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# Environmental Performance and Technological Interregional Spillovers

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**Abstract**

The achievement of positive environmental performances at the national level could strongly depend on differences within local capabilities of both institutions and the private business sector. Environmental regulation per se (especially if set at the national level) can be a weak instrument if the institutional and business environment could not transform regulation strengths into opportunities. As well as the environmental accounting matrix for 10 air polluting emissions is now available for the 20 Italian regions (and 24 productive sectors), we have analysed which are the main drivers at the regional level promoting positive environmental performances, and which are the foremost gaps at the sectoral level which reduce the capacity to obtain them.

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**Keywords**: Environmental Accounts, Environmental Policy, Technological Innovation, Innovation Spillovers, NAMEA, Emission Efficiency, Shift-Share Analysis

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## 1. Introduction

This paper develops empirical analyses using a regional NAMEA (*National Accounting Matrix including Environmental Accounts*) dataset that for the first time as far as we know covers all regions of a country. We aim at both disentangling structural (sector/geographic) and efficiency factors behind a regional environmental performance, and assessing what drivers – productivity, innovation, policy – may be relevant in determining environmental performances and the income-environment relationships at regional level.

Briefly, the NAMEA approach originated in a series of studies carried out by Statistics Netherlands. The first NAMEA was developed by the Dutch Central Bureau of Statistics (De Boo et al., 1993). At international level firstly appeared works such as Ike (1999), Vaze (1999), and Keuning et al. (1999); Steenge (1999) provided a policy-oriented analysis related to the possible policy implications.[2]

The first Italian (national) NAMEA, referring to 1990 data, was published by ISTAT (2001); data updated to 2007 will be released in 2010. Beyond the emissions related to the productive activities, national NAMEA data also include emissions derived from three household consumption activities (transport, heating, and other, such as painting and solvent use); however, we have excluded from the analysis these sources of emissions because our interest lies mainly in productive activities (for which the available macro sectors are primary, industry and services, disaggregated into 51 sectors in the national matrix classified by NACE codes). In the NAMEA tables environmental pressures (air emissions and virgin material withdrawal) and economic data (value added, final consumption expenditures and full-time equivalent job) are assigned to the economic branches of resident units or to the household consumption categories directly responsible for environmental and economic phenomena.

An improvement of NAMEA that we exploit in this paper is the 'regionalisation' of the data generation. An Italian regional NAMEA (or RAMEA), for the year 2005, has recently been published (ISTAT, 2009) and involves 20 regions, 24 productive sectors and the same 10 pollutants of the national one.[3] By comparing regional and national environmental sector intensities, via a specific descriptive tool - the shift-share analysis – and through a cross-sectional econometric analysis, we aim to demonstrate the utility of NAMEA for environmental and industrial policy making. In referring to a regional framework, the analysis is interesting since it allows the investigation to focus on structural and idiosyncratic features compared to national averages, providing useful insights for regional policy making on environmental, industrial and economic development dynamics, which is the keystone of economic development. It enables economic policies to be differentiated by regions on the basis of the observed heterogeneity in economic-environmental relationships.

Within the recent and rare studies exploiting NAMEA data with advances in regional studies frameworks, we should highlight the close-by study by Stauvermann (2007), who presents a Dutch study based on a regional NAMEA. This work and the research project are highly relevant to and complement our analysis in terms of the aim to bring together different European research experience, in the interests of establishing a future EU-based

[2] For an overview of the methodological issues related to NAMEA, we refer the reader to Femia and Panfili (2005), Mazzanti and Montini (2009, 2010), Mazzanti et al. (2008a, 2008b) and finally ISTAT (2007), the Italian national statistics agency that produces and elaborates NAMEA. De Haan and Keuning (1996) and De Haan (2004) are seminal papers.

[3] For an overview of recent developments in regional NAMEA (or RAMEA) in Italy see the institutional site www.arpa.emr.it/ramea. Stauvermann (2007, p. 73) and Goralzcyck and Stauvermann (2008) present some comparative environmental performances from a RAMEA EU project involving Italy (Emilia-Romagna region, coordinated through ARPA, the regional environment agency), UK (South east of England), Poland (Malpolska region), Netherlands (Noord-Brabant), focusing on greenhouse gases (GHG) per unit of production.

NAMEA, which may be used to assess 'sustainable production and consumption' performances (Watson and Moll, 2008), where trade issues also play a major role. EUROSTAT expects to release a EU27 NAMEA by 2011; current data availability is patchy even for major countries.

Within this empirical framework, this paper aims at analyse which are the main drivers at regional level capable to promote positive environmental performances, and which are the foremost gaps at the sectoral level which reduce the capacity to obtain them. An environmental accounting approach such that of Italian regional NAMEA, in fact, allows considering both the regional and sectoral dimensions, as well as many different pollutants associated to several environmental themes such as climate change, local air pollution, soil and water degradation. Through a specific descriptive tool - the shift-share analysis - we explore some details on productive-structural and efficiency features at the regional level, while econometric estimations allow shaping a clearer picture of the main drivers (policy related ones, but also the private innovation) of the local economy producing or preventing environmental degradation.

The paper is structured as follows. Section 2 presents the methodology both for shift-share analysis and the reference model for cross-sectional econometric analysis; section 3 presents the dataset framework and how we specify spillovers between regions on innovation and emissions. Section 4 presents shift-share analyses empirical findings that disentangle structural and efficiency factors behind environmental performances. Section 5 presents the empirical model and econometric analyses of the income-environment relationship at regional level integrated by technological spillover and spatial potential effects. Section 6 concludes with policy suggestions and further research hints.

## 2. Applied analyses on regional NAMEA

### 2.1 The shift-share analysis

To explore the role of the regional productive structures regarding emissions efficiency across regions, shift-share analysis (Esteban, 2000, 1972) is preliminary used in order 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 emissions intensity, represented by 'total emissions – of a particular pollutant - on value added', defined as $EM/VA$ for Italy - the benchmark, and as $EM_r/VA_r$ for the analysed region $r$. This indicator is decomposed as the sum of $(EM^k/VA^k)*(VA^k/VA)$, where $VA^k/VA$ is the share of sector value added on total value added, for the sector $k$, with $k$ defined from 1 to q (q = 24 - the number of NACE sectors included in the regional NAMEA)[4].

For clarity, we redefined the index of emissions intensity as $X$ for the national average ($X$=$EM/VA$), as $X_r$ for the region $r$ ($X_r$ =$EM_r/VA_r$), and as $X^k$ for each $k$ sector (for the region $X^k_r$ =$EM^k_r/VA^k_r$, for Italy $X^k$ =$EM^k/VA^k$). We then defined the share of sector value added as $P^k$=$VA^k/VA$ for Italy and $P^k_r$=$VA^k_r/VA_r$, for the region.

On this basis we can easily identify three effects, as prescribed by the *shift-share decomposition*. The first effect $m$ ('structural' or *industry mix*), is

[4] See table A1 in appendix for the productive sectors and NACE codes considered.

$$m_r = \sum_k (P_r^k - P^k) X^k$$

$m_r$ assumes a positive (negative) value if the region is 'specialized' ($P_r^k - P^k > 0$) in sectors associated with lower (higher) environmental efficiency, given that the gap in value added sector shares is multiplied by the value $X$ of the national average ('as if' the region were characterized by average national efficiency). The factor $m_r$ assumes lower values if the region $r$ is specialized in (on average) more efficient sectors.
The second factor, defined as the 'differential' or 'efficiency', is:

$$p_r = \sum_k P^k (X_r^k - X^k)$$

$p_r$ assumes a positive (negative) value if the region is less (more) efficient in terms of emissions (the *shift* between regional and national efficiency), under the assumption that ('as if') value added sector shares were the same for the region, and for Italy ($P_r^k - P^k = 0$).

Finally, the effect of 'covariance' between these two equations, or the 'allocative component', is given by:

$$a_r = \sum_r (X_r^k - X^k)(P_r^k - P^k)$$

The $a_r$ factor assumes a minimum value if the region is specialized in sectors where it presents the highest 'comparative advantage' (low intensity of emissions), then the covariance factor is between $m_r$ and $p_r$. As table 1 sketches, such investigations provide some interesting insights even useful as food for thought for policy.

[TABLE 1 NEAR HERE]

**2.2 Modelling the environmental performance**

Let us consider environmental performance (through emissions *EM* per unit of value added) 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 price ($P_k^r$). Emissions can be expressed as:

$$E_k^r = f\left(Y_k^r, T_k^r, P_k^r\right) \qquad [1]$$

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

$$E_k^r = A Y_k^{r\left(b_1 + b_2 \ln Y_k^r\right)} T_k^{r\,b_3} P_k^{r\,b_4} \qquad [2]$$

and the logarithmic transformation of equation [2] takes the form of

$$\ln E_k^r = A_k^r + b_1 \ln Y_k^r + b_2 \left(\ln Y_k^r\right)^2 + b_3 \ln T_k^r + b_4 \ln P_k^r + \varepsilon_k^r \quad [3]$$

where the variable $A_k^r$ assumes the role of a sector/region-specific fixed effect and $\varepsilon_k^r$ is the error term. As we are interested in an evaluation of the environmental performance of our sector expressed as a measure of emission intensity, we transform equation [3] by scaling it with value added, thus obtaining the following reduced form

$$e_k^r = \left(a_k^r + 1\right) + b_1 \ln Y_k^r + b_2 t_k^r + b_3 p_k^r + \varepsilon_k^r \quad [4]$$

where the lower case letters indicate the value of each variable in terms of sector/region specific value added. As recently addressed by Mazzanti and Zoboli (2009a), when technology is included in the environmental efficiency function, it is interesting to disentangle the effects related to strict technological innovation from the effects of labour productivity, thus replacing the term $\ln Y_k^r$ in eq. [4] with a properly defined labour productivity measure.

The effect related to technology in a standard emission demand model is represented by the state of technology in the production function, where more innovative firms are those which usually adopt more resource saving and/or less polluting technologies. Hence, the sign of the $b_2$ coefficient is expected to be negative, where the higher the efforts in technological innovation of the firm/sector, the lesser the emission intensity.

As recent models on innovation and economic growth have increasingly appreciated the role of technological learning and knowledge spillovers, we have tested the role of technological spillovers not only related to economic growth but also to environmental performances. As Gray and Shadbegian (2007) have emphasized, there is some positive correlation between the effect of extra regional environmental regulation and the regional environmental performance. Nonetheless, to the best of our knowledge there is no attempt at the empirical level to assess the role of regional innovation spillovers on the environmental performances. To this purpose Kyriakopoulou and Xepapadeas (2009) find that at the theoretical level environmental policy acts as a centrifugal force, by restricting industrial activities, while knowledge externalities have a centripetal force fostering agglomeration patterns. The authors conclude in favour of the existence of a pollution haven hypothesis, according to which polluting industries have a tendency to relocate to areas with less stringent environmental regulations. They also affirm that environmental regulation and knowledge spillovers may act as countervailing forces, where knowledge spillovers occur where firms may exploit agglomeration economies, while environmental policy reduces this clustering of economic activity.

