. Secondly, they may be mainly developed by other enterprises or institutions and thirdly, they may be developed jointly with external partners. According to the results reported by De Marchi (2011) it could be expected that a positive relationship exists between EMEIs and the joint development of process innovations with external partners. Against this background it could be argued that firms complementing their internal innovation efforts with the innovation efforts of their external partners would be more likely to introduce EMEIs and would also be more likely to benefit from a marked reduction in energy and material intensities induced by EMEIs than firms following the other two innovation strategies. Furthermore, we conduct industry-specific analyses in order to take into account potential heterogeneity of industries with respect to the relationship between EMEIs and process innovation strategies.

Using data obtained from the fourth Community Innovation Survey, we empirically investigate the relationship between EMEIs and three process innovation strategies for a sample of European manufacturing firms. The estimation results point to the relevance of process innovation strategies since both, the probability of introducing EMEIs and the effectiveness of EMEIs, are associated with the firms' process innovation strategies. Firms that let mainly develop their process innovations by other firms or institutions tend to be less likely to introduce EMEIs at all and efficiency improvements induced by EMEIs tend to be lower, too. However, neither the results based on total sample estimation nor the results based on industry-specific regressions suggest that firms developing their process innovations jointly with external partners differ significantly from firms developing their process innovations mainly in-house. Hence, our results do not provide empirical evidence for the hypothesis that cooperation with external partners is more important for firms introducing EMEIs than for other firms.

The article is structured as follows. In the next section, we provide a conceptual framework in which we review some literature on innovation strategies and knowledge-sourcing. Section III presents the data. Descriptive statistics and the regression results for the total sample as well as for the industry-specific approach are presented in Section IV. In the last Section (Section V), we discuss the results and give some conclusion on limitations in this study and on possible avenues for future research.

II. Conceptual framework

Firms may employ different strategies in order to develop their innovations. They may, for instance, develop innovations together with external partners, like other enterprises or institutions. A major reason why firms may follow such a ‘cooperation strategy’ is to tap external knowledge in order to profit from the partners’ expertise and to complement own internal knowledge with external knowledge (Cassiman and Veugelers 2006). Firms may cooperate formally or informally with other enterprises or institutions, like suppliers, customers, competitors, consultants, commercial labs, and universities (Attalah 2002; Bönte and Keilbach 2005; Cassiman and Veugelers 2002; Belderbos et al. 2004; López 2008).

Management may also opt, however, for an ‘in-house strategy’, i.e. developing innovations mainly within the enterprise. It might evaluate external knowledge as not relevant because relevant internal knowledge is already in place, it may isolate innovation activities from external firms or institutions to prevent a leakage of knowledge, or it may restrain the development of innovations by external partners because employees are unwilling to adopt innovations that they did not develop themselves, also known as the “not invented here”-syndrome (Katz and Allen 1982).

At the other extreme firms may follow an ‘external strategy’ and fully rely on external knowledge to develop their own products and processes without conducting intramural R&D. Firms may, for instance, contract out (buy) R&D activities (Veugelers and Cassiman 1999; Cassiman and Veugelers 2006) or they may be active in other forms of external knowledge acquisition, like the hiring of qualified researchers or the acquisition of companies (Arora and Gambardella 1990; Grandstrand et al. 1992; Cockburn and Henderson 1998; Ahuja and Katila 2001). Empirical evidence suggests that external knowledge-sourcing is often employed by innovating firms due to a possible lack of relevant knowledge inside the firm (Haour 1992; Rigby and Zook 2002; Chesbrough 2003) or the inability to develop new products or processes in-house at sufficient speed (Lokshin et al. 2008).

Firms may opt for the ‘cooperation strategy’ or the ‘external strategy’ because the engagement in external knowledge-sourcing may be associated with beneficial effects. As Grant (1996, p. 380) notes “… the critical source of competitive advantage is knowledge integration rather than knowledge itself.” Hence the integration of (relevant) knowledge outside the firm is also supposed to be beneficial for competitive advantage and requires a firm’s attendance towards embedding external knowledge into the innovation process (Chesbrough 2003). Cassiman and Veugelers (2006) empirically investigate the innovation activities of Belgian manufacturing firms and find that the product innovation performance of firms which complement internal and external knowledge is higher than the performance of firms that solely use either internal or external knowledge for their innovation activities.

Another strand of literature suggests that firms may also consider a substitution of internal innovation activities by external knowledge-sourcing. Based on transaction costs and property rights theory (Arrow 1962; Williamson 1985; Grossman and Hart 1986), it is argued that fully outsourcing R&D while abandoning intramural R&D might allow firms to exploit the co-operation partner's knowledge and to benefit from the partner's economies of scale in specialization (Veugelers and Cassiman 1999). Some studies have confirmed that internal and external innovation strategies are rather substitutes than complements (Pisano 1990; Blonigen and Taylor 2000; Laursen and Salter 2006).

However, one important drawback of the 'external strategy' is that a firm's absorptive capacity may diminish. This would imply that a firm might be unable to find appropriate R&D partners contributing to the firm's innovation process and the ability to understand the knowledge associated with the R&D activities conducted by other enterprises or institutions may fade (Cohen and Levinthal 1990). In this context, it is often argued that the ability to detect and to utilize relevant knowledge outside the firm seems to play a critical part in boosting innovation performance and is found to be driven by internal R&D activities. Internal R&D may facilitate the search and identification of relevant external knowledge, because of enhanced capabilities or absorptive capacities and it enables firms to better understand the outcome of R&D activities conducted by other firms or institutions (Cohen and Levinthal 1989, 1990; Zahra and George 2002). Results of empirical studies suggest that an excessive reliance on external knowledge is negatively related to the firms' productivity and product innovation performance (Bönte 2003; Lokshin et al. 2008; Grimpe and Kaiser 2010).

