Jacobian spillovers in environmental technological proximity: the role of Mahalanobis index on European patents within the Triad

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Jacobian Spillovers in Environmental Technological Proximity: The Role of Mahalanobis index on European Patents within the Triad

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Abstract

The aim of this paper is to investigate the role of Jacobian externalities stemmed from different technological sectors for international firms engaged both in environmental and in dirty activities. Firms' innovation, measured, as the development of new patents, is a key factor behind the achievement of desired economic performances. Empirical literature usually deals with the integration between ecological efficiency and product value enhancement. The results of these studies lead to the lack of integrated innovation adoption behind environmental productivity performance. In this work, we analyse the integration between more environmental goals in an original way, by applying different methodologies to compute technological proximity, based on the Mahalanobis approach. To this end, we use information from 240 large international firms, located in three economic areas: USA, Japan and Europe and we select their environmental and dirty patents from European Patent Office data.

Keywords: Innovation; Technology spillovers; Environmental relatedness.

JEL codes: O32; O33; Q5.

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1. Introduction

The empirical literature about environmental innovations and their effects on firms' productivity (Marin and Lotti, 2016) and, in particular, on firms' ecological performance (Costantini, Mazzanti, Montini, 2013); Gilli, Mancinelli, Mazzanti, 2014) is very rich.

European Environmental targets on emissions depend upon technological evolution of firms' industrial sectors. European economy must undergo important radical changes to assure long run sustainability.

Environmental innovations represent a fundamental role in the process of integration between competitiveness and sustainability (Cainelli et al. 2012; De Marchi, 2012; Harbach, 2008; Kemp and Pontoglio, 2011).

Literature about innovation framework has paid attention to the complementarity between dirty innovations and environmental ones (Hall et al. 2012; Mancinelli and Mazzanti, 2009; Mohnen and Roller, 2005).

In this paper, we focus our attention on the analysis of integration process between only ecological activities. To this end, we identify technological patent classes of three environmental targets for 240 large International firms, located in the USA, Japan and Europe: water pollution abatement, waste management efficiency and energy production efficiency and we evaluate their Mahalanobis proximities.

The paper is structured as follows: Section 2 presents a review of the empirical literature about the integration process between dirty and environmental activities; Section 3 describes the data used in the empirical analysis; Section 4 discusses the environmental technological proximities for firms selected in our sample; Section 5 presents the empirical analysis about three environmental targets: water pollution abatement, waste management efficiency and energy production efficiency by economic area; Section 6 concludes.

2. Literature review

Ghisetti and Quatraro (2017) and Costantini, et al. (2016) show that there is a bulk of literature, that highlights the importance of policy interventions for stimulation the adoption of environmental innovations and green technologies that have positive influence on environmental and economic performance of country/region (Carrión-Flores et al., 2013; Nesta et al., 2014; Acemoglu et al., 2012; Del Río González, 2009; Kammerer, 2009; Popp et al., 2009 (and also Popp, 2002, 2006, 2010); Fischer and Newell, 2008; Rehfeld et al., 2007; Wagner, 2007; Brunnermeier and Cohen, 2003; Reinhardt, 1998; Porter and van der Linde, 1995). Barbieri et al., 2016 propose a comprehensive literature review of studies on the environmental innovations and their effects onto environmental performance. Among the recent papers that estimate the determinants and the effects of environmental innovations on environmental performance, Ghisetti and Quatraro (2017) highlight the following studies Gilli et al., 2014; Costantini et al., 2013; Cainelli et al., 2013; Ghisetti and Quatraro, 2013; Mazzanti and Zoboli, 2009.

NAMEA (National Accounting Matrix including Environmental Accounts) models are extensively used in the analysis of effects of environmental innovations on environmental performance. Since the Italian case is "only full regionalized NAMEA available in the EU" (as mentioned in Costantini, Mazzanti and Montini, 2013, p. 103) NAMEA in regional or country level is often used for Italian regions or sectors of the economy. The examples of application of NAMEA approach for measuring the effects of environmental innovations are Ghisetti and Quatraro; 2017; Costantini et al., 2013; Ghisetti and Quatraro, 2013; Marin and Mazzanti, 2013; Marin et al., 2012; Mazzanti and Montini, 2010; Mazzanti et al., 2008; Mazzanti and Montini, 2010; Mazzanti and Zoboli, 2009).

Antonioli and Mazzanti (2017) use the methodology of multidimensional questionnaire. In particular, they study the involvement of trade unions on the environmental innovation activity in 555 Italian manufacturing firms in the Emilia-Romagna region for a period 2006 – 2008. According to Antonioli and Mazzanti (2017) there other papers that study firms' environmental innovations on the basis of survey methodology include such studies as Mazzanti et al., 2016; Borghesi et al., 2015; Triguero et al., 2013; Horbach et al., 2012; Cainelli et al., 2012; Kesidou and Demirel, 2012; Veugelers, 2012.

D'Amato, A., Mancinelli, S., & Zoli (2016) also use the methodology of survey (Survey of Public Attitudes and Behaviors toward the Environment) to study the environmental behaviour of households in England. As mentioned by these authors there are other examples of surveys of households' environmental behaviour in different countries. Examples here are Korea (Hong, 1999); Canada (Ferrara and Missios, 2005); Norway (Kipperberg, 2007); USA (Kinnaman and Fullerton, 2000; Fullerton and Kinnaman, 1996; Hong et al., 1993).

In table A.1 in the Appendix we provide the summary of recent studies on spillovers of environmental innovations and green technologies.

3. Data

We use information from OECD, REGPAT database, February 2016[1]. This dataset covers firms' patent applications to the European Patent Office (EPO) including patents published up to December 2015. The dataset covers regional information for most OECD and EU27 countries, plus BRICS countries.

In order to explore the correlation between environmental technology classes, we match the name of the same 240 firms to applicant's name from European Commission (2013), as in Aldieri, 2013.

The matching between the firms and their counterpart in OECD, REGPAT database, February 2016 is not easy and leads to one difficulty: many large firms have several R&D performing subsidiaries in several countries and thus it is hard to link the patents applied by these subsidiaries to the parent company. Unfortunately, we cannot prepare an accurate mapping because of changes through mergers and acquisitions processes.

We follow two steps: patents are assigned to firms on the basis of their generic name; this procedure is repeated for each firm of our sample (Aldieri, 2013).

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[1] See Maraut et al. (2008) for the methodology used for the construction of REGPAT. Please contact Helene.DERNIS@oecd.org to download REGPAT database.

According to Kemp and Pearson (2007), environmental innovation is "*the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives*".