Looking at the geographical distribution of polluting emissions in Italy, there is a spatial concentration of dirty sectors in restricted areas which may not always correspond to regions with relatively less stringent environmental regulation. The pollution haven hypothesis is thus rejected in the Italian case. The exploitation of agglomeration economies and the existence of knowledge externalities seem to be the prevailing centripetal forces explaining the clustering of the economic activities.

Finally, the effect related to prices for environmental externalities are often represented by the incidence of environmental regulation on average production costs, as a for instance the environmental tax ratio to GDP or the environmental protection expenditures by firms as percentage of value added (Costantini and Crespi, 2008).

In our dataset we are not able to model specific effects for different sector and we can only consider an overall regional environmental regulatory framework which allows shaping a fixed structural effect associated to higher propensity to invest by the Public Administration in environmental protection activities. Also in this case the coefficient $b_3$ is expected to be negative, where the more stringent is the regulatory framework at the (general) regional level, the lesser is the emission intensity at the sectoral level. Public expenditures for environmental protection may be considered as a proxy of the willingness to pay of citizens to preserve natural environment, practically expressed by exploiting their voting preferences during the regional government elections. To some extent, we can interpret public environmental expenditures as a general propensity to reduce pollution, representing a broad approximation of the regional regulatory strength (Farzin and Bond, 2006).

### 3. Dataset description

The core part of the dataset is based on the 2005 Italian regional NAMEA, to our knowledge the only full regional NAMEA in the EU. Panel structures are expected in the future as new data become available. Environmental pressures (10 air pollutants[5]) 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 shaping a full dataset with information of environmental and economic aspects. In our dataset we have 23 *k-th* sectors ($\forall k = 1,...,n$)and 20 *r-th* ($\forall r = 1,...,q$) regions.

Patents data are drawn from REGPAT dataset elaborated by Eurostat from OECD-EUROSTAT PATSTAT database, gathering all patents by each region for the 3 digits IPC classification granted by the European Patents Office. The number of patents classes at the 3 digits level is 633, and we have considered all patent applications to the EPO by priority year at the regional level. The regional distribution of patent applications is assigned by Eurostat according to the inventor's region of residence.

We have adopted an *ad hoc* sector classification in order to assign patents (as classified by IPC codes) to specific manufacturing sectors (as classified by NACE codes) relying on previous concordance proposals such as the OECD Technology Concordance and the methodology developed by MERIT and SPRU. Patent classes are assigned to NACE economic sectors and NAMEA codes by using the concordance classification proposed by Schmoch *et al.* (2003) resulting into 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 the sectoral level (Antonelli *et al.*, 2008). We have adopted patent counts as the explanatory variable for technological innovation due the less disaggregated data available for R&D expenditure data for the Italian regions. Some drawbacks[6] characterize patents as a valid alternative of R&D data as an economic indicators, but previous studies at the regional level highlighted helpfulness of patent applications as a measure of production of innovation (Acs *et al.*, 2002).

We argue that the potential positive influence from innovating activities on the emission levels arise with a temporal lag, as the adoption of new technologies is not perfectly simultaneous with the invention itself. As we are considering the impact of innovation on environmental performance as a side effect of the innovative

[5] Carbon dioxide ($CO_2$), nitrous oxide ($N_2O$), methane ($CH_4$), nitrogen oxides ($NO_X$), sulphur oxides ($SO_X$), ammonia ($NH_3$), non-methane volatile organic compounds (NMVOC), carbon monoxide (CO), particulate matter ($PM_{10}$) and lead (Pb).

[6] Especially, the extreme volatility of yearly data.

capacity at the sectoral level, one year lag seems to be the most appropriate choice for modelling the linkages between environment and technological innovation. We have also computed patents to value added ratios in order to account for the innovation intensity of each sector.

In order to compute interregional spillovers we consider that the probability of innovation to spill from one region to another strictly depends on the fact that localization economies are associated with the concentration of a particular sector in the two regions. Hence, it is not only a matter of geographical distances which allows explaining the existence and the strength of innovation spillovers. Los (2000) and Frenken *et al.* (2007) propose to adopt an index capturing the technological relatedness between industrial sectors by computing the similarity between two sectors' input mix from input-output tables. When data availability reduces the possibility to compute a technology mix similarity, an alternative solution is to form a similarity matrix based on specialization indicators (Van Stel and Nieuwenhuijsen, 2004). In our case, we have considered knowledge spillovers coming from the same sector located in other regions, thus reducing problems of lacking information and considering pure agglomerative effects related to environmental performances.

The relative specialization index (RSI) is thus obtained from the following equation:

$$RSI_k^r = \frac{t_k^r}{\sum_{k=1}^{n} t_k^r} \Bigg/ \frac{t_{ITk}}{\sum_{k=1}^{n} t_{ITk}} \qquad [5]$$

where $t_k^r$ is the five-years average of patents to valued added ratios for each *k-th* sector and *r-th* region, while $t_{ITk}$ is the same measure at the national level.

The innovation spillovers (IS) for each *k-th* sector and *r-th* region un-weighted by the geographical distance are expressed as the

$$IS_k^{rs} = \left( \frac{\left| RSI_k^r - RSI_k^s \right|}{\sqrt{RSI_k^r + RSI_k^s}} \right)^{-1} \cdot t_k^s \quad \forall s \neq r \qquad [6]$$

The geographical distances here adopted are calculated as number of kilometres between the economic centres in each region bilaterally, by using the automatic algorithm based on highways distances with the shortest time criterion.

Following Bode (2004), we have tested several alternative criteria for geographical distances, as well as the spatial weights from which regions *s* knowledge spillovers may occur cannot be assigned a priori to a specific spatial regime. Since there is no a priori information on which spatial regime should be preferred, we have tested three different plausible regimes: i) the binary contiguity concept where only border regions matter for knowledge spillovers (binary contiguity); ii) the *k* nearest neighbours concept (testing an average 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 take place only between direct neighbours that share a common border. We have only considered the first-order contiguity with direct neighbours, giving weight $w_{rs}$ = 1 to each *s* 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.

$$D_1SPILL_k^r = \sum_{s=1, s\neq r}^{m} \left( IS_k^{rs} w_{rs} \right) \text{ with } \quad w_{rs} = 1 \text{ only if } s \text{ neighbouring } r \qquad [7]$$

*ii) k nearest neighbours*

We have also tested the role of knowledge spillovers strictly related to the effective geographical distances and not only in terms of common border by placing weight $w_{rs}$ = 1 to each s region at a specific common distance and $w_{rs}$ = 0 to all regions with a greater distance. The maximum distance commonly found in the empirical literature bringing to positive knowledge spillovers at the regional level is around 300 km (Bottazzi and Peri, 2003). In our dataset putting a threshold distance on 300 km means to include all neighbouring regions plus some few other regions only in specific cases. A smaller value - as for instance 250 km as another common measure of maximum distance - will perfectly coincide with our definition of neighbouring regions thus overlapping with our first-order binary contiguity matrix perfectly. This 300 km maximum distance ($D_2$) is related to the maximum time necessary to have regular face-to-face contacts. The influence of regions whose economic centres are more than 150 minutes from the centre of region *r* is assumed to be negligible.

$$D_2SPILL_k^r = \sum_{s=1, s\neq r}^{m} \left( IS_k^{rs} w_{rs} \right) \text{ with } \quad w_{rs} = D_{rs}^{-1} \text{ only if } D_{rs} \leq 300km \text{, otherwise } w_{rs} = 0 \qquad [8]$$

*iii) inverse distances*

The third hypothesis also tested 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 we consider that 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*. The weight assigned to each region *s* ($s \neq r$) 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.

$$D_3SPILL_k^r = \sum_{s=1, s\neq r}^{n} \left( IS_k^{rs} w_{rs} \right) \text{ with } \quad w_{rs} = D_{rs}^{-1} \qquad [9]$$

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

An alternative measure may result into an exponential inverse distance, but in our case results are not affected, and the pure geographical distance weights without any restriction (borders or a fixed ring of 300km) are associated with no technological spillovers.

As including innovation variables built on patent data reduce number of NAMEA sectors in the analysis, and particularly forced us to exclude the "Electricity, gas and water supply" sector due to non homogeneity of data availability for all regions, we have calculated emissions from electricity consumption for each sector as a measure of indirect emissions (while remembering that RAMEA provides only direct emissions). In this way emissions associated to the "Electricity, gas and water supply" sector can be easily excluded while accounting for emissions due to energy consumption directly at the sectoral level. This change in emissions data allows us to obtain two additional valuable tools. The first one is to not consider emissions related to the electricity production, whose energy mix choices are often decided at the national rather than at the regional level. The second advantage is related to the direct effect associated to 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 due the relatively higher costs in respect with the other environmental resources. We must consider the fact that energy taxation in Italy is rather high, and the benefits from adopting energy saving technologies should be rather higher than the adoption costs.

We have calculated electricity consumption for each sector by using data provided by TERNA (the Italian major electricity transmission grid operator) and we have assigned related emissions by using an average national emission intensity factor per KWh for GHG (equal to 0.38 for GHG) and acidification emissions (0.016 for ACID).[7]

Maddison (2006) has emphasized that emissions 'from abroad' influence intra-regional emissions, given the existence of spatial correlation problems. We argue that other than only statistical influence of spatial correlation, the emissions produced by the neighbouring regions may well represent the role of agglomeration phenomena in explaining environmental performances (Gray and Shadbegian, 2007).

One can argue that the agglomeration effects on emissions may be explained by simple variety indices based on the relevance of similarity in relative specialization indices based on value added or labour units. In our case, emissions are not correlated at all with the existence of general agglomeration indices, but they are strongly influenced by the emission flows from the same sectors in neighbouring regions. We have built a sort of negative environmental spillovers as the sum of sectoral emissions $EM$ (per unit of $VA$) from other regions ($EM/VA^{s}_{k}$ with $s \neq r$) weighted by distances expressed in the three different regimes described above ($D_1$, $D_2$ and $D_3$).

In this case we can somehow interpret this variable as a sign of agglomerative effect 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 cleaner production technologies will decrease, so that a sort of polluting firms clusters emerge for selected geographical areas.