Firms' absorptive capacities are not only crucial for innovations in general but are also important with regard to environmental process innovation or cleaner production technologies (Christmann 2000; del Rio González 2005). In particular, Christmann (2000) argues that non existing capabilities for the development and implementation of pollution decreasing process innovations may hinder firms to exploit cost saving potentials. Recently, De Marchi (2011) argues that environmental innovations represent a technological frontier on which firms are still inexperienced making external knowledge-sourcing for such innovations even more crucial as compared to other innovations. Indeed, De Marchi (2011) finds that Spanish manufacturing firms cooperating with external partners on their innovation activities experience a higher performance with respect to environmental innovations than other firms.

Against this background, we expect that EMEIs are related to the firms' innovation strategies. However, in contrast to existing empirical studies that do not distinguish between innovation strategies related to product innovations and innovation strategies related to process innovations, we strictly focus on process innovation strategies. In particular, we hypothesize that firms employing the 'in house' strategy and firms following the 'external' strategy for their process innovations have a lower probability of introducing EMEIs at all than firms employing the 'cooperation' strategy. Furthermore, we expect that firms following the 'cooperation' strategy are more likely to implement EMEIs with a marked effect on energy and material efficiency.

III. Data

III.1 Sample

We use data obtained from the fourth Community Innovation Survey (CIS IV) conducted in 2005. This data set provides information about innovation activities of manufacturing firms' in 20 European countries in the years from 2002 to 2004. The survey is based on a harmonized questionnaire which is used in all European countries. We restrict our analysis to firms having introduced process innovations in the years from 2002 to 2004.[1] In the questionnaire, a process innovation is defined as the implementation of a new or significantly improved production process, distribution method, or support activity for the goods or services produced. Furthermore, the process innovation must be new to the firm, but it does not need to be new to the sector or market. In the regression analysis we are left with 15,782 firms from 19 European countries.[2]

III.2 Measurement

Dependent variables

In the questionnaire firms are asked to assess various effects of process innovations introduced in the years 2002 to 2004. Amongst others, firms are requested to evaluate the impact of these process innovations on the reduction of materials and energy per unit of

[1] We conducted data cleaning with respect to the firms' R&D intensities in order to avoid that the results are sensitive to outliers.

[2] The countries which are surveyed are: Bulgaria, Czech Republic, Denmark, Estonia, Spain, Finland, France, Greece, Hungary, Iceland, Italy, Lithuania, Luxemburg, Latvia, Norway, Portugal, Romania, Sweden, Slovenia, and Slovakia. We excluded Romania from our empirical analysis, since in Romania almost all of the manufacturing firms report that EMEIs are not relevant which may distort the estimation results.

output. Since this question explicitly focuses on the energy and material reducing effects of process innovations, the effects of product innovations are not considered. Companies assess the impact on a four point Likert scale from *Not relevant*, *Low*, *Medium*, to *High*. It can be expected that respondents who opt for *Not relevant* do so because their enterprise has not engaged in the development of EMEIs. In contrast, if firms' engage in innovation activities aimed at reducing energy and materials per unit output, respondents might opt for *Low*, *Medium*, or *High* in the case of EMEIs are relevant to the firm. In order to account for these qualitatively different interpretations, we distinguish between two dependent dummy variables: The first dummy variable takes on the value one if a respondent assesses the impact of EMEIs as *Low*, *Medium*, or *High* and equals zero if a respondent assesses EMEIs as *Not relevant.* The second dummy variable takes on the value one if a firm assesses the impact of EMEIs as *Medium* or *High* and is zero if a firm assesses the impact as *Low*. This allows us to analyze whether firms employing certain process innovation strategies are more likely to introduce EMEIs at all (first dummy variable) and whether certain innovation strategies are associated with stronger effects of EMEIs (second dummy variable).[3]

Explanatory variables

Our data set contains information about the development of process innovations. Interviewees report whether their firms' process innovations introduced in the years 2002 to 2004 are

(i) *mainly developed by the enterprise or the enterprise group*,
(ii) *developed by the enterprise together with other enterprises or institutions*, or
(iii) *mainly developed by other enterprises or institutions*.

From these three options interviewees have to choose the one which is considered to be the most appropriate. Because respondents can only opt for one of the three options, we are able to create three mutually exclusive dummy variables each of them capturing a particular process innovation strategy. These strategies differ with respect to the extent to which external knowledge is put into use for the development of firms' process innovations.

In contrast to existing empirical studies, we make use of a more specific measurement of innovation strategies in the sense that these strategies are particularly related to the development of process innovations instead of using more general data on the firms'

[3] Note that the empirical analysis focusing on the second dummy variable is restricted to the sample of firms that assess the impact of EMEIs as relevant.

innovation activities which might possibly relate to the development of *product* and/or *process* innovations.

Control variables

According to Cohen and Klepper (1996), larger firms are more likely to invest in process innovations as they can spawn the costs for their development over a larger output. Therefore, we control for firm size, which we measure as the logarithm of the number of employees in 2002. We also control for whether the company sells its goods or services in foreign markets to capture the effect that a possible more competitive environment makes firms more willing to invest in cost-reducing innovations. In order to further capture the innovation behavior of the manufacturing firms, we additionally control for the firms' R&D intensities, whether the enterprise performs its R&D activities on a continuous or occasional base, and whether the company belongs to an enterprise group. Another issue which might make firms willing to reduce their energy and material intensity is the use of information provided by trade associations that usually attempt to provide such information to their member firms (King and Lenox 2000). In our study, we take a broader view on possible information sources which may also comprise universities or other public research institutions. In order to take into account the use of publicly available knowledge, we use data indicating whether information provided by either conferences, trade fairs, exhibitions, scientific journals and technical publications, or professional and industry associations are used for new innovation projects or contribute to the completion of existing innovation projects. In Table 1 we give an overview of all the variables and their measurement used in the regression analysis.

Insert Table 1 around here

IV. Results

IV.1 Descriptive Statistics

To set the scene, Figure 1 illustrates the differences between firms employing different process innovation strategies with respect to perceived relevance of EMEIs. The share of firms evaluating EMEIs as relevant is higher than the share of firms evaluating EMEIs as not relevant if the introduced process innovations are mainly developed within the enterprise

('Mainly Enterprise') and if the process innovations are developed together with other enterprises or institutions ('Enterprise with others'). In contrast, the share of firms estimating EMEIs as relevant is by eight percentage points lower as the share of firms assessing EMEIs as not relevant if firms' process innovations are mainly developed by other enterprises or institutions.

