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Environmental Performance, Innovation and Regional Spillovers

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Abstract

The achievement of positive Environmental Performance (EP) at national level could strongly depend on differences in regional features, namely economic specialization, regulation stringency and innovation capabilities of both public institutions and the private business sector. We apply both shift-share and econometric analysis on a new NAMEA available for the 20 Italian Regions, in order to provide evidence of the role played by sector innovation, technological spillovers and regional policies in shaping the geographical distribution of EP. The Italian North-South divide regarding industrial development and productive specialisation patterns seems to affect regional EP. Nonetheless, such pattern presents some interesting differences, revealing a more heterogeneous distribution of emissions, which may reflect the role of other driving forces. In particular, agglomerative effects seem to prevail over purely internal factors - environmental efficiency of neighbouring regions strongly influence the internal EP. This means that together with the clustering of specific sectors into restricted areas as a standard result in regional economics, there is also some convergence in the adoption of cleaner or dirtier production process techniques. Finally, regional technological spillovers seem to play a more effective role in improving environmental efficiency than 'sector internal innovation', revealing that accounting for spatial features is crucial to understand the key drivers of EP.

J.E.L. codes: Q53; Q55; Q56; R15

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1. INTRODUCTION

This paper investigates the economic drivers which might influence the geographical distribution of EP (EP herafter) by using a new and innovative hybrid environmental-economic accounting matrix applied to the Italian regions, based on the NAMEA approach (National Accounting Matrix including Environmental Accounts).[1] The regionalisation of the data generation is a relatively new framework[2]. The great advantage is that it adds the geographical dimension to the already existing sectoral one, allowing to disentangle the structural and efficiency factors behind a regional EP.

A well consolidated literature recognizes that productivity dynamics is the core economic driver explaining EP (Marin and Mazzanti, 2011), relying on the so-called environmental Kuznets curves (EKC) and IPAT realms, where an inverted U-shaped curve may theoretically represent links between economic development and EP (Andreoni and Levinson, 2001). Explanations for the existence of an inverted U-shaped path have been considered both on the demand and the supply side (Munasinghe, 1995; for a survey on EKC see Costantini and Martini (2010) and Dinda, 2004). Since our interest is mainly on the supply side, in their seminal contribution Grossman and Krueger (1995) have indicated three different channels through which economic growth affects the quality of environment. The scale effect explains why growing economic activity leads, *ceteris paribus*, to increased environmental damage. The composition effect relies on structural changes of economic systems (Sirquin, 2010), namely shifts from a heavy manufactured system to a service-oriented economy. The technological effect argues that

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[1] As a background, the first NAMEA was developed by the Dutch Central Bureau of Statistics (De Boo *et al.*, 1993), and earlier contributions such as Ike (1999), Keuning *et al.* (1999), Steenge (1999), and Vaze (1999) provided empirical analyses related to the possible policy implications deriving from sector-specific EP. A new collection of works is Costantini et al. (2011) In the NAMEA tables, environmental pressures, in particular air emissions, and economic data (value added, final consumption expenditures and full-time equivalent job) are assigned to the economic branches of resident units directly responsible for environmental and economic phenomena.

[2] For an overview of recent developments in regional NAMEA projects in the EU, see Goralzcyck and Stauvermann (2008) and Stauvermann (2007). A recent publication coming out the EU RAMEA project (http://www.arpa.emr.it/ramea) that covered some EU regions of Italy, UK, Netherlands, Poland is Sansoni *et al.* (2010).

economic sectors may adopt less polluting technologies, either because of market-driven technological progress or government regulation, as emphasized by Cole *et al.* (2005). As recently addressed by Mazzanti and Zoboli (2009), regarding the scale effect, if labour productivity is under investigation, we may observe that - for a given technical emission efficiency - productivity gains will reduce the emissions per unit of value added, thus improving EP. This result may be well explained if we consider that labour productivity gains go hand in hand with increasing capital intensity, which often corresponds also to energy efficiency gains (Gruebler *et al.* 1999). This last point in strictly related to the role of innovation in the production process, since capital investments may be essential for reaching higher technology paths and resource efficiency, giving to technological innovation a leading role in explaining the de-linking between EP and growth (Mazzanti and Zoboli, 2009).

While an increasing number of empirical analyses emphasized the potential role of a sector-based investigation in describing the environmental efficiency patterns of distinguished economic sectors (De Haan, 2004; De Haan and Keuning, 1996; Mazzanti and Montini, 2010a,b; Mazzanti *et al.*, 2008), most of the analyses lack an explicit consideration of how the technological and composition effects are embedded in regional/geographical contexts.

To the best of our knowledge there are no attempts to investigate which kind of innovation prevails in shaping the sector delinking process. To this purpose, we argue that internal innovation partially explains environmental efficiency gains, while the role of knowledge spillovers may help discovering if the technology diffusion process will improve EP as well as economic growth. As emphasized by Gibbs (2006), regional analyses based on economic and environmental accounts may contribute to establishing fruitful research grounds along environmental issues that remain comparatively under researched, providing normative prescriptions for a properly designed environmental policy in a context of geographical and economic heterogeneity.

In this sense, recent efforts in the economic geography literature will give us useful analytical tools for shaping the role of innovation and spillovers at regional level. In particular, we refer to the rich literature debating on the impact of different kinds of agglomeration economies on technological innovation patterns and economic development at the regional level. More specifically, we aim at studying if the well-known existing agglomeration effects in economic terms for the Italian regions (Brioschi et al., 2002; Cefis et al., 2009; Cainelli et al., 2006, 2007) may also explain, in addition to well known innovation and performance effects, the geographical distribution of EP. If a clustering process occurs and environmental-friendly or "hot spot" areas emerge, we argue that some forms of spillovers between regions and sectors may help us explaining EP better than using only the traditional driving forces early proposed by environmental economics literature.

This specific assumption could be taken in a sector-based analysis when regional features are also accounted for. Since Italian manufacturing sectors are historically characterized by clusters and agglomerative economies (Cefis et al., 2009), the role of the centripetal and centrifugal forces are assumed to be crucial also for explaining EP.

The original contribution of this paper is to explore how environmental efficiency is distributed among regions and sectors in the Italian context, trying to discover if some agglomerative effects occur and if they correspond to a regional or sectoral criterion. When the geographical distribution of EP is characterized by a clustering effect, what driving factors are influencing such agglomerative phenomena is also relevant. We examine such factors by placing a particular emphasis on the role of geographical spillovers.

The paper is structured as follows. Section 2 presents the models of empirical applications, the shift-share methodology and the econometric strategy. Section 3 presents the dataset and how we specify innovation and environmental spillovers. Section 4 presents the empirical findings based on the shift-share analysis that disentangle structural and efficiency factors. Section 5 presents the results from the econometric estimations on regional environmental efficiency drivers. Section 6 concludes the paper.

2. MODELLING EP

This section provides a conceptual background for the empirical analyses. We first adopt a decomposition approach, represented by the shift-share analysis, in order to catch if a region-based or a sector-based criterion prevails in the allocation of different EP, followed by a consequential spatial econometric estimation. These two analytical tools pursue different but complementary aims. The former gives a preliminary sketch of regional EP features where sector-based clustering effects seem to exist independently from geographical patterns, the latter allows to quantify to which extent sectoral and regional features influence emissions efficiency.

2.1 THE SHIFT-SHARE ANALYSIS

Shift-share analysis (Esteban, 1972, 2000) is first used to decompose the source of change of the specified dependent variable into regional specific components (the *shift*) and the portion that follows national growth trends (the *share*).

Our starting point is the aggregate indicator of emission intensity, represented by total emissions of a particular pollutant on value added, defined as (E/Y) for Italy as the benchmark, and as (E^r/Y^r) for the analysed *r-th* region. This indicator is calculated by the sum of $(E_k/Y_k)*(Y_k/Y)$ - with k defined from 1 to n (n = 24 NACE sectors included in the regional NAMEA) - where (Y_k/Y) is the share of sectoral value added on total value added, for the *k-th* sector,.[3]

Let us define, for simplicity, the index of emission intensity for the national average as $X = (E/Y)$, and as $X^r = (E^r/Y^r)$ for the *r-th* region where r = 1,…, q (q = 20 Italian regions), and as $X_k = (E_k/Y_k)$ for each *k-th* sector resulting in $X_k^r = (E_k^r/Y_k^r)$and in $X_k = (E_k/Y_k)$ respectively for each region and Italy. We then define the share of value added for each sector as $P_k = (Y_k/Y)$ for Italy, and $P_k^r = (Y_k^r/Y^r)$ for the *r-th* region. On this basis, we can easily identify three effects, as prescribed by the shift-share decomposition approach and thus, for each pollutant, the difference between the regional emission intensity and the national average (X^r-X) is equal to the sum of the three effects $m^r + p^r + a^r$ explained as follows.