[7] We have considered an average value at the 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 but it is concerted at the national level. Considering also that the electricity produced into each region may be now consumed wherever thanks to the electricity market liberalization, it is not possible to assume a priori the energy mix related to the specific electricity consumed by each firms.

$$D_1ENVEXT_k^r = \sum_{s=1,s\neq r}^{m}\left[(EM/VA)_k^s w_{rs}\right] \text{ with } \quad w_{rs}=1 \text{ only if } s \text{ neighbouring } r \qquad [10]$$

$$D_2ENVEXT_k^r = \sum_{s=1,s\neq r}^{m}\left[(EM/VA)_k^s w_{rs}\right] \text{ with } \quad w_{rs}=D_{rs}^{-1} \text{ only if } D_{rs}\leq 300km\text{, otherwise } w_{rs}=0 \qquad [11]$$

$$D_3ENVEXT_k^r = \sum_{s=1,s\neq r}^{m}\left[(EM/VA)_k^s w_{rs}\right] \text{ with } \quad w_{rs}=D_{rs}^{-1} \qquad [12]$$

Environmental regulation is represented by three alternative expenditure measures, related to public current expenditures, capital expenditure and R&D expenditures for environmental protection activities as emerging from accounting documents of each region (ISTAT, 2007a). Table A3 (in appendix) has a description of each variable.

## 4. Empirical evidence from shift-share analysis

For brevity we restrict comments on main regions and five externalities / pollutants ($CO_2$, $SO_X$, $NO_X$, PM10, NMVOC). Table 2 presents how regions behave with respect to the national average when emission intensities are compared before their decomposition. Table 3 already shows a quite evident North-South break in environmental-economic performances, that we may further investigate in its innovation/policy/industrial structure drivers. Nevertheless, it also shows that some central and southern regions (Lazio and Campania) behave quite well, while some rich industrial regions (Veneto, Friuli Venezia Giulia) perform not so satisfactorily, then highlighting idiosyncrasies and criticalities that may be related to more complex issues bringing together geographical, economic and policy issues. The aim of shift-share analysis is specifically that of disentangling how production specialization and efficiency per se determine the overall performance of a region. Remaining on an overall picture, table 3 shows for $CO_2$ and $SO_X$ the relative emission intensity of regions.

[TABLE 2 NEAR HERE]

[TABLE 3 NEAR HERE]

If we look inside the decomposition of industry mix and efficiency/differential components, interesting insights emerge. Figure 1 sums up in a sketch the industry mix heterogeneous effect (all results are available upon request in detail, table 4 presents an example of shift-share for Lombardy): while it is evident that more industrialized regions of the North are penalized by this component (Lombardy, Emilia Romagna, Veneto, three main industrial regions) and southern regions benefit from an environmental perspective of their less industrialized specialization, it is noteworthy that, among main and largest regions, Lazio (the region of Rome, see Mazzanti and Montini, 2009, for a specific shift-share on Lazio) as service oriented region benefits and two small but economically important regions in the North with high degree of autonomy, such as Trentino Alto Adige and Friuli Venezia Giulia, also benefit on average from the industry mix component. Summing up, then this part of the shift-share analysis tells us that the North-South division regarding industrial development obviously affects the environmental comparative advantage of a region, other things being equal. But this is half the story we can tell.

[FIGURE 1 NEAR HERE]

Figure 2 presents the results for the pure efficiency (given an homogenous industry mix across regions) impacts. Results are to some extent more interesting. We also note that the size of the efficiency gap between a region and the national average – in case of pure efficiency - is on average higher with regard that of the industry mix difference. It may be plausible and expected that efficiency drives differences more than structural factors of a regional economy, in comparative terms. The efficiency gap is the main driving force behind regional comparative advantage (table 5 shows various case of best and worst situations that highlight how efficiency and North-South breaks are jointly relevant in explaining different striking performances). This is good news to some extent since emission intensity as here defined as an efficiency indicator (*EM/VA*) is relatively effectively influenced by innovation investments and policy stimulus (regulatory and market based).

[FIGURE 2 NEAR HERE]

It is noteworthy that Friuli Venezia Giulia, a developed industrialized region associated to high income per capita, performs badly on average, and not for its industry mix, but for specific (in) efficiency features. The North East as a whole, an area of the country with high economic performances driven by export intensive manufacturing, appears to perform worse than the north-western part of the industrialized North, Piedmont and Lombardy[8]. The former is actually the region that as far as the subset of 5 emissions we here consider is always performing better than the average both with respect to industry mix and efficiency. In other northern industrial regions, on average, but not for all emissions in all cases, efficiency tends to compensate for industry mix unfavourable features. Given the often proposed dichotomy between the type of industrial development occurring in the North-East of Italy, relatively more based on SME (small and medium enterprises) firms and districts rather than on large corporate firms with outsourcing collars, it is of interest to stress that at least at macro level, the economic development model based on SME seems to link less strictly economic and environmental performances. At a descriptive level, we note that, though not all innovative activities is captured by official data in SME environments (Mazzanti and Zoboli, 2009b), the R&D performances of the north-western part of the country is massively higher[9]. Besides $CO_2$, emission related regulatory efforts are quite regionally specific and a full regional analysis would be deserved. Energy mix and energy policy highly affect regional performances. One case is Friuli Venezia Giulia, an industrial region with high performances high

[8] The most industrialized regions are definitely Lombardy (NW), Veneto and Emilia Romagna (NE), with a GDP share of around 33-34%. Actually, Piedmont and Friuli Venezia Giulia are less industrial. Piedmont, also an historical industrial region, is now only at 29% of GDP. The high performance we highlight for Trentino Alto Adige is explained by efficiency, but also by a service based economy.

[9] The Italian average, North-West and North-East shares of R&D/GDP are: 1.14; 1.33; 0.79 (total), 0.55; 0.92; 0.38 (private); 0.24; 0.19; 0.15 (public except University). The 1995-2006 growth is nevertheless higher in NE, with NO showing a negative growth for private R&D. Within NE, we signal the relatively better performance of Emilia Romagna in private R&D. Labour productivity in 2008 is higher in NE with respect to NW, as a consequence of stronger growth since 1995.

innovative industrial niches but also industrial sites that exploit coal quite intensively, determining in association to a lack or inertia of regulatory efforts a gap, ceteris paribus, with other northern regions. The reasoning on regional energy structure also points to the evident good performance of a region like Trentino Alto Adige (table 5) which emerges with the best gap in 3 out of 5 emissions here scrutinized. This region is less industrial than other northern ones, and depend massively also on renewable energy (hydroelectric among others). Energy sector is relevant as in southern regions, around 3% of value added, but the type of energy mix changes drastically the performance. If for $CO_2$ it is for example clear that the *EM/VA* ratio is generally worst for the "Electricity, gas and water supply" (code E) sector, we remark how in SOx the bad performance of the North-East is driven by energy being the worst among all in the *EM/VA* indicator (only cases in Italy Veneto, Tuscany, Friuli Venezia Giulia); in such case we highlight the outlier situation of Trentino Alto Adige, only region that associates E sector to the best performance for both NOx and SOx.

The good performance of Lazio on $PM_{10}$ deserves attention[10]. While we refer the reader to Mazzanti and Montini (2009) for a detailed analysis on the specific performance of a service oriented economy such as that of Lazio and Campania (respectively with the 77% and about 70% of regional GDP represented by service), showing similar good performance in this analysis, we take advantage of this case study to remark the 'direct' nature of NAMEA emissions. Accounting for indirect generation of emissions would probably change some comparison. Though sticking to this intrinsic NAMEA feature, a weakness within the benefits of using a fully coherent integrated emission-economic accounting system, we will tackle this issue in the following sections by 'adapting' the empirical model we use of econometric analysis of *EM/VA* drivers.

Thus, shift-share analysis has shown that the North-South breaking economic and environmental performance, a fact which is obviously to be scrutinized by decision makers, is the crucial part of the story, with some interesting exceptions (Table 5). The South of Italy is then suffering from a type of industrial development (industry remains at 20-23% of GDP)[11] and a productive specialization that, although strategic for the country as a whole and consistent with a Kuznets like development within a country 'economic history', witnesses potential strong trade offs, not joint dynamics, between economic performances and environmental performances (Mazzanti and Zoboli, 2009a). We also remark how such intense and polluting development has not helped much the south in closing the gap with the North. Such different and potentially diverging performances may undermine the overall country performance in the end.

North vs South and within North and South performances could well be affected by differences in innovation and regulatory efforts. The main aim of econometric analysis in par. 5 is to study in a multivariate environment how geographical and sector based factors play a role and are weighted against other possible drivers of environmental performance, among others innovation related factors (R&D, patents), public related interventions (environmental targeted expenditures, regional policy features), as well as spatial elements (spillovers, correlation and clustering of economic and environmental performances) that could matter in determining a specific outcome we observe.

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[10] Most regions in the North (Lombardy, Veneto, Emilia Romagna, Tuscany) show a very bad $PM_{10}$ performance for the primary sector. DI sector is the major driver of $PM_{10}$ overall.

[11] We note that performances are far more heterogeneous in industry and manufacturing. As far as services are concerned, sector I (transport) is always the worst regarding the EM/VA level.

[TABLE 4 NEAR HERE]

## 5. Emission intensity drivers: econometric evidence

### 5.1 Public expenditures and R&D

We first run baseline regressions testing sector and geographical effects and labour productivity as economic driver, taking as reference an EKC like empirical model[12] testing the core income-environment (eventually non linear) relationship controlled for sector and geographical factors. Further, all baseline regressions are corrected for heteroskedasticity.

The model of reference is thus the following:

$$\ln E_k^r = A_k^r + b_1 \ln LP_k^r + b_2 \left(\ln LP_k^r\right)^2 + b_3 \ln T_k^r + b_4 \ln EE_k^r + \varepsilon_k^r$$

where ($E_k^r$) represents emissions (EM) per unit of value added (VA) for each *k*-th sector in each *r*-th region as a function of labour productivity level[13] ($LP_k^r$), private/public technology factors ($T^r$), and public environmental expenditures ($EE^r$). $A_k^r$ assumes the role of a sector/region-specific fixed effect and $\varepsilon_k^r$ is the error term.[14]

In addition, in order to introduce and control for the relevance of 'spatial' issues, we include as additional covariate a 'spatial distance lag' variable that introduces into the model the emission/value added performances of units of production within a certain distance[15].

Finally, given the intrinsic spatial feature of our data and conceptual model, even after the introduction of the 'spatial covariate', the relevance of spatial correlation has been analyzed through specific diagnostic[16]; in the case the spatially corrected model is necessary[17], we only show in tables properly corrected final regression. It may be possible, given the different nature of spatial relations regarding the data at hand, that the inclusion of a covariate correcting for spatial issue is not sufficient.

Thus, baseline specifications and those entering public expenditures or alternatively, to mitigate collinearity, R&D, are regressed correcting for spatial correlation using diverse ways of correction.