Insert Figure 1 about here

Figure 2 reports the share of firms that evaluate the effect of the introduced process innovations on the reduction of energy and materials per unit output as *High* or *Medium* versus the share of firms evaluating the effect as *Low*. While the share of firms reporting a *high* or *medium* EMEI performance is higher for firms that developed process innovations mainly 'in-house' or together with other enterprises or institutions, the share of firms reporting a higher EMEI performance is lower if firms' process innovations are mainly developed by other enterprises or institutions. The descriptive statistics of other variables as well as a correlation matrix of explanatory are reported in Tables A and B in the Appendix.

Insert Figure 2 about here

IV.2 Estimation results

As our two dependent variables are dummy variables, we make use of probit models and present results of regressions based on the total sample as well as industry-specific estimation results. We report industry-specific results since the relationship between EMEIs and innovation strategies may differ between industries. Moreover, the incentive of European manufacturing firms to introduce EMEIs may be determined by country-specific laws and regulations. We account for such country-specific fixed effects by including country-specific dummy variables.[4]

[4] Although there are a number of EU laws and regulations that affect innovation activities of manufacturing firms all over Europe, governments of the EU member states still pursue different policies and approaches to increase energy and material efficiency (Baumann and Simmerl 2011).

Results of estimations based on the total sample

In Table 2, we first report the estimated coefficients and the respective marginal effects for each of our explanatory variables. We estimate two models. In the first model the dependent binary variable takes on the value one if interviewees evaluate EMEIs as relevant and is zero otherwise. In the second model the dependent binary variable takes on the values one if respondents assess the effect of EMEIs as medium or high and is zero if the effect they assess it as low.

We are mainly interested in the estimated effects of firms' process innovation strategies. We include two dummy variables reflecting the 'in-house' innovation strategy (process innovations are mainly developed within the enterprise or enterprise group) and the 'external' innovation strategy (process innovations are mainly developed by other enterprises or institutions). The reference category is the 'cooperation' innovation strategy (process innovations are developed together with other enterprises and institutions). If firms that jointly develop process innovations with other firms or institutions are more likely to introduce EMEIs and are more likely to introduce EMEIs with a marked efficiency effect, the estimated effect of the 'in-house' and the 'external' innovation strategy should be negative and statistically significant.

The estimated effect of the 'external' innovation strategy is indeed negative and statistically significant. Hence, results indicate firms which let mainly develop their process innovations by other enterprises or institutions tend to be less likely to introduce EMEIs at all and these firms are also less likely to introduce process innovations which lead to marked energy and material efficiency improvements. The estimated effect of the 'in-house' innovation strategy, however, is positive but statistically insignificant. This implies that it does not matter whether firms follow the 'in-house' strategy or whether they follow the 'cooperation' strategy.

Insert Table 2 about here

Next to our main explanatory variables, we include various control variables. Our results suggest that EMEIs are positively related to firms' internal R&D activities. While the estimated effect of R&D intensity is positive and statistically significant in both regressions, the estimated effects of the two dummy variables reflecting 'Continuous R&D' and

'Occasional R&D' are only statistically significant in the first regression. Hence, these results provide further empirical evidence for the relevance of in-house innovation activities. The estimated effect of the dummy Public Info' reflecting the use of publicly available is positive in both regressions but is statistically significant only in the first regression. Export activities of firms do not seem to matter at all. Moreover, industry- and country-specific fixed effects capturing all unobserved country- and industry-specific characteristics are statistically significant.

Industry-specific estimation results

Next we present industry-specific estimation results for industries at the 2-digit NACE classification level in order to take into account possible heterogeneity between industries. Table 3 reports the results of 15 European manufacturing industries.[5] In order to save space, we focus on the main estimated effects of our main explanatory variables ('Mainly Enterprise' and 'Mainly others') and do not present the estimated effects of control variables which are entered on the horizontal axis. Furthermore, we only present the marginal effects. As can be seen from Table 3, the estimated marginal effect of the variable 'Mainly others' is statistically significant in only five out of the 15 manufacturing industries, i. e. in the pulp and paper, rubber and plastic, basic metals, machinery and equipment, and in the furniture and recycling industry. However, the sign of the estimated effect of this variable is negative in all industries, which explains the negative and statistically significant effect found in regressions based on the total sample. In contrast, the estimated effect of the variable 'Mainly Enterprise' is never statistically significant and its estimated marginal effect is negative in six industries but positive in nine industries. These results suggest that firms that let mainly develop their process innovations by other firms or institutions are less likely to introduce EMEIs than firm cooperating with other firms or institutions, whereas firms that mainly develop their process innovations 'in-house' are not less likely to introduce EMEIs.

Insert Table 3 about here

----

[5] The industry 'manufacturing of coke, refined petroleum, and nuclear fuel' was excluded from the analysis because the number of observations is too low.

Table 4 reports the results of the investigation of EMEI performance. The estimated marginal effect of the dummy variable ‘Mainly others’ is negative in ten industries but the negative effect is statistically significant in only three industries. In two industries the effect is positive and statistically significant (textiles and pulp, papers). The estimated marginal effect of the variable ‘Mainly Enterprise’ is statistically significant in one industry (textiles) where the effect is positive. Hence, with respect to the EMEI performance results of these industry-specific regressions do only partly confirm the results of regressions based on the total sample. Again, the estimated effect of the variable ‘Mainly Enterprise’ is not statistically significant in 14 industries and the sign of the estimated effect is negative in nine industries but positive in 6 industries. Hence, our industry-specific results do not provide empirical evidence for the hypothesis that firms that mainly develop their process innovations together with other firms or institutions (‘cooperation strategy’) are more likely to introduce EMEIs with a marked effect on energy and material efficiency than firms using alternative process innovation strategies.

