Geography, environmental efficiency and Italian economic growth: a spatially-adapted Environmental Kuznets Curve

Ciriaci, Daria and Palma, Daniela

European Commission, JRC Institute for Prospective Technological Studies, Enea

25 May 2010

Geography, environmental efficiency and Italian economic growth:

a spatially-adapted Environmental Kuznets Curve

Daria Ciriaci and Daniela Palma[1]

Submitted

*Abstrac*t: The present paper tests the hypothesis that environmental degradation and per capita income follow an inverted-U-shaped relationship (the so-called Environmental Kuznets Curve) at the Italian Nut3 level over the period 1990-2005. We adopt a spatial econometric approach to account for the localised nature of environmental damage. In this spatially-adapted EKC, we explicitly introduced the role of *energy intensive sectors* to control for local industrial structure. The experiment brought to light the existence of significant heterogeneity at the Italian Nut3 level and highlighted major differences between geographical clusters from the point of view of "ecological efficiency".

Keywords: Environmental Kuznets curves; Spatial econometrics; global and local pollutants; Geographically Weighted Regression Model.

JEL classification: C21, O13, Q20

[1] European Commission, Joint Research Centre, *Institute for Prospective Technological Studies* (IPTS), Seville – Spain, and LUISS Guido Carli, Rome, Italy. Corresponding author, e-mail: dciriaci@gmail.it. The views expressed are purely those of the writer and may not in any circumstances be regarded as stating an official position of the European Commission. ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development), Rome, Italy, e-mail: daniela.palma@enea.it.

1. Economic growth and environmental degradation

Over the past fifteen years increasing interest has arisen in assessing the extent to which the pursuit of economic growth and a cleaner environment are convergent rather than conflicting objectives (Grossman and Krueger, 1992). In the literature the hypothesis that the level of environmental degradation and per capita income follow an inverted-U-shaped relationship is known as the Environmental Kuznets Curve (EKC; Panayotou, 1993). Basically, the EKC's reduced form model involves regressing per capita emissions (or concentrations) on per capita income, per capita income squared and cube values, and a time trend. As a matter of fact, given the predominant macroeconomic cross-country approach to the EKC, empirical works have so far generally failed to consider the presence of relevant industry-specific determinants of pollution intensity, namely the causal relationship running from the spatial distribution of economic activity to growth. Furthermore the vast majority of these empirical works use panel data structures, estimating a functional form common to all countries/regions "up to some deterministic vertical shift specific to every country/region of year of the panel" (Ordás Criado, 2007), and assume spatial stationarity. To our knowledge only a few empirical works (Rupasingha *et al.*, 2004; Ordas Criado, 2007; Maddison, 2007 and 2006) have attempted to account for the existence of spatial relationships and spatial non-stationarity in the EKC framework. However, such analyses model the EKC relationship for the study area as a whole, and do not address the issue of local spatial variation, a choice which might lead to poor understanding of the relationship investigated. In this respect, the case of Italy may be a good testing ground for the role played by spatial heterogeneity in reshaping the environmental Kuznets relationship. In fact, the persistence of industrial "agglomerated" areas and per capita income divergences between Italy's central-northern and southern provinces[2] (Graziani, 1978; Paci and Saba, 1997; Ciriaci and Palma, 2008) are distinctive features of Italian economic development and have recently become the object of renewed interest in Italian economic literature (Onida, 2004).

This research contributes to the recent empirical literature on the EKC curve by adopting a Geographically Weighted Regression (GWR) model (Fotheringham et al., 2002) to account for spatial non-stationarity in the environmental Kuznets relationship at the Italian Nuts3 regional level[3] (i.e. provinces). The EKC hypothesis was tested for *t* equal to 1991, 1996, 2001 and 2005 for four major air pollutants differing in terms of the spatial scale of their impact: carbon dioxide (CO_2) and methane (CH_4), usually referred to as "global pollutants", and carbon monoxide (CO) and non-methane volatile organic compounds (NMVOC), usually referred to as "local pollutants". As the transition of an economy towards a lower carbon emission production structure is considered one of the main factors accounting for the EKC hypothesis, we introduced specialization in energy intensive sectors into our spatially adapted EKC as a control variable.

In particular, our "spatially" adapted EKC is expected to (1) highlight major

---

[2] In this paper we define as Italian northern regions: Emilia-Romagna, Liguria, Valle d'Aosta, Piedmont, Lombardy, Trentino A.A., Friuli Venezia-Giulia and Veneto. Lazio, Tuscany, Umbria, and The Marches are central regions, while the southern ones are Campania, Abruzzi, Molise, Puglia, Basilicata, Calabria, Sicily and Sardinia.

[3] NUTS stands for Nomenclature of Territorial Units for Statistics used by Eurostat. In this nomenclature NUTS2 refers to Basic Administrative Units whose first level of disaggregation gives rise to NUTS3 Territorial Units, i.e. provinces.

differences among Italian provinces from the point of view of “environmental efficiency” with respect to the underlying industrial structure, and (2) bring out further local differences depending on the different geographical relevance of the air pollutants considered. Hence, although closely related to the environmental Kuznets curve literature, the analysis proposed in the present paper substantially differs from previous empirical works on account of the relevance given to the spatial dimension of pollution phenomena, i.e. the geographical dimension of the EKC, as well as the within-country methodology approach used and the attention devoted to energy intensive sectors.

The paper is organized as follows. Section 2 reviews the main contributions on the EKC focusing on its main theoretical explanations. Section 3 discusses the spatial structure of data and examines a number of spatial econometric issues and the use of GWR (3.1). This material is included for completeness, but most of the details can be skipped by those readers who are more interested in the practical applications. Furthermore, section 3 presents the augmented spatially adapted EKC model (3.2). Section 4 adopts the GWR approach to test the spatially adapted EKC at the Italian Nuts 3 regional level, and Section 5 concludes the paper.

2. Theoretical explanations behind the EKC

The EKC hypothesis represents a long-term relationship, a single-economy development path characterized by different stages *over* time. Clearly, this development trajectory can be observed over time or in cross-region cross sectional data representing several countries/regions with different levels of income corresponding to their emission levels. This is why, although the EKC hypothesis is essentially a *within*-country story, most of the empirical support[4] has come almost entirely from cross-country data, preferably following time series and panel approaches. In fact, if we assume that each country/region follows its own EKC, then at any cross section of time we should observe some relatively poor countries/regions at their initial stage of EKC, some developing ones approaching the peak or starting to decline, and others, relatively richer, in the descending stage of EKC.

As the EKC hypothesis gained credibility as a stylized fact, an increasing more theoretically-oriented literature emerged. Within it, some works took a macro approach, seeking to explain the socio and macroeconomic mechanisms behind the EKC (Cole *et al*., 1997; Suri and Chapman, 1998; Agras and Chapman, 1999; Andreoni and Levinson, 2001; Bimonte, 2002), while a few others preferred a more micro-based approach, aiming to explain the linkages between environmental innovation and firm performance (Porter and Van der Linde, 1995; Mazzanti and Zoboli, 2005).

The "macro" strand of this theoretically-oriented literature on EKC identified three main channels along which economic growth affects the quality of the environment, namely the scale of production, technological progress, and structural change. With regard to the first of these, *ceteris paribus*, corresponding to higher levels of GDP are higher levels of pollution as increasing output requires more inputs; thus more natural resources are used up in the production process. The negative impact of the scale effect on the environment tends to prevail during the initial stages of growth but will eventually be outweighed, over time, by the

[4] As many reviews of the EKC literature are available (Dasgupta *et al*., 2002; Cole, 2004; Dinda, 2004), the present paper does not attempt to go over the empirical evidence again.

positive impact of structural and technological change, which tends to lower the emission level (Vukina *et al.*, 1999)[5].

With reference to technological change, the literature stressed that it may consist either in a more efficient use of inputs or in substitution of less for more environment-friendly inputs, and/or in a shift *within* a sector toward new, less environmentally harmful process or product, less generation of waste, and transformation of waste to less environmentally harmful forms (Komen *et al.*, 1997; Galeotti, 2007). Clearly, the pattern of investments and their distribution over the various means of environmental protection are profoundly affected by environmental policies and incentives, and by the structural characteristics of the various firms.

Regarding the *third* channel - structural change -, a number of works (Grossman and Krueger, 1993; Vukina *et al.*, 1999) have underlined that environmental degradation tends to increase as the structure of an economy changes from agricultural to industrial, but starts on a descending slope as the structure changes from energy intensive industry to knowledge-based industries and services. This view emphasises the importance of structural change from energy-intensive heavy industry to services characterized by lower environmental impact.

As a matter of fact, findings based on the vast empirical evidence have mostly proved controversial, with significant discrepancies emerging with respect not only to different pollutants or measures of environmental degradation, but also to different income-level groups of countries over time. In general, the functional

---

[5] Furthermore, as income grows, people achieve a higher standard of living and care more about the quality of the environment where they live, which may be seen as a *luxury* good . In this regard, it is worth stressing that in the EKC literature the role of income distribution is mainly ignored, while it may play an important role in determining environmental quality. For a discussion *see* Torras and Boyce (1998), and Magnani (2000).

shape of the EKC relationship cannot be uniquely determined as it is conditional on various structural features at the country and local level. For instance, using a global sample of countries Stern and Common (2001) found a monotonically increasing relationship between emissions per capita and per capita income, but when the data set is restricted to high-income countries, an inverse U-shaped relationship emerged. Similarly, Dijkgraaf and Vollebergh (1998) analysed carbon dioxide emissions for a panel of countries and found evidence of an inverted U-shaped relationship, but when EKCs were separately estimated for each of the countries, different results emerged prompting the authors to question the existence of a *global* EKC (Maddison, 2006).