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[12] Conceptually speaking, the model refers to Mazzanti and Zoboli (2009a) and to the conceptual treatment we offer in model [1] and consequent transformations presented in section 2.2.

[13] Represented by value added per full-time equivalent job.

[14] Both factors are lagged to mitigate endogeneity related to simultaneity: environmental expenditures are introduced for 2004 (2004-2006 is the currently available time series), while R&D is introduced using various proxies for periods 2001-2002 and 2003-2004, and variations between the two. More specifically, public environmental expenditures are captured by the following variables: current and capital regional expenditures (on GDP), and the share within current and capital allocated to environmental R&D, environmental protection, management & use of natural resource; variables capturing the variations between 2004 and 2005 are also tested. As far as R&D is concerned, we introduce private and public sector R&D (on GDP), and various covariates capturing both the variation between 2001-2002 and 2003-2004 and the interaction between private and public R&D, to provide evidence on potential joint effects.

[15] See section 3, equation 10 and 11, that comments on distance related corrections.

[16] Tests are consistently performed with GEODA without geographical dummies.

[17] For the choice of the spatially corrected econometric model, we follow basically the following approach: first a OLS model is estimated. Afterwards, Lagrange Multiplier (LM) tests for the spatial error model or the spatial lag model using ordinary least squares (OLS) residuals are employed to decide whether spatial correlation is present or not. If the null hypothesis of a test for a spatial autoregressive process is rejected, a spatial variant is calculated.

### 5.1.1 Carbon dioxide

The baseline specification witnessing labour productivity, geographical (North-West, North-East and Centre Italy) and sector dummies (manufacturing sector at two digits, energy, services and primary sector are used throughout this paragraph) shows a significant U-shape form of the income-environment relationship. Sector dummies show expected signs with energy highly positive significant and services negatively significant. All in all, a first results that will be confirmed throughout the paper is the relatively stronger explanatory weight of sectors compared to that of geographical elements.

If we omit the energy sector, the U-shape vanishes and turns into a linear negative one (Mazzanti and Zoboli, 2009a): this may be plausible given the high emission high productivity features of the sector. Nevertheless, in adding the 'spatial covariate' we note that first its explanatory power is very high (1% significance), though its inclusion does not change much the economic and statistical significance of other covariates.

Thus, correcting by the spatial covariate, U-shape remains[18], and sector and geographical areas are significant as above. The further spatially corrected model, following the specific diagnostic, leads here and below[19], to a final spatial lag model which is more efficient but does not witness any relevant change in economic and statistical significance. Then, spatially corrected models are needed and necessary as the diagnostic for spatial dependence suggests; they improve fit and efficiency but do not generally alter results from an economic point of view.

Specification 1 in table 6 presents baseline estimates corrected for the diverse type of spatial issues we attempted to consider. Moving on analyzing the other drivers of emission intensity we note the followings. For carbon, both capital based and current spending is not significant. The specifications of such spending are instead significant, but only in not spatially corrected regressions. The only spending covariate maintaining its significance after all corrections are carried out[20] is the dummy showing increases in capital spending (model 2, table 6). The sign is here and below positive for most 'spending covariates': the explanation might be that such public expenses, though here technically lagged to avoid simultaneity, presents structural 'endogeneity' features. Expenditures are higher where environmental problems are harsher.

As far as R&D covariates are concerned, most factors remain significant even after the spatial correction: the change in private R&D (model 3), the share of public R&D on regional GDP (model 4), and the dummy capturing the increase in public R&D are all significant with negative sign. Further, both public/private R&D interactions, using shares and dummy (model 5), are significant. The evidence is thus strikingly in favor of a positive correlation between (joint) public and private efforts in R&D and emission performances.

[TABLE 6 NEAR HERE]

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[18] Even when omitting energy. The TP is above the mean and median, but not higher than all the high value manufacturing sectors.

[19] Overall, in all regressions studied in this and the following paragraph the suggested spatially corrected model regards 'lag' and not 'error'. A "spatial lag" is a variable that essentially averages the region-sector neighboring values of a location which is represented in our case by a specific region-sector combination. The spatial lag can be used to compare the region-sector neighboring values with those of the location itself. Which locations are defined as neighbors in this process is specified through a row-standardized spatial weights matrix based, in our case, on the contiguity of the regions. By convention, the location at the center of its neighbors is not included in the definition of neighbors and is therefore set to zero. It has to be noted that our cross section dataset refers to 20 regions x 23 sectors; it means that the potential neighbors for the textile sector in the Veneto region is represented by the textile sector in the contiguous regions and similarly for other sectors. Thus our contiguity weights matrix has 460 rows (or a smaller number of rows when specific statistical units are excluded form the analysis), one for each combination region-sector.

[20] It is worth noting that the inclusion of D2 only does not alter statistical significances.

### 5.1.2 Acidification

The non corrected baseline specification is worth noting for geographical effects: coherently with shift-share analyses, the North-East presents very significant positive coefficient.

Table 7 (specification $SO_X(1)$) highlights that for $SO_X$ the income-environment relationship is, as found by other authors (Marin and Mazzanti, 2009, Vollebergh et al., 2009) not significant. The drivers of emission intensity are predominantly others. Manufacturing and energy Sector covariates show expected signs.

For $SO_X$, both current-based and capital based public spending are significant, as noted and commented on above with a positive sign (model $SO_X(2)$ and $SO_X(3)$).

Nevertheless, the variation in current spending between 2005 and 2004 shows a negative sign (regression not shown): this highlights that though structural correlation may be positive in levels (such spending is a quasi-fixed factors in the shirt medium run), the variation of spending can negatively correlate to environmental performances, contributing then to abatement at regional level.

R&D is again highly significant with significant negative signs. The evidence shows that, differently from carbon, is only public R&D that matters after correcting by spatial 'lag' correlation: the various changes in public R&D and the changes of jointly taken private and public R&D drive down emissions on value added (see model $SO_X(4)$, not all regressions are shown). In the end, for $SO_X$, public stimulus to innovation weights more than private ones.

The other acidification emission $NO_X$ firstly presents a geographical performance in favor of all central-northern regions. In spatially corrected regressions, a U-shape income-environment relationship is confirmed[21]. Among spending specifications, as above, no factor is significant after the final correction[22].

As far as innovation is concerned, both private and public R&D on GDP is significant with expected negative signs. The change in public R&D and the interaction between public and private R&D are also significant. A general significant effect on innovation, with emphasis on the public side and mainly on the always significant 'interaction' terms, that clearly signal an effect depending on joint implementation of innovation drivers (models $NO_X(2\text{-}4)$).

[TABLE 7 NEAR HERE]

### 5.1.3 Local pollutants

In both cases, the regression not corrected by the spatial lag model show that the northern and central regions perform better than the southern and islands. Spatially (lag) corrected estimates show U-shapes in relation to income, with a TP higher than in previous cases but still within range.

Most manufacturing sectors drive emissions up, while services consistently drive them down.

While on the public spending side no worthwhile results emerge, again the role of R&D seems important. Private spending on GDP and the interaction between private and public R&D shares negatively affects regional emissions on value added (Table 8, model NMVOC(1-2)).

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21 Energy sector does not seem to be here the main element behind this U-shape.

22 We note that environmental R&D, environmental protection and use/management of natural resources, as shares of current and capital spending, often arise significant with negative sign in specifications corrected by D2. This significance generally vanishes when using the spatial lag model.

$PM_{10}$ presents somewhat different evidence: from a sectoral perspective DI (ceramic) emerge again as stronger emitter, in addition to agriculture, while services and within manufacturing DK (machinery and equipment) and DB (textile) instead present negative coefficients; the relation to productivity is linear and negative in regressions that include D2, but turns out to be not significant when using the spatial lag model in the end. Though they appear initially significant, final corrections instead make disappear the significance of capital based environmental protection and R&D environmental share of spending (Table 8, model $PM_{10}$(1-4)). Turning to general R&D, evidence neatly shows that both private and public regional R&D matter taken separately and interacted to each other.

[TABLE 8 NEAR HERE]

Summing up, emission efficiency is related to labour productivity by non linear U-shapes (carbon, NOx, NMVOC). In other cases, the dominant role played by sectors overwhelms income significance. Sectors weight relatively more than geographical factors. The additional drivers we test show that when properly correcting for spatial correlation, R&D is always very significant in driving down emission per unit of value across al emissions, both through separate effects of private and public R&D and by joint effects. 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.

### 5.2 Technological innovation and interregional spillovers

We have tested our hypotheses on the relative strength of the effects associated to internal and extra regional innovation and public environmental expenditures for GHG and ACID, whose diffusion is different. The potential reaction from the community will be consistent to these differences, as for the more localized polluting emissions we expect that the impact of knowledge externalities will be higher. When the emitting firm is damaged by its own emissions or those produced by its neighbours, the reaction to negative externalities is expected to be stronger, because the subject which produces the damage and sustains the costs associated to these externalities will coincide. The collective action (played by consumers but also by firms) will be stronger and the convenience to exploit innovation externalities coming from closer areas is potentially higher. The inducement effect on a technology path oriented toward less-polluting production processes will come also from the private initiative, and not only from public enforcement. In this sense, the probability that an innovation will be suitable also for environmental protection purposes will be higher, and also the probability of a higher diffusion speed will increase.

The impact of labour productivity in explaining the environmental performance is rather high in the case of both GHG and ACID emissions, and the negative coefficient associated to this variable can be interpreted as a positive correlation between productivity gains with environmental efficiency gains. As we have disentangled pure innovation effects from all other characteristics in the production function, we may affirm that labour productivity allows explaining all structural features in the production process such us the adoption of environmental management systems, quality control, highly efficient mechanical appraisals.

We have also included a specific variable related to energy intensity by computing the electricity consumption to value added ratio for each specific sector, thus catching all the possible sector specific effect associable to energy consumption. And we have introduced a dummy variable which absorb the effect of specific dirty industries.[23] In this way productivity gains and innovation effects can be interpreted as the real impact on environmental efficiency related to investments in technology and labour productivity. It is worth noticing that the level of internal innovation, expressed as the number of patents per value added, plays a limited role in explaining environmental efficiency gains, as the coefficient is always negative as we expected, but with a low value and limited statistical robustness, in both GHG and ACID cases. We can interpret this result by considering the fact that our innovation variable relates to the general efforts (measured as an output indicators rather than an input as R&D private expenditures) by firms/sectors to produce technology without specific environmental purposes. Looking at model (3) in Table 9 without the spatial lag correction, we can see that when the variable related to public R&D environmental expenditures is included among the regressors, the internal innovation variable is no more statistically significant.