As in Marin and Lotti (2016), environmental innovations are identified through appropriate indicators on patent data, according to their technological class[2]. In Table 1, we report those patents with IPC code belonging to the groups selected by the OECD or the World Intellectual Property Organization (WIPO).

Table 1. Environmental patent classes

Macro category	**Sub-category**	**IPC**
Water	Water pollution abatement	C02F, E03F, E02B, C09K, C05F, B63J, E03C, E03B
Waste management	Solid waste collection	E01H, B65F
	Material recovery, recycling, and reuse	A23K, A43B, B03B, B22F, B29B, B30B, B62D, B65H, B65D, C03B, C03C, C04B, C08J, C09K, C10M, C22B, D01G, D21B, D21C, D21H, H01B, H01J, H01M
	Waste management n. e. c.	B09B, C10G, A61L
	Waste disposal	F03G, B60K, B60L, B09B, B65F
	Treatment of waste	A61L, A62D, B03B, B09C, D21B
	Consuming waste by combustion	F23G
	Reuse of waste materials	A43B, B22F, C04B, C05F, C08J, C09K, C11B, C14C, C21B, C25C, D21F, B29B, B62D, C08J, C10G, C10L, C22B, D01G, D21C, H01J, H01M
Energy	Integrated emissions control	F02B, F02M, F01N, F02D, G01M, F02P
	Post-combustion emissions control	F01M, F01N, F02B, F02D, F02M, G01M, B01D, B01J, B60, B62D
	Technologies specific to propulsion using electric motor	B60K, B60L, B60R, B60S, B60W
	Technologies specific to hybrid propulsion	B60K, B60W
	Fuel efficiency-improving vehicle	B62D, B60C, B60T, B60G, B60K, B60W
	Insulation	F04B, E06B
	Heating	F24D
	Lighting	H01J, H05B
	Wind energy	F03D, H02K, B63B, E04H, B60K, B60L, B63H
	Solar energy	H01L, H01G, H02N, C01B, C23C, C30B, G05F, F21L, F21S, H02J, H01H, H01M, F24J, E04D, F22B, F25B, F26B, G02B
	Geothermal energy	F01K, F24F, F24J, H02N, F25B, F03G

As we may see from Table 1, we investigate the technological proximity between classes for three environmental goals of firms: water pollution abatement, waste management efficiency and ener-

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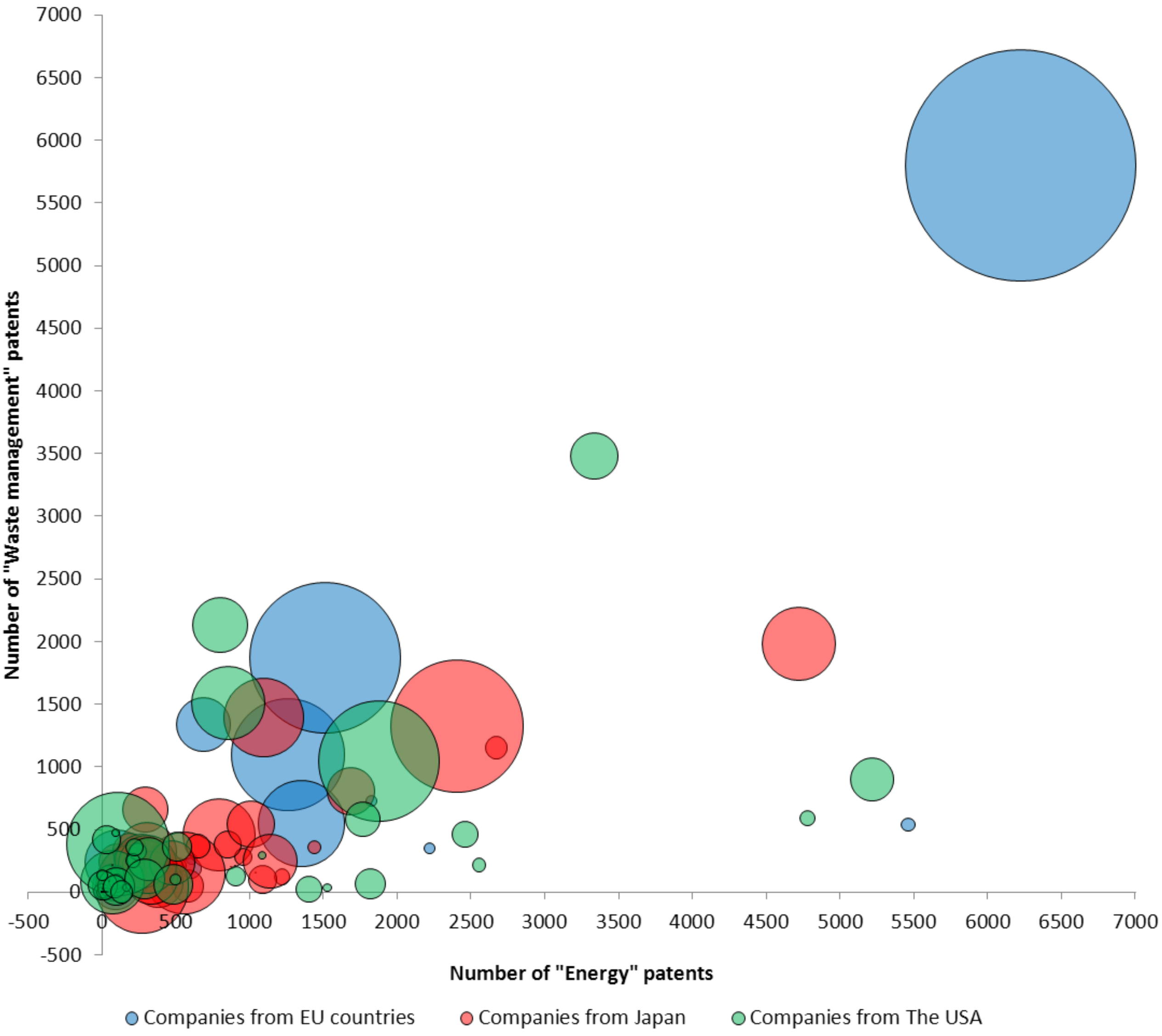
[2] http://www.oecd.org/env/consumption-innovation/indicator.htm

gy production efficiency. In particular, we analyze the integration process degree between environmental technology classes, as discussed in the previous sections.



Note: Bubble size (square) is set as number of patents in "Water" category. Relations between size of all bubbles is set to 100%. For companies with zero patent activity in "Water" category, bubble size is set as 0.01. Due to their micro-size they are not visible on the graph.