The first effect related to the structure or the industry mix (m^r), is given by:

[3] See Table A1 in the Appendix for the list of sectors and NACE codes considered.

$$m^r = \sum_{k=1}^{n} (P_k^r - P_k) X_k \qquad [1]$$

where m^r assumes a positive (negative) value if the region is specialised ($P_k^r - P_k > 0$) in sectors associated with lower (higher) environmental efficiency, given that the gap in sector-specific value added shares is multiplied by the value X_k of the national average (as if the region were characterised by average national efficiency). The factor m^r assumes lower values if the *r-th* region is specialised in (on average) more efficient sectors.

The second factor represents the differential or efficiency feature (p^r), and is given by:

$$p^r = \sum_{k=1}^{n} P_k (X_k^r - X_k) \qquad [2]$$

where p^r assumes a positive (negative) value if the region is less (more) efficient in terms of emissions (the *shift* between regional and national efficiency) based on the assumption that sector-specific value added shares were the same for the region and for Italy ($P_k^r - P_k = 0$).

Finally, the covariance effect (a^r) is:

$$a^r = \sum_{k=1}^{n} (X_k^r - X_k)(P_k^r - P_k) \qquad [3]$$

The a^r factor assumes a minimum value if the region is specialised in sectors where it presents the highest 'comparative advantage' (low intensity of emissions) and the covariance factor is then between m^r and p^r.

2.2 MODELLING DRIVING FACTORS AND SPILLOVERS EFFECTS

Let us consider environmental pressure here expressed through pollutant emissions for each *k-th* sector in each *r-th* region (E_k^r) as a function of production level (Y_k^r), technology (T_k^r), and environmental policy (Pol_k^r) as suggested by Cole *et al.* (2005). Emissions is expressed as the following general function:

$$E_k^r = f\left(Y_k^r, T_k^r, Pol_k^r\right) \qquad [4]$$

As suggested in Medlock and Soligo (2001), emission level may be expressed as a non-constant income elasticity function in the form of:

$$E_k^r = A_k^r Y_k^{r\left(\delta + \gamma \ln Y_k^r\right)} T_k^{r\phi} Pol_k^{r\lambda} \qquad [5]$$

and the logarithmic transformation of equation [5] takes the form of:

$$\ln E_k^r = a_k^r + \delta \ln Y_k^r + \gamma \left(\ln Y_k^r\right)^2 + \phi \ln T_k^r + \lambda \ln Pol_k^r + \varepsilon_k^r \qquad [6]$$

where a_k^r assumes the role of technology-specific fixed effects and ε_k^r is the error term. Equation [6] conceptually links to EKC form, assuming that δ should be positive and γ negative. Since we are interested in an evaluation of the EP of our sector expressed as a measure of emission intensity, we transform equation [5] by scaling it with region/sector specific value added, thus obtaining the following reduced form:

$$e_k^r = \alpha_k^r + \beta_1 \ln Y_k^r + \beta_2 t_k^r + \beta_3 pol_k^r + \varepsilon_k^r \qquad [7]$$

where the lower case letters indicate the value of each variable in terms of region/sector specific value added. From eq. [6] $\beta_1 = \gamma$, and recalling that in a EKC framework γ is negative, consequently β_1

assumes negative values. Regarding the technology-specific fixed effects (α_k^r), we disentangle it into two components, where both region and sector-specific effects may be included. In addition, Mazzanti and Zoboli (2009) state that when technology is included in an environmental efficiency function, it is interesting to disentangle the effects related to strict technological innovation from the effects of labour productivity gains, thus replacing the term $\ln Y_k^r$ in eq. [7] with a properly defined labour productivity measure. In this case, we assume that, *ceteris paribus*, when a productive sector presents higher labour productivity, its EP will increase, thus a negative sign for the β_1 coefficient should come out. This assumption may be plausible if one considers some factors recently addressed as mainly responsible for relatively higher labour productivity gains in selected industrialized countries, namely corporate social responsibility behaviours by more innovative firms and the impure public good nature of environmental innovations, which may mitigate market failures inducing a combination of productivity and environmental efficiency gains (Horbach, 2008; Rubbelke, 2003; Ziegler and Nogareda, 2009).

Turning to the effect related to technology, in a standard emission demand model it is represented by the state of technology in the production function where the more innovative firms are those which usually adopt more resource saving and/or less polluting technologies. Hence, the sign of the β_2 coefficient is also expected to be negative where the higher the efforts in technological innovation, the lower the emission intensity.

Since recent regional economic growth models have increasingly appreciated the role of technological learning and knowledge spillovers, the role of technological spillovers as potential drivers of EP should be also investigated. For instance, as emphasized by Gray and Shadbegian (2007), there is some positive correlation between the effect of extra regional environmental regulation and regional EP. Nonetheless, to the best of our knowledge, there has been no attempt at empirical level to assess the role of regional innovation spillovers in explaining EP. To this end, Kyriakopoulou and Xepapadeas (2009) find that environmental policy acts as a centrifugal force since increasing compliance costs reduce the advantage of localizing industrial activities in that region whereas knowledge externalities have a centripetal force fostering agglomeration patterns. They affirm that environmental regulation and knowledge spillovers may act as countervailing forces where knowledge spillovers occur where firms may exploit agglomeration economies whereas environmental policy reduces this clustering of economic activity.

These general findings may only be plausible if we disentangle these potential countervailing effects at sectoral level while considering specific structural features both at geographical and productive level. Since environmental regulation will increase compliance costs for polluting activities only, it may be the case that a stringent regulatory framework also acts as a centripetal force, indirectly fostering an agglomeration pattern of cleaner productions via the inducement effect (Popp, 2002, 2005).[4] We interpret regional regulatory setting as one of the geographical knowledge attractors, combined with standard innovation factors as dominant design and knowledge platforms (Antonelli and Colombelli, 2010).

Therefore, regulation and technological innovation strategies may act coherently to generate an agglomeration effect of high-tech less-polluting activities. On this basis, we expect a positive effect on EP related to stringent environmental policies (pol_k^r), or, in other words, in this case the β_3 coefficient is also expected to be negative where the more stringent the regulatory framework is at regional level, the lower the emission intensity is at sectoral level.

Finally, according to Maddison (2006) when emissions also come 'from abroad' (acid rain precursors as SOx) the existence of spatial correlation problems is to be recognised and tackled. Other than providing only a statistical spatial correlation, the emissions produced by sectors located in the

[4] Induced innovation effects have been strongly linked to the origin and development of the Porter hypothesis (Porter and van der Linde, 1995), claiming that it is not automatic that environmental regulations would be likely to reduce the competitiveness of the sectors involved and increase firm production costs. Environmental regulation enhances economic performance, at least in the medium run through induced innovation (Jaffe and Palmer, 1997), as the net effect on economic performance may turn out to be positive with regard to innovation offsets. There is also increasing consensus on the potential win-win effects deriving from well combined environmental and innovation strategies (Jaffe *et al.*, 2005). In this respect, the use of an appropriate mix of innovation and environmental policies emerges as a crucial factor in directing economic systems towards sustainable economic growth (van den Berg *et al.*, 2007).

neighbouring regions capture the role of agglomeration phenomena and are explaining EP in a different way from what environmental regulation does. A specific variable representing environmental spillovers from other regions should therefore be included in eq. [7]. Hence, considering both environmental and innovation spillovers, eq. [7] is transformed as follows:

$$e_k^r = \alpha_k^r + \underset{-}{\beta_1} lp_k^r + \underset{+}{\beta_2} es_k^r + \underset{-}{\beta_3} t_k^r + \underset{-}{\beta_4} ts_k^r + \underset{-}{\beta_5} pol_k^r + \varepsilon_k^r \qquad [8]$$

where lp_k^r is labour productivity, while es_k^r and ts_k^r represent the effects of environmental and innovation spillovers coming from the other Italian regions, empirically modelled as described below. We expect a positive sign for the β_2 coefficient, that depends upon the existence of agglomerative forces producing concentration of dirty activities into circumscribed geographical areas. We do expect β_4 to be also negative, coherently with the role played by internal innovation (β_3), since we assume that the existence and diffusion of technologies from other regions will increase the probability that a more environmental-friendly production technique is available.

3. THE EMPIRICAL DESIGN OF ENVIRONMENTAL AND INNOVATION SPILLOVERS

The core part of the dataset is based on the 2005 Italian regional NAMEA, to our knowledge the only full regionalised NAMEA available in the EU for a country. Environmental pressures and economic data (value added, households' consumption expenditures and full-time equivalent job) are assigned to the economic branches of resident units. The accounting approach allows a full dataset to be shaped with information on environmental and economic aspects. Our dataset is organised as a $(q \times n) \times 1$ vector where n is the total number of k sectors ($\forall k = 1,...,n$, with n = 24) and q is the number of r regions ($\forall r = 1,...,q$, with q = 20), with a potential number of observations equal to 480.