Insert Table 4 about here

V. Discussion and Conclusions

From a management perspective a major incentive for improving the firms’ energy and material efficiency is the reduction of production costs, since firms may gain competitive advantage and increase their market shares (Hart 1995; Porter and van der Linde 1995; Shrivastava 1995; Esty and Porter 1998; Chen et al. 2006). Energy and material efficiency innovations (EMEIs) are often considered as crucial for the improvement of energy and material efficiency and they may also improve ecological sustainability (Frondel et al. 2007). Indeed, recent empirical evidence suggests that environmental innovations are important drivers of a reduction of toxic emissions in the US (Carrión-Flores and Innes 2010).

In this article it is argued that firms may follow different process innovation strategies. Process innovations may be mainly developed within the firm (‘in-house’ strategy), mainly developed by other enterprises or institutions (‘external’ strategy), or jointly with other enterprises or institutions (‘cooperation’ strategy). This article contributes to the literature by empirically examining the relationship between these three process innovation strategies and EMEIs using data of manufacturing firms in Europe.

Our results suggest that firms' EMEIs are related to firms' process innovation strategies. Firms which employ the 'external' strategy and let develop their process innovations mainly by other enterprises or institutions are less likely to introduce EMEIs at all and are also less likely to introduce process innovations which are associated with a marked increase in energy and material efficiency. The results of industry-specific estimations point to the same direction but are less clear-cut. The negative relationship between firms' propensity to introduce EMEIs and the mainly external development of process innovations is negative in all industries but not always statistically significant. Furthermore, our estimation results do not suggest that the 'cooperation' strategy, i.e. the joint development of process innovations with external partners, is especially important for EMEIs. With respect to the relevance and performance of EMEIs, firms which mainly develop their process innovations in-house do not significantly differ from firms developing their process innovations together with other enterprises or institutions. In a nutshell, our results suggest that it does not matter whether firms developing their process innovations mainly in-house or together with others but firms relying mainly on the external development of their process innovations are less likely to introduce EMEIs that improve their efficiency considerably.

Other empirical studies find positive effects of R&D cooperation on innovation performance in general (Cassiman and Veugelers 2006) and positive effects on environmental innovations (De Marchi 2011). Our results, however, do not provide empirical evidence for the relevance of cooperation for EMEIs, since firms that are mainly developing their process innovations together with other firms or institutions are not more likely to introduce EMEIs than firms developing their process innovations mainly in-house. A possible explanation could be that our empirical analysis strictly focuses on process innovations. Indicators for innovation strategies as well as our indicators for EMEIs refer to process innovations. In contrast, existing studies do not distinguish between cooperation related to product innovations and cooperation related to process innovations. However, firms may benefit less from joint development of process innovations as compared to the joint development of product innovations, since it might be much more difficult to the transfer of knowledge associated with process innovations between firms and institutions. Gopalakrishnan et al. (1999) and Gopalakrishnan and Bierly (2001) state that knowledge associated with process innovations tends to be more complex and firm-specific as compared to knowledge associated with product innovations. This may explain why a majority of manufacturing firms in our sample report that they mainly develop their process innovations ‘in-house’.

Although our results do not suggest that firms developing process innovations jointly with other firms or institutions are more likely to introduce successful EMEIs, this process innovation strategy may still be profitable. For instance, firms may engage in research partnerships and jointly develop process innovations in order to save costs by reducing duplication of research (Hagedoorn et al. 2000). Unfortunately, we do not have data on the costs associated with different process innovation strategies which would be needed to examine the profitability of various process innovation strategies.

Furthermore, environmental policy may not only foster the development of energy and material efficiency improving technologies through stricter environment regulations but may also support firms’ innovation activities. According to our results, the introduction of EMEIs is positively related to firms’ R&D activities and the use of public information sources, like scientific journals and conferences. This may indicate that firms engaging in innovation activities that are related to EMEIs, may not only rely on the results of applied research but also on basic research conducted in universities and public research institutions. However, our results do not suggest that the use of publicly available knowledge is also positively correlated to a higher EMEI performance which could provide a possible avenue for future empirical research.

Several limitations of our study may be also considered in the future. Since our empirical analysis is based on cross-sectional data, the results do not provide ultimate answers about the direction of causation. Therefore, future research could make use of panel data to examine the influence of changes in firms’ process innovation strategies on EMEIs and to control for unobserved firm-specific effects. Furthermore, there is still a need to collect more fine-grained data on process innovation strategies. Although our data allow us to analyze the link between energy and material efficiency improving process innovations and different process innovation strategies, we do not know whether firms employ the same strategies for all process innovations and we do not have information about the external partners engaged in the development of process innovations.

APPENDIX:

A. Descriptive Statistics

VARIABLES	Reduction of energy and materials per unit output is *Not relevant*		Reduction of energy and materials per unit output is *relevant*	
	Number (Share)	Mean	Number (Share)	Mean
Export	2,593 (67%)		9,025 (76%)	
Number Employees		144		302
R&D Intensity		0.0327		0.0378
Enterprise Group	1,408 (36%)		5,629 (47%)	
Continuous R&D	1,178 (30%)		5,399 (45%)	
Occasional R&D	911 (23%)		2,595 (22%)	
Public Info	2,422 (62%)		9,729 (82%)	

Note: 3,885 firms estimate the effects of the introduced process innovations on the reduction of energy and materials per unit as *Not relevant* in the years from 2002 to 2004 and 11,897 firms estimate the effect as relevant, thus as either *Low*, *Medium*, or *High*.