Hence, as the body of literature on EKC grew, it became increasingly evident that no simple, predictable relationship between an aggregate measure of environmental quality and per capita income could be singled out. Moreover, several shortcomings emerged, such as the lack of a micro-based theoretical background, empirical results too much sensitive to the sample of countries chosen, to the pollutant measurement adopted (emissions or concentrations), the functional form chosen, and methodological approach (cross-country, panel etc.). As a result, the EKC came in for a barrage of critical fire (Perman and Stern, 2003).

Nonetheless, interest in the EKC debate has continued to grow, while the need became evident for a more articulated conceptual framework for clearer focus on the alleged EKC relationship. This has led to increasing investigation into the structural determinants of the EKC relationship, while growing emphasis has been placed on the role played by technological progress. Interestingly enough, the recent micro-strand of the literature deals with environmental innovation, environmental regulation and economic performance, emphasizing the need for a deeper understanding of the complex and peculiar nature of environmental innovation and its influence on firm performance while criticizing the mainly macro approach analyzed above.

In any case, this micro adapted EKC hypothesis - which would capture the relationship between economic activity agglomeration and environmental quality at the local level, where emissions are generated - cannot be tested easily because of the lack of emission data at plant level. To remedy the shortcoming, some authors (Mazzanti and Zoboli, 2005) tested an adapted EKC hypothesis where the link under study was the correlation between labour productivity (value added per employee), and environmental efficiency (emissions per unit of value added) at sector level. In their work, they found evidence of a negative correlation between labour and environmental efficiency for Italy over the period 1990-2002, accounting for it with the so-called potential "double externalities" (Jaffe *et al.*, 2005). That is to say, increasing environmental efficiency with environmental innovations may enhance competitiveness and firm performance with or even without a policy "incentive". It follows that labour and environmental efficiency are complementary: firms may simultaneously increase the level of production and reduce bad outputs (Collins and Harris, 2005). Innovation aimed at reducing environmental impact, in fact, cannot be easily disentangled from other types of innovation. Technological advances designed to reduce environmental externalities may imply innovation spillovers (Jaffe *et al.*, 2005): there is a significant interrelatedness between the goal of a cleaner environment and that of a technology-driven process of economic growth. Increasing returns from innovation reinforce the dynamics of income growth, supporting the view that structural economic change may well lead to significant enhancement of environmental efficiency (Jaffe *et al.*, 2005).

At the same time, further investigation of the mechanisms underlying innovation processes has shown that knowledge flows are geographically localized and that technological similarities between innovating and receiving entities facilitate the diffusion of innovation. Most of the contributions on the topic highlight the fundamental role of geographical proximity in catalysing the transmission and absorption of technological and scientific knowledge, spread mainly through informal means (interpersonal contacts, face-to-face communications, meetings, seminars, on-the-job training, etc.) whose effectiveness decreases with distance between agents (Feldman, 1994; Greunz, 2003; Jaffe *et al.*, 1995).

3 Modelling the local income-pollution relationship: the GWR model

Although geographical areas form the basic unit of analysis in most EKC studies, virtually all have ignored underlying spatial relationships among cross-sectional units (Rupasingha *et al.*, 2004). To our knowledge, only few recent works have considered the spatial dimension of the EKC relationship (Rupasingha *et al.*, 2004; Ordas Criado, 2007; Maddison, 2007 and 2006)[6], thereby proving the fallacy of inference based on a non-spatial model specification when cross-regional analyses are performed. However, in such analyses model estimation is

[6] For instance, Rupasingha *et al.* (2004) used county-level data from the United States, accounting for spatial autocorrelation, and found that all of the spatial models show highly statistically significant coefficients for the spatial autocorrelation parameters, suggesting that inference based on a non-spatial specification is invalid for US county-level data. Maddison (2006) using a panel of sulphur dioxide, nitrogen oxides, volatile organic compounds and carbon monoxide emissions, augmented a conventional EKC by spatially weighted values of the dependent and independent variables on the base of the hypothesis that countries are affected by events in neighbouring states. Ordas Criado (2007) highlighted the extreme sensitivity of the income-pollution relationship to region- or country-specific factors using a balanced panel of 48 Spanish provinces on four air pollutant emissions (CH_4, CO, CO_2 and NMVOC) over the 1990-2002 period. They performed nonparametric poolability tests to check the temporal and spatial homogeneity of the panel and their results are compared with the conventional F-tests for a balanced panel.

carried out for the study area as a whole, which might lead to poor understanding of the relationship investigated if this exhibits significant local spatial variation.

As a matter of fact, in spatial economic modelling considerable attention has recently been devoted to the relevance of spatial variation in geographical space. Social and economic processes are typically non-stationary over space, and assessment of data variability across space should take into account spatial variation around different locations. This is clearly of the utmost importance the more there is a local relevance of the phenomenon inspected, as it can be observed in the case of air pollution emissions with respect to their anthropogenic source of origin.

Over the past few years, in the geographical literature, the attention dedicated to local analytical techniques in dealing with spatial non-stationarity has risen considerably, and the focus has increasingly concentrated on the GWR technique proposed by Fotheringham, Brundson and Charlton (Fotheringham *et al.*, 2002). GWR methodology has been developed along the lines indicated in the extensive literature there now is on "local" linear regression models, well-known in statistical literature (see Loader, 1999; Hastie *et al.*, 2001), as it is based on the use of a kernel function to calculate local weights for regression estimates. Kernel weighting, unlike traditional local regression modelling, is applied to observations in geographical rather than attribute space, and the methodological focus is on assessing local variation in the regression coefficients, rather than data smoothing as in a-spatial local regression techniques. In GWR estimation spatial proximity between data observed at different locations is at the basis of the weighting scheme used for model calibration, allowing data from closer observations to be weighted more than data from observations farther away. The specification of a basic GWR model, for each calibration location, s=1,…,n, is:

$$y(s) = X(s)\beta(s) + \varepsilon(s) \quad (1)$$

where y(s) is the dependent variable at location s, X(s) is the row vector of explanatory variables at location s, β(s) is the column vector of regression coefficients at location s, and ε (s) is the random error at location s. Hence, regression parameter estimates are allowed to vary according to location in space, implying that each coefficient in the model is now a function of *s*, a point within the geographical space of the study area. The regression coefficients are estimated for each calibration location by weighted least squares yielding the following vector of estimates:

$$\hat{\beta}(s) = [X^T W(s) X]^{-1} X^T W(s) y \quad (2)$$

where $X = [X(1);X(2);\ldots;X(n)]^T$ is the design matrix of explanatory variables, including a column of 1's for the intercept; W (s) = diag [w1(s), …, wn(s)] is the diagonal weights matrix calculated for each calibration location; y is the nx1 vector of dependent variables; and $\hat{\beta}(s) = (\hat{\beta}_{s0}, \hat{\beta}_{s1}, \ldots, \hat{\beta}_{sp})$ is the vector of p+1 local regression coefficients at location *s* for *p* explanatory variable and intercept. As a result $\hat{\beta}(s)$ gives rise *to a map of local estimated parameters*.

Among the many specifications of the kernel function (Fotheringam *et al*. 2002), one of the most commonly used, and the one used in the present study, is the bi-square nearest neighbour function:

$$W_j(s) = \begin{cases} \left[1 - \left(d_{sj}/b\right)^2\right] & if \quad j \in \{Ns\} \\ 0 & if \quad j \notin \{Ns\} \end{cases} \quad (3)$$

where d_{sj} is the distance between the calibration location s and location j, b is the distance to the N*th* nearest neighbour (i.e. the spatial bandwidth), and the set {Ns} includes the observations that are within the distance of the N*th* nearest neighbour. With regard to the kernel bandwidth, an adaptive formulation is all the more advisable the more the data points across the territory under study are characterized by varying sparseness, a situation that occurs frequently in socio-economic applications and that, in extreme cases, can even make the estimation of some parameters impossible due to insufficient variation in small samples.

Major concerns arise, however, when inference on GWR local parameter estimates has to be carried out in order to determine whether spatial heterogeneities characterize the underlying data generating process. In this respect a great deal of attention has been dedicated to testing individual parameter stationarity adopting a Monte Carlo approach[7], or less computationally intensive formal test statistics for spatial non-stationarity and heterogeneity (Leung *et. al.* (2000a, 200b). Substantial interpretation of local parameters based on GWR estimates has, however, been tackled only recently, affording useful insights into estimation biases due to the dependencies that may arise between the local regression coefficients (Wheeler and Tiesfelsdorf, 2005; Wheeler, 2007). For the sake of interpretation, careful attention should moreover be paid to the local estimates of the intercept term. In fact, significant deviations of the estimated local intercept values from the average global intercept estimate may point to the possibility of other aspects that are not locally accounted for by the model specified.

---

[7] This test is based on the sampling distribution of the standard deviation of the GWR parameter estimate under the null hypothesis that the parameter of interest is globally fixed (Fotheringham *et al.*, 2002 p. 93).