Differently from the shift-share analysis, where we considered specific pollutant emissions in order to have a clear picture of the distribution at sectoral level of emission intensity among regions, when testing drivers of EP as expressed by eq. [8], we adopt the environmental aggregation (provided by

NAMEA), by which specific pollutants are summed up as greenhouse gases (GHG)[5] and pollutants responsible for acidification process (ACID)[6]. This choice enables us to make further considerations on potential different impacts of the same drivers associated with environmental damage with a different geographical distribution, since the effects of GHG are global, whereas ACID emissions are more localised and trans-boundary effects may be confined to neighbouring regions.

In order to represent the two dimensions of technological innovation, the internal variable (t_k^r) and the inter-regional intra-sector spillover effect (ts_k^r) respectively, we considered a patent count approach due to more aggregated data available for regional R&D expenditures at the sectoral level. Some drawbacks characterise patents as a valid alternative to R&D data as an economic indicator, but previous studies at regional level have highlighted the helpfulness of patent applications as a measure of production of innovation (Acs *et al.*, 2002).

Patent data are drawn from the REGPAT dataset elaborated by Eurostat from the OECD PATSTAT database, gathering all patents for each region according to the 3 digit IPC classification granted by the European Patent Office (EPO), geographically classified relying on postal codes of the applicants. The number of patent classes at the 3 digit level is 633, and we considered all patent applications to the EPO by priority year at regional level[7].

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[5] To calculate the total GHG emissions, the CO_2, CH_4 and N_2O emissions are converted in tonnes of CO_2 equivalent, by multiplying each gaseous emission for the corresponding Global Warming Potential (GWP).

[6] To aggregate the different pollutant emissions (NO_X, SO_X and NH_3) that contributes to the acidifying phenomenon, the specific Potential Acid Equivalent (PAE) corresponding to each one is considered.

[7] We have adopted an *ad hoc* sector classification in order to assign patents (as classified by IPC codes) to specific sectors (as classified by NACE codes) relying on previous concordance proposals such as the OECD Technology Concordance and the methodology developed by Schmoch *et al.* (2003), resulting in 13 available sectors (see Table A2 in the Appendix). As a result of the high variance of patenting activity over time, we have considered patents in the time span 2000-2004 in order to calculate a five-years average value as the best proxy of innovation stock at sectoral level with one time lag in respect with emissions data (Antonelli *et al.*, 2010).

The potential positive influence of innovating activities on EP arises with temporal lags since the adoption of new technologies is not perfectly simultaneous with the invention itself. When considering the impact of innovation on EP as a side effect of innovative capacity at sectoral level, one year lag seems to be the most appropriate choice. Bearing in mind that eq. [8] expresses all terms scaled by value added, we computed patents to value added ratios in order to account for 'Innovation intensity'.

In order to include the potential role of interregional spillovers, we first consider that the probability of innovation to spill from one region to another strictly depends on the fact that localisation economies are associated with the concentration of a particular sector in the two regions. Hence, it is not only a matter of geographical distance which explains the existence and the strength of innovation spillovers, but also cognitive proximity, since knowledge will diffuse more likely when competences and knowledge stocks of the inventors and adopters are closely related.

Following empirical findings by Costa and Iezzi (2004) on technological spillovers among the Italian regions, we considered only Marshall type externalities, as innovation spillovers mainly derive from firms belonging to the same industry, while Jacob type externalities among sectors are rather smaller. To some sense, cognitive proximity and technological relatedness as well-known drivers for effective learning (Boschma and Frenken, 2009; Boschma and Iammarino, 2009, among the others) are here considered as factors influencing the adoption of similar production process techniques without any implication in terms of regional economic growth. When related variety is included, also Jacob type externalities play some role in enhancing economic performance. We acknowledge that it is a consolidated result that the economy's composition at the regional level will also affect economic growth (Frenken *et al.*, 2007) but there is much more controversies in interpreting such influence over EPs.

In this specific context Marshall type externalities prevail since clustering effects of technology related sectors prevail, as manufacturing sectors are here broadly defined where Jacob type externalities may not be a plausible driver for spillovers. Nonetheless, this last point could be the next research step, especially when a panel version of the Italian regional NAMEA will be available, allowing for considering dynamic issues.

Los (2000) and Frenken *et al.* (2007) propose an index that captures the technological relatedness between industrial sectors, by computing the similarity between two sectors' input mix from input-output tables that we adapt to our case study if we consider that the two sectors are homogeneous from a classification point of view, but they may be rather different since they belong to two different regions.

Since data availability on input-output information at sector level is limited, an alternative solution is to form a similarity matrix based on technological specialisation indicators (Van Stel and Nieuwenhuijsen, 2004).

The relative specialization index (RSI) here adopted is as follows:

$$RSI_k^r = \frac{t_k^r}{\sum_{k=1}^{n} t_k^r} \Bigg/ \frac{t_k^{IT}}{\sum_{k=1}^{n} t_k^{IT}} \qquad [9]$$

where t_k^r is the five-years average of patents to value added ratios for each *k-th* sector and *r-th* region whereas t_{ITk} is the same measure at national level, as $t_{ITk} = \sum_{r=1}^{q} t_k^r$.

The bilateral innovation spillovers (ts_k^{rs}) for each *k-th* sector from the *s-th* region to the *r-th* region un-weighted by the geographical distance are expressed as:

$$ts_k^{rs} = \left(\frac{\left| RSI_k^r - RSI_k^s \right|}{\sqrt{RSI_k^r + RSI_k^s}} \right)^{-1} \cdot t_k^s \quad \forall s \neq r \qquad [10]$$

The similarity weighting matrix is somehow different from that proposed by Los (2000) and also adopted by Frenken *et al.* (2007), since it relies on a trade similarity approach which allows us maintaining a sector-based disaggregation.

The resulting (*q* x *q*) matrix of spillovers for each *k-th* sector (with a vector of 0 in the diagonal dimension $\forall s = r$) is then synthesised into a linear vector by using geographical distances for aggregating the *s-th* elements. The geographical distances here adopted are calculated as the number of kilometres between the economic centres in each region bilaterally, by using the automatic algorithm based on highway distances with the shortest time criterion adopted by the Italian Automobile Association (ACI), which is the national official reference for distances calculation.[8]

Following Bode (2004), we test three different plausible regimes: i) the binary contiguity concept where only neighbouring regions matter for knowledge spillovers; ii) the *k* nearest neighbours concept (testing a bound *k* distance of 300 km); iii) the pure inverse distances.

i) first-order binary contiguity

The binary contiguity concept (D_1) assumes that interregional knowledge spillovers only take place between direct neighbours that share a common border. We consider the first-order contiguity with direct neighbours, giving weight $w_{rs} \neq 1$ to each *s-th* region neighbouring region *r* and $w_{rs} = 0$ to all other regions. Consequently the variable reflecting interregional knowledge spillovers is defined as the sum of knowledge available in directly neighbouring regions as:

$$D_1 ts_k^r = \sum_{s=1, s\neq r}^{n} \left(ts_k^{rs} w_{rs} \right) \quad \text{with} \quad w_{rs} = 1 \quad \text{only if } s \text{ neighbouring } r \qquad [11]$$

ii) k nearest neighbours

We test the role of knowledge spillovers strictly related to effective geographical distances and not only in terms of common border by placing weight $w_{rs} = 1$ to each *s-th* region at a specific common distance and $w_{rs} = 0$ to all regions with a greater distance (D_2). The maximum distance commonly found in the empirical literature leading to positive knowledge spillovers at regional level is around 300 km related to

[8] The official distances provided by ACI are computed in order to give a homogeneous criterion for funding business travel costs, thus representing the best available proxy for costs of face to face contacts which are recognized as the main channel for regional knowledge spillovers.

the maximum time for having regular face-to-face contacts (Bottazzi and Peri, 2003). Establishing a threshold distance of 300 km involves including all neighbouring regions plus a few other regions only in specific cases. A smaller value - such as, for instance, 250 km - will coincide with our definition of neighbouring regions thus overlapping with our first-order binary contiguity matrix perfectly. In this case, interregional spillovers for each *k-th* sector and each *r-th* region results as follows:

$$D_2 ts_k^r = \sum_{s=1, s \neq r}^{n} \left(ts_k^{rs} w_{rs} \right) \quad \text{with} \quad w_{rs} = 1 \text{ only if } D_{rs} \leq 300km \text{, otherwise } w_{rs} = 0 \qquad [12]$$

with D_{rs} denoting the bilateral geographical distance between the economic centres of *r* and *s*.