Figure 1. Distribution of patent activity on "Water", "Waste management" and "Energy" categories in the studied 240 large international firms

Figure 1 plots the patent activity of the 240 studied firms in three patent classes (Energy, Water and Waste management). For better visualization, we color firms from EU in blue, from Japan – in Red, firms from the USA. As we can see, the vast majority of firms are concentrated in the low patent activity zone.

Figure 2. Distribution of dirty/ecological patents by economic area

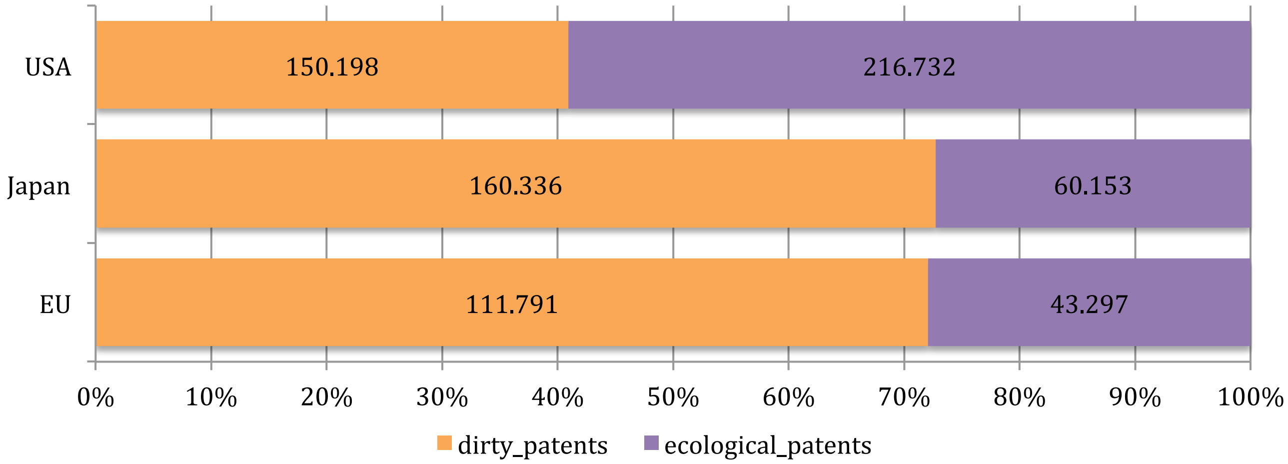
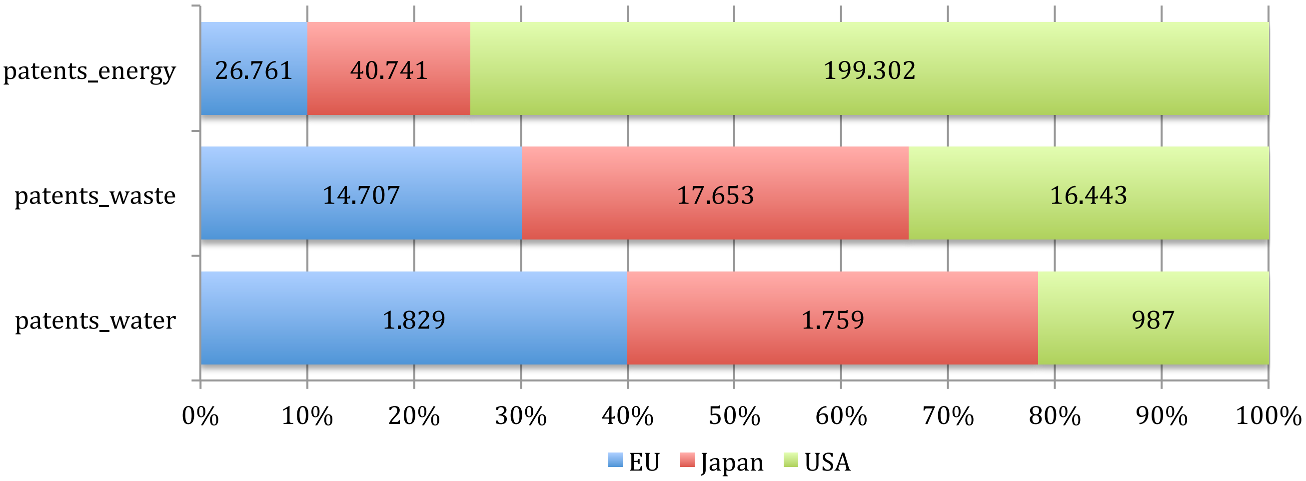


Table 3. Distribution of environmental patents by economic area



In Figure 2, we compare dirty patents versus ecological ones by economic area: the American firms produce more ecological patents than dirty ones, while Japanese and European firms are yet technologically linked to dirty activities innovations.

Figure 3 presents the distribution of environmental patents by economic area. In particular, in our analysis we consider three environmental goals: water pollution abatement, waste management efficiency and energy production efficiency. As we may observe, American firms are specialized in the energy production efficiency process, while European firms innovate mainly for water pollution abatement.

4. Environmental Technological Proximity

A relevant issue in the empirical analysis on knowledge flows is the computation of technological proximity, which reflects the intensity of spillovers between the source and the recipient of innovation.

In the literature, there are different approaches to use patent data on the technological proximity computation. From one hand, we may identify the 'relatedness of technology fields', which can be distinguished into ex ante and ex post approach (Cantwell and Noonan, 2001). As far as the post approach, Teece et al. (1994) and Engelsman and van Raan (1991) argue that technological diversification of firms in several technological classes is not random: according to 'survivor principle', firms which combine relative activities are more likely to survive. In the ex ante approach, the relatedness is measured by the co-occurrence of classifications in patent documents (Breschi et al., 2003; Nesta and Saviotti, 2005).

From on another hand, we may consider the proximity between patent portfolios. In this perspective, the most used measure is the uncentered correlation coefficient, introduced by Jaffe (1986). This procedure rests in the construction of a technological vector for each firm based on the distribution of its patents in a multi-dimensional space and the proximity is the uncentered coefficient between the corresponding technology vectors (Aldieri and Cincera, 2009; Aldieri, 2011 and 2013).

Other procedures to compute proximity are relative to the Euclidean distance (Rosenkopf and Almeida, 2003; Cincera, 2005) and the Min-complement measure developed by Bar and Leiponen (2012).