3.1 The estimated equation

From the point of view of local environmental efficiency, the above discussed considerations on spatial non stationarity, bounded knowledge flows, technological proximity and social capability, as well as the Italian evidence on the agglomeration of economic activity, suggest that estimation of a spatially adapted EKC - taking into account the localised nature of environmental externalities and spatial heterogeneity - should highlight the occurrence of high/medium and low environment efficient clusters.

In our spatially adapted equation we use an alternative specification of the dependent variable, and we augment the basic specification of the EKC relationship to control for the role of energy-intensive sectors as a major source of air pollution. Our endogenous variable is the ratio of emissions to the number of industrial workers, in order to better account for congestion and intensity of economic activity at the spatial scale under study. We rely upon the hypothesis that urban areas experience greater pollution independently of population density, as they tend to be more industrialized. In this respect, we assume that the number of workers in industry in each province is a realistic measure of the "degree of urbanization" and we use it to normalize the emission variable at the local level instead of resident population. To control for the role of energy-intensive sectors, we introduced the ratio of the number of workers in energy-intensive sectors to the number of industrial workers in general. To define them we refer to the European Emission Trading Scheme, Directive 2003/87/CE, which defines as high-emission sectors those of energy, ferrous metals, cements and lime, glass, ceramics, pulp and paper[8] (the so-called ETS sectors).

The estimated equation is the following[9]:

$$y_{i,t} = \hat{\beta}_0 + \hat{\beta}_1\, GDPpc_{i,t} + \hat{\beta}_2 \left(GDPpc_{i,t}\right)^2 + \hat{\beta}_3 \left(GDPpc_{i,t}\right)^3 + \hat{\beta}_4\, ind\_mix_{i,t} + \varepsilon_{i,t} \qquad i = 1 \ldots 103$$

where y_{it} is the ratio of emissions to the number of industrial workers in province *i* at time *t*, $GDPpc_{i,t}$ is per capita income in province *i* at time *t*, $ind\_mix_{i,t}$ is the ratio of the number of workers in energy intensive sectors in province *i* at time *t* to the number of industrial workers in province *i* at time *t*; e_{it} is the error term. The data on GDP per capita by provinces are national account figures delivered at the Nuts3 level. As far as the GDP variable is concerned, it should be moreover noticed that the Nut3 level seems the more appropriate measure of scale to be considered for a better match with emission data given their close relationship to local sources of economic activity (Deacon and Norman, 2004).

Table 1

The EKC hypothesis was tested at the Italian Nuts3 level (provinces) for *t* equal to 1991, 1996, 2001 and 2005. This time period was chosen for two reasons. First of all, preliminary empirical investigations showed that in Italy, over the last fifteen

[9] We did not, consider the relevance and composition of international trade as has been done in the EKC literature at the country level (Agras and Chapman, 1999; Suri and Chapman, 1998). In these works it is argued that countries that export more manufactured goods tend to have a higher energy consumption as external trade reflects the energy consumption of a country. However, trade indicators at sub-country level have not the same significance and relevance as those defined at the country level so it would not be possible to use them to consider the energy content of production at the local level.

years (1990-2005), the energy intensity of industry and services increased but, given the transition from industry to services and the relatively lower energy intensity of the latter, a negative correlation between economic growth and environmental pressure is found (ISTAT, 2009). Furthermore, the period is long enough to evaluate major changes occurring over time.

The source for the number of industrial workers at the Nuts3 level is the national census of industry for the years 1991, 1996, 2001, while for the year 2005 data were estimated on the basis of the Italian business register ASIA[10]. Data on emissions (CO_2, CH_4, NMVOC, and CO) were taken from the latest issue (September 2008) of the national emission register at the Nuts3 level officially published by the Italian Institute for Environmental Protection and Research (ISPRA). Table 1 presents the explanatory variables included in the model, and reports the descriptive statistics.

4. Results

[10] The census data on industry at the local level refer to local plant units, while statistics by business units were the only ones included in the ASIA register until early 2009. Estimates of industrial workers based on the ASIA register have been possible thanks to the new issue published in 2009, which for the first time included figures by local plant units. In order to account for the different sources of the data, the figures on industrial workers drawn from the ASIA register have been adjusted to the proportions of the census figures. The total amount of workers for both the industry and the ETS sectors has been estimated for the year 2005, applying to the total 2001census figure the percentage change between 2005 and 2001 of the total number of workers at the national level (business accounts). The data at the Nuts3 level were then estimated applying to the new totals the percentage weights obtained from the Nuts3 series of the ASIA business register.

According to the GWR estimation approach, if a relationship between variables is distinctively represented at the local level, then significant differences should emerge in greater evidence in the local parameter estimates than in the global ones. Regression results are therefore provided for both global and local estimation and compared for all the years investigated. In section 4.1, we present and interpret the results of global estimation (reported in Table 2) and major improvements obtained through GWR estimation, while in section 4.2 closer analysis of the local estimation is carried out separately for each pollutant considered (Tables 3-6).[11]

4.1. Global estimates

As far as the global regressions are concerned (table 1), major differences can be seen between the model fit of the global pollutants (CO_2 and CH_4), and that of the local pollutants (NMVOC and CO). In fact, while the fit of the data is good for the local pollutants, with a monotonic decrease of the R squared values in the interval [0.6 - 0.3], for the global pollutants (particularly for CO_2) it is rather poor and marked by monotonic increase of the R squared values in the interval [0.10 – 0.30]. Less ambiguous indications are, however, obtained for the regression parameter estimates as, for all the pollutants, they bear out a significant inverse relationship between environmental damage and per capita income over the period 1991-2005.

[11] As far as local regression parameter estimates are concerned, and according to the caveats mentioned for interpretation of the GWR results, spatial patterns were preliminarily examined and the relationships were found meaningful in terms of the problem investigated (Wheeler and Tiefelsdorf, 2005).

Careful examination of the local regression results is, however, needed to gain insight into the EKC relationship under study. As clearly shown in tables, the relevance of the GWR estimation emerges for all the pollutants considered with greater goodness of fit than otherwise found in the case of the global estimates. Besides, the F values of the ANOVA GWR model test[12] (tables 2-5) are significant, which implies that the GWR model represents an improvement over the global model.

The significant improvement of the GWR model fit for all the pollutants considered is indicative of the fact that spatial non-stationarity is a crucial aspect to take into account. This is tantamount to saying that the EKC relationship is shaped upon the characteristic spatial variability of relevant socio-economic processes across geographical space. This aspect is somewhat more stringent in the case of local pollutants as a consequence of the spatial scale of their impact with respect to the emission sources and hence of the local relevance of environmental damage. The better fit found in global regressions for these pollutants is, in this sense, an indication of their closer relationship with economic processes at the local level. However, no substantive meaning can be applied to this result, as the spatial dimension of local pollutants is not captured at the global level, and interpretation of the relationship investigated could be even seriously biased.

In the following sub–section we will present detailed discussion of the EKC model estimation for each of the pollutants considered, with special attention to the relevant mapped GWR parameter estimates. In the appendix, we included 6 maps of the t values of the local estimates. As the number of maps was elevated

[12] The ANOVA tests the null hypothesis that the GWR model represents no improvement over a global model.

(four parameters in each equation for four pollutants and four years), we decided to show only the t values of per capita income estimates for the last year available (2005)[13].

Table 2

Due to the relatively stable structure of Italy's North-South declining GDP trend, and indeed of the major associated aspects of the underlying production system (such as the higher degree of industrialization in the northern areas), the dynamics of the localised spatial pattern of the GWR parameter estimates can be interpreted in the light of the specific "environmental efficiency" that a given area has been able to develop as a result of local specific factors such as different labour and capital endowments, differences in technology, infrastructures and climate, which determine a high level of local heterogeneity.

4.2. Local estimates

*4.2.*1 Global pollutants: CO_2 and CH_4

Table 3

[13] Given the results obtained in the case of CO_2, in this case a different choice was made: we included the maps of the t values associated to the ratio of the number of workers in energy intensive sectors. In any case, the other maps are available on request.

As far as CO_2 emissions are concerned[14], the results of the local fit of the EKC equation point to the general relevance of this pollutant and highlight the emergence - over the period analyzed - of structural factors deeply rooted at the territorial level and highly differentiated over geographical space. In fact, although the improvement in the GWR estimation over the global regression is significant, the goodness of fit yields R squared values mostly around 0.3. Moreover, the local estimates of the intercept term are mostly non-significant, indicative of the fundamental contribution of the specified variables to explanation of the spatial heterogeneity of the observed per capita CO_2 emissions.

A significant local relationship between per capita emission of CO_2 and per capita GDP is found only in 1991 and 2001 for, respectively, 10 and 28 provinces. Analysis of the mapped t values of the local parameter estimates in 1991 reveals a significant monotonic increasing relationship in the North-Eastern provinces of Veneto and in 4 provinces of the Centre belonging to Umbria and The Marches. In 2001, a localized decreasing relationship emerged in 4 north-western provinces along the border with France, and in the South in the provinces of, Puglia, Basilicata, Calabria, Sicily, and Sardinia.