B. Correlation Matrix of Variables

VARIABLES	Export	Log(employees)	R&D Intensity	Enterprise Group	Continuous R&D	Occasional R&D	Public Info	Mainly Enterprise	Mainly others
Export	1								
Log(employees)	0.3463	1							
p-Value	0.0000								
R&D Intensity	-0.0400	-0.1255	1						
p-Value	0.0000	0.0000							
Enterprise Group	0.2478	0.5030	-0.0734	1					
p-Value	0.0000	0.0000	0.0000						
Continuous R&D	0.2634	0.3183	0.0831	0.2369	1				
p-Value	0.0000	0.0000	0.0000	0.0000					
Occasional R&D	-0.0211	-0.0813	-0.0410	-0.0225	-0.4517	1			
p-Value	0.0081	0.0000	0.0000	0.0048	0.0000				
Public Info	0.0854	0.1281	0.0377	0.0206	0.1384	-0.0157	1		
p-Value	0.0000	0.0000	0.0000	0.0096	0.0000	0.0485			
Mainly Enterprise	0.0071	-0.0328	0.0036	0.0280	0.0747	0.0226	-0.0006	1	
p-Value	0.3703	0.0000	0.6482	0.0004	0.0000	0.0045	0.9421		
Mainly others	-0.0703	-0.0883	-0.0027	-0.1058	-0.1685	-0.0584	-0.0506	-0.4766	1
p-Value	0.0000	0.0000	0.7387	0.0000	0.0000	0.0000	0.0000	0.0000	

Note: 15,782 observations are used.

References

Ahuja G. and Katila R. (2001) Technological Acquisitions and the Innovation Performance of Acquiring Firms: A Longitudinal Study, *Strategic Management Journal*, Vol. 22(3), pp. 197-220.

Arrow K. (1962) Economic welfare and the allocation of resources for invention, The rate and Direction of Inventive Activity, in: R. Nelson (Ed.), Princeton University Press, Princeton, NJ, pp. 609-626.

Arora A. and Gambardella A. (1990) Complementarity and external linkages: The strategies of the large firms in biotechnology, *Journal of Industrial Economics*, Vol. 38(4), pp. 361-379.

Atallah G. (2002) Vertical R&D spillovers, cooperation, market structure, and innovation, *Economics of Innovation and New Technology*, Vol. 11(3), pp. 179-209.

Baumann F. and Simmerl G. (2011) Between Conflict and Convergence: The EU Member States and the Quest for a Common External Energy Policy, CAP Discussion Paper, Research Group on European Affairs.

Belderbos R., Carree M., Diederen B., Lokshin B., and Veugelers R. (2004) Heterogeneity in R&D cooperation strategies, *International Journal of Industrial Organization*, Vol. 22(8-9), pp. 1237-1263.

Blonigen B. and Taylor C. (2000) R&D intensity and acquisitions in high-technology industries: Evidence from the US electronic and electrical equipment industries, *Journal of Industrial Economics*, Vol. 48(1), pp. 47-70.

Bönte W. (2003) R&D and productivity: internal vs. external R&D – evidence from West German manufacturing industries, *Economics of Innovation and New Technology*, Vol. 12(4), pp. 343-360.

Bönte W. and Keilbach M. (2005) Concubinage or marriage? Informal and formal cooperations for innovations, *International Journal of Industrial Organization*, Vol. 23(3-4), pp. 279-302.

Carrión-Flores C.E. and Innes R. (2010) Environmental Innovation and Environmental Performance, *Journal of Environmental Economics and Management*, Vol. 59(1), pp. 27-42.

Cassiman B. and Veugelers R. (2002) R&D cooperation and spillovers: some empirical evidence from Belgium, *American Economic Review*, Vol. 92(4), pp. 1169-1184.

Cassiman B. and Veugelers R. (2006) In Search of Complementarity in Innovation Strategy: Internal R&D and External Knowledge Acquisition, *Management Science*, Vol. 52(1), pp. 68-82.

Chen Y.-S., Lai S.-B., and Wen C.-T. (2006) The influence of green innovation performance on corporate advantage in Taiwan, *Journal of Business Ethics*, Vol. 67(4), pp. 331-339.

Chesbrough H. (2003) The era of open innovation, *Sloan Management Review*, Vol. 44, pp. 35-41.

Christmann P. (2000) Effects of "Best Practices" of Environmental Management on Cost Advantage: The Role of Complementary Assets, *Academy of Management Journal*, Vol. 43(4), pp. 663-680.

Cockburn I. and Henderson R. (1998) Absorptive capacity, coauthoring behavior and the organization of research in drug discovery, *Journal of Industrial Economics*, Vol. 46, pp. 157-182.

Cohen W.M. and Klepper S. (1996) Firms size and the nature of innovation within industries: the case of process and product R&D, *Review of Economics and Statistics*, Vol. 78(2), pp. 232-243.

Cohen W.M. and Levinthal A. (1989) Innovation and Learning: The two faces of R&D, *Economic Journal*, Vol. 99(397), pp. 569-596.

Cohen W.M. and Levinthal A. (1990) Absorptive Capacity: A New Perspective on Learning and Innovation, *Administrative Science Quarterly*, Vol. 32(1), pp. 128-152.

De Marchi V. (2011) Environmental innovation and R&D cooperation: Empirical evidence from Spanish manufacturing firms, *Research Policy,* doi: 10.1016/j.respol.2011.10.002.

del Rio González P. (2005) Analysing the Factors Influencing Clean Technology Adoption: A Study of the Spanish Pulp and Paper Industry, *Business Strategy and the Environment*, Vol. 14(1), pp. 20-37.

Esty D.C. and Porter M.E. (1998) Industrial ecology and competitiveness: Strategic implications for the firm, *Journal of Industrial Ecology*, Vol. 2(1), pp. 35-43.

Frondel M., Horbach J., and Rennings K. (2007) End-of-Pipe or Cleaner Production? An Empirical Comparison of Environmental Innovation Decisions, *Business Strategy and the Environment*, Vol. 16(8), pp. 571-584.

Gopalakrishnan S., Bierly P., and Kessler E.H. (1999) A reexamination of product and process innovations using a knowledge-based view, *Journal of High Technology Management Research*, Vol. 10(1), pp. 147-166.

Gopalakrishnan S. and Bierly P. (2001) Analyzing innovation adoption using a knowledge-based approach, *Journal of Engineering and Technology Management*, Vol. 18(2), pp. 107-130.