The aim of this paper is to investigate the integration degree between technology classes of environmental patents. Since Jaffe's proximity assumes flows only occur within the same technology class, Marshall, Arrow, Romer (MAR) or intra-industry or specialized externalities (Marshall, 1890; Arrow, 1962; Romer, 1986; Glaesar, Kallal, Scheinkman and Shleifer, 1992), but rules out spillovers between different classes, Jacobian or inter-industry or diversified externalities (Jacobs, 1969), we use the Mahalanobis index (Bloom et al., 2013 and Aldieri, 2013), based on the frequency that patents are taken out in different classes by the same firm, the co-location (Lychagin et al., 2016).

To compute the Mahalanobis proximity, we have to define some notations (Aldieri, 2013). First, the *(N, C)* matrix $T = [T_1', T_2', \ldots, T_N']$ which contains in each row firms' patent shares in the C technological classes, where C = 8 for water pollution abatement, C = 37 for waste management efficiency and C = 46 for energy production efficiency. Second, we define a normalized *(N, C)* matrix $\widetilde{T} = \left[T_1' / \left(T_1 T_1'\right)^{\frac{1}{2}}, T_2' / \left(T_2 T_2'\right)^{\frac{1}{2}} \ldots T_N' / \left(T_N T_N'\right)^{\frac{1}{2}} \right]$, in which each row is simply normalized by the firm's patent share dot product. Third, we define the *(N, N)* matrix $P = \widetilde{T}\widetilde{T}'$, which is just the standard Jaffe (1986) uncentered correlation coefficient measure between firms *i* and *j*. Fourth, we define a *(C, N)* matrix $\widetilde{X} = \left[T_{(:,1)}' / \left(T_{(:,1)} T_{(:,1)}'\right)^{\frac{1}{2}}, \ldots T_{(:,N)}' / \left(T_{(:,N)} T_{(:,N)}'\right)^{\frac{1}{2}} \right]$ where $T_{(:,i)}$ is the ith column of *T* and C = 8 for water pollution abatement, C = 37 for waste management efficiency and C = 46 for energy production efficiency. Now, we can define the *(C, C)* matrix $\Omega = \widetilde{X}\widetilde{X}'$ in which each element is the standard Jaffe (1986) 0 to 1 uncentered correlation measure between patent classes (rather than between firms). Thus, the Mahalanobis proximity measure is defined as $\widetilde{P} = \widetilde{T}\Omega\widetilde{T}'$.

For example, Table 2.a illustrates the Mahalanobis proximity between technology classes for water pollution abatement for all economic areas, while Tables 2.b, 2.c and 2.d for Europe, Japan and the US respectively.

Table 2.a. Mahalanobis proximity between water environmental goal (all data)

	C02F	E03F	E02B	C09K	C05F	B63J	E03C	E03B
C02F	1.00	0.09	0.05	0.22	0.10	0.12	0.14	0.00
E03F	0.09	1.00	0.20	0.07	0.18	0.16	0.00	0.00
E02B	0.05	0.20	1.00	0.13	0.08	0.07	0.00	0.00
C09K	0.22	0.07	0.13	1.00	0.14	0.03	0.07	0.07
C05F	0.10	0.18	0.08	0.14	1.00	0.00	0.09	0.00
B63J	0.12	0.16	0.07	0.03	0.00	1.00	0.00	0.00
E03C	0.14	0.00	0.00	0.07	0.09	0.00	1.00	0.02
E03B	0.00	0.00	0.00	0.07	0.00	0.00	0.02	1.00

Notes: The highest values of Mahalanobis proximity are highlighted in green, while the lowest values – in red.

Table 2.b. Mahalanobis proximity between water environmental goal (data for Europe)

	C02F	E03F	E02B	C09K	C05F	B63J	E03C	E03B
C02F	1.00	0.11	0.07	0.32	0.08	0.11	0.44	0.00
E03F	0.11	1.00	0.38	0.18	0.44	0.85	0.00	0.00
E02B	0.07	0.38	1.00	0.05	0.05	0.45	0.00	0.00
C09K	0.32	0.18	0.05	1.00	0.42	0.00	0.08	0.19
C05F	0.08	0.44	0.05	0.42	1.00	0.00	0.00	0.00
B63J	0.11	0.85	0.45	0.00	0.00	1.00	0.00	0.00
E03C	0.44	0.00	0.00	0.08	0.00	0.00	1.00	0.00
E03B	0.00	0.00	0.00	0.19	0.00	0.00	0.00	1.00

Table 2.c. Mahalanobis proximity between water environmental goal (data for Japan)

	C02F	E03F	E02B	C09K	C05F	B63J	E03C	E03B
C02F	1.00	0.14	0.01	0.22	0.03	0.20	0.14	0.00
E03F	0.14	1.00	0.00	0.06	0.00	0.00	0.00	0.00
E02B	0.01	0.00	1.00	0.16	0.17	0.00	0.00	0.00
C09K	0.22	0.06	0.16	1.00	0.14	0.00	0.06	0.02
C05F	0.03	0.00	0.17	0.14	1.00	0.00	0.00	0.00
B63J	0.20	0.00	0.00	0.01	0.00	1.00	0.00	0.00
E03C	0.14	0.00	0.00	0.06	0.00	0.00	1.00	0.03
E03B	0.00	0.00	0.00	0.02	0.00	0.00	0.03	1.00

Table 2.d. Mahalanobis proximity between water environmental goal (data for USA)

	C02F	E03F	E02B	C09K	C05F	B63J	E03C	E03B
C02F	1.00	0.00	0.07	0.22	0.32	0.00	0.18	0.00
E03F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E02B	0.07	0.00	1.00	0.20	0.07	0.00	0.00	0.00
C09K	0.22	0.00	0.20	1.00	0.02	0.16	0.13	0.13
C05F	0.32	0.00	0.07	0.02	1.00	0.00	0.61	0.00
B63J	0.00	0.00	0.00	0.16	0.00	1.00	0.00	0.00
E03C	0.18	0.00	0.00	0.13	0.61	0.00	1.00	0.00
E03B	0.00	0.00	0.00	0.13	0.00	0.00	0.00	1.00

5. Statistical analysis

From the previous analysis, we get twelve matrices: three matrices based on Mahalanobis proximity between technology classes for water (8 x 8 = 64 indicators), waste (37 x 37 =1369 indicators) and energy (46 x 46 =2116 indicators) environmental goals for all economic areas; three matrices for each environmental target and for each economic area.

In order to investigate the integration degree between environmental technology classes, we consider the correlation between environmental proximity of each economic area with respect to that relative to all economic areas, which measures the frontier value on average. In this way, we can understand whether there is statistically significant variation in the ecological technological process, able to justify the gap of environmental performance with respect to dirty activities productivity, as discussed in the literature review section.