iii) inverse distances

The third spatial regime relates to the assumption that the intensity of interregional knowledge spillovers may be subject to spatial transaction costs in the sense that the intensity of influences between any two regions diminishes continuously with increasing distance. In this case, the smaller the distance between *r* and any other region *s*, the higher the weight assigned to *s* with respect to its influence on *r*. Hence, the weight assigned to each region *s* ($\forall s \neq r$) is proportional to the inverse distance between *r* and *s*. Hence, the variable reflecting interregional knowledge spillovers is given by the distance-weighted (D_3) sum of knowledge available in all other regions:

$$D_3 ts_k^r = \sum_{s=1, s \neq r}^{n} \left(ts_k^{rs} w_{rs} \right) \quad \text{with} \quad w_{rs} = D_{rs}^{-1} \qquad [13]$$

Since including innovation variables built on patent data reduced the number of NAMEA sectors in the analysis to 12, forcing us to exclude the "Electricity, gas and water supply" sector (E in NACE codes), we calculated emissions from electricity consumption for each sector as a measure of indirect emissions (while remembering that NAMEA only provides direct emissions). In this way, emissions associated with the electricity sector is easily excluded while accounting for emissions due to energy consumption indirectly at sectoral level. This change in emission data allows us to obtain two additional valuable tools. The first one is not to consider emissions related to electricity production, whose energy mix choices are often decided at national rather than at regional level. The second advantage is related to the direct effect associated with innovation adoption on energy consumption. The decision to adopt technological innovation with a positive environmental (side) effect mostly depends on the possibility to exploit the resource-saving property of the innovation itself, and energy consumption reduction is particularly appreciated by Italian firms due to the relatively higher costs compared with other environmental resources.

We calculated electricity consumption for each sector by using data provided by TERNA (the Italian major electricity transmission grid operator), then assigning related emissions by using an average national emission intensity factor per KWh for GHG and ACID factors, with parameters respectively equal to 0.38 and 0.016.[9]

Since EP is affected by agglomeration effects associated with a cluster-based choice of the adopted production technique, the term (es_k^r) related to environmental spillovers in eq. [8] has been proxied by the emission intensity of the same sector into the other regions. To this end, the environmental spillovers is the sum of sectoral emissions per unit of value added from the other regions (e_k^s) valid for $\forall s \neq r$, weighted by distances expressed in the three different regimes described above (D_1, D_2 and D_3).

To some extent, this variable is the revealed signal of agglomerative effects for each sector related to the technological frontier adopted. If, *ceteris paribus*, firms are located in one region surrounded by regions where firms adopt polluting production technologies, the probability that firms will adopt

[9] We have considered an average value at national level assuming a common energy mix for all the Italian regions, depending on the fact that the decision of the energy mix adopted for each power plant is not completely regionally-based. Considering also that the electricity produced into each region may now be consumed anywhere due to electricity market liberalization, it is not possible to assume the exact energy mix related to the specific electricity consumed by firms.

cleaner production technologies will decrease, so that a sort of polluting firms cluster emerges for selected geographical areas independently from the specific sector under investigation. Coherently with technological spillovers, the environmental spillovers have been tested with three different spatial regimes as follows:

$$D_1 es_k^r = \sum_{s=1, s\neq r}^{n} \left(e_k^s w_{rs}\right) \text{ with } w_{rs} = 1 \text{ only if } s \text{ neighbouring } r\text{, otherwise } w_{rs} = 0 \quad [14]$$

$$D_2 es_k^r = \sum_{s=1, s\neq r}^{n} \left(e_k^s w_{rs}\right) \text{ with } w_{rs} = 1 \text{ only if } D_{rs} \leq 300km\text{, otherwise } w_{rs} = 0 \quad [15]$$

$$D_3 es_k^r = \sum_{s=1, s\neq r}^{n} \left(e_k^s w_{rs}\right) \text{ with } w_{rs} = D_{rs}^{-1} \quad [16]$$

Finally, since environmental policies are a driver of EP in eq. [8], the incidence of environmental regulation on average regional income is used as proxy (Costantini and Crespi, 2008). Data for different sectors are not available; regional environmental regulatory frameworks allow considering a fixed structural effect. Public expenditures for environmental protection may be considered the willingness of citizens to pay to preserve natural environment, practically expressed by exploiting their voting preferences during the regional government elections for policy makers who pledge to make stronger efforts in environmental protection (Farzin and Bond, 2006). Environmental regulation is then represented by three alternative public expenditure measures:[10] current, capital and R&D expenditures for environmental protection activities (ISTAT, 2007).[11]

4. THE GEOGRAPHICAL DISTRIBUTION OF EP

For the sake of simplicity, in the shift-share analysis we present results for main regions and on five

[10] See Table A3 for details.

[11] We acknowledge the existence of aggregation issues because of our regulation measures should ideally be at the sector level, but no data are available at the moment for the Italian regions with sector specification.

pollutants (CO_2, SO_X, NO_X, PM10, NMVOC)[12]. Table 1 shows how Italian regions behave with respect to the national average when emission intensities are compared before the decomposition, while Table 2 shows a quite clear North-South divide.

Table 1 – Regional performance – n. of pollutants out of 10 with a better performance than the national average

10 out of 10	Marche (C), Lazio (C) and Campania (C)
9 out of 10	Trentino Alto Adige (NE)
8 out of 10	Lombardia (NW) and Toscana (C)
7 out of 10	Piemonte (NW), Valle d'Aosta (NW) and Liguria (NW)
6 out of 10	Emilia Romagna (NE) and Abruzzo (C)
5 out of 10	Veneto (NE)
4 out of 10	Calabria (S)
3 out of 10	Molise (S) and Sicily (S)
2 out of 10	Friuli-Venezia Giulia (NE) and Umbria (C)
1 out of 10	Puglia (S) and Basilicata (S)
0 out of 10	Sardinia (S)

Note: Regional areas in brackets: NW= North West; NE= North East, C=Centre, S=South and Islands.

Table 2 – CO_2 and SO_X emission intensity (kg x 1M€ of value added, increasing order)

Region	CO_2	Region	SO_X
Trentino Alto Adige	136	Trentino Alto Adige	39
Campania	141	Valle d'Aosta	45
Valle d'Aosta	153	Abruzzo	69
Piemonte	185	Campania	78
Lazio	204	Lombardia	99
Marche	206	Lazio	101
Lombardia	209	Marche	108
Abruzzo	258	Piemonte	108
Veneto	267	Calabria	123
Emilia Romagna	270	Basilicata	224
Toscana	278	Emilia Romagna	226
ITALY	**301**	Molise	276
Calabria	307	Veneto	300
Umbria	342	**ITALY**	**315**
Friuli Venezia Giulia	353	Toscana	349
Basilicata	430	Umbria	373
Liguria	472	Friuli Venezia Giulia	539
Sicily	547	Puglia	859
Molise	689	Liguria	886
Sardinia	824	Sicily	1,347
Puglia	971	Sardinia	1,530

Nevertheless, it also shows that some Central and Southern regions (Lazio and Campania) behave quite well whereas some rich industrial regions (Veneto, Friuli Venezia Giulia) do not perform so satisfactorily, highlighting idiosyncrasies and criticalities that may be related to more complex issues

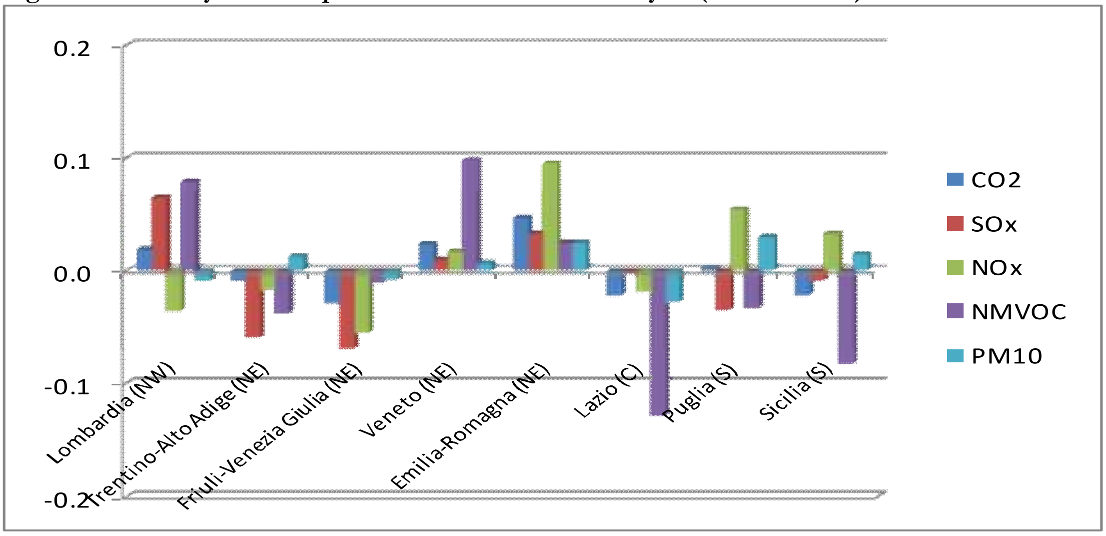
[12] The other five pollutants considered in the Italian regional NAMEA are CH_4, N_2O, CO, NH_3, Pb. Results are available.

bringing together geographical, economic and policy issues.