Grandstrand O., Bohlin E., Oskarsson C., and Sjöberg N. (1992) External technology acquisition in large multitechnology corporations, *R&D Management*, Vol. 22(2), pp. 111-134.

Grant R.M. (1996) Prospering in Dynamically-Competitive Environments: Organizational Capability as Knowledge Integration, *Organization Science*, Vol. 7(4), pp. 375-387.

Grimpe C. and Kaiser U. (2010) Balancing Internal and External Knowledge Acquisition: The Gains and Pains from R&D Outsourcing, *Journal of Management Studies*, Vol. 47(8), pp. 1483-1509.

Grossman S. and Hart O. (1986) The costs and benefits of ownership: A theory of vertical and lateral integration, *Journal of Political Economy*, Vol. 94(4), pp. 691-719.

Hagedoorn J., Link A.N., and Vonortas N.S. (2000) Research partnerships, *Research Policy*, Vol. 29(4-5), pp.567-586.

Haour G. (1992) Stretching the knowledge-base of the enterprise through contract research, *R&D Management*, Vol. 22(2), pp. 177-182.

Hart S.L. (1995) A Natural-Resource-Based View of the Firm, *Academy of Management Review*, Vol. 20(4), pp. 986-1014.

Horbach J. (2008) Determinants of environmental innovations. New evidence from German panel data sources, *Research Policy*, Vol. 37(1), pp. 163-173.

Jaffe A., Newell R.G., and Stavins R.N. (2002) Environmental policy and technological change, *Environmental and Resource Economics*, Vol. 22(1), pp. 41-69.

Jaffe A., Newell R.G., and Stavins R.N. (2005) A tale of two market failures: technology and environmental policy, *Ecological Economics*, Vol. 54(2-3), pp. 164-174.

Katz R. and Allen T. (1982) Investigating the not invented here (NIH) syndrome: a look at the performance, tenure, and communication patterns of 50 R&D projects, *R&D Management*, Vol. 12(1), pp. 7-19.

King A.A. and Lenox M.J. (2000) Industry self-regulation without sanctions: The Chemical industry’s responsible care program, *Academy of Management Journal*, Vol. 43(4), pp. 698-716.

Kjaerheim G. (2005) Cleaner production and sustainability, *Journal of Cleaner Production*, Vol. 13(4), pp. 329-339.

Laursen K. and Salter A. (2006) Open for Innovation: The Role of Openness in explaining Innovation Performance among U.K. Manufacturing Firms, *Strategic Management Journal*, Vol. 27(2), pp. 131-150.

Lokshin B., Belderbos R., and Carree M. (2008) The Productivity Effects of Internal and External R&D: Evidence from a Dynamic Panel Data Model, *Oxford Bulletin of Economics and Statistics*, Vol. 70(3), pp. 399-413.

López A. (2008) Determinants of R&D cooperations: evidence from Spanish manufacturing firms, *International Journal of Industrial Organization*, Vol. 26(1), pp. 113-136.

Pisano G.P. (1990) The R&D Boundaries of the firm: an empirical analysis, *Administrative Science Quarterly*, Vol. 35(1), pp. 153-176.

Porter M.E. and van der Linde C. (1995) Green and competitive: ending the stalemate, *Harvard Business Review*, September-October, pp. 120-133.

Rennings K. (2000) Redefining innovation – eco-innovation research and the contribution of ecological economics, *Ecological Economics*, Vol. 32(2), pp. 319-332.

Rennings K., Ziegler A., Ankele K., and Hoffmann E. (2006) The influence of different characteristics of the EU environmental management and auditing scheme on technical environmental innovations and economic performance, *Ecological Economics*, Vol. 57(1), pp. 45-59.

Shrivastava P. (1995) Environmental technologies and competitive advantage, *Strategic Management Journal*, Vol. 16(S1), pp. 183-200.

Veugelers R. and Cassiman B. (1999) Make and buy in innovation strategies: evidence from Belgian manufacturing firms, *Research Policy*, Vol. 28(1), pp. 63-80.

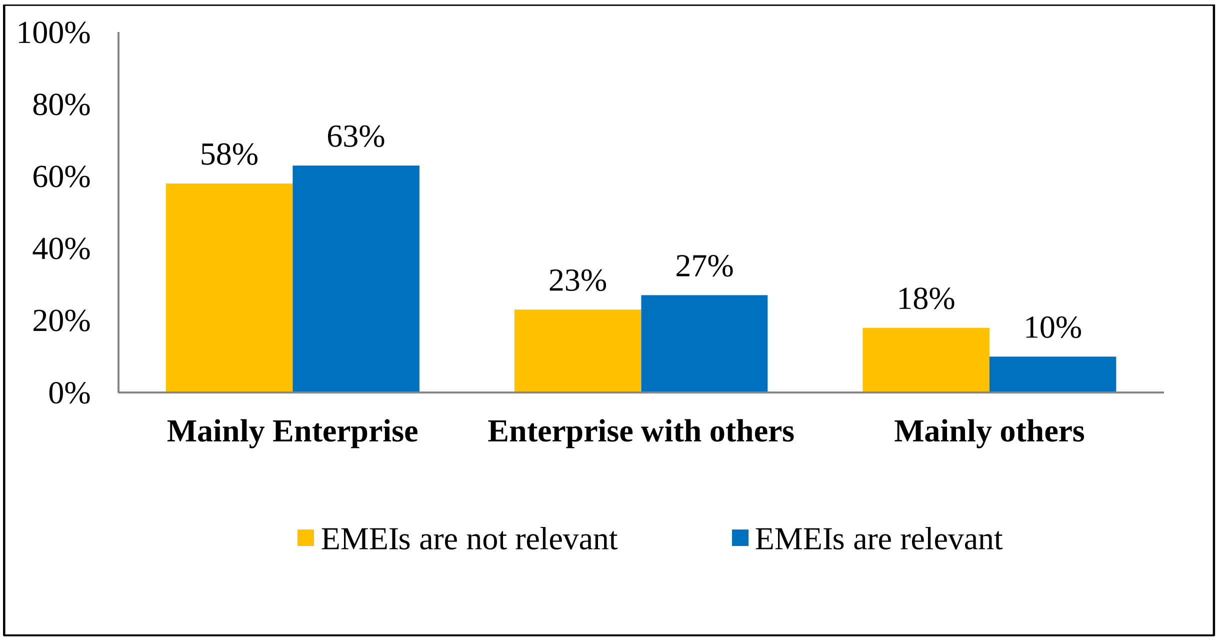
Williamson O. (1985) The economic Institutions of Capitalism: Firms, Markets, Relational Contracting, The Free Press, New York.