Table 3. Correlations between environmental proximities

	EUROPE		JAPAN		USA	
WATER	0.88*	[0.82 - 0.93]	0.98*	[0.97 - 0.99]	0.84*	[0.75 - 0.90]
WASTE	0.58*	[0.54 - 0.61]	0.81*	[0.79 - 0.82]	0.92*	[0.91 - 0.92]
ENERGY	0.69*	[0.67 - 0.71]	0.69*	[0.66 - 0.71]	0.86*	[0.85 - 0.87]

Note: * Correlation significant at the 1% . Confidence intervals are indicated in squared brackets

As we may observe from Table 3, American firms compared to frontier values are characterized by high integration between all environmental activities, while European firms are less integrated for waste management efficiency and energy production efficiency and Japanese firms evidence less integration in energy production process. Thus, there is statistically significant variation in correlation between environmental proximities in each economic area and frontier values. This result seems to indicate that the leak of firms' environmental performance in developed countries should be explained also taking into account the integration between ecological activities and not only the integration process between dirty and ecological activities.

6. Conclusions

The aim of this paper is to investigate the role of Jacobian externalities stemmed from different technological sectors for international firms engaged both in environmental and in dirty activities. Literature about innovation framework has paid attention to the complementarity between dirty innovations and environmental ones. The results of these studies lead to the lack of integrated innovation adoption behind environmental productivity performance. In this paper, we focus our attention on the analysis of integration process between only ecological activities. To this end, we identify technological patent classes of three environmental targets for 240 large International firms, located in the USA, Japan and Europe: water pollution abatement, waste management efficiency and energy production efficiency.

Since Jaffe's proximity assumes flows only occur within the same technology class (MAR externalities), but rules out spillovers between different classes (Jacobian externalities), we use the Mahalanobis index, based on the frequency that patents are taken out in different classes by the same firm, the co-location.

In order to investigate the integration degree between environmental technology classes, we consider the correlation between environmental proximity of each economic area with respect to that relative to all economic areas, which measures the frontier value on average. In this way, we can understand whether there is statistically significant variation in the ecological technological process, able to justify the gap of environmental performance with respect to dirty activities productivity. The findings of statistical analysis evidence that American firms compared to frontier values are characterized by high integration between all environmental activities, while European firms are less integrated for waste management efficiency and energy production efficiency and Japanese firms evidence less integration in energy production process. Thus, there is statistically significant variation in correlation between environmental proximities in each economic area and frontier values. This result seems to indicate that the leak of firms' environmental performance in developed countries should be explained also taking into account the integration between ecological activities and not only between dirty and ecological activities.

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References

Acemoglu, D., Aghion, P., Bursztyn, L., & Hemous, D. (2012). The environment and directed technical change. *The American Economic Review*, *102*(1), 131-166.

Aldieri L. (2011). Technological and geographical proximity effects on knowledge spillovers: evidence from the US patent citations. *Economics of Innovation and New Technology*, 20, 597-607.

Aldieri L. (2013). Knowledge technological proximity: evidence from US and European patents. *Economics of Innovation and New Technology*, 22, 807-819.

Aldieri, L. and Cincera, M. (2009). Geographic and technological R&D spillovers within the triad: micro evidence from US patents. *The Journal of Technology Transfer*, 34, 196-211.

Antonioli, D., & Mazzanti, M. (2017). Towards a green economy through innovations: The role of trade union involvement. *Ecological Economics*, *131*, 286-299.

Arrow K. J. (1962). The economic implications of learning by doing. *Review of Economic Studies,* 29, 155-172.

Bar T. and Leiponen A. (2012). A measure of technological distance. *Economics Letters,* 116, 457-459.

Barbieri, N., Ghisetti, C., Gilli, M., Marin, G., & Nicolli, F. (2016). A survey of the literature on environmental innovation based on main path analysis. *Journal of Economic Surveys*, *30*(3), 596-623.

Bloom, N., Schankerman, M., and Van Reenen, J. (2013). Identifying technology spillovers and product market rivalry. *Econometrica*, 81(4), 1347-1393.

Borghesi, S., Cainelli, G., & Mazzanti, M. (2015). Linking emission trading to environmental innovation: evidence from the Italian manufacturing industry. *Research Policy*, *44*(3), 669-683.

Breschi, S., Lissoni, F., and Malerba, F. (2003). Knowledge-relatedness in firm technological diversification. *Research Policy, 32*(1), 69-87.

Brunnermeier, S. B., & Cohen, M. A. (2003). Determinants of environmental innovation in US manufacturing industries. *Journal of environmental economics and management*, *45*(2), 278-293.

Cainelli G., Mazzanti M. and Montresor S. (2012). Environmental innovations, local networks and Internalization. *Industry and Innovation*, 19(8), 697-734.

Cainelli, G., Mazzanti, M., & Zoboli, R. (2013). Environmental performance, manufacturing sectors and firm growth: structural factors and dynamic relationships. *Environmental Economics and Policy Studies*, *15*(4), 367-387.

Cantwell, J., and Noonan, C. (2001, June). Technology relatedness and corporate diversification 1890- 1995. Paper presented at *Nelson Winter Conference, Denmark, 12-15 June* 2001.

Carrión-Flores, C. E., Innes, R., & Sam, A. G. (2013). Do voluntary pollution reduction programs (VPRs) spur or deter environmental innovation? Evidence from 33/50. *Journal of environmental economics and management*, *66*(3), 444-459.

Cincera, M. (2005). Firms' productivity growth and R&D Spillovers: an analysis of alternative echnological proximity measures. *Economics of Innovation and New Technology*, 14(8), 657-682.

Costantini, V., Crespi, F., Marin, G., & Paglialunga, E. (2016). Eco-innovation, sustainable supply chains and environmental performance in European industries. *Journal of Cleaner Production,* doi.org/10.1016/j.jclepro.2016.09.038

Costantini, V., Mazzanti, M., & Montini, A. (2013). Environmental performance, innovation and spillovers. Evidence from a regional NAMEA. *Ecological Economics*, 89, 101-114.

D'Amato, A., Mancinelli, S., & Zoli, M. (2016). Complementarity vs substitutability in waste management behaviors. *Ecological Economics*, *123*, 84-94.

De Marchi V. (2012). Environmental innovation and R&D cooperation: empirical evidence from Spanish manufacturing firms. *Research Policy*, 41(3), 614-623.

del Río González, P. (2009). The empirical analysis of the determinants for environmental technological change: A research agenda. *Ecological Economics*, *68*(3), 861-878.