For GHG emissions it is worth noticing that environmental efficiency spillovers (the spatial effect related to emission efficiency of the same sector located in neighbouring regions) play a significant role in better explaining environmental performances, and statistical robustness is clearly reinforced by using the spatial lag model.[24] The maximum distance where the environmental efficiency spillovers occurs coincide with regions in the range of 300 km, so that emission intensity of the same sector into other regions influences internal emission intensity within two spatial regimes, the $D_1$ and $D_2$, eq. [10] and eq. [11] respectively.[25] The positive coefficient can be interpreted as a first evidence on the existence of clusters not only intended as agglomeration of specific sectors into restricted areas, but also as a first influence of technology adopted in the production processes. As far as the environmental efficiency of the neighbouring sectors decreases (corresponding to an increase of polluting emissions per value added) the internal environmental performance for each specific sector decreases as well. This means that together with the agglomeration of specific sectors into restricted areas, there is also some convergence in the production process. In fact, when controlling for sector specific fixed effects (expressed by the dirty sectors dummy), the negative impact on environmental performance related to environmental spillovers still remains. To some extent, we may affirm that the clustering process of specific polluting sectors into selected geographical areas may be followed by common choices in the adoption of cleaner or dirtier technologies, which help us explaining why the same sector specialization into different regions may be characterized by different emission intensities or efficiency as found in the previous shift-share analysis.

[TABLE 9 NEAR HERE]

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[23] The specific industries with value 1 are: Agriculture, Manufacture of coke, refined petroleum products and nuclear fuel, Manufacture of chemicals and chemical products, Manufacture of other non-metallic mineral products, Electricity, gas and water supply.

[24] The diagnostic for spatial dependence has been run for every specification; the proper spatially corrected econometric model has been estimated when the diagnostic is significant. The variables with a spatial dimension as environmental efficiency spillovers and technological spillovers benefit the more from the spatial lag models with respect to the standard OLS and generally the spatial correction in the model, due to the significant diagnostic for spatial dependence, do not alter our findings at all.

[25] Tables 9 and 10 report coefficients for $D_1$ spatial regimes, but results are also consistent with $D_2$. Regime $D_3$ is not significant both for environmental (eq. [12]) and technological (eq. [9]) spillovers. For the sake of simplicity, results are not reported in the Tables but they are available upon request from the authors.

Technological interregional spillovers seem to play a more effective role in improving environmental efficiency, as coefficients in all the three specification are negative and statistically significant, with an increasing robustness in the spatially-lagged models. The higher impact of innovation spillovers compared to internal innovation may be well explained by the nature itself of our innovation variable. As we have already stressed, it is not related to the availability of specific environmental-friendly technologies, but to a more general innovative capacity at the sector level. Hence, the wider is the range of available technologies (proxied by innovation spillovers) in the neighbouring area, the higher is the probability that there are also environmental-friendly technologies.[26]

As we are including among our regressors variables related to regional innovation and technological spillovers from the other regions in the same time period (one year lag) a multicollinearity problem may arise if regional innovation can be explained by spillovers. In order to check for robustness of our model we have tested a potential endogeneity of the regressor explaining regional innovation by performing the Hausman test on the two alternatives, a standard OLS and an instrumental variable estimator where regional patents are instrumented by spillovers and other common variables in the technology diffusion literature. The test rejected the hypothesis that the IV estimator better performs than the OLS, which remains consistent and efficient.[27]

[TABLE 10 NEAR HERE]

As regarding to public environmental expenditures as a proxy of the economic value given to environmental externalities by the local community, the coefficients have the expected negative sign as an increase in the social price of negative externalities should force firms to adopt more efficient production processes. Variables related to current and capital expenditures, as well as to specific R&D environmental expenditures, have been tested with temporal lags. The temporal lag reflects the assumption of a sort of inducement effect played by environmental regulation, expecting that environmental efficiency will improve after a certain time due to high investment costs to accomplish with the regulatory commitments.[28]

Nonetheless, results are not robust and this is mainly due to our data which are sector invariant. In this sense, it could be very useful to have specific sectoral data on private environmental expenditures in order to catch potential complementarity effects between this dimension and the general innovative capacity.

According to this, Gray and Shadbegian (2007) find that there is some role for private environmental management systems adopted by neighbouring firms in explaining own environmental performance for polluting plants: in our case we have not found any significant effect on emission intensity reduction relative to both internal efforts and neighbouring environmental regulatory system, while we have found robust effects associated to the existence of polluting sectors clusters.

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[26] 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, but results are not statistically significant. Thus the only significant result is associated to the technological spillovers from innovation activities of firms in the same sector located in the neighbouring regions.

[27] We have also tested robustness of our specification by including alternatively the two innovation dimensions and coefficients remain stable in signs and statistically significant both for regional innovation and regional spillover effects.

[28] Tables 9 and 10 report results for one lag, but also for the other lag structures results remain unchanged.

## 6. Conclusions

The achievement of positive environmental performances at the national level could strongly depend on differences within local capabilities of both institutions and the private business sector. Environmental regulation - especially if set at the national level - can be a weak instrument if the institutional and business environment could not transform regulation strengths into opportunities. This paper has developed diverse and complementary empirical analyses using the 2005 Italian regional NAMEA.

The shift share analysis has given to us the possibility to disentangle how production specialization and (environmental) efficiency per se determine the overall performance of a region. The decomposition of industry mix and efficiency/differential components revealed by the shift-share analysis tells us that the Italian North-South division regarding industrial development (and industrial specialization) obviously affects the environmental comparative advantage of a region, other things being equal. However when we examine the pure efficiency impacts (given an homogenous industry mix across regions), results show that the size of the efficiency gap between a region and the national average is on average higher with regard that of the industry mix difference. It may be plausible that efficiency drives differences more than structural factors of a regional economy. This represents good news to some extent since emission intensity as here defined as an (in) efficiency indicator (emissions/value added) may be effectively influenced by innovation investments and policy stimulus (regulatory and market based). It is noteworthy that Friuli Venezia Giulia, a developed industrialized north-eastern region associated to high income per capita, performs badly on average, and not for its industry mix, but for specific (in) efficiency features. The North-East as a whole, an area of the country with high economic performances driven by export intensive manufacturing, appears to perform worse than the north-western part of the industrialized North, Piedmont and Lombardy. The former is actually the region that, considering the 5 emissions used in the shift-share analysis, is always performing better than the average with respect both to industry mix and efficiency.

The spatial econometric analyses have explored how geographical and sector based factors play a role against other possible drivers of environmental performance, such as innovation related factors (R&D, patents), public related interventions (environmental expenditures, regional policy features), as well as spatial elements (technological spillovers, correlation and clustering of economic and environmental performances). For GHG emissions (contrasting to ACID emissions) it is worth noticing that environmental efficiency spatial spillovers (related to emission efficiency of the same sector in neighbouring regions) play a significant role in better explaining environmental performances. The maximum distance where the environmental efficiency (corresponding to an increase of polluting emissions per value added) spillovers significantly occur, coincide with regions in the range of 300 km. This result can be interpreted as first evidence on the existence of clusters not only intended as agglomeration of specific sectors into restricted areas, but also as a first influence of technology adopted in the production processes. As far as the environmental efficiency of the neighbouring sectors decreases, the internal environmental performance for each specific sector decreases as well. This means that together with the agglomeration of specific sectors into restricted areas, there is also some convergence in the production process. In fact, when we control for sector specific fixed effects (as evidenced by a dirty sectors dummy), the negative impact on environmental performance related to environmental spillovers still remains. It seems that the clustering process of specific polluting sectors into selected geographical areas may be followed by common choices in the adoption of cleaner or dirtier technologies, which help us explaining why the same sector specialization into different regions may be characterized by different emission intensities or efficiency as found in the shift-share analysis.

As a concluding remark, we can consider that our results have shown that North vs South and within North and South Italian performances may well be affected by differences in innovation and regulatory efforts. The current and future definition of industrial, innovation, environmental policy efforts at national and regional level could thus led to a joint link between economic and environmental approaches in most if not all, regions of Italy.

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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 defence; 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<br>DA16 - Manufacture of tobacco products | A21-A22-A23-A24-C12-C13 |
| 5 | DB17 - Manufacture of textiles<br>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<br>DH25 - Manufacture of rubber and plastic products<br>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<br>DE22 - Publishing, printing, reproduction of recorded media | B31-B42-B43-B44-D21-G09 |
| 9 | DF23 - Manufacture of coke, refined petroleum products and nuclear fuel<br>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<br>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.<br>DL30 - Manufacture of office machinery and computers<br>DL31 - Manufacture of electrical machinery and apparatus n.e.c.<br>DL32 - Manufacture of radio, television and communication equipment and apparatus<br>DL33 - Manufacture of medical, precision and optical instruments, watches and clocks<br>DM34 - Manufacture of motor vehicles, trailers and semi-trailers<br>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 |
| Labour productivity$^2$ | Value added per full-time equivalent job unit (squared) |
| Environ. Spillovers (D1) | Specific pollutant emissions in directly neighbouring regions |
| Environ. Spillovers (D2) | Specific pollutant emissions in regions ≤ 300 km maximum distance |
| Var.Env.Cap.Exp.04/05+ (dummy) | Environmental expenditure (capital) variation 2005-04 (1 if positive) |
| Var.Priv.Exp.2005/04-2003/02 | Private expenditure variation (2005/04-2003/02) |
| PubExp GDP (share) | Public expenditure out of total regional GDP |
| PrivExp GDP (share) | Private expenditure out of total regional GDP |
| PrivExpXPubExp | Private expenditure X Public expenditure (interactive variable) |
| Priv.&Pub.Exp + (dummy) | Private and Public expenditure (1 if both positive) |
| Energy intensity | Electricity consumption to value added ratio for each specific sector |
| Electricity surplus (dummy) | Dummy for regional electricity surplus |
| Env.Reg.Curr.Exp. | Environmental regional expenditure 2004 (current) |
| Env.Reg.Cap.Exp. | Environmental regional expenditure 2004 (capital) |
| Env.Reg.Prot.Exp (share) | Environmental protection regional expenditure (out of total environmental expenditure) |
| Env.Reg.R&D.Exp (share) | Environmental R&D regional expenditure (out of total environmental expenditure) |
| Internal Innovation | Number of patents per value added |
| Techn. Reg. Spillovers | Sum of knowledge (sectoral patents) available in directly neighbouring regions |
| Dirty Sectors dummy | Dummy for heavy polluting sectors |