Unlike the other pollutants analyzed, a relevant aspect that emerges in the case of CO_2 is, rather, the local significance of the energy-intensive sectors, observed from 2001 on. In particular, in 2001 and 2005 the ratio of the number of workers in energy intensive sectors enter the equation with a positive sign and is found

[14] We checked for major CO_2 emission point sources (mostly ports, but in a few cases large power stations as well as very large refineries and chemical plants) and we detected 12 spatial outliers in the provinces where these are located. Hence observations at these locations were smoothed by averaging the values with those of their first order neighbors.

significant in most southern provinces (*see* Maps 1 and 2, Appendix). Besides, in 2005 the share of workers in energy intensive sectors turned out to be locally significant in some central and north-eastern provinces as well. Interestingly, this structural aspect emerges after the Kyoto Protocol was adopted for use in 1997, suggesting that the southern provinces might have been less efficient than the others. This finding might be interpreted in the light of the Porter hypothesis (1995): at the firm level the environmental "problem" and the existence of binding regulation could act as incentives to "green" innovation. In this case, after the Kyoto Protocol had been drawn up but before it came into force (in 2005), Italian firms located in Northern Italy started restructuring[15] their production processes to reduce CO_2 emissions, intensifying their innovative activities, while the southern firms lagged behind. However, this is by no means surprising, given the structural characteristics of the industrial system in Southern Italy, where the predominance of very small firms and traditional sectors hampers innovative business performance at the systemic level (Onida, 2004).

By and large, the effects of expectations of future binding environmental policies on the firms' strategies appear highly differentiated at the local level in Italy, and follow the familiar industrial pattern according to which the innovative firms – able to move along the technological frontier - are located in well defined clusters in Northern Italy (Ciriaci and Palma, 2008). This can also be equally interpreted as the emergence of a localized pattern of environmental efficiency, while taking account of the importance of the local dimension of innovation processes. The

[15] It might be argued that the promotion of cogeneration or combined heat and power (CHP) by the Italian Government in 1999 (Decreto Legislativo 79/99 as known as "Decreto Bersani") have influenced firms strategies, particularly those in the "energy intensive" industries such as the pulp and paper industries (Assocarta, 2007).

localized relevance of the underlying innovation processes of the southern provinces emerges in the fact that the impact of the ETS industries in terms of CO_2 emissions reveals a much lower level of energy efficiency than obtained in the northern provinces. Furthermore, as carbon dioxide emissions are also to a great extent accounted for by transport, it might be argued that the advances in technology achieved by the northern provinces have been significantly determined by the coming into force of the Euro 3/4/5 standards on air pollution introduced from 1999 on, and conformed to by the vehicles registered from 2001 on, as shown by the much higher concentration of new vehicles in these areas (ISTAT, 2004).

Table 4

Closer examination of the GWR regression performed on CH_4 reveals remarkable differences in terms of CO_2 and the structure of the whole relationship, at both the global and the local level. In this respect we should first consider the lack of significance of the energy-intensive sector variable over the period studied, at both the global and the local level. As far as local per capita income is concerned, the relationship is found significant mainly in the southern provinces where a stable quasi-L-shaped (or otherwise called hockey-stick) relationship prevails, particularly from 2001 on. In fact, in 1991 the relationship is found to be significantly quasi-L-shaped in some provinces in the central part of Italy as well. From 2001 on, and especially in 2005, significant spatial heterogeneity is predominantly due to the behaviour of the southern provinces (Table 3; see Map 3 and 4, Appendix). To sum up, analysis of the GWR parameter estimates reveals fairly complex behaviour with a highly localized quasi-L-shaped relationship between emissions per industrial worker and per capita GDP in the more agriculture-based southern provinces, behaviour that can be interpreted in the light of the prominent role played by the agricultural sector in producing CH_4 emissions. The structural differential between the central-northern and southern areas and the specific relevance of local contexts for CH_4 emissions are yet further highlighted by the spatial estimates of the intercept term: a significant local variability is found in all the years considered, and the local values are increasingly significant along a North-South trend. In particular, the local estimates of the intercept term in the southern areas reveal higher than expected CH_4 emissions given the observed values of the independent variables, pointing to the existence of other relevant local aspects that are not captured by the specified model.

*5.2.*1 Local pollutants: NMVOC and CO

As far as the NMVOC emissions per industrial worker and per capita GDP local relationship is concerned, the estimation results suggested a significant - and stable over time – quasi-L-shaped relationship in some central provinces (mainly in Lazio) and in most southern provinces while, unlike the global estimation, the "energy-intensive sector" is never found as a determinant of local heterogeneity. More specifically, in 1991 per capita income is significant in 41 Italian provinces, and in all cases enters the equation with a negative sign. The second term is found significant in a lower number of provinces (36), 29 in South Italy and 7 in Central Italy, and a quasi-L-shaped environmental-per capita income relationship emerged. In 1996 the first term is significant in 41 provinces while the second term in 35. A U-shaped relationship is found in all southern provinces but Sardinias' ones where a monotonic decreasing relationship emerged. In 2001 and 2005 the U-shaped relationship is confirmed for most southern provinces (with the remarkable exception of Sardinias' provinces).

Table 5

As a matter of fact, the equation shows a remarkable loss of specification with a decreasing goodness of fit and local per capita GDP parameter estimates losing local significance over the period considered: in general a clear cut between northern, central and southern provinces emerged (i.e. Maps 5 and 6, Appendix). Given the local character of the pollutant considered, the decrease in local heterogeneity observed seems to suggest an effective impact of regulations on "environmental efficiency" at the firm level as the environmental regulations obliged single firms - belonging to the industries affected by the regulation itself - to respect certain standards irrespective of their location. At the same time, analysis of the local estimates of the intercept term reveals quite a remarkable persistence of a structural differential between the northern-central and southern provinces, confirming the decisive role of local conditions for "environmental efficiency": the significantly higher values of the spatial estimates of the intercept term found in the southern provinces are amply indicative of their development gap (Directive 1999/13/CE).

Table 6

Of all the pollutants considered, CO shows the highest GWR estimation fit with increasing R squared values scoring over 0.8 in 2005. Stable environmental-income relationships are found while, as in the case of NMVOC, the “energy-intensive” variable never emerges as a significant determinant of the heterogeneity observed at the local level. However**,** the GWR estimates of the GDP parameter appear to be the compound result of highly differentiated and clustered local behaviour 1991 per capita income is significant and shows a negative sign in 57 provinces. The number of provinces in which a significant local relationship is found decreases in the case of the second term: in this case, it is positive in 47 provinces. When t values are mapped, a quasi-L-shaped relationship emerges in the central (with the exception of Tuscany) and southern provinces, and a decreasing one in the northern provinces located along the Adriatic coast. In 1996, a quasi-L-shaped relationship is confirmed for the same central provinces, and Abruzzi, while a Kuznets emerged in the provinces belonging to Puglia, Calabria, and Basilicata, in the extreme South of Italy, while no longer appearing significant in the northern part of Italy. For 2001, from the mapped t values per capita income proved significant in 32 provinces, 28 entering the equation with a negative sign, 4 with a positive sign. As far as the second term is concerned, it is still significant in 32 provinces, but the sign is now reversed: positive in 25 provinces, negative in 7. That is to say, for 2001, in 25 provinces (21 in Lazio, Campania, Abruzzi, and The Marches, and 4 located along the border between Italy and France) a quasi-L-shaped relationship is found. In 3 other north-western provinces (located close to the border with France), a monotonic decreasing relationship emerged. In the 3 provinces of Puglia (extreme South of Italy) and 1 of Basilicata a Kuznets curve is found. In 2005 a quasi-L-shaped relationship emerged in some central provinces (mainly in Lazio and Umbria), 3 north-western provinces, and in some southern provinces (mainly in Campania, Abruzzi and Molise; see Maps 7 and 8, Appendix). A Kuznets curve is found for the provinces of Puglia, Basilicata, and Calabria. Clearly, the comparison between the GWR estimates and those found at the global level, where a monotonic decreasing relationship emerged in the case of CO, confirmed that a cross-region "global" econometric approach is not appropriate as it averages out fundamental industry characteristics and other relevant economic factors specific to the local level. In this respect further insights are gained with analysis of the local estimates of the intercept term. In fact, significant local deviations from the average global value of the intercept estimates emerge, giving rise to patterns of spatially clustered provinces across all the territory. Clearly this highlights the specific relevance of other local factors to different degrees of spatial agglomeration, not fully captured by the adapted equation, and confirms the very local character of CO emissions, which are greatly affected by traffic conditions in urban areas (ISPRA, 2009).

6. Concluding remarks

As air pollution tends to be more concentrated near its source and relatively high levels of spatial agglomeration and intra-local business networking characterise Italian territory, the present paper estimated a "spatially" adapted EKC hypothesis. The results confirmed that local income is the more appropriate measure of scale to be considered, and the methodological approach chosen enhanced the geographical dimension of the relationship under study. Overall, our results confirm that even in the "globalisation era" it is still worth looking into local economies as a crucial dimension of economic development and environmental efficiency.

The empirical findings presented in this study indicate a significant relationship between the evolution of per capita GDP and four different measures of air pollution intensity: CO_2 emissions per industrial worker, CH_4 emissions per industrial worker, NMVOC emissions per industrial worker, and CO emissions per industrial worker. On performing global regression estimation, a monotonic decreasing relationship emerged for all the pollutants considered. However, the results obtained from assessment of the localized relationship through GWR spatial estimation brought to light the existence of significant heterogeneity at the Italian Nut3 level.