Engelsman, E. C., & Van Raan, A. F. J. (1991). Mapping of technology. A first exploration of knowledge diffusion amongst fields of technology. Policy Studies on Technology and Economy (BTE) Series, No. 15. The Hague.

European Commission (2013). The 2013 EU Industrial R&D Investment Scoreboard, JRC Scientific and Technical Research series. http://iri.jrc.ec.europa.eu/scoreboard.html;

Ferrara, I., & Missios, P. (2005). Recycling and waste diversion effectiveness: evidence from Canada. *Environmental and Resource Economics*, *30*(2), 221-238.

Fischer, C., & Newell, R. G. (2008). Environmental and technology policies for climate mitigation. *Journal of environmental economics and management*, *55*(2), 142-162.

Fullerton, D., & Kinnaman, T. C. (1996). Household responses to pricing garbage by the bag. *The American Economic Review*, *86*(4), 971-984.

Ghisetti, C., & Quatraro, F. (2013). Beyond inducement in climate change: Does environmental performance spur environmental technologies? A regional analysis of cross-sectoral differences. *Ecological Economics*, *96*, 99-113.

Ghisetti, C., & Quatraro, F. (2017). Green Technologies and Environmental Productivity: A Cross-sectoral Analysis of Direct and Indirect Effects in Italian Regions. *Ecological Economics*, 132, 1-13.

Gilli M., Mancinelli S. and Mazzanti M. (2014). Innovation complementarity and environmental productivity effects: Reality or delusion? Evidence from the EU. *Ecological Economics*, 103, 56-67.

Glaeser S., Kallal H. D. , Scheinkman J. A., Shleifer A. (1992). Growth of cities, *Journal of Political Economy,* 100, 1126-1152.

Hall B., Mairesse J. and Lotti F. (2012). Evidence on the impact of R&D and ICT investment on innovation and productivity in Italian firms. *Economics of Innovation and New Technology*, 22(3), 300-328.

Hong, S. (1999). The effects of unit pricing system upon household solid waste management: The Korean experience. *Journal of Environmental Management*, *57*(1), 1-10.

Hong, S., Adams, R. M., & Love, H. A. (1993). An economic analysis of household recycling of solid wastes: the case of Portland, Oregon. *Journal of environmental economics and management*, *25*(2), 136-146.

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

Horbach, J., Rammer, C., & Rennings, K. (2012). Determinants of eco-innovations by type of environmental impact—The role of regulatory push/pull, technology push and market pull. *Ecological economics*, *78*, 112-122.

Jacobs J. (1969). The economy of cities. Random House, New York.

Jaffe A. B. (1986). Technological opportunity and spillovers of R&D: Evidence from firms' patents, profits and market value. *American Economic Review*, 76, 984–1001.

Kammerer, D. (2009). The effects of customer benefit and regulation on environmental product innovation.: Empirical evidence from appliance manufacturers in Germany. *Ecological Economics*, *68*(8), 2285-2295.

Kemp R. and Pearson P. (2007). Final report on the MEI project measuring eco innovation. UM MERIT, Maastricht.

Kemp R. and Pontoglio S. (2011). The innovation effects of environmental policy instruments-a typical case of the blind men and the elephant? *Ecological Economics*, 72, 28-36.

Kesidou, E., & Demirel, P. (2012). On the drivers of eco-innovations: Empirical evidence from the UK. *Research Policy*, *41*(5), 862-870.

Kinnaman, T. C., & Fullerton, D. (2000). Garbage and recycling with endogenous local policy. *Journal of Urban Economics*, *48*(3), 419-442.

Kipperberg, G. (2007). A comparison of household recycling behaviors in Norway and the United States. *Environmental and Resource Economics*, *36*(2), 215-235.

Lychagin S., Pinkse J., Slade M. E. and Van Reenen J. (2016). Spillovers in Space: Does Geography Matter? *Journal of Industrial Economics,* 10.1111/joie.12103.

Mancinelli S. and Mazzanti M. (2009). Innovation, Networking activities and complementarity. Empirical evidence on SME performances for a local economic system in Northern Italy. *Annals of Regional Science*, 43(3), 567-597.

Marin G. and Lotti F. (2016). Productivity effects of eco-innovations using data on eco-patents. *Industrial and Corporate Change*, doi: 10.193/icc/dtw014.

Marin, G., & Mazzanti, M. (2013). The evolution of environmental and labor productivity dynamics. *Journal of evolutionary economics*, *23*(2), 357-399.

Marin, G., Mazzanti, M., & Montini, A. (2012). Linking NAMEA and Input output for 'consumption vs. production perspective'analyses: Evidence on emission efficiency and aggregation biases using the Italian and Spanish environmental accounts. *Ecological Economics*, 74, 71-84.

Marshall A. (1890). Priciples of economics. Macmillan, London.

Mazzanti, M., & Montini, A. (2010). Embedding the drivers of emission efficiency at regional level—Analyses of NAMEA data. *Ecological Economics*, *69*(12), 2457-2467.

Mazzanti, M., & Zoboli, R. (2009). Environmental efficiency and labour productivity: Trade-off or joint dynamics? A theoretical investigation and empirical evidence from Italy using NAMEA. *Ecological Economics*, 68(4), 1182-1194.

Mazzanti, M., & Zoboli, R. (2009). Environmental efficiency and labour productivity: Trade-off or joint dynamics? A theoretical investigation and empirical evidence from Italy using NAMEA. *Ecological Economics*, *68*(4), 1182-1194.

Mazzanti, M., Antonioli, D., Ghisetti, C., & Nicolli, F. (2016). Firm Surveys relating Environmental Policies, Environmental Performance and Innovation. *Technical Report, OECD.*

Mazzanti, M., Montini, A., & Zoboli, R. (2008). Economic dynamics, Emission trends and the EKC hypothesis. New evidence using NAMEA data for Italy. *Economic system research*, *20*(3), 279-305.

Mohnen P. and Roller L. H. (2005). Complementarities in innovation policy. *European Economic Review*, 49, 1431-1450.

Nesta, L., and Saviotti, P. (2005). Coherence of the Knowledge Base and the Firm's Innovative Performance: Evidence from the US Pharmaceutical Industry. *Journal of Industrial Economics*, 53(1), 123-142.

Nesta, L., Vona, F., & Nicolli, F. (2014). Environmental policies, competition and innovation in renewable energy. *Journal of Environmental Economics and Management*, *67*(3), 396-411.

OECD, REGPAT database, February 2016.