If we examine the industry mix and efficiency components, interesting insights emerge.

Regarding the industry mix, Figure 1 clearly shows that while it is evident that more industrialised regions in the North are penalised by this structural component (Lombardia, Emilia Romagna, Veneto, three main industrialised regions).[13]

Figure 1 – Industry mix component§ from shift-share analysis (coefficient *m*)



Note: § Below zero values indicate positive performances
NW= North West; NE= North East, C=Centre, S=South and Islands.

It is also significant that, among the largest regions, Lazio (the region of Rome), as a service-oriented region benefits from its productive structure in environmental terms, and two small but economically important regions in the North, with a high degree of (fiscal and legislative) autonomy and cultural idiosyncrasies (including regional languages), such as Trentino Alto Adige and Friuli Venezia Giulia, also benefit on average from the industry mix component.

Summing up, this part of the shift-share analysis tells us that the North-South divide regarding industrial development obviously affects the environmental comparative advantage of a region, other things being equal. But this is only one side of the story.

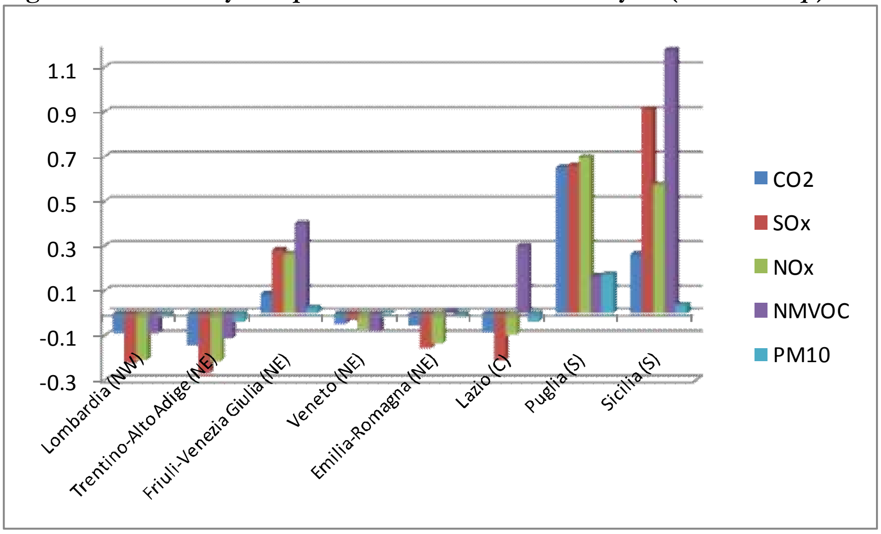
The efficiency gap seems to be the main driving force behind regional comparative advantage showing various cases of best and worst situations that highlight how efficiency and North-South structural

[13] All detailed results of the shift-share analysis are available upon request from the authors.

differences are jointly relevant in explaining different striking performances (Figure 2).

It is noteworthy that Friuli Venezia Giulia, a developed industrialised region associated with high income per capita, performs badly on average, and not because of its industry mix, as we commented on above, but because of specific inefficiency features. The North-East as a whole, an area of the country with high economic performance driven by export intensive manufacturing and some heavy industry, appears to perform worse than the North-West (Piedmonte and Lombardia).[14] The former is currently the region that always performs better than average with regard to both industry mix and efficiency.

Figure 2 – Efficiency component§ from shift-share analysis (coefficient *p*)



Note: § Below zero values indicate positive performances
NW= North West; NE= North East, C=Centre, S=South and Islands.

In other Northern industrial regions, on average, but not for all emissions, efficiency gains tend to compensate for unfavourable industry mix features. Given the often proposed dichotomy between the type of industrial development in the North-East of Italy, based on small and medium enterprises (SMEs) and districts rather than on large corporate firms with outsourcing collars, it is interesting to stress that at least at macro level, the economic development model based on SMEs seems to link less strictly economic and EP at the general level, while inducing a more localized correlation effect

[14] The most industrialized Italian regions are definitely Lombardia (NW), Veneto and Emilia Romagna (NE), with a GDP share of around 33-34%.

between agglomeration economies and environmental and innovation spillovers.

One interesting case is Friuli Venezia Giulia, which is characterised by high innovative industrial niches but also hosts industrial sites that exploit coal quite intensively. The reasoning on regional energy structure also points to the evident good performance of a region like Trentino Alto Adige which emerges with the best gap in 3 out of 5 emissions examined (Table 1). This region is less industrialised than other northern ones, and also depends enormously on renewable energy (mostly hydroelectric). Energy sector is also relevant in Southern regions, but the type of energy mix drastically affects performance. We use this result to comment on the direct nature of NAMEA emissions whereas accounting for the indirect generation of emissions would partially change the results. In the following sections we will be accounting for indirect emissions caused by electricity consumption.

Shift-share analyses show that at least at the macro level the North-South divide is, as mostly expected, the crucial part of the story, but in addition some sector-driven agglomerative effects seem to prevail in selected and localized areas.

Let us now aggregate the polluting emissions into two main environmental issues as climate change and acidification (hereafter referred as GHG and ACID, respectively).[15] In this way we figure out that while at aggregate regional level the emission intensity is distributed accordingly with different economic levels, strong exceptions arise when industrial sectors are singled out. Figures 3 and 4 represent the geographical distribution of labour productivity and EP, here distinguished for the two environmental themes, for two manufacturing sectors representing an energy intensive one, namely sector 9 in Table A2 (Figure 3), corresponding to manufacture of coke, refined petroleum products and chemical products, and a high technology sector (Figure 4), corresponding to manufacture of machinery, electrical machinery, medical, precision and optical instruments, etc. (sector 12 in Table A2).

[15] For details on specific converting coefficients for all pollutants see the technical notes on NAMEA available from De Boo *et al*. (1993).

Figure 3 – Regional distribution of Value added per worker, GHG and ACID emissions for NAMEA Sector #9 (NACE codes: DF-DG)

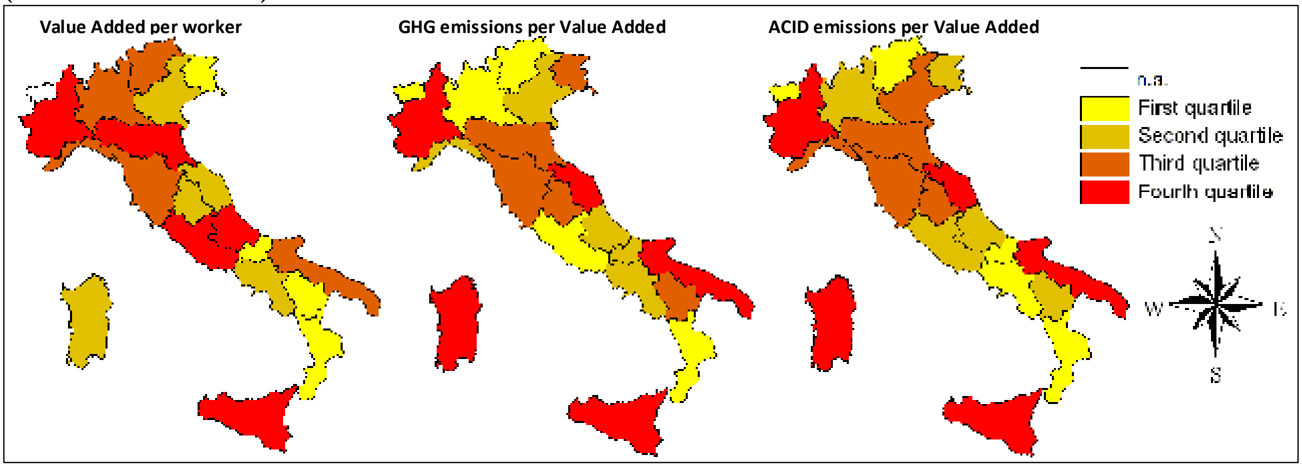
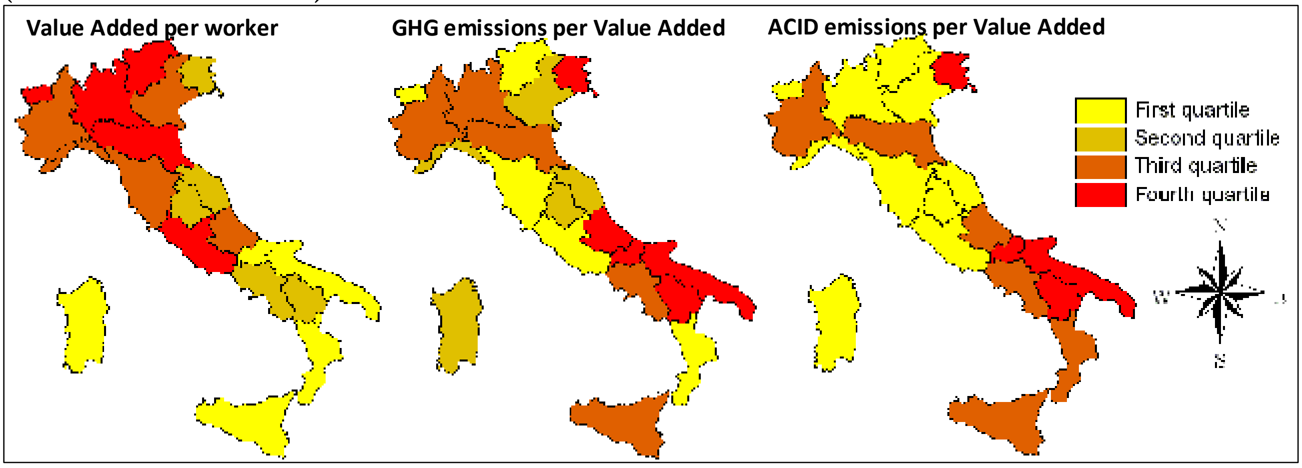