**TABLES and FIGURES**

Table 1 – Possible situation of regional environmental performances according to shift-share parameters and policy actions

| *industry mix (m)* | *efficiency (p)* | *Lines of actions* |
|---|---|---|
| + | + | Optimal situation: environmental policy functional to the economic system performance |
| - | - | Worse situation: necessity of strong joint actions on environmental policy and industrial policy sides |
| + | - | Development industrial policy aimed at enhancing the structural environmental performances jointly with competiveness |
| - | + | Environmental and innovation policy favoring more energy and emission efficiency in the sectors which are more relevant in economic and environmental terms in the region |

Note: + means the emission intensity is lower than the national average for the specific component of shift-share

Table 2 – Regional performances§ with regard the national average (geographical area in brackets)

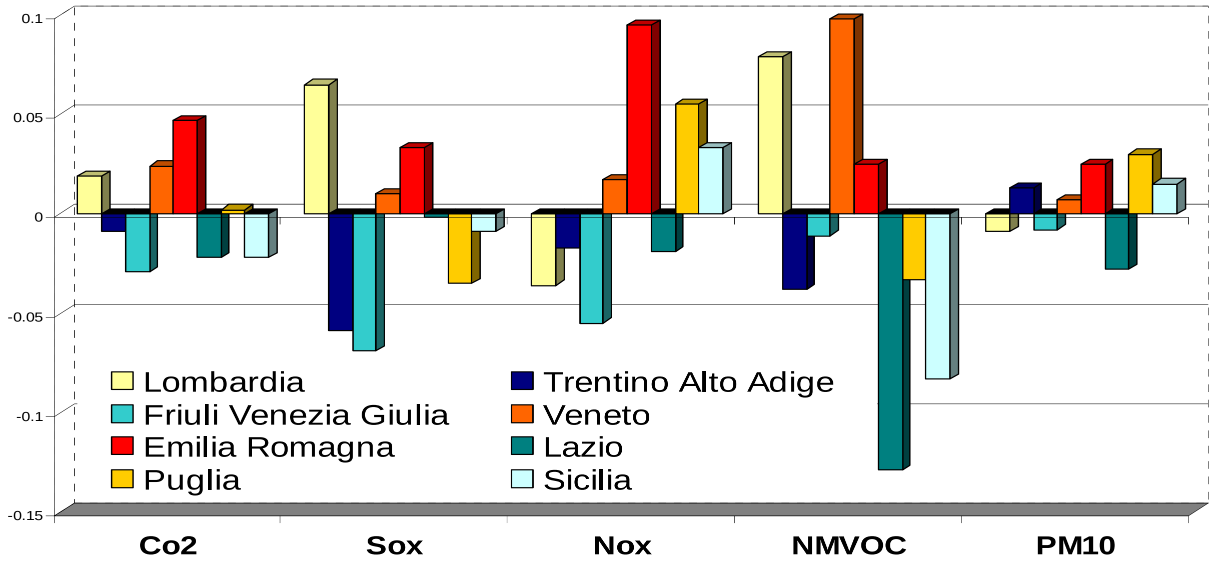
| | |
|---|---|
| 10 out of 10 | Marche (C), Lazio (C) and Campania (C) |
| 9 out of 10 | Trentino Alto Adige (NE) |
| 8 out of 10 | Lombardy (NO) and Tuscany (C) |
| 7 out of 10 | Piedmonte (NO), Valle d'Aosta (NO) and Liguria (NO) |
| 6 out of 10 | Emilia Romagna (NE) and Abruzzo (C) |
| 5 out of 10 | Veneto (NE) |
| 4 out of 10 | Calabria (S), Sicily (I) and Umbria (C) |
| 1 out of 10 | Puglia (S) and Basilicata (S) |
| 0 out of 10 | Sardinia (I) |

Notes: NW= North West; NE= North East, C=Centre, I=Islands, S=South.
§ number of pollutans out of 10 with a better performance than the national average.

Table 3 – Regional performances: $CO_2$ and $SO_X$ emission intensity (kg x 1M€ of value added, increasing order)

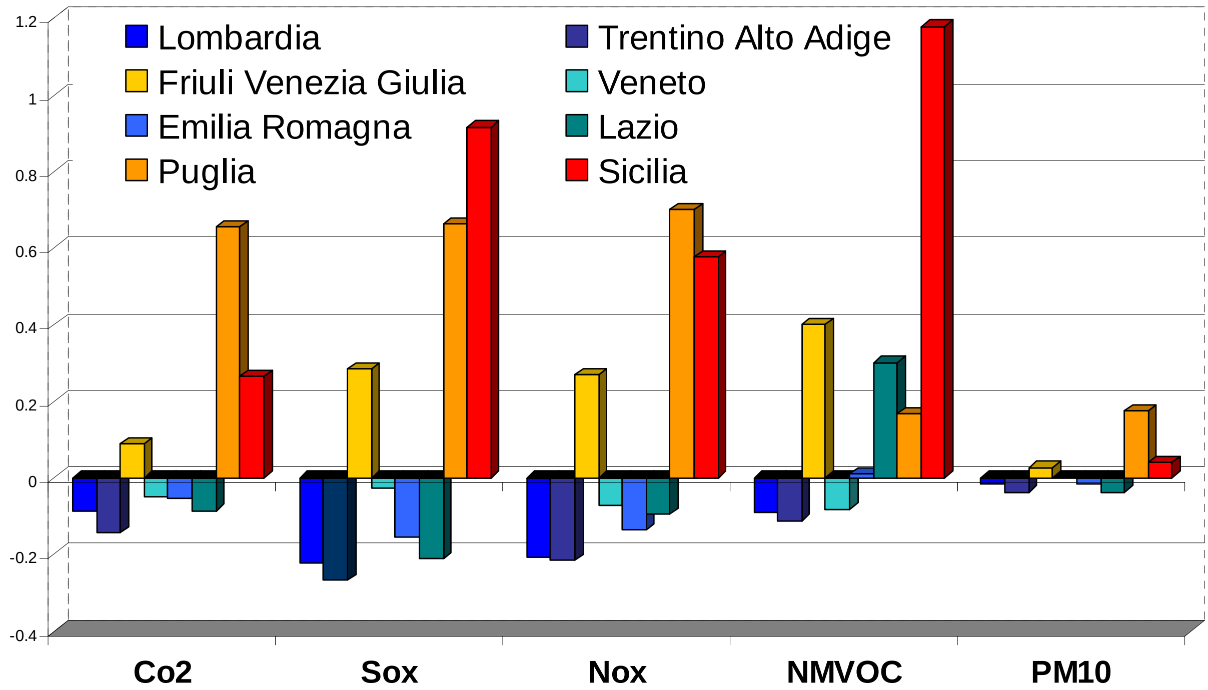
| Region | $CO_2$ | Region | $SO_X$ |
|---|---|---|---|
| Trentino Alto Adige | 136 | Trentino Alto Adige | 39 |
| Campania | 141 | Valle d'Aosta | 45 |
| Valle d'Aosta | 153 | Abruzzo | 69 |
| Piedmonte | 185 | Campania | 78 |
| Lazio | 204 | Lombardy | 99 |
| Marche | 206 | Lazio | 101 |
| Lombardy | 209 | Marche | 108 |
| Abruzzo | 258 | Piedmonte | 108 |
| Veneto | 267 | Calabria | 123 |
| Emilia Romagna | 270 | Basilicata | 224 |
| Tuscany | 278 | Emilia Romagna | 226 |
| Italy | 301 | Molise | 276 |
| Calabria | 307 | Veneto | 300 |
| Umbria | 342 | Italy | 315 |
| Friuli Venezia Giulia | 353 | Tuscany | 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 |

Figure 1 – Shift-share results: industry mix / production specialization component (*m*)#




Note: # the smaller the indicator the better is the environmental performance.

Figure 2 – Shift-share results: efficiency / differential component (*p*)#




Note: # the smaller the indicator the better is the environmental performance.

Table 4 – Example of shift-share analysis for Lombardy (Lom)

| *Emission* | $X_{Lom}$ | $X$ | $X_{Lom} - X$ | *Difference%* | *m* | *p* | *a* | *m+p+a* |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | 1.192 | 1.448 | -0.255 | -18% | -0.309 | 0.441 | -0.386 | -0.255 |
| CO | 0.383 | 0.990 | -0.607 | -61% | 0.042 | -0.521 | -0.127 | -0.607 |
| $CO_2$ | 0.209 | 0.301 | -0.091 | -30% | 0.019 | -0.089 | -0.021 | -0.091 |
| $N_2O$ | 0.067 | 0.095 | -0.028 | -29% | -0.011 | 0.020 | -0.037 | -0.028 |
| $NH_3$ | 0.370 | 0.311 | 0.059 | 19% | -0.143 | 0.384 | -0.182 | 0.059 |
| NMVOC | 0.411 | 0.460 | -0.048 | -10% | 0.079 | -0.090 | -0.037 | -0.048 |
| $NO_X$ | 0.465 | 0.713 | -0.248 | -35% | -0.036 | -0.208 | -0.003 | -0.248 |
| Pb | 0.231 | 0.210 | 0.020 | 10% | 0.061 | -0.020 | -0.020 | 0.020 |
| $PM_{10}$ | 0.074 | 0.111 | -0.037 | -33% | -0.009 | -0.017 | -0.009 | -0.037 |
| $SO_X$ | 0.099 | 0.315 | -0.216 | -68% | 0.065 | -0.222 | -0.058 | -0.216 |

Table 5 – Largest gaps and main driver between regions and Italian average

| | $CO_2$ | $SO_X$ | $NO_X$ | NMVOC | $PM_{10}$ |
|---|---|---|---|---|---|
| *Emissions/Value added* | | | | | |
| Italy | 0.301 | 0.315 | 0.713 | 0.460 | 0.111 |
| best region | Trentino Alto Adige | Trentino Alto Adige | Lombardy | Trentino Alto Adige | Lazio |
| gap region/Italy | 0.136 | 0.079 | 0.465 | 0.241 | 0.055 |
| worst region | Puglia | Sardinia | Sardinia | Sicily | Puglia |
| gap region/Italy | 0.971 | 1.53 | 1.574 | 0.749 | 0.3 |
| Ratio worst/best | 7.14 | 19.37 | 3.38 | 3.11 | 5.45 |
| *Shift-share parameters* | | | | | |
| best region for industry mix (m) or efficiency (p) | Trentino Alto Adige | Trentino Alto Adige | Lombardy | Trentino Alto Adige | Lazio |
| gap region/Italy | 0.144 | 0.268 | 0.208 | 0.215 | 0.037 |
| main factor | p | p | p | p | p |
| worst region gap for industry mix (m) or efficiency (p) | Puglia | Sardinia | Sardinia | Sicily | Puglia |
| gap region/Italy | 0.654 | 1.481 | 0.956 | 1.179 | 0.175 |
| main factor | p | p | p | p | p |