Zahra S.A. and George G. (2002) Absorptive Capacity: A Review, Reconceptualization, and Extension, *Academy of Management Review*, Vol. 27(2), pp. 185-203.

Table 1: Variable names and measurement

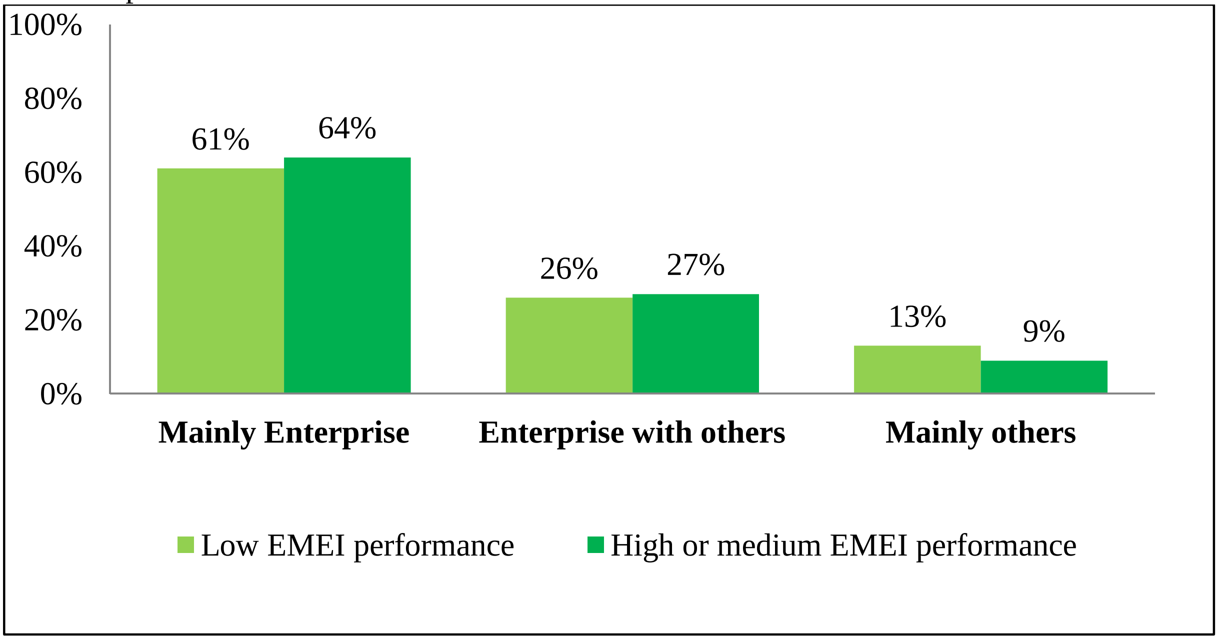
Variable	Measurement
Relevant effect (1st dependent variable)	1: if the company assesses the effect of reducing energy and materials per unit output as either *High*, *Medium*, or *Low* as the result of the introduced process innovations during the years from 2002 to 2004, 0: the effect is assessed as *Not relevant*
High or Medium effect (2nd dependent variable)	1: if the company assesses the effect of reducing energy and materials per unit output as *High* or *Medium* as the result of the introduced process innovations during the years from 2002 to 2004, 0: the effect is assessed as *Low*
Mainly Enterprise	1: if the process innovations are mainly developed by the enterprise or enterprise group, 0: otherwise
Enterprise with others	1: if the process innovations are developed by the enterprise together with other enterprises or institutions, 0: otherwise
Mainly others	1: if the process innovations are mainly developed by other enterprises or institutions, 0: otherwise
Log(employees)	Logarithm of the number of employees in 2002
R&D Intensity	Total innovation expenditure in 2004 divided by the enterprise' total sales in 2004
Export	1: if the firm sells its goods or services in other countries than the domestic country during the years from 2002 to 2004, 0: otherwise
Enterprise group	1: if the enterprise belongs to a enterprise group, 0: otherwise
Continuous R&D	1: if the company performs its R&D continuously during the years from 2002 to 2004, 0: otherwise
Occasional R&D	1: if the company performs its R&D occasionally during the years from 2002 to 2004, 0: otherwise
Public Info	1: if the company used either conferences, trade fairs, exhibitions, scientific journals and technical publications, or professional and industry associations as information source for new innovation projects or contributed to the completion of existing innovation projects during the years from 2002 to 2004, 0: otherwise

Figure 1: Share of firms according to their process innovation strategy and their estimation of whether EMEIs are relevant or not relevant to the firm



Source: Fourth Community Innovation Survey (CIS IV).

Figure 2: Share of firms according to their process innovation strategy and their estimation on EMEI performance



Source: Fourth Community Innovation Survey (CIS IV).