Figure 4 – Regional distribution of Value added per worker, GHG and ACID emissions for NAMEA Sector #12 (NACE codes: DK-DL-DM)



The two Figures clearly reveal that apart from the North-South divide, there are some clustering processes which are more localized, but more importantly the geographical distribution of labour productivity similarity does not exactly corresponds with the distribution of EP. We observe that environmental efficiency is heterogeneously distributed also comparing the GHG vs. the ACID theme. If we exclude Sardinia, because of its far island status, the Moran's I[16] indicates the presence of spatial autocorrelation in the intensity (on the value added) of acidifying emissions (p-value 0.007) but not in

[16] The (univariate) Moran's I measures the type and strength of spatial autocorrelation from spatial interaction effects (e.g., externalities or spillover effects) in a data distribution. This statistic determine the extent of linear association between the values in a given location with values of the same variable in neighboring locations.

the GHG emissions (p-value 0.283). These results indicate a clustering phenomenon that is significant for local pollutants (acidifying) but not for global (GHG) ones.

Hence, given that the geographical distribution of polluting emissions reveals in some cases a strong spatial concentration of dirty sectors in restricted areas which may not always correspond to regions with relatively less stringent environmental regulation or lower capital and innovation intensity, a deeper investigation of such EP clustering process is needed.

5. The DRIVING FORCES OF ENVIRONMNETAL PERFORMANCE

The econometric estimations aim to investigate the relative strength of the effects associated with labour productivity, internal and external innovation drivers as well as the role of the environmental regulatory framework. In particular we test the influence of such factors over the geographical and sectoral distribution of EP for GHG and ACID (Table 3 and 4, respectively), characterised by interesting differences in the diffusion paths. To some extent, the reaction from the community will be consistent with these differences, since we expect the impact of knowledge externalities to be higher for more localised polluting emissions, as ACID represents.

Distinguished regression models have been estimated for the two environmental themes here considered in order to understand if such expected divergences are confirmed by the empirical analysis. The empirical investigation relies on OLS estimations on 12 manufacturing sectors. We run regressions with the robust standard errors specification.

As a first outcome, we note that the impact of labour productivity on explaining the EP is rather high in both models, and the expected negative coefficient associated with this variable is interpreted as a positive correlation between productivity and environmental efficiency gains which is an expected result depending on the interplay of multiple drivers along the evolution of innovation, industrial and policy paths. Consistently with expectations and other analyses on NAMEA data in Italy (Marin and Mazzanti, 2011), this coefficient is larger for ACID than for GHG (almost doubled).

We affirm that labour productivity explains all structural features in the production process such us the adoption of environmental management systems, quality control, highly efficient mechanical appraisals, which are not specifically caught by the innovative capacity of the economic sector captured by patent intensity (correlated factors, Antonioli and Mazzanti, 2009) .[17] Moreover, we included a specific variable related to energy intensity for each sector, and we introduced a dummy variable which absorbs the effect of specific dirty industries. In this way, productivity gains and innovation effects is interpreted as the real impact on environmental efficiency related to investments in technology and labour productivity drivers. Consistently with differences in the two environmental themes, sector-specific features seem to be prominent for the explanation of environmental efficiency behaviour in the case of ACID emissions.

Secondly, environmental efficiency spillovers play a significant role in explaining EP especially for GHG emissions. The spatial regime where the environmental spillovers seem to play the major effect coincides with regions in the range of 300 km, as estimated coefficients are higher for both GHG and ACID. Nonetheless, some differences emerge between the two environmental themes, since for GHG all the three spatial regimes are statistically robust and coefficient values present small discrepancy, while for ACID the D_2 spatial regime seems to be the more robust and significant.

The expected positive coefficient is interpreted as the existence of clusters, that are not only intended as agglomeration of specific sectors into restricted areas, but also as a an effect of the technology adopted. The lower environmental efficiency of the neighbouring sectors is, the lower the internal EP of each specific sector. This means that together with the agglomeration of specific sectors into restricted areas, there is also some convergence in production processes and techniques. To some extent, the clustering process of specific polluting sectors in relation to contiguous geographical areas is plausibly followed by common choices in the adoption of cleaner or dirtier technologies.

[17] The specific dirty industries assuming value 1 in the dummy are: Agriculture, Manufacture of coke, refined petroleum products and nuclear fuel, Manufacture of chemicals and chemical products, Manufacture of other non-metallic mineral products.

Table 3 – Drivers of regional EP for GHG emissions

Dep var GHG	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Labour productivity	-0.756*** (-4.13)	-0.671*** (-3.85)	-0.688*** (-4.05)	-0.714*** (-4.12)	-0.501*** (-2.94)	-0.542*** (-3.17)	-0.522*** (-3.09)
Internal Innovation	-0.009 (-0.33)	-0.001 (-0.04)	0.002 (0.01)	0.005 (0.16)	0.009 (0.32)	0.003 (0.11)	0.014 (0.50)
Energy Intensity	0.645*** (14.67)	0.541*** (11.64)	0.531*** (12.23)	0.549*** (10.63)	0.567*** (11.41)	0.557*** (12.31)	0.583*** (10.18)
Dirty Sector dummy	1.331*** (12.81)	0.996*** (7.33)	0.925*** (6.64)	1.033*** (7.17)	0.976*** (7.08)	0.894*** (6.31)	0.997*** (6.67)
Environ. Spillovers D_1		0.243*** (3.84)			0.236*** (3.57)		
Environ. Spillovers D_2			0.289*** (4.40)			0.288*** (4.40)	
Environ. Spillovers D_3				0.229*** (3.05)			0.216*** (2.74)
Tech. Reg. Spillovers D_1					-0.125*** (-2.97)		
Tech. Reg. Spillovers D_2						-0.097** (-2.57)	
Tech. Reg. Spillovers D_3							-0.152*** (-2.98)
Constant	4.121*** (6.77)	4.083*** (6.72)	2.77*** (5.01)	4.014*** (6.80)	3.013*** (4.67)	2.184*** (3.69)	3.01*** (4.91)
Regional dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No obs.	209	209	209	209	209	209	209
Adj R-sq	0.78	0.80	0.81	0.79	0.81	0.81	0.81
F-stat	32.22	42.3	44.92	40.35	39.6	45.31	41.55
Root MSE	0.63	0.61	0.60	0.62	0.60	0.59	0.60
Hausman Chi-sq					0.23 (0.63)	0.02 (0.89)	0.05 (0.82)
Average VIF value					1.54	1.45	1.73
LM (lag)	0.03 (0.86)	0.01 (0.94)	0.01 (0.97)	0.01 (0.97)	0.12 (0.72)	0.02 (0.89)	0.15 (0.69)
LM (error)	3.88 (0.05)	3.19 (0.07)	3.40 (0.07)	2.50 (0.11)	3.31 (0.07)	3.34 (0.07)	3.18 (0.07)
Robust LM (error)	4.95 (0.03)	3.64 (0.06)	3.94 (0.05)	2.90 (0.09)	3.33 (0.07)	3.67 (0.06)	3.12 (0.08)

Notes: ***, **, *, for *p-values* of 0.01, 0.05, 0.1, respectively; robust *t-stat* values in parentheses. For Hausman spatial diagnostic tests (LM (lag) and LM (error)) p-values in parentheses.