At the local level a quasi-L-shaped "average" relationship predominates in the southern provinces and in some provinces in the central regions (Lazio, Abruzzi, Molise, Tuscany), confirming how misleading it can be to estimate a functional form common to all regions and assume spatial-stationarity. A Kuznets relationship is found in 1996, 2001 and 2005 in the case of CO for the provinces in Puglia, Calabria and Basilicata. Furthermore, for all the pollutants investigated, the localised behaviour of the estimated relationship often affords insight into the emergence of clustered areas where the relationship tends to diverge from the prevailing behaviour. This seems to suggest the existence of more and less "environmentally efficient" areas which tend to cluster. In this respect it should be also noted that the southern regions often behave very differently from the northern ones, thereby highlighting the role of the local context in development dynamics and, more specifically, the relevance of the dualistic structure of the Italian economy to environmental impact.

Moreover, the GWR estimates highlighted the significant influence of various specific local factors related to the structure of the underlying economic system. In this respect, the empirical evidence shows that the impact of the “energy intensive” sectors, explicitly introduced into the model as a control variable, is captured mainly at the global level as an “average effect”, thus confirming the extraordinary relevance which had in fact earned them attention in environmental regulation. Actually, the share of energy intensive sectors does not account for the local heterogeneity observed.

The empirical results underline the importance of spatial heterogeneity for environmental pressure. This strong potential impact may depend on either specific features of the sector production specialization of the Italian provinces or the spatial concentration of industrial activities, which seem to reflect the geography of the Italian industrial districts. Clearly, from a policy point of view, the issue of environmental innovation in local systems is particularly important given the high density of firms in certain provinces, which may generate critical damaging local «hot spots» in emission production (Montini and Zoboli, 2004). This negative environmental feature could be offset if a higher than average innovative propensity were to emerge in these clusters where, by exploiting networking relationships and knowledge spillovers due to proximity. At the same time, even though in absolute terms those areas are “hot spots”, in relative terms, compared with the southern provinces, are relatively more efficient.

References

Agras, J., Chapman, D. (1999) A dynamic approach to the Environmental Kuznets Curve hypothesis, Ecological Economics, 28, 267– 77.

Andreoni, J., Levinson, A. (2001) The simple analytics of the Environmental Kuznets Curve, Journal of Public Economics, 80, 269– 86.

Assocarta (2007) Le attività di Assocarta nel 2007, Roma: Edizione Tecniche Nuove.

Becattini G. (1987) Mercato e forze locali: il distretto industriale. Bologna: Il Mulino.

Bimonte, S. (2002) Information access, income distribution, and the Environmental Kuznets Curve, Ecological Economics, 41,145–56.

Ciriaci D., Palma D. (2008) The Role of Knowledge-based Supply Specialization for Competitiveness: a Spatial Econometric Approach, *Papers in Regional Science*, Special issue on Spatial Econometrics, 87, 453-75.

Cole, M.A., Rayner, A.J., Bates, J.M. (1997) The Environmental Kuznets Curve: an empirical analysis, Environment and Development Economics, 2, 401-16.

Cole, M.A. (2004) Trade, the pollution haven hypothesis and environmental Kuznets curve: examining the linkages, Ecological Economics, 48, 71-81.

Dasgupta, S., Laplante, B., Wang, H., Wheeler, D. (2002) Confronting the Environmental Kuznets Curve, Journal of Economic Perspectives, 16, 147–68.

Deacon R., Norman C. (2004) Is the environmental Kuznets curve an empirical regularity?. Economics Working Paper Series, 22-03. University of California at Santa Barbara.

Dinda, S., (2004) Environmental Kuznets curve Hypothesis: a survey, Ecological Economics, 49, 431-55.

Dijkgraaf, E., Vollebergh H.R.J. (1998), Growth and environment—is there a Kuznets curve for carbon emissions? in: Paper presented at the Second ESEE Conference, University of Geneva, Geneva.

European Commission (2007) Contributing to an integrated approach on competitiveness, energy and environment policies, Ensuring future sustainability and competitiveness of European enterprises in a carbon and resource constrained world, Fourth Report, Bruxelles.

Feldman, M. (1994) The geography of innovation. Boston : Kluwer Academic Publishers.

Fingleton B. (2001) Externalities, Economic Geography, and Spatial Econometrics: Conceptual and Modeling Developments, International Regional Science Review, 2, 197-207.

Fotheringham A.S., Brunsdon C., Charlton M. (2002) Geographically weighted regression. The analysis of spatially varying relationships. New York : John Wiley & Sons Ltd.

Greunz, L. (2003) Geographically and Technologically Mediated Knowledge Spillovers between European Regions, The Annals of Regional Science, 37, 657-680.

Galeotti, M. (2007) Economic growth and the quality of the environment: taking stock, Environment, Development and Sustainability, 9, 427-54.

Graziani, A. (1978) The Mezzogiorno in the Italian Economy, Cambridge Journal of Economics, 2, 355-72.

Grossman, G.M., Krueger, A.B. (1993) Environmental impacts of the North American Free Trade Agreement. In: Garber, P. (Eds.) The U.S. –Mexico Free Trade Agreement, pp. 13–56. Cambridge: MIT Press. , Grossman, G.M., Krueger, A.B. (1996) The inverted-U: what does it mean? Environment and Development Economics, 2, 119–22.

Hardle, W. (1990) Applied nonparametric regression. New York: Cambridge University Press.

Hastie T., Tibshirani R., Friedman J. (2001) The Elements of Statistical Learning: Data Mining, Inference and Prediction. Springer-Verlag. New York.

Holtz-Eakin, D. and T. M. Selden (1995), Stoking the fires? CO2 emissions and economic growth, Journal of Public Economics, 57, 85-101.

ISPRA (2009) Quinto rapporto sulla qualità dell'ambiente urbano, Rome.

ISTAT (2004) Statistiche dei Trasporti, Rome.

ISTAT (2009) Le emissioni atmosferiche delle attività produttive e delle famiglie, Rome

Jaffe A., Newell, R., Stavins, R. (2005) A tale of two market failures: technology and environmental policy, Ecological Economics, 54, 164–74.

Jaffe A., Peterson, S., Portney, P., Stavins, R. (1995) Environmental regulation and the competitiveness of U.S. manufacturing: what does the evidence tell us?, Journal of Economic Literature, 33, 132–63.

Komen, R., Gerking, S., Folmer, H. (1997) Income and environmental R&D: empirical evidence from OECD countries, Environment and Development Economics, 2, 505–15.

Leung Y., Mei C.L., Zhang W.X. (2000a) Statistical tests for spatial nonstationarity based on the geographically weighted regression model, Environment and Planning A, 32, 9-32.

Leung Y, Mei CL, Zhang WX (2000b) Testing for spatial autocorrelation among the residuals of the geographically weighted regression, *Environment and Planning A*, 32, 971-890

Loader, C. (1999) *Local Regression and Likelihood*, Springer. New York.

Maddison, D. (2006) Environmental Kuznets curves: a spatial econometric approach, *Journal of Environmental Economics and Management*, 51, 218-30.

Maddison, D. (2007) Modelling sulphur emissions in Europe: a spatial econometric approach, *Oxford Economic Papers*, 59, 726-743.

Magnani, E. (2000) The Environmental Kuznets Curve, environmental policy and income distribution, *Ecological Economics*, 32, 431–43.

Mazzanti, M., Zoboli, R. (2005) The Drivers of Environmental Innovation in Local Manufacturing Systems, *Economia Politica*, 22, 399-436.

Onida F. (2004) *Se il piccolo non cresce. Piccole e medie imprese italiane in affanno*. Bologna: Il Mulino.

Ordás Criado, C. (2007) Temporal and spatial homogeneity in air pollutants panel EKC estimations, *Environmental and Resource Economics*, forthcoming.

Paci R., Saba E. (1997) The empirics of regional economic growth in Italy, 1951-1993, *Contributi di ricerca*, Crenos.

Panayotou, T. (1993) Empirical tests and policy analysis of environmental degradation at different stages of economic development, ILO, Technology and Employment Programme, Geneva.

Perman R., Stern D. (2003) Evidence from panel unit root and cointegration tests that the Environmental Kuznets Curve does not exist, *Australian Journal of Agricultural and Resource Economics*, 47, 325-47.

Porter, M.E., Van der Linde, C. (1995) Toward a new conception of the environment-competitiveness relationship, *The Journal of Economic Perspectives*, 9, 97-118.

Stern, D. I. and M. S. Common (2001) Is there an environmental Kuznets curve for sulfur?, *Journal of Environmental Economics and Management*, 41, 162-78.

Stern, D. (2000), Applying Recent Developments in Time Series Econometrics to the Spatial Domain, *The Professional Geographer*, 52:37-49.

Suri, V., Chapman, D. (1998) Economic growth, trade and energy: implications for the environmental Kuznets curve, *Ecological Economics*, 25,195-208.

Torras, M., Boyce, J.K. (1998) Income, inequality, and pollution: a reassessment of the environmental Kuznets curve, *Ecological Economics*, 25, 147–60.

Vukina, T., Beghin, J.C., Solakoglu, E.G. (1999) Transition to markets and the environment: effects of the change in the composition of manufacturing output, *Environment and Development Economics*, 4, 582-98.