Popp, D. (2002). Induced innovation and energy prices. *The American Economic Review*, 92(1), 160-180.

Popp, D. (2006). International innovation and diffusion of air pollution control technologies: the effects of NOX and SO 2 regulation in the US, Japan, and Germany. *Journal of Environmental Economics and Management*, 51(1), 46-71.

Popp, D. (2010). Exploring links between innovation and diffusion: adoption of NOx control technologies at US coal-fired power plants. *Environmental and Resource Economics*, *45*(3), 319-352.

Popp, D., Newell, R.G., Jaffe, A.B., 2009. Energy, the Environment, and Technological Change (*No. w14832). National Bureau of Economic Research.*

Porter, M. E., & Van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *The journal of economic perspectives*, *9*(4), 97-118.

Quatraro, F. (2010). Knowledge coherence, variety and economic growth: Manufacturing evidence from Italian regions. *Research Policy*, 39(10), 1289-1302.

Rehfeld, K. M., Rennings, K., & Ziegler, A. (2007). Integrated product policy and environmental product innovations: An empirical analysis. *Ecological economics*, *61*(1), 91-100.

Reinhardt, F. L. (1998). Environmental product differentiation: Implications for corporate strategy. *California management review*, *40*(4), 43-73.

Romer P. M. (1986). Increasing returns and long-run growth, *Journal of Political Economy,* 94, 1002-1037.

Rosenkopf, L. and Almeida, P. (2003). Overcoming local search through alliances and mobility. *Management Science,* 49(6), 751-766.

Teece, D. J., Rumelt, R., Dosi, G. and Winter, S. (1994). Understanding corporate coherence: Theory and evidence. *Journal of Economic Behavior & Organization*, 23(1), 1-30.

Triguero, A., Moreno-Mondéjar, L., & Davia, M. A. (2013). Drivers of different types of eco-innovation in European SMEs. *Ecological economics*, *92*, 25-33.

Veugelers, R. (2012). Which policy instruments to induce clean innovating?. *Research Policy*, *41*(10), 1770-1778.

Wagner, M. (2007). The link between environmental innovation, patents, and environmental management. *DRUID (Copenhagen Business School), Denmark*.

Appendix

TableA.1. Summary of recent studies on spillovers of environmental innovations and green technologies.

Basic paper description	Model used and key results
2017, Ghisetti and Quatraro. Panel of Italian regions for 2002–2005	**Models:** National Accounting Matrix with Environmental Accounts; hybrid environmental-economic accounting matrix; Spatial Durbin Model **Results** (cited from pp. 6 – 8). **1.** Improvements in EP (environmental productibity) are driven by EIs (Environmental innovations) generated in vertically related sectors. **2.** An increase of EI engenders an increase of EP, i.e. either an increase of value added or a decrease of emissions or both. **3.** impact of GT on EP, both direct and moderated by vertical linkages, is positive and robust for all the classes of emissions considered, both those having a global effect (CO2 and GHG) and those with a more localized effect (NOx and AC). **4.** EI's effects on EP pass also through the user-producer dynamics. **5.** EPs in one region do not affect the EPs of its neighbors, as what they actually influence is the environment 'at large'.
2017, Antoniolia, Mazzanti. 555 Italian manufacturing firms in the Emilia-Romagna region, 2006 – 2008	Models: A multidimensional questionnaire that investigates several dimensions of firm innovation activity; environmental innovation function. Results: (as cited by pp. 293 – 296). **1.** Sector relatedness matters: being a firm in a sector subject to the ETS (a polluting sector) increases the probability of adopting energy-saving EIs (environmantal inovations). in addition, heavy manufacturing sectors are often subject to more stringent policies and may tend to innovate more rate of diffusion of EIs within the same municipality influence the probability of adoption for any type of EI. **2.** The adoptions of more complex organisational and technological innovations (EMASISO, CO2) are the cases where both information and bargaining matter. **3.** When the costs for EIs are higher, intermediate solutions (e.g. unions consultation) do not provide sufficient benefits the weakest role of unions-management interactions in terms of statistical significance (10% significance level both for union information and bargaining) is found for emission reducing technologies, where simpler technological (e.g. end of pipe) solutions predominate.
2016, D'Amato, Mancinelli, Zoli. 2,009 observations of Survey of Public Attitudes and Behaviors toward the Environment, England, 2009.	**Methods:** Survey of Public Attitudes and Behaviors toward the Environment; Structural equation modeling results. **Results** (as cited from pp. 91 – 92). **1.** Even though recycling policies act as a stimulus for individual recycling behaviors and indirectly (as far as the complementarity relation is confirmed) for reduction choices, results about total effects reveal that their impact on individual waste reduction is quite low, however much less than the effect environmental values have on reduction behavior itself. **2.** Investing in environmental education and increasing pro-environmental attitudes of individuals may be an effective instrument to stimulate waste reduction. **3.** Individuals in older age groups appear to recycle more, whilst age is not significant in explaining reduction actions; the higher recycling effort of elderly people is generally explained by considering that in several cases they are retired and therefore tend to have more time to sort products out for recycling or re-use. **4.** More educated people appear to reduce more waste, whilst both the presence of children and the number of people in the household are insignificant on waste behaviors.
2016, Costantini, Crespi, Marin, Paglialunga. 14 manufacturing sectors in 27 EU countries, 1995 - 2007	**Model** Log-liner panel regressions **Results** (as cited from pp. 24 – 25). **1.** Eco-innovation is an effective way of favouring the transition to a low-carbon sustainable economy. **2.** Eco-innovations seem to be capable of directly reducing the environmental impact of production in the sectors where they originate, but also of positively shaping the environmental performance of other sectors via market transactions. **3.** Green technologies developed in upstream sectors both at the national and international level help to foster environmental performance, whatever GHG emissions type is considered. **4.** Corporate governance mechanisms that positively manage inter-firm collaborations in the form of user-producer interactions in the green innovation value chain have great potential for exploiting the environmental benefits of green technologies. **5.** International linkages turned out to be an important source of environmental gains, specific capabilities are needed for the design and effective implementation of governance mechanisms that manage the increasing complexity of suppliers' involvement in sustainable production. **6.** Inducing eco-innovation activities in industrial sectors via public policies specifically oriented towards environmental (and climate) protection turns out to be an effective way of improving environmental performance at the sector level. specific attention should be paid to including sustainable value chains considerations in the design of a policy mix.
2014, Mancinelli, Mazzanti. 27 EU countries, 2006 – 2010, sectoral-level data	**Model**: cross section framed regression **Results** (as cited from pp. 64 – 65). **1.** Complementarity is not characterizing. **2.** The EU economy as a whole for what concerns the 'use' of EI as a driver of environmental productivity in the carbon dioxide realm. **3.** Investing in EI and other techno-organizational practices has not led to environmental productivity improvements. Evidence does change when narrowing down on manufacturing sectors that are heavier and subject to stricter regulations