Table 4 – Drivers of regional EP for ACID emissions

Dep var ACID	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Labour productivity	-1.543***	-1.383***	-1.301***	-1.313***	-1.201***	-1.139***	-1.051***
	(-6.16)	(-5.32)	(-5.73)	(-4.76)	(-4.61)	(-4.94)	(-3.93)
Internal Innovation	-0.019	-0.017	-0.013	-0.010	-0.006	-0.010	0.004
	(-0.53)	(-0.47)	(-0.36)	(-0.28)	(-0.17)	(-0.29)	(0.10)
Energy Intensity	0.404***	0.373***	0.358***	0.352***	0.398***	0.389***	0.392***
	(8.97)	(7.60)	(8.01)	(6.88)	(7.59)	(8.15)	(7.18)
Dirty Sector dummy	2.559***	2.272***	2.034***	2.155***	2.247***	2.008***	2.084***
	(20.76)	(9.05)	(7.03)	(8.55)	(9.03)	(6.97)	(8.46)
Environ. Spillovers D_1		0.109			0.106		
		(1.35)			(1.31)		
Environ. Spillovers D_2			0.195**			0.191**	
			(2.16)			(2.12)	
Environ. Spillovers D_3				0.163*			0.162**
				(1.90)			(1.96)
Tech. Reg. Spillovers D_1					-0.134**		
					(-2.40)		
Tech. Reg. Spillovers D_2						-0.111**	
						(-2.29)	
Tech. Reg. Spillovers D_3							-0.204***
							(-3.12)
Constant	4.596***	4.423***	3.489***	4.228***	3.281***	2.833***	2.865***
	(5.41)	(5.21)	(4.47)	(4.89)	(3.51)	(3.46)	(3.28)
Regional dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No obs.	209	209	209	209	209	209	209
Adj R-sq	0.77	0.77	0.77	0.77	0.78	0.78	0.79
F-stat	47.96	49.87	54.32	49.8	48.30	54.90	50.78
Root MSE	0.77	0.77	0.77	0.77	0.76	0.76	0.75
Hausman Chi-sq					0.04 (0.84)	0.01 (0.93)	0.05 (0.83)
Average VIF value					1.70	1.83	1.98
LM (lag)	0.03 (0.86)	0.02 (0.89)	0.01 (0.92)	0.01 (0.93)	0.10 (0.76)	0.07 (0.79)	0.21 (0.65)
LM (error)	0.68 (0.41)	0.71 (0.40)	0.79 (0.37)	0.44 (0.50)	0.87 (0.35)	1.12 (0.29)	1.11 (0.29)

Notes: ***, **, *, for *p-values* of 0.01, 0.05, 0.1, respectively; robust *t-stat* values in parentheses. For Hausman and spatial diagnostic tests (LM (lag) and LM (error)) p-values in parentheses.

On the other hand, it is worth noting that the level of internal innovation, expressed as the number of patents per value added, plays no role in explaining environmental efficiency since the coefficient presents low size and no statistical robustness in all specifications. This is plausible given that our innovation variable relates to the general efforts to produce technology, without specific environmental purposes. Further research steps could be to consider specific environmental innovation rather than a general innovative capacity, when the efforts by OECD and WIPO will be conducive to a well established and consolidated methodology to classify patents for environmental protection purposes

(OECD, 2008).

On the contrary, technological interregional spillovers seem to play a more effective role. The higher impact of innovation spillovers compared with internal innovation is again explained by the nature of our innovation variable a general innovation output.. The higher the knowledge flows from other regions, the more likely the availability of environmental-friendly technologies, and the higher the reduction in emission intensity.[18] The portfolio of innovations available within a sector at national level (similar to the business group effect for firm, Belenzon and Berkowitz, 2007) could extend the set of possible innovation choices at regional level. Firms belonging to a defined sector can eventually find the (environmental) innovations they need in the national framework: intra sector knowledge flows contribute to this aim.

In the case of innovation spillovers, the three spatial regimes all give robust results, meaning that innovation effects spread out of the regional borders with no limit distance. On the contrary, the highest effect is associated to the D_3 regime, meaning that the higher the availability of technological innovation at the sector level, the more likely the capacity of each sector to choose the best environmental-friendly technology and the better the EP.

Consistently with our expectations, the positive influence of technological spillovers on EP is higher for more localised pollutants (ACID) since the collective reaction to better perceived environmental damage will be to adopt the innovations available in each sector more rapidly and diffusely. In this case, the size of the coefficient – its economic significance – is larger comparing to GHG, also confirming the evidence previously found for labour productivity.

A multicollinearity problem may arise if regional innovation is explained by spillovers, as a standard result in regional economic convergence literature. In order to check for robustness of our model, we

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[18] We have also tested the potential influence of a general internal spillovers effect coming from all other sectors and a general spillover effect coming from all other sectors of the other regions (Jacobs type externalities), but results are not statistically significant. Thus the only significant result is associated to the existence of Marshall-Arrow-Romer type externalities as technological spills over from innovation activities of firms in the same sector located in the neighbouring regions.

tested both potential multicollinearity of internal and external innovation as well as potential endogeneity of the regressor explaining regional innovation by performing the Variance Inflation Factor (VIF) and the Hausman test on the two alternatives, a standard OLS and an instrumental variables (IV) estimator where regional patents are instrumented by spillovers and other common variables (as R&D private and public efforts). All average VIF values are far below 5.00 which is the threshold minimum level revealing a multicollinearity problem, while Hausman statistics clearly do not reject the hypothesis that the OLS estimator is worse than the IV one. Thus the OLS remains consistent and efficient.

Since also spatial correlation may bias results, we implemented robustness checks[19]. As Lagrange Multipliers (LM) tests for the existence of both spatial lag or spatial error reveal, only a weak spatial dependence emerges from the LM error test for GHG estimation, while for ACID specifications no significant spatial dependence evidence is present.[20]

Finally, with regard to the role of environmental regulation (table 5), we tested the role of the three alternative measures (current, capital, and R&D public expenditures for environmental protection at the

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[19] The spatial weights matrix used to test the presence of spatial dependence is based on a *rook* weights matrix (a contiguity-based matrix) for the Italian regions initially calculated with the Geoda 0.9.5-i software. For the Italian regions the *queen* weights matrix (that considers borders and vertices) is equal to the *rook* one (that considers only borders). However further work has been done because our dataset is not only constituted by 20 statistical geo-units (regions) but 209 statistical units (19 regions - because Sardinia has been excluded considering the far island status - times 11 NAMEA sectors). As suggested by Anselin (e.g. personal correspondence) a "trick" to obtain such a spatial weights matrix is to replicate the initial one - opportunely recoded each time - for the number of considered sectors. Thus the final weights matrix has the same number of observations of the considered cross sector-region dataset.

[20] We checked in the case of GHG if a spatially corrected model produces better results, but all coefficients remain unchanged in significance and statistical robustness. The spatial dependence diagnostics referred to the econometric specifications explore different aspects with respect to the (univariate) spatial autocorrelation tested in the §4. Thus the apparent contrasting results for the spatial dependent diagnostic in the GHG and ACID specifications with respect to the univariate spatial autocorrelation test for the GHG and ACID intensity reflect the influence of the whole set of (sectoral) regressors on the spatial interaction effects.

regional level) taken with one temporal lag. The choice of the temporal dimension is quite obvious since the regulatory framework may induce firms to be more environmental responsible only after some period of time.

While previous findings do not change when the regulatory effort is included, some interesting differences emerge when comparing the two environmental themes. All coefficients show an expected negative sign since an increase in the social price of negative externalities would force firms to adopt more efficient production processes, but for GHG only R&D public expenditures for environmental protection seems to positively influence EP.

On the contrary, the regulatory framework seems to be more effective for ACID emissions, since all the three measures have a positive influence on environmental efficiency gains with robust statistical significance. Also in this case empirical results seem to be in line with expectations, since the capacity of the collective policy action to force the local government to adopt more stringent environmental standards and rules is more effective when there is an higher perception of the damage from the community.

The evidence for GHG is explained by the well-known weakness of Italian environmental policy which does not present a structural policy making for addressing climate change and high stringency (Johnstone et al., 2010), besides the EU trading scheme that came after 2005.

As a final robustness check, we tested the potential effects of neighbouring environmental regulatory system in line with Gray and Shadbegian (2007): no significant effect on emission intensity is found. Regional regulation effects prevail, when significant. The picture is then one where regional firms/sectors exploit on the one hand the incentives (and subsidies) offered by regional regulators, and on the other hand the wider 'innovation portfolio' provided by the sector related technology at national level. The two could present complementary aspects.