Wheeler, D., Tiefelsdorf, M. (2005) Multicollinearity and correlation among local regression coefficients in geographically weighted regression, *Journal of Geographical Systems*, 7, 1-28.

Wheeler, D. (2007) Diagnostic tools and a remedial method for collinearity in geographically weighted regression, *Environment and Planning*, 39, 2464-81.

Table 1

Table 1. Descriptive statistics					
Variable	Obs	Mean	Std. Dev.	Min	Max
Gdp_pc_1991	103	11,32	2,74	6,00	18,00
Gdp_pc_1996	103	14,93	3,87	7,62	23,87
Gdp_pc_2001	103	18,58	4,90	10,03	31,19
Gdp_pc_2005	103	20,57	5,04	11,63	33,61
CO_2/N_1991	103	79,37	90,93	13,40	515,98
CO_2/N_1996	103	95,63	113,11	13,15	656,26
CO_2/N_2001	103	96,85	117,20	12,88	662,07
CO_2/N_2005	103	126,57	159,21	7,26	1062,69
CH_4/N_1991	103	0,39	0,26	0,06	1,64
CH_4/N_1996	103	0,44	0,33	0,06	1,80
CH_4/N_2001	103	0,42	0,32	0,03	2,15
CH_4/N_2005	103	0,46	0,40	0,02	2,11
NMVOC/N_1991	103	0,38	0,22	0,07	1,12
NMVOC/N_1996	103	0,39	0,23	0,07	1,08
NMVOC/N_2001	103	0,28	0,18	0,08	0,85
NMVOC/N_2005	103	0,28	0,22	0,06	1,07
CO/N_1991	103	1,40	1,05	0,30	7,67
CO/N_1996	103	1,45	1,29	0,28	10,60
CO/N_2001	103	1,03	0,92	0,19	7,48
CO/N_2005	103	0,92	1,00	0,12	7,99
ETSN/N_1991	103	11,75	5,89	1,89	38,94
ETSN/N_1996	103	11,18	5,37	1,27	31,02
ETSN/N_2001	103	10,33	4,96	1,17	35,96
ETSN/N_2005	103	15,01	7,48	1,79	48,74

Gdp_pc= Gdp per capita (euros, thousands); N = workers in industry (thousands);
Emissions (CO2, CH4, NMVOC, CO)= grams;
ETSN= workers in energy intensive sectors (thousands);

Tab 2. Global regression results.

	1991	1996	2001	2005	1991	1996	2001	2005
	CO^2				CH^4			
R^2 adjusted	0,11	0,11	0,13	0,23	0.23	0.24	0.29	0.31
Intercept	55.93	98.52	99.74	110.41	1.73	1.55	1.84	2,02
	(2.37)	(3.32)	(3.45)	('2.57)	(4.89)	(3.63)	(4.9)	(3.69)
Per capita income	-2,513	-3.815	-3.34	-4.04	-0.23	-0.0123	-0.135	-0.137
	(-1.64)	(-2.63)	(2.97)	(-2.68)	(-3.48)	(-2.09)	(-3.32)	(-2.57)
Per capita income^2	-	-	-	-	0,00	0,00	0,00	0,00
	-	-	-	-	(2.95)	(1.41)	(2.55)	(1.92)
Energy intensive sectors	3,02	03:05	3.97	4.92	0.005	0.005	0.006	0.01
	(3.098)	(2.23)	(2.49)	3.66	(1.38)	(0.94)	(1.09)	(2.15)
	CO				NMVOC			
R^2 adjusted	0.6	0.51	0.52	0,48	0.42	0,47	0.34	0.31
Intercept	4.92	6.27	3.82	3.75	1.21	1.23	0.76	0.92
	(4.45)	(4.72)	(4.28)	(3.13)	(4.64)	(4.88)	(3.76)	(3.09)
Per capita income	-0.662	-0.66	-0.32	-0.33	-0.14	-0.99	-0.045	-0.061
	(-3.2)	(-3.62)	(-3.38)	(-2.79)	(-2.86)	(-2.89)	(-2.06)	(-2.09)
Per capita income^2	-0.00	-0.00	-0.00	-0.00	0,00	0,00	0,00	0,00
	(-2.34)	(-2.75)	(-2.55)	(2.28)	(2.05)	(1.91)	(1.26)	(1.54)
Energy intensive sectors	0.085	0.091	0.084	0.066	0.01	0.011	0.009	0.009
	(6.97)	(5.27)	(6.46)	(6.42)	(3.76)	(3.45)	(2.90)	(3.34)

Notes: t values in brackets;

Tab 3. Geographically Weighted Regression results, Geodesic distances, CO^2				
	1991	1996	2001	2005
R^2 adjusted	0.20	0,11	0.22	0,29
F	4,05	0.85	4,16	4,34
Intercept - Median	22.9	87.77	64.3*	70,11
Per capita income - Median	-0.4**	-2.89	-2.17*	-2.18
Energy intensive sectors - Median	1,97	2,02	1.06**	3.23**

*Notes: *Monte Carlo test significance at the 10% level; **Monte Carlo test significance at the 5% level; ***Monte Carlo test significance at the 1% level; **** Monte Carlo test significance at the 0.1% level*

Tab 4. Geographically Weighted Regression results, Geodesic distances, CH^4				
	1991	1996	2001	2005
R^2 adjusted	0.4	0.49	0,61	0,5
F	4.78	6.18	11.42	6.32
Intercept - Median	2.44****	1.16****	1.59****	1.49*
Per capita income - Median	-0.2****	-0.1****	-0.13****	-0.112*
Per capita income^2 - Median	0.00*	0.00****	0.00****	0,00
Energy intensive sectors - Median	0.007	0.005	0.007	0.005

*Notes: *Monte Carlo test significance at the 10% level; **Monte Carlo test significance at the 5% level; ***Monte Carlo test significance at the 1% level; **** Monte Carlo test significance at the 0.1% level*

Tab 5. Geographically Weighted Regression results, Geodesic distances, NMVOC				
	1991	1996	2001	2005
R^2 adjusted	0.49	0.49	0.37	0,36
F	4.68	3.42	2.49	3.50
Intercept - Median	0.66***	0.78**	0.56*	0.59**
Per capita income - Median	-0.07****	-0.04***	-0.027**	-0.3**
Per capita income^2 - Median	0.00***	0.00***	0.00**	0.00**
Energy intensive sectors - Median	0.009	0,009	0.009	0.007

*Notes: *Monte Carlo test significance at the 10% level; **Monte Carlo test significance at the 5% level; ***Monte Carlo test significance at the 1% level; **** Monte Carlo test significance at the 0.1% level*

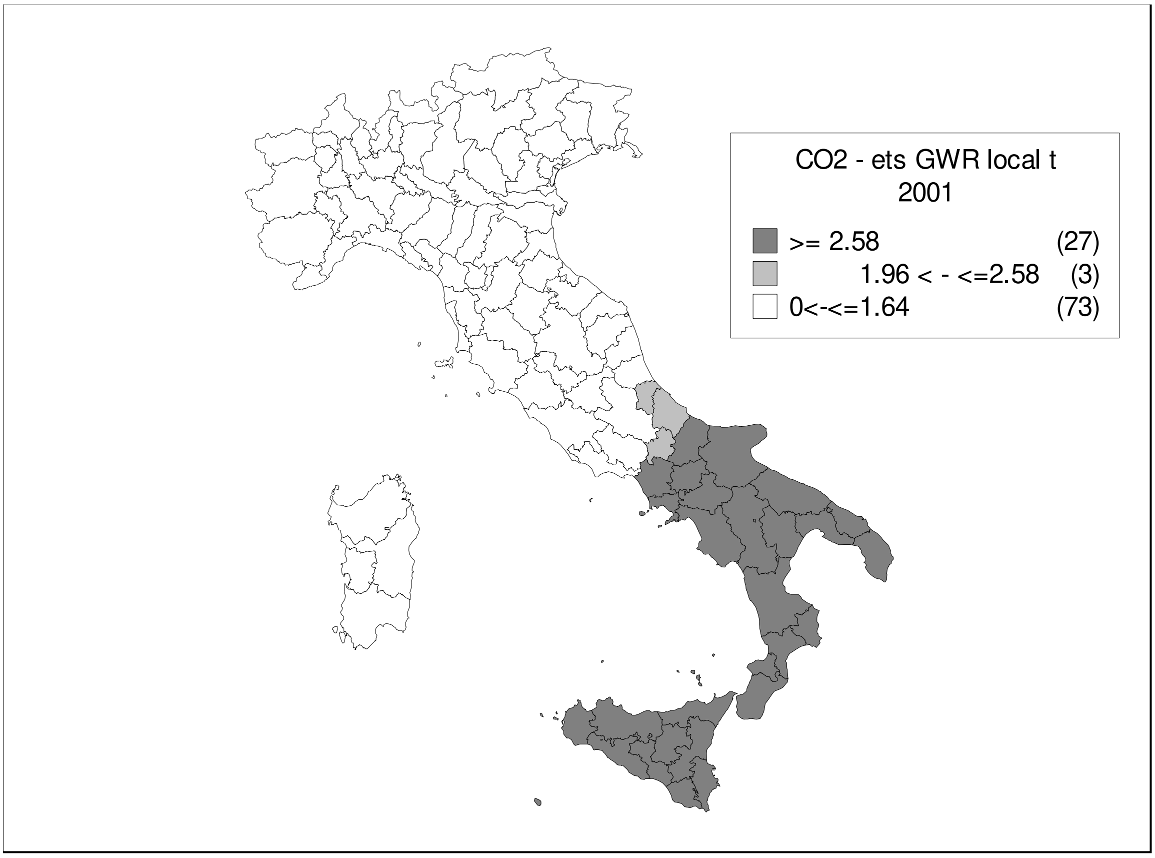
Tab 6. Geographically Weighted Regression results, Geodesic distances, CO				
	1991	1996	2001	2005
R^2 adjusted	0.67	0,85	0.82	0.82
F	10.94	10.12	7.78	8.15
Intercept - Median	3.73****	5.36****	2.75****	3.41****
Per capita income - Median	-0.5****	-0.4****	-0.2****	-0.21****
Per capita income^2 - Median	0.00****	0.00****	0.00****	0.00****
Energy intensive sectors - Median	0.05	0.034	0.024	0.022