Basic paper description	Model used and key results
	compared to the services side. Innovation investments exert effects over a medium-long term dynamics. **4.** The adoption of integrated innovations before the 2008–2009 downturn has supported environmental productivity within and after the peak of the crisis. EU case study also shows risks of further divergence in both economic and environmental performances between innovative northern countries and southern EU laggards. **5.** The new re-manufacturing goals in the EU policy agenda interestingly interconnects our evidence with sustainability and competitiveness targets. The more innovative capacity of-manufacturing relatively to services is highlight by our analysis. **6.** The innovation capacity of manufacturing is crucial to enhance the EU climate change performances in addition to competitiveness. **7.** Mild decrease in GHG emissions the EU has experienced hugely depends upon incremental innovations, which are in addition not integrated among them in a significant goal-oriented way. **8.** The lack of integration documents the non-radicalness of the innovation strategy that economic sectors have pursued so far, at least on average
2013, Costantini, Mazzanti, Anna Montini. 20 Italian regions, 24 sectors of economy in each, 2005	**Models**: National Accounting Matrix with Environmental Accounts; environmental Kuznets curve (EKC) and the Impact-Population-Affluence-Technology (IPAT); Spatial Simultaneous Model. **Results** (as cited from pp. 110-112). **1.** Achievement of positive environmental performance at national level could strongly depend on differences in local capabilities and conditions and on consequential environmentally and technologically related spillovers. **2.** The Italian North–south divide, considering both the industry specialization and the efficiency components, affects regional EP (Environmental Performance). **3.** For GHG in particular, environmental spillovers play a significant role in explaining region and sector specific EP. **4.** technological and environmental spillovers are highly relevant. For GHG in particular, environmental spillovers play a significant role in explaining region and sector specific EP. This result may be interpreted as evidence of the existence of clusters that are not only intended as an agglomeration of specific sectors into restricted areas, but also as the existence of a geographically driven common technology pattern. **5.** The aggregation process of specific polluting sectors into selected geographical areas may be associated with common choices in the adoption of cleaner or dirtier technologies, evidence which helps us to explain why the same sector specialization into different regions may be characterized by different emission intensities or efficiency as we found in the descriptive analysis too. **6.** Technological interregional spillovers seem to play a more effective role in improving environmental efficiency than internal innovation, with an increasing effect for more localized pollutants. In this case, the greater overlapping of polluters and agents perceiving environmental damage for more localized emissions also allows explaining the stronger effectiveness of environmental regulation at regional level in fostering environmental efficiency gains.
2012, Marin, Mazzanti, Montini. Spain and Italy in 1995, 2000, 2005, disaggregation of 60 sectors.	**Models:** National Accounting Matrix including Environmental Accounts (NAMEA); Environmental Extended-Input Output Analysis — EEIOA **Results** (as cited from pp. 77 – 82). **1.** A weak reduction in environmental pressures caused by industrial activities from 1995 to 2005 appears; efficiency improvements in production processes and product design could be present but a composition effect cannot be excluded. the amount of emissions embodied in imports is greater than the amount of emissions embodied in export (i.e. the country is a net exporter of emissions). **2.** Unlike the Italian case, aggregation does not alter the status of Spain as net exporter of emissions for the full set of emissions and Years special attention must be paid when interpreting the EE-IOA of country estimated amounts of embodied emissions, both in domestic final demand and those directly associated with the production sectors when the sectoral aggregation level has a low definition as considered in some recent similar studies.
2010, Quatraro. Manufacturing sector in Italian regions in 1981–2002	**Models:** Cobb-Douglas production function for regional economy; index of multifactor productivity; spatial dependence; regional knowledge indicators model. **Results** (as cited from pp. 1296 - 1297). **1.** Cross regional differences in the accumulation of knowledge capital stock matter in explaining productivity differentials, as is shown by the positive and significant coefficient on the regional total expertise. **2.** More related are the diverse technological activities carried out within the region, the higher the rates of productivity growth. **3.** The effects of variety are statistically significant in none of the models, while knowledge capital and knowledge coherence confirm to positively and significantly affect regional productivity growth. **4.** Both agglomeration and the relative location quotient show negative and significant coefficients, supporting the relevance of the idiosyncratic features of regional development paths in Italy. **5.** The coefficient for spatial autocorrelation is positive and significant across all the models, corroborating the argument of cross-regional transmission of productivity gains.
2010, Mazzanti, Montini. Italy and the Lazio region	**Models**: Structural Decomposition Analysis, Environmental Accounts and Regional NAMEA. **Results** (as cited from pp 2465 – 2466). **1.** For all emissions included in NAMEA the shift share investigation indicates that the Lazio region, where Rome is located, is comparatively more environmentally efficient than the national average. this difference is lower energy consumption per capita and lower en-

Basic paper description	Model used and key results
	ergy intensity (electrical energy) on GDP, compared to the national averages. energy and electrical energy intensity in Lazio's manufacturing sector is the lowest in Italy. **2.** Income–environment relationship as related to labour productivity are presenting non linear U-shapes. R&D is always very significant in driving down emission per unit of value across all emissions, both through separate effects of private and public R&D and by joint effects. **3.** Innovation seems to matter more than regional expenditures targeted on environmental externalities, and finally the role of public/private complementary innovation forces in enhancing efficiency is highlighted.
2009, Mazzanti, Zoboli. Italy, 29 sector branches, 1991–2001	**Methods**: NAMEA (National Accounting Matrix with Environmental Accounts) sector-level time series panel dataset. **Results** (as cited from pp. 1193): 1. There is a positive relationship between 'labour productivity' and 'environmental productivity' (emissions efficiency) in the Italian experience. This macro-aggregate evidence is driven by sector dynamics in a non-homogenous way, across pollutants. If services tend to show always a 'complementary relationships between efficiency of emissions and labour productivity, industry is to some extent characterised by inverted U-shaped dynamics for GHG and NOx. 2. The prevailing technological dynamics is one in which the intensification of capital in the Italian economy has led, ex post, both to increasing value added per employee and to reducing air emissions per value added, which corresponds to the descending part of an EKC in these two variables, or to an EKC pattern in which a jointly increasing productivity has substituted for a trade-off between value added and environmental efficiency.