Table 5 – The role of environmental regulation

	GHG			ACID		
	(1)	(2)	(3)	(4)	(5)	(6)
Labour productivity	-0.501***	-0.542***	-0.522***	-1.201***	-1.139***	-1.051***
	(-2.94)	(-3.17)	(-3.09)	(-4.61)	(-4.94)	(-3.93)
Internal Innovation	0.009	0.003	0.014	-0.006	-0.01	0.004
	(0.32)	(0.11)	(0.50)	-(0.17)	(-0.29)	(0.10)
Energy Intensity	0.567***	0.557***	0.583***	0.398***	0.389***	0.392***
	(11.41)	(12.31)	(10.18)	(7.59)	(8.15)	(7.18)
Dirty Sector dummy	0.976***	0.894***	0.997***	2.247***	2.008***	2.084***
	(7.08)	(6.31)	(6.67)	(9.03)	(6.97)	(8.46)
Environ. Spillovers D1	0.236***			0.106		
	(3.57)			(1.31)		
Environ. Spillovers D2		0.288***			0.191**	
		(4.40)			(2.12)	
Environ. Spillovers D3			0.216***			0.162**
			(2.74)			(1.96)
Tech. Reg. Spillovers D1	-0.125***			-0.134**		
	(-2.97)			(-2.40)		
Tech. Reg. Spillovers D2		-0.097**			-0.111**	
		(-2.57)			(-2.29)	
Tech. Reg. Spillovers D3			-0.152***			-0.204***
			(-2.98)			(-3.12)
Env. Reg. Current Exp.	-0.105			-0.62**		
	(-0.81)			(-2.05)		
Env. Reg. Capital Exp.		-0.005			-0.272**	
		(-0.03)			(-2.03)	
Env. Reg. R&D Exp.			-0.163**			-0.288**
			(-2.58)			(-2.27)
Constant	2.95***	2.187***	2.527***	4.738***	4.143***	1.84**
	(4.54)	(3.54)	(3.85)	(5.78)	(5.90)	(2.11)
Regional dummies	Yes	Yes	Yes	Yes	Yes	Yes
No obs.	209	209	209	209	209	209
Adj R-sq	0.81	0.81	0.80	0.77	0.78	0.79
F-stat	39.60	45.31	41.55	48.30	54.90	50.78
Root MSE	0.60	0.59	0.60	0.76	0.76	0.75

6. CONCLUSIONS

The achievement of positive EP at national level could strongly depend on differences in local capabilities and conditions. The decomposition of economic-environment accounting in industry specialization and efficiency components tells us that the Italian North-South divide affects regional EP. On the one hand, such strong North-South differences in performance may reflect coherence with economic development stages and priorities but, on the other hand, can also signal regulatory and industrial policy failures or successes occurring even at similar income levels. Industrial regional specialisation matters but efficiency effects also play a crucial role. The North-East as a whole, a leading economic area of the country driven by export intensive manufacturing sectors, appears to perform worse than the Western part of the industrialised North. Traditional elements of the North-South divide are not the once and for all explanation of regional EP in Italy.

Looking in depth into sector environmental efficiency drivers, econometric analyses reveal that technological and environmental spillovers are highly relevant. Especially for GHG environmental efficiency spillovers play a significant role in explaining regional sector EP. This result is interpreted as a first evidence of the existence of clusters that are not only intended as agglomeration of specific sectors into restricted areas, but also as the existence of a geographically driven common technology patterns. The clustering process of specific polluting sectors into selected geographical areas is associated to common choices in the adoption of cleaner or dirtier technologies, evidence which helps us explaining why the same sector specialisation into different regions may be characterised by different emission intensities or efficiency as we found through the decomposition.

A second important result is that technological interregional spillovers seem to play a more effective role in improving environmental efficiency than internal innovation, with an increasing effect for more localised pollutants. The greater overlapping between polluters and agents perceiving the environmental damage in the case of more localised emissions also explains the stronger effectiveness of environmental regulation at the regional level in fostering environmental efficiency gains.

The policy advice we can derive is that current and future design of industrial, innovation, and environmental policies at national and regional level should account for linkages between economic and environmental issues as well as addressing for geographical and sector features which influence regional economic growth but also environmental efficiency paths.

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APPENDIX

Table A1 – Productive branches and NACE code

Productive branches (ATECO 2001)

Title	NACE Code
Agriculture, hunting and forestry	A
Fishing	B
Mining and quarrying	C
Manufacture of food products, beverages and tobacco	DA
Manufacture of textiles and textile products	DB
Manufacture of leather and leather products	DC
Manufacture of wood and wood products, Manufacture of rubber and plastic products, Manufacturing n.e.c.	DD-DH-DN
Manufacture of pulp, paper and paper products	DE
Manufacture of coke, refined petroleum products and nuclear fuel, Manufacture of chemicals, chemical products and man-made fibres	DF-DG
Manufacture of other non-metallic mineral products	DI
Manufacture of basic metals and fabricated metal	DJ
Manufacture of machinery and equipment n.e.c., Manufacture of electrical and optical equipment, Manufacture of transport equipment	DK-DL-DM
Electricity, gas and water supply	E
Construction	F
Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods	G
Hotels and restaurants	H
Transport, storage and communication	I
Financial intermediation	J
Real estate, renting and business activities	K
Public administration and defense; compulsory social security	L
Education	M
Health and social work	N
Other community, social and personal service activities	O
Household related activities	P
Total	

Table A2 – Concordance classification for NACE sectors, NAMEA sectors and IPC codes

CODE NAMEA	CODE NACE	CODE IPC
1	A - Agriculture	A01
3	C - Mining and quarrying	E21
4	DA15 - Manufacture of food products and beverages DA16 - Manufacture of tobacco products	A21-A22-A23-A24-C12-C13
5	DB17 - Manufacture of textiles DB18 - Manufacture of wearing apparel; dressing; dyeing of fur	A41-A42-D01-D02-D03-D04-D05-D06
6	DC19 - Tanning, dressing of leather; manufacture of luggage	A43-B68-C14
7	DD20 - Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials DH25 - Manufacture of rubber and plastic products DN36 - Manufacture of furniture; manufacturing n.e.c.	A44-A45-A46-A47-A63-B09-B27-B29-C02-C30-G10
8	DE21 - Manufacture of pulp, paper and paper products DE22 - Publishing, printing, reproduction of recorded media	B31-B42-B43-B44-D21-G09
9	DF23 - Manufacture of coke, refined petroleum products and nuclear fuel DG24 - Manufacture of chemicals and chemical products	C01-C05-C06-C07-C08-C09-C10-C11-C40-F16
10	DI26 - Manufacture of other non-metallic mineral products	B28-B32-C03-C04
11	DJ27 - Manufacture of basic metals DJ28 - Manufacture of fabricated metal products, except machinery and equipment	B25-B26-C21-C22-C23-C25-D07-E02-E05
12	DK29 - Manufacture of machinery and equipment n.e.c. DL30 - Manufacture of office machinery and computers DL31 - Manufacture of electrical machinery and apparatus n.e.c. DL32 - Manufacture of radio, television and communication equipment and apparatus DL33 - Manufacture of medical, precision and optical instruments, watches and clocks DM34 - Manufacture of motor vehicles, trailers and semi-trailers DM35 - Manufacture of other transport equipment	A61-A62-B01-B02-B03-B04-B05-B06-B07-B08-B21-B22-B23-B24-B30-B41-B60-B61-B62-B63-B64-B65-B66-B67-B81-B82-F01-F02-F03-F04-F15-F21-F23-F24-F25-F26-F27-F41-F42-G01-G02-G03-G04-G05-G06-G07-G08-G11-G12-H01-H02-H03-H04-H05
13	E - Electricity, gas and water supply	E03-F17-F22-F28-G21-H02
14	F - Construction	E01-E04-E06

Source: own elaborations on Schmoch *et al.* (2003)

Table A3 – Variables description

Labour productivity	Value added per full-time equivalent job unit
Environ. Spillovers (D1)	Sector-specific pollutant emissions in directly neighbouring regions eq. [14]
Environ. Spillovers (D2)	Sector-specific pollutant emissions in regions ≤ 300 km maximum distance eq. [15]
Environ. Spillovers (D3)	Sector-specific pollutant emissions in all regions eq. [16]
Energy intensity	Electricity consumption to value added ratio for each specific sector
Env.Reg.Curr.Exp.	Environmental regional expenditure 2004 (current)
Env.Reg.Cap.Exp.	Environmental regional expenditure 2004 (capital)
Env.Reg.R&D.Exp	Environmental R&D regional expenditure 2004
Internal Innovation	Number of patents per value added; five-year average 2000-2004
Tech. Reg. Spillovers (D1)	Sector-specific innovation spillovers from patents intensity (five-year average 2000-2004) available in directly neighbouring regions eq. [11]
Tech. Reg. Spillovers (D2)	Sector-specific innovation spillovers from patents intensity (five-year average 2000-2004) available in regions ≤ 300 km maximum distance eq. [12]
Tech. Reg. Spillovers (D3)	Sector-specific innovation spillovers from patents intensity (five-year average 2000-2004) available in all regions eq. [13]
Dirty Sector dummy	Dummy for heavy polluting sectors as explained in footnote n. 10