Table 6 – OLS and spatial models for $CO_2$ emissions

| | OLS with diagnostic for spatial dependence | | | | | Spatially-lagged models | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (1) | (2) | (3) | (4) | (5) |
| Labour productivity | -3.133** | -4.057*** | -3.665*** | -3.863*** | -3.774*** | -2.532** | -3.698*** | -3.248*** | -3.471*** | -3.376*** |
| | -2.40 | -3.11 | -2.89 | -2.97 | -2.89 | -2.17 | -3.06 | -2.64 | -2.82 | -2.74 |
| Labour productivity² | 0.367** | 0.494*** | 0.444*** | 0.479*** | 0.462*** | 0.309** | 0.465*** | 0.403** | 0.440*** | 0.424*** |
| | 2.14 | 2.90 | 2.65 | 2.82 | 2.71 | 2.01 | 2.94 | 2.51 | 2.73 | 2.64 |
| Environ.Spillovers(D1) | 0.416*** | 0.376 | | | | 0.311*** | 0.283*** | | | |
| | 10.64 | 9.00*** | | | | 8.84 | 7.33 | | | |
| Environ.Spillovers(D2) | | | 0.411*** | 0.414*** | 0.406*** | | | 0.278*** | 0.284*** | 0.272*** |
| | | | 9.06 | 9.14 | 8.94 | | | 6.48 | 6.62 | 6.36 |
| Var.Env.Cap.Exp.04/05+ (dummy) | | 0.221** | | | | | 0.224** | | | |
| | | 2.21 | | | | | 2.41 | | | |
| Var.Priv.Exp.2005/04-2003/02 | | | -0.533** | | | | | -0.566** | | |
| | | | -2.17 | | | | | -2.44 | | |
| PubExp GDP (share) | | | | -52.062*** | | | | | -41.092** | |
| | | | | -2.72 | | | | | -2.27 | |
| Priv.&Pub.Exp + (dummy) | | | | | -0.177* | | | | | -0.217** |
| | | | | | -1.75 | | | | | -2.29 |
| Constant | 5.134** | 6.603*** | 4.547* | 4.275* | 4.222* | 4.274* | 6.138*** | 4.644** | 4.352* | 4.360* |
| | 2.08 | 2.66 | 1.91 | 1.73 | 1.70 | 1.93 | 2.67 | 1.98 | 1.86 | 1.86 |
| Sectoral dummies | Yes | Yes | Yes | Yes | Yes | Yes | | | Yes | |
| Spatial Lag | | | | | | 0.402 | 0.341*** | 0.309*** | 0.291*** | 0.315*** |
| | | | | | | | 7.82 | 6.84 | 6.41 | 6.97 |
| No obs. | 399 | 418 | 418 | 418 | 418 | 399 | 418 | 418 | 418 | 418 |
| Adj R-sq | 0.64 | 0.63 | 0.62 | 0.63 | 0.62 | 0.71 | 0.68 | 0.67 | 0.66 | 0.66 |
| F-stat | 50.99 | 44.51 | 47.05 | 44.46 | 43.73 | | | | | |
| LM (lag) | 60.95 (0.00) | 38.77 (0.00) | 23.14 (0.00) | 20.08 (0.00) | 23.77 (0.00) | | | | | |
| Robust LM (lag) | 60.65 (0.00) | 43.32 (0.00) | 54.71 (0.00) | 56.48 (0.00) | 51.07 (0.00) | | | | | |
| LM (error) | 15.20 (0.00) | 9.47 (0.00) | 0.66 (0.41) | 0.07 (0.79) | 1.21 (0.27) | | | | | |
| Robust LM (error) | 14.90 (0.00) | 10.02 (0.00) | 32.25 (0.00) | 36.47 (0.00) | 28.51 (0.00) | | | | | |
| Log L | | | | | | -487.41 | -557.09 | -565.06 | -565.31 | -565.5 |
| Breusch-Pagan test | | | | | | 216.37 | 346.27 | 328.49 | 307.03 | 305.52 |
| LR test | | | | | | 62.75 | 40.13 | 27.27 | 24.01 | 28.07 |

Table 7 – OLS and spatial models for $SO_X$ and $NO_X$ emissions

| | OLS with diagnostic for spatial dependence | | | | | | | | Spatially lagged models | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $SO_X$(1) | $SO_X$(2) | $SO_X$(3) | $SO_X$(4) | $NO_X$(1) | $NO_X$(2) | $NO_X$(3) | $NO_X$(4) | $SO_X$(1) | $SO_X$(2) | $SO_X$(3) | $SO_X$(4) | $NO_X$(1) | $NO_X$(2) | $NO_X$(3) | $NO_X$(4) |
| Labour productivity | 0.030 | 0.059 | 0.107 | 0.0149 | -3.37*** | -3.31*** | -3.743*** | -3.664*** | 0.142 | 0.172 | 0.209 | 0.137 | -2.362*** | -2.43*** | -2.56*** | -2.53*** |
| | 0.12 | 0.22 | 0.40 | 0.06 | -3.33 | -3.34 | -3.72 | -3.66 | 0.56 | 0.68 | 0.82 | 0.54 | -2.78 | -2.87 | -3.04 | -3.01 |
| Labour productivity² | | | | | 0.411*** | 0.412*** | 0.460*** | 0.452 | | | | | 0.293*** | 0.305*** | 0.320*** | 0.317*** |
| | | | | | 3.25 | 3.32 | 3.65 | 3.60 | | | | | 2.75 | 2.88 | 3.02 | 3.00 |
| Environ.Spillovers(D1) | 0.33*** | 0.347*** | 0.362** | 0.319*** | 0.440*** | 0.455*** | 0.427*** | 0.433*** | 0.266*** | 0.279*** | 0.294*** | 0.246*** | 0.142** | 0.157*** | 0.132*** | 0.139*** |
| | 6.71 | 6.97 | 7.09 | 6.51 | 10.95 | 11.45 | 10.68 | 10.88 | 5.57 | 5.85 | 5.99 | 5.27 | 2.53 | 4.57 | 3.92 | 4.12 |
| Electricity surplus (dummy) | 0.337* | 0.201 | 0.319 | | 0.018 | 0.008 | 0.231* | 0.217** | 0.230 | 0.088 | 0.216 | | 0.018 | 0.026 | 0.153* | 0.140* |
| | 1.73 | 0.99 | 1.64 | | 0.18 | 0.09 | 2.26 | 2.22 | 1.22 | 0.45 | 1.15 | | 0.22 | 0.33 | 1.81 | 1.72 |
| Env.Reg.Curr.Exp. | | 67.51** | | | 52.90*** | | | | | 69.96** | | | 31.96* | | | |
| | | 2.22 | | | 3.49 | | | | | 2.40 | | | 2.53 | | | |
| Env.Reg.Cap.Exp. | | | 51.11** | | | | | | | | 46.71** | | | | | |
| | | | 2.22 | | | | | | | | 2.11 | | | | | |
| Priv.&Pub.Exp+(dum.) | | | | -0.389** | | | | | | | | -0.51*** | | | | |
| | | | | -2.03 | | | | | | | | -2.78 | | | | |
| PrivExp GDP (share) | | | | | | -64.43*** | | | | | | | | -31.93*** | | |
| | | | | | | -5.01 | | | | | | | | -2.92 | | |
| PubExp GDP (share) | | | | | | | -54.99*** | | | | | | | | -36.74* | |
| | | | | | | | -2.85 | | | | | | | | -2.29 | |
| PrivExpXPubExp | | | | | | | | -10587*** | | | | | | | | -6573*** |
| | | | | | | | | -3.60 | | | | | | | | -2.68 |
| Constant | -3.9*** | -4.10*** | -4.32*** | -3.57*** | 6.206 | 6.360*** | 7.037** | | -3.56*** | -3.73*** | -3.93*** | -3.09*** | 4.44*** | 4.705*** | 4.897*** | 4.820 |
| | -3.57 | -3.73 | -3.89 | -3.23 | 3.12 | 3.27 | 3.56 | | -3.30 | -3.47 | -3.61 | -2.87 | 2.66 | 2.84 | 2.96 | 2.92 |
| Sectoral dummies | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Spatial Lag | | | | | | | | | 0.219*** | 0.222*** | 0.214*** | 0.250*** | 0.632*** | 0.610*** | 0.639 | 0.631 |
| | | | | | | | | | 4.63 | 4.73 | 4.54 | 5.37 | 18.69 | 17.60 | 19.09 | 18.67 |
| No obs. | 418 | 418 | 418 | 418 | 418 | 418 | 418 | 418 | 418 | 418 | 418 | 418 | 418 | 418 | 418 | 418 |
| Adj R-sq | 0.45 | 0.47 | 0.45 | 0.45 | 0.57 | 0.59 | 0.57 | 0.57 | 0.49 | 0.49 | 0.49 | 0.50 | 0.70 | 0.70 | 0.70 | 0.70 |
| F-stat | 23.37 | 22.43 | 22.43 | 23.51 | 35.94 | 37.84 | 35.33 | 36.05 | | | | | | | | |
| LM (lag) | 13.14 | 13.59 | 12.46 | 17.17 | 80.56 | 68.91 | 83.38 | 80.77 | | | | | | | | |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | | | | | | | | |
| Robust LM (lag) | 20.77 | 24.27 | 23.50 | 29.57 | 109.79 | 88.96 | 93.44 | 97.64 | | | | | | | | |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | | | | | | | | |
| LM (error) | 1.76 | 1.25 | 0.92 | 1.90 | 19.84 | 15.32 | 26.67 | 23.06 | | | | | | | | |
| | (0.18) | (0.26) | (0.33) | (0.17) | (0.00) | (0.00) | (0.00) | (0.00) | | | | | | | | |
| Robust LM (error) | 9.40 | 25.52 | 11.97 | 14.29 | 49.06 | 35.38 | 36.73 | 39.92 | | | | | | | | |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | | | | | | | | |
| Log L | | | | | | | | | -846.12 | -843.28 | -843.86 | -843.31 | -499.00 | -497.54 | -499.74 | -498.60 |
| Breusch-Pagan test | | | | | | | | | 182.28 | 214.56 | 212.54 | 195.34 | 368.33 | 331.80 | 334.56 | N/A |
| LR test | | | | | | | | | 14.38 | 14.94 | 13.79 | 18.84 | 107.15 | 97.26 | 109.83 | 107.17 |