Table 2: Probit estimation results based on the total sample

	EMEIs – Relevant effect		***EMEIs – High or Medium effect***	
VARIABLES	Coefficient	Marginal Effect	Coefficient	Marginal Effect
Innovation strategies				
Mainly Enterprise[1]	0.0240	0.00727	0.0192	0.00724
	(0.0276)	(0.00837)	(0.0283)	(0.0107)
Mainly others[1]	-0.207***	-0.0661***	-0.108**	-0.0411**
	(0.0393)	(0.0131)	(0.0445)	(0.0172)
Control variables				
Export	0.0411	0.0125	0.0171	0.00644
	(0.0283)	(0.00868)	(0.0311)	(0.0117)
Log(Employees)	0.0952***	0.0287***	0.0616***	0.0232***
	(0.0101)	(0.00304)	(0.0102)	(0.00385)
R&D Intensity	1.590***	0.480***	1.086***	0.408***
	(0.243)	(0.0734)	(0.242)	(0.0908)
Enterprise group	0.0344	0.0104	0.0274	0.0103
	(0.0284)	(0.00856)	(0.0296)	(0.0111)
Continuous R&D[2]	0.217***	0.0646***	0.0464	0.0174
	(0.0310)	(0.00907)	(0.0331)	(0.0124)
Occasional R&D[2]	0.0728**	0.0216**	0.0162	0.00607
	(0.0324)	(0.00949)	(0.0357)	(0.0134)
Public Info	0.634***	0.212***	0.0590	0.0223
	(0.0281)	(0.0101)	(0.0360)	(0.0137)
Country Dummies	YES***		YES***	
Industry Dummies	YES**		YES***	
Constant	-0.773***		-0.490**	
	(0.196)		(0.213)	
Prob>Chi2	0.0000		0.0000	
Pseudo R2 (Mc Fadden)	0.0882		0.0364	
Observations	15,782		11,897	

Notes: 1) Dummy variable, reference category: process innovations are developed by the enterprise together with other enterprises or institutions (‘cooperation’ strategy). 2) Reference category is that the firm conducts no intramural R&D. Marginal effects calculated at the mean. Robust standard errors in parentheses. Significance levels at *** p<0.01, ** p<0.05, * p<0.1

Table 3: Industry-specific probit estimation results (NACE 2-digit level)
(dependent variable: EMEIs – *Relevant effect*)

INDUSTRY	**Mainly Enterprise**[1]	**Mainly others**[1]	Control Variables	Pseudo R-square	Number Observations
Food, Beverages, Tobacco	-0.0292 (0.0221)	-0.0542 (0.0353)	YES***	0.0944	2,099
Textiles	0.0541 (0.0347)	-0.0391 (0.0466)	YES***	0.1311	1,143
Leather	0.0409 (0.0779)	-0.112 (0.111)	YES***	0.1196	250
Wood	0.0208 (0.0496)	-0.0620 (0.0694)	YES***	0.1212	568
Pulp, Paper	0.0590 (0.0480)	-0.130* (0.0679)	YES***	0.1650	446
Publishing, Printing	-0.00670 (0.0484)	-0.0390 (0.0597)	YES***	0.0747	698
Chemicals	-0.00657 (0.0293)	-0.0732 (0.0600)	YES***	0.0843	1,233
Rubber, Plastic	-0.00541 (0.0345)	-0.0973* (0.0591)	YES***	0.1369	910
Non-Metallic Prod.	0.0220 (0.0365)	-0.0161 (0.0538)	YES***	0.1077	889
Basic Metals	0.0175 (0.0443)	-0.151* (0.0773)	YES***	0.1736	493
Metal Products	-0.0126 (0.0280)	-0.0635 (0.0408)	YES***	0.1175	1,536
Machinery	0.0112 (0.0268)	-0.0852* (0.0476)	YES***	0.1223	1,509
Electrical Machinery	-0.00121 (0.0226)	-0.0278 (0.0383)	YES***	0.0731	1,861
Motor Vehicles	0.00856 (0.0296)	-0.0694 (0.0534)	YES***	0.1055	995
Furniture, Recycling	0.0229 (0.0353)	-0.118** (0.0552)	YES***	0.0958	955

Notes: 1) Dummy variable, reference category: process innovations are developed by the enterprise together with other enterprises or institutions (‘cooperation’ strategy). Marginal effects calculated at the mean. Robust standard errors in parentheses. Significance levels at *** p<0.01, ** p<0.05, * p<0.1

Table 4: Industry-specific probit estimation results (NACE 2-digit level)
(dependent variable: EMEIs – *High or Medium effect*)

INDUSTRY	**Mainly Enterprise**[1]	**Mainly others**[1]	Control Variables	Pseudo R-square	Number Observations
Food, Beverages, Tobacco	-0.00326 (0.0284)	-0.145*** (0.0478)	YES***	0.0374	1,603
Textiles	0.0985** (0.0433)	0.127** (0.0537)	YES***	0.0938	830
Leather	0.118 (0.0966)	0.000968 (0.149)	YES	0.1224	182
Wood	-0.00470 (0.0598)	-0.147 (0.0934)	YES	0.0627	403
Pulp, Paper	0.0379 (0.0636)	0.156** (0.0770)	YES	0.0554	352
Publishing, Printing	-0.0242 (0.0623)	-0.0510 (0.0767)	YES***	0.0818	474
Chemicals	0.0611 (0.0399)	0.0409 (0.0726)	YES***	0.0412	968
Rubber, Plastic	-0.000687 (0.0422)	0.00663 (0.0710)	YES***	0.1136	715
Non-Metallic Prod.	-0.0484 (0.0485)	-0.0249 (0.0768)	YES***	0.0707	632
Basic Metals	-0.0744 (0.0556)	-0.185* (0.109)	YES***	0.0848	376
Metal Products	0.0322 (0.0358)	-0.0939* (0.0545)	YES***	0.0488	1,110
Machinery	-0.00634 (0.0343)	-0.00213 (0.0611)	YES***	0.0408	1,176
Electrical Machinery	-0.0458 (0.0304)	-0.0721 (0.0526)	YES***	0.0383	1,445
Motor Vehicles	-0.0121 (0.0392)	-0.0920 (0.0747)	YES***	0.0477	772
Furniture, Recycling	0.00391 (0.0466)	-0.0212 (0.0707)	YES***	0.0795	732

Notes: 1) Dummy variable, reference category: process innovations are developed by the enterprise together with other enterprises or institutions ('cooperation' strategy). Marginal effects calculated at the mean. Robust standard errors in parentheses. Significance levels at *** p<0.01, ** p<0.05, * p<0.1