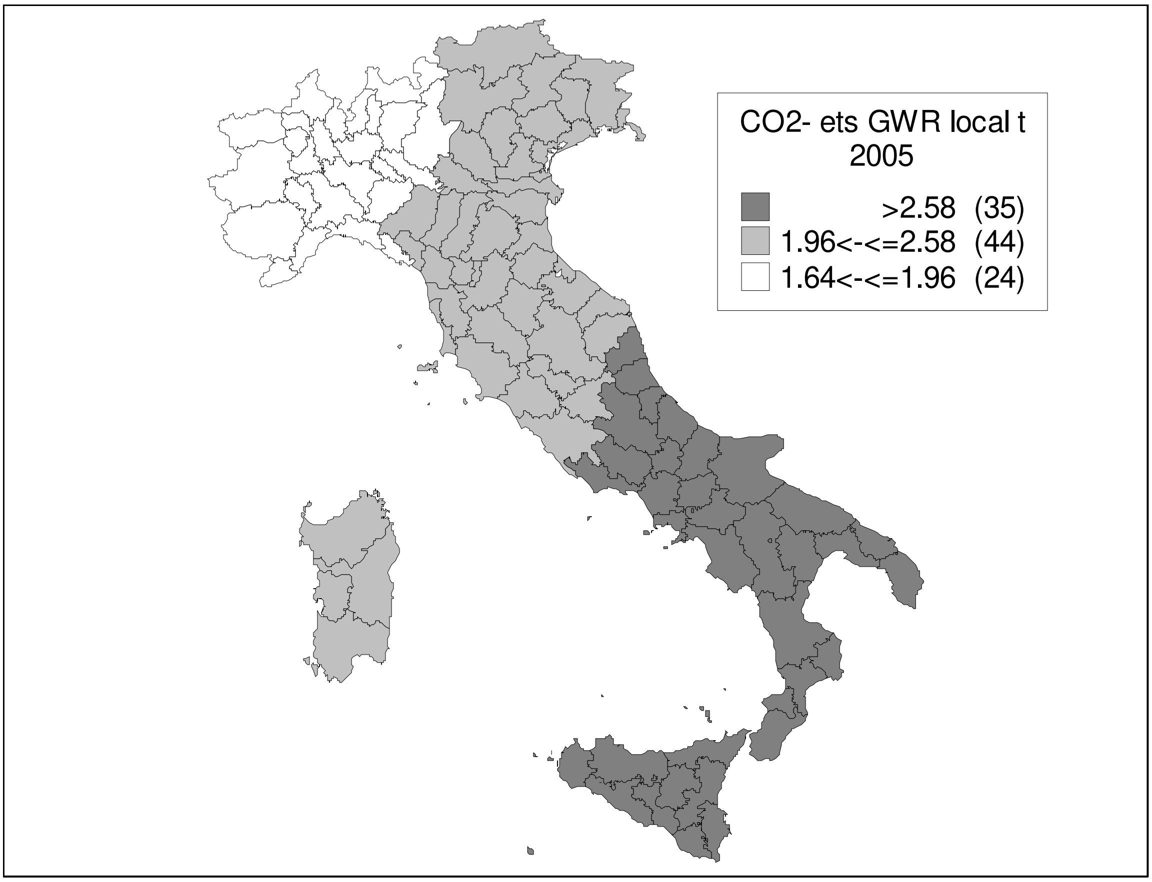
*Notes: *Monte Carlo test significance at the 10% level; **Monte Carlo test significance at the 5% level; ***Monte Carlo test significance at the 1% level; **** Monte Carlo test significance at the 0.1% level*

As far as the local estimates of the squared per capita income are concerned, it should be specified that significant local parameter estimates were found different from zero so as to reproduce a quasi-L-shaped behavior in the income-emission relationship.