Table 8 – OLS and spatial models for NMVOC and $PM_{10}$ emissions

| | OLS with diagnostic for spatial dependence | | | | | | Spatially-lagged models | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NMVOC(1) | NMVOC(2) | $PM_{10}$(1) | $PM_{10}$(2) | $PM_{10}$(3) | $PM_{10}$(4) | NMVOC(1) | NMVOC(2) | $PM_{10}$(1) | $PM_{10}$(2) | $PM_{10}$(3) | $PM_{10}$(4) |
| Labour productivity | -4.22*** | -3.873*** | -0.357*** | -0.275 | -0.226* | -0.277** | -3.933*** | -3.791*** | -0.187 | -0.153 | -0.105 | -0.148 |
| | -3.68 | -3.43 | -2.60 | -2.05 | -1.63 | -2.06 | -4.14 | -3.99 | 1.55 | -1.27 | -0.88 | -1.22 |
| Labour productivity² | 0.455** | 0.423*** | | | | | 0.458*** | 0.444*** | | | | |
| | 3.05 | 2.88 | | | | | 3.69 | 3.59 | | | | |
| Environ.Spillovers(D1) | 0.630*** | 0.653*** | 0.391*** | 0.454*** | 0.437*** | | 0.336*** | 0.356*** | 0.254*** | 0.300*** | 0.297*** | |
| | 18.78 | 19.47 | 9.46 | 10.77 | 10.70 | | 10.87 | 11.29 | 7.05 | 7.95 | 8.20 | |
| Environ.Spillovers(D2) | | | | | | 0.459 | | | | | | 0.268*** |
| | | | | | | 10.64 | | | | | | 6.87 |
| Electricity surplus (dummy) | | | 0.179* | -0.171 | 0.045 | | | | 0.021 | -0.160 | -0.064 | |
| | | | 1.78 | -1.40 | 0.44 | | | | 0.23 | -1.47 | -0.72 | |
| PrivExp GDP (share) | | -44.54*** | | | -73.15*** | | | -19.69** | | | -52.61*** | |
| | | -3.84 | | | -5.41 | | | -2.01 | | | -4.38 | |
| PubExp GDP (share) | | | | | | -52.320*** | | | | | | -37.45** |
| | | | | | | -2.78 | | | | | | -2.22 |
| Env.Reg.Prot.Exp (share) | | | | -7.415*** | | | | | | -3.837** | | |
| | | | | -3.50 | | | | | | -2.03 | | |
| Env.REg.R&D.Exp (share) | | | | -23.354 | | | | | | -13.815*** | | |
| | | | | -4.44 | | | | | | -2.95 | | |
| Constant | 8.619*** | 7.981*** | -0.277 | 0.100 | -0.323 | -2.653*** | 7.815*** | 7.560*** | -0.210 | -0.018 | -0.248 | -1.71*** |
| | 3.94 | 3.70 | -0.49 | 0.18 | -0.59 | -4.63 | 4.30 | 4.17 | -0.43 | -0.03 | -0.51 | -3.30 |
| Sectoral dummies | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Spatial Lag | | | | | | | 0.504*** | 0.487*** | 0.419*** | 0.387 | 0.389*** | 0.376*** |
| | | | | | | | 15.24 | 14.62 | 11.41 | 10.44 | 10.81 | 10.04 |
| No obs. | 418 | 418 | 418 | 418 | 418 | 418 | 418 | 418 | 418 | 418 | 418 | 418 |
| Adj R-sq | 0.84 | 0.85 | 0.65 | 0.68 | 0.68 | 0.67 | 0.89 | 0.89 | 0.73 | 0.74 | 0.74 | 0.73 |
| F-stat | 150.10 | 146.46 | 52.32 | 50.28 | 54.33 | 56.21 | | | | | | |
| LM (lag) | 98.99 (0.00) | 86.54 (0.00) | 81.67 (0.00) | 65.63 (0.00) | 68.16 (0.00) | 51.95 (0.00) | | | | | | |
| Robust LM (lag) | 89.12 (0.00) | 92.87 (0.00) | 61.50 (0.00) | 59.39 (0.00) | 62.95 (0.00) | 80.22 (0.00) | | | | | | |
| LM (error) | 22.13 (0.00) | 11.91 (0.00) | 25.51 (0.00) | 14.41 (0.00) | 13.43 (0.00) | 1.57 (0.21) | | | | | | |
| Robust LM (error) | 12.25 (0.00) | 18.24 (0.00) | 5.34 (0.02) | 8.17 (0.00) | 8.22 (0.00) | 29.84 (0.00) | | | | | | |
| Log L | | | | | | | -463.98 | -461.61 | -536.70 | -531.32 | -526.89 | -539.17 |
| Breusch-Pagan test | | | | | | | 187.07 | 207.32 | 275.67 | 291.98 | 301.44 | 270.92 |
| LR test | | | | | | | 122.75 | 112.37 | 87.59 | 72.99 | 77.74 | 62.56 |

Table 9 – Spatial models for GHG emissions and technological spillovers

| | OLS with diagnostic for spatial dependence | | | Spatially-lagged models | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (1) | (2) | (3) |
| Labour productivity | -0.707*** | -0.695*** | -0.671*** | -0.676*** | -0.665*** | -0.650*** |
| | (-4.77) | (-4.68) | (-4.56) | (-4.71) | (-4.64) | (-4.57) |
| Environ. Spillovers | 0.081 | 0.090* | 0.099** | 0.171*** | 0.183*** | 0.185*** |
| | (1.60) | (1.79) | (2.06) | (3.01) | (3.27) | (3.43) |
| Internal Innovation | -0.033* | -0.031* | -0.022 | -0.030* | -0.029* | -0.022 |
| | (-1.90) | (-1.78) | (-1.31) | (-1.79) | (-1.68) | (-1.38) |
| Techn. Reg. Spillovers | -0.046* | -0.051** | -0.043* | -0.057** | -0.060** | -0.055** |
| | (-1.90) | (-2.06) | (-1.76) | (-2.40) | (-2.52) | (-2.30) |
| Energy Intensity | 0.639*** | 0.634*** | 0.627*** | 0.647*** | 0.644*** | 0.639*** |
| | (15.44) | (15.24) | (15.68) | (16.06) | (15.89) | (16.35) |
| Env. Reg. Current Exp. | -0.123* | | | -0.086 | | |
| | (-1.88) | | | (-1.34) | | |
| Env. Reg. Capital Exp. | | -0.081 | | | -0.054 | |
| | | (-1.48) | | | (-1.00) | |
| Env. Reg. R&D Exp. | | | -0.050* | | | -0.035 |
| | | | (-1.76) | | | (-1.27) |
| Dirty Sectors dummy | 1.197*** | 1.184*** | 1.171*** | 1.223*** | 1.215*** | 1.206*** |
| | (9.36) | (9.25) | (9.30) | (9.80) | (9.73) | (9.80) |
| Constant | 3.904*** | 3.886*** | 3.464*** | 3.740*** | 3.712*** | 3.428*** |
| | (7.25) | (7.10) | (6.53) | (7.17) | (7.02) | (6.69) |
| Spatial Lag | | | | -0.113*** | -0.119*** | -0.116*** |
| | | | | (-2.59) | (-2.75) | -(2.64) |
| No obs. | 209 | 209 | 209 | 209 | 209 | 209 |
| Adj R-sq | 0.74 | 0.74 | 0.74 | 0.76 | 0.76 | 0.76 |
| F-stat | 76.66 | 75.99 | 76.45 | | | |
| LM (lag) | 3.11 (0.08) | 3.55 (0.06) | 3.39 (0.07) | | | |
| Robust LM (lag) | 7.38 (0.01) | 7.78 (0.01) | 7.25 (0.01) | | | |
| LM (error) | 1.25 (0.26) | 1.03 (0.31) | 0.81 (0.37) | | | |
| Robust LM (error) | 5.51 (0.02) | 5.27 (0.02) | 4.66 (0.03) | | | |
| Log L | | | | -199.19 | -199.58 | -199.27 |
| Breusch-Pagan test | | | | 74.07 | 61.84 | 50.46 |
| LR test | | | | 4.38 | 4.98 | 4.65 |

Table 10 – Spatial models for ACID emissions and technological spillovers

| | OLS with diagnostic for spatial dependence | | | OLS with regional mummie | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (1) | (2) | (3) |
| Labour productivity | -1.375*** | -1.394*** | -1.347*** | -1.323*** | -1.343*** | -1.356*** |
| | (-7.08) | (-7.25) | (-7.19) | (-6.66) | (-6.76) | (-7.05) |
| Environ. Spillovers | 0.027 | 0.016 | 0.043 | 0.060 | 0.050 | 0.043 |
| | (0.39) | (0.24) | (0.71) | (0.84) | (0.70) | (0.64) |
| Internal Innovation | -0.016 | -0.020 | -0.012 | -0.035 | -0.037* | -0.036* |
| | (-0.75) | (-0.94) | (-0.61) | (-1.62) | (-1.72) | (-1.73) |
| Techn. Reg. Spillovers | -0.043 | -0.046 | -0.042 | -0.109*** | -0.107*** | -0.106*** |
| | (-1.52) | (-1.60) | (-1.45) | (-3.10) | (-3.03) | (-3.03) |
| Energy Intensity | 0.424*** | 0.430*** | 0.418*** | 0.439*** | 0.443*** | 0.447*** |
| | (8.97) | (9.16) | (9.17) | (9.34) | (9.46) | (9.73) |
| Env. Reg. Current Exp. | -0.045 | | | 0.009 | | |
| | (-0.58) | | | (0.12) | | |
| Env. Reg. Capital Exp. | | -0.072 | | | -0.022 | |
| | | (-1.07) | | | (-0.26) | |
| Env. Reg. R&D Exp. | | | -0.009 | | | -0.042 |
| | | | (-0.25) | | | (-1.17) |
| Dirty Sectors dummy | 2.447*** | 2.474*** | 2.404*** | 2.346*** | 2.374*** | 2.393*** |
| | (10.95) | (11.33) | (11.54) | (10.09) | (10.23) | (10.78) |
| Constant | 4.306*** | 4.429*** | 4.135*** | 3.857*** | 3.968*** | 3.768*** |
| | (6.17) | (6.33) | (6.18) | (5.27) | (5.19) | (5.39) |
| Geographical dummies | | | | Yes | Yes | Yes |
| No obs. | 209 | 209 | 209 | 209 | 209 | 209 |
| Adj R-sq | 0.73 | 0.73 | 0.73 | 0.74 | 0.74 | 0.74 |
| F-stat | 81.04 | 81.48 | 80.89 | 50.38 | 50.40 | 50.84 |
| LM (lag) | 2.44 (0.12) | 2.80 (0.09) | 2.21 (0.14) | | | |
| Robust LM (lag) | 0.25 (0.62) | 0.25 (0.62) | 0.17 (0.68) | | | |
| LM (error) | 5.44 (0.02) | 6.11 (0.01) | 4.73 (0.03) | | | |
| Robust LM (error) | 3.24 (0.07) | 3.56 (0.06) | 2.70 (0.10) | | | |