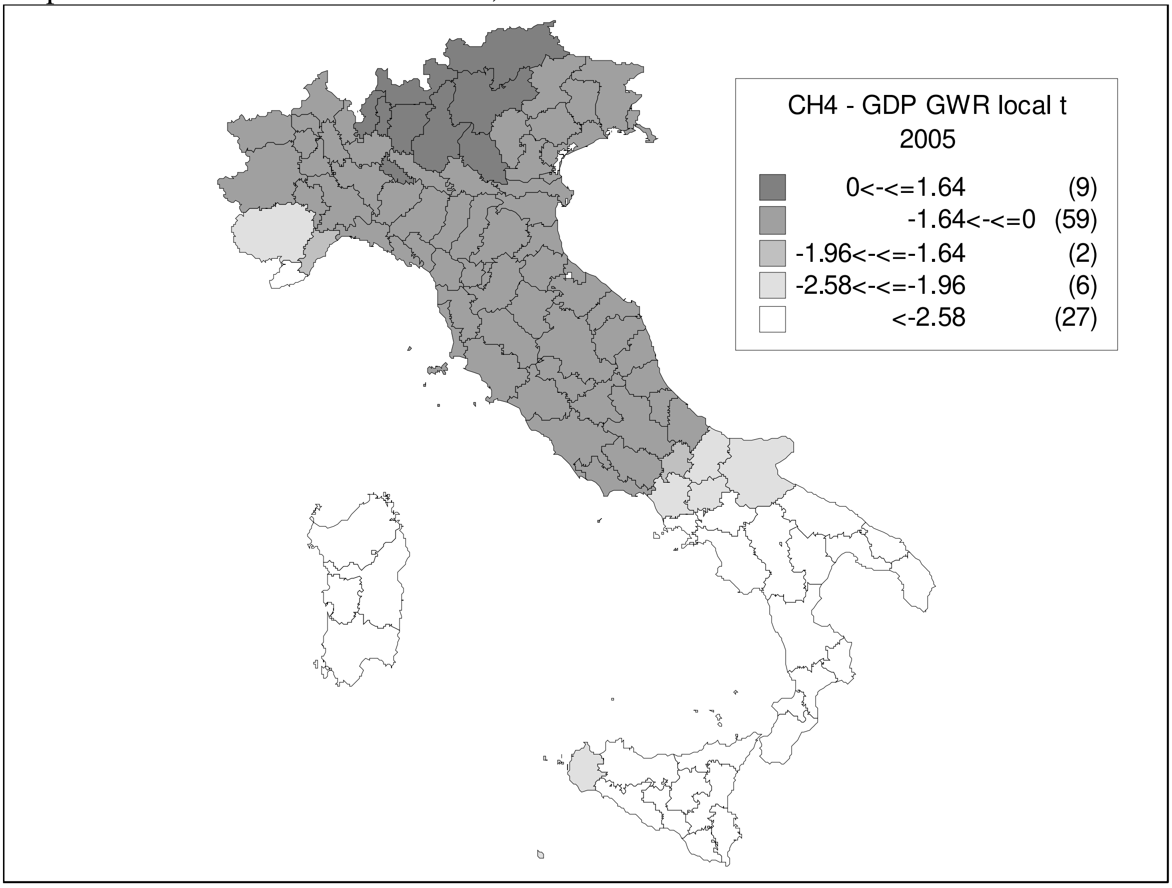
APPENDIX

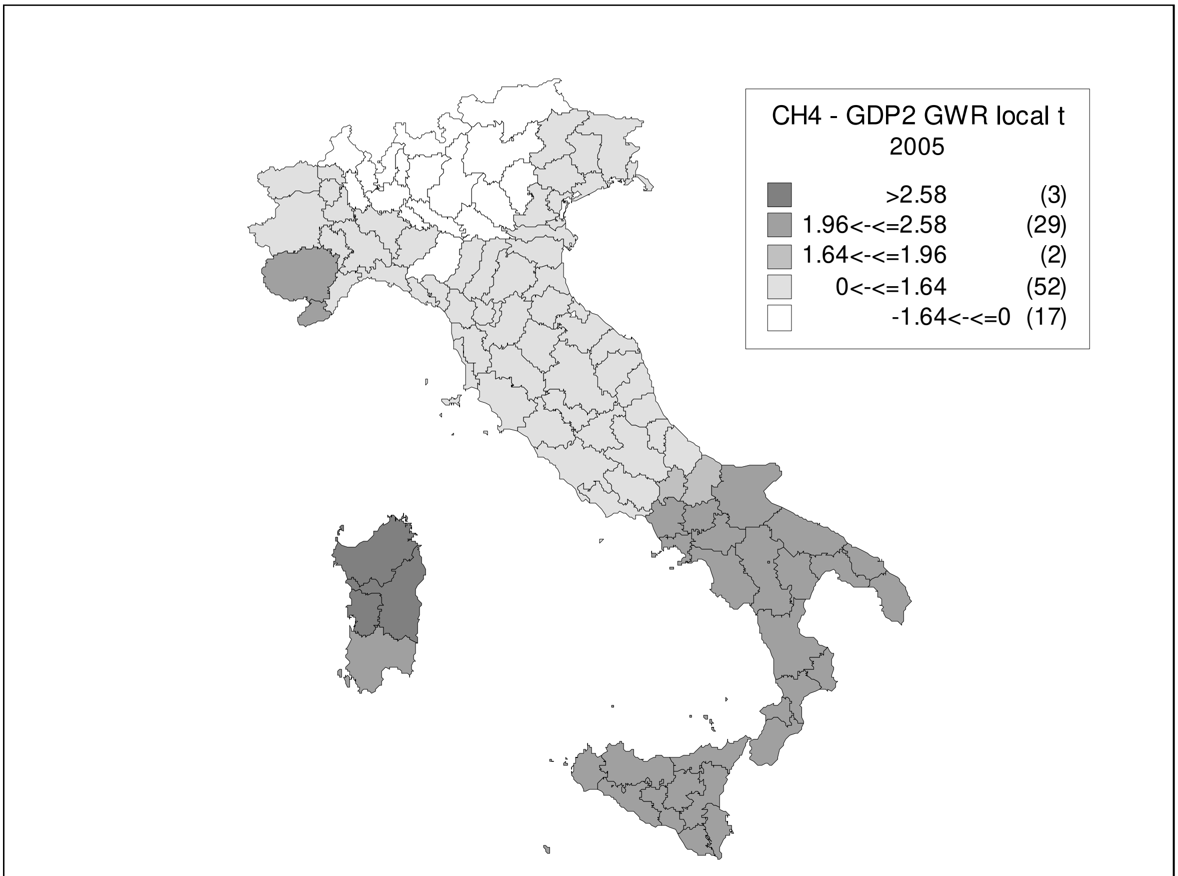
Maps 1 and 2. Carbone dioxide: Local t values, ratio of the number of workers in energy intensive sectors (ETS; 2001 and 2005)



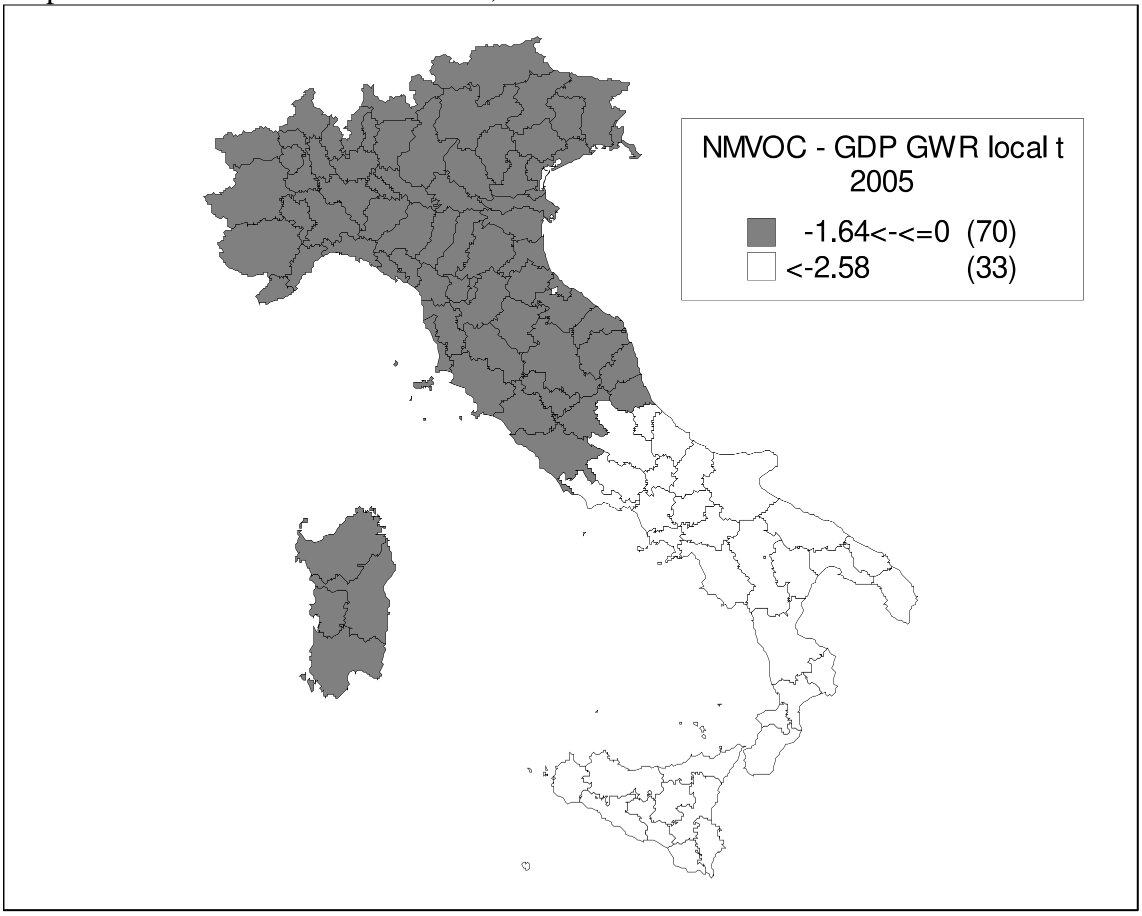


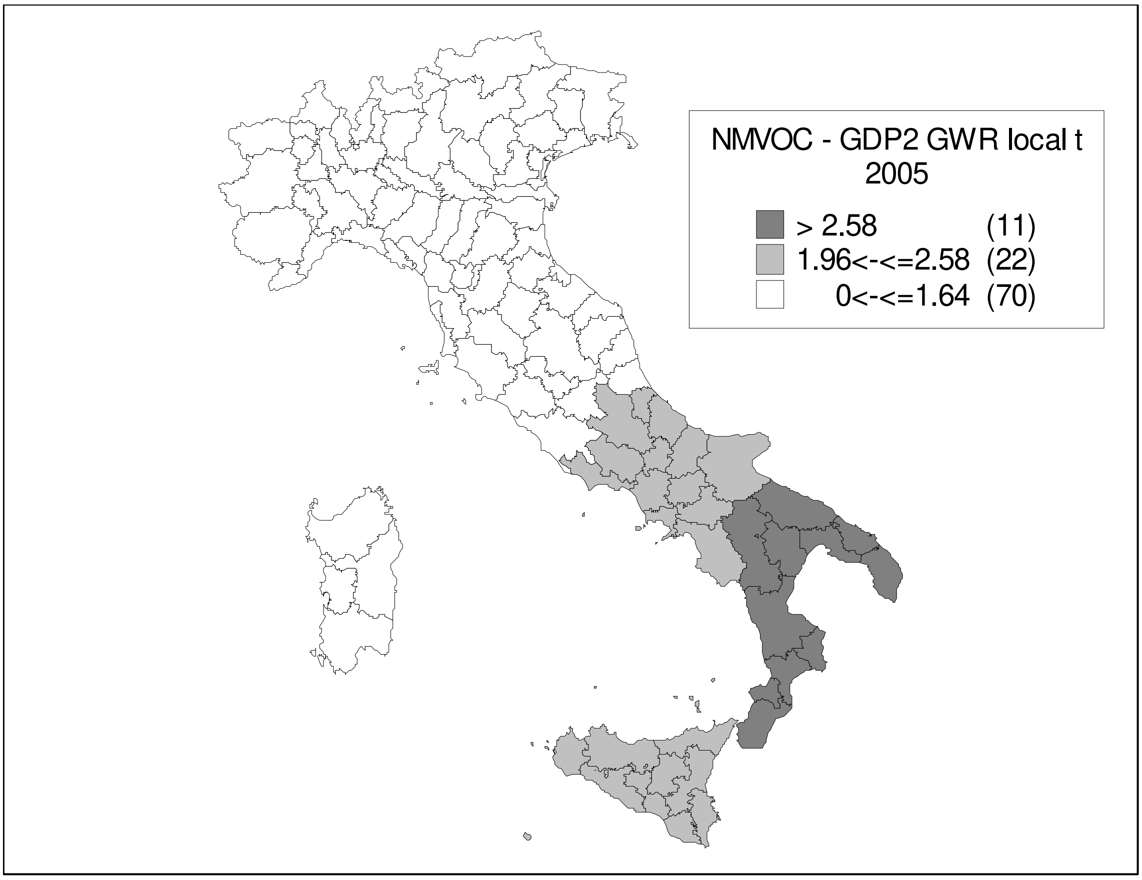
Maps 3 and 4. Methane: local t values, GDP and GDP2 in 2005.





Maps 5 and 6 NMVOC: local t values, GDP and GDP2 in 2005.





Maps 7 and 8 Carbone monoxide: local t values, GDP and GDP2 in 2005.