University of Cyprus
Department of Economics

Working Paper 06-2017

Air pollution spillovers and U.S. state productivity growth

Neophyta Empora

Department of Economics, University of Cyprus, P.O. Box 20537, 1678 Nicosia, Cyprus
Tel.: +357-22893700, Fax: +357-22895028, Web site: http://www.ucy.ac.cy/econ/en

Working paper

Air pollution spillovers and U.S. state productivity growth.

Neophyta Empora*

This study investigates the effect of pollution and pollution spillovers on the Total Factor Productivity (*TFP*) growth among the 48 contiguous U.S. states, for the period 1965-2002. Specifically, this study accounts for the spatial relationship between the states that arises from the transboundary nature of Sulphur dioxide (SO_2) emissions and investigates how the dispersion of pollution affects economic growth. The relationship between *TFP* growth, pollution and pollution spillovers is estimated using a semiparametric smooth coefficient model that allows estimating the output elasticity of pollution and pollution spillovers for each state and each period and accounts for possible nonlinearities in the data. According to the results, the effect of spillover pollution on growth is negative and larger in magnitude than the positive effect of a state's own emissions: decreases in emissions might not be so harmful for productivity growth.

JEL: C14, O13, O40
Key Words: *TFP* Growth, Pollution, Transboundary Pollution Spillovers, Semiparametric Estimation.

---

* Empora: Department of Economics, University of Cyprus P.O. Box 20537, Nicosia 1678, Cyprus (e-mail: embora.neophyta@ucy.ac.cy).

1 Introduction

It is well established that emissions turn to harmful pollutants that can travel across state borders.[1] This paper accounts for the spatial relationship between the states that arises from the transboundary nature of emissions and investigates how the dispersion of emissions affects economic growth. Specifically, this paper measures the effect of pollution spillovers on the Total Factor Productivity (*TFP*) growth among the 48 contiguous U.S. states, for the period 1965-2002. The empirical relationships are explored using nonparametric econometric methods that allow obtaining heterogeneous estimates (for each state and period) as well as the pattern of these estimates. The analysis uses SO_2 emissions; SO_2 emissions can be transported over hundreds or thousands of kilometers away from the emitting source and deposited on the area of a downwind state. WBK & Associates Inc. (2003) report that when SO_2 is released it can remain in the atmosphere from 2 to 8 days (Katz, 1977), from 1 to 3 days according to Hidy (1994) and from 1 to 5 days according to the Hazardous Substances Data Bank (HSDB, 2002).[2]

The fact that emissions travel across state boundaries can create an environment where states may engage in strategic interaction. For example states, as a response to the pollution they receive from other states, may decrease or increase their emissions, depending on the "damage" they cause. Maddison (2007) notes that it is usually assumed that the reaction function of a country with respect to the emissions of other countries is downward sloping. This is true if the perceived marginal damage of a country is convex to the emissions of others (see Freeman, 1993, and Førsund and Strøm, 1994, for a discussion on the damage functions). If the marginal damage function is negatively sloped with respect to the pollution received by others then the emission function is upward slopping of other countries´ emissions. The effect of the pollution spillovers on *TFP* growth, provided by the estimates obtained in this paper, can be used as an indicator of "damage", if one wants to use this term. Depending on how

---

[1] Hence the term tranbandoury pollution.

[2] This is the so-called "residence time" of SO_2 in the atmosphere. It is determined by the rate of removal of SO_2 from the atmosphere; "Once SO_2 is released into the atmosphere, it may be converted to other compounds and/or removed from the atmosphere by various mechanisms. Processes such as oxidation, wet deposition, dry deposition, absorption by vegetation and by soil, dissolution into water and other processes contribute to the removal of SO_2 from the atmosphere" (WBK & Associates Inc., 2003, p.6).

much a state is affected by other states´ emissions, that is depending on the level of pollution spillovers as well as the emissions that the state is producing (its “own emissions”), their estimated effect on growth will give an inside for the state´s incentives to change or not its emissions levels. Two offsetting effects on growth are expected to take place from the generation of emissions. On one hand the pollution spills in a state (hereafter named: spillins) from other states are expected to have negative effect on growth.[3] The pollution a state is receiving from other states is a negative externality, both because of its effect on the environment (including the reduction of e.g. labor productivity, see Empora & Mamuneas (2011) for more extended discussion on the negative externality effect of emissions that applies here also) as well as in the sense of Baumol and Oates (1988, p.17) definition: “An externality is present whenever some individual´s (say A´s) utility or production relationships include real variables, whose values are chosen by others (persons, corporations, governments) without particular attention to the effects of A´s welfare”. The effect of “neighbors” emissions on productivity growth also captures possible environmental policy reactions (and thus pollution abatement cost variations) to the environmental policies of the neighbors.[4] On the other hand a state´s “own emissions” have an overall positive effect (the estimates in Empora & Mamuneas (2011) provide the evidence on this) and are expected to continue having a positive effect after accounting for pollution spillovers. Which of the two effects is the greatest in absolute value is what, in terms of productivity gains or losses, will determine the incentives of states to change their emissions policy. Given these incentives and the fact that states are responsible for most of the enforcement of environmental standards, this will potentially offer important policy implications about the success or failure of specific environmental policies and programs.

Most of the models proposed in the literature do not account for the relationship between transboundary pollution spillovers and economic growth. Only very few papers have taken

---

[3] The use of the term “pollution spillins” or “pollution received” throughout the paper is not a measure of the quantity of *depositions* within a state. Instead, higher pollution spillins in a state is meant to proxy the assumption that when states defined as “neighbors” to a state, are responsible for greater generation of transboundary pollution, increase in their emissions results in increase in the possible pollution spillins in that state.

[4] Fredriksson and Millimet (2002) find that states’ environmental regulations are affected by those of their neighbors. There is also a lot of work in the literature investigating the effect of regulations on measures of competitiveness; environmental regulations increases the costs of firms due to pollution abatement but it can also be productivity engaging through technological progress in the production and pollution abatement techniques. Pasurka (2008) offers an interesting review on the topic.

into account the spatial relationship between countries that arises from the transboundary nature of pollutants (Murdoch, Sandler, Sargent, 1997; Hauer and Runge, 2000; Stern, 2000; Ansuategi, 2003; and Maddison, 2006; 2007). These papers are part of the ECK literature and (the empirical ones) mainly use data on sulfur emissions in a panel of European countries. Fredriksson and Millimet (2002) account also for environmental spillovers but in the context of environmental regulations; they use environmental regulations as the dependent variable to investigate the direction and the magnitude of the strategic interaction between U.S. states. They find that states are affected by their neighbors. In terms of water pollution spillovers, Sigman (2005) examines water quality in state rivers across the U.S. states and finds evidence of free riding behavior among the states. The environmental laws in the U.S. are at a large extend federally set, nevertheless, the U.S. states have significant flexibility in implementation and enforcement. The Clean Air Act Amendments (initiated in the 1970s and continue until today) which are implemented at the federal level gives states considerable freedom in selecting the ways of pollution control and thus in defining their environmental policy. It seems that transboundary pollution together with the nature of the environmental policy setting and enforcement in the U.S. allows states to act strategically. The purpose of this paper is not to estimate reaction functions due to transboundary spillovers; rather it provides estimates of their effect on growth, which in turn can be used as indicators influencing the motives and the behavior of the states thus generating possible strategic interaction between states.

The contribution of this paper can be summarized in the following. First and most importantly is that, unlike previous work, this study provides estimates of the effect of the pollution a state is receiving, proxied by neighboring states´ emissions, on *TFP* growth. Second, the nonparametric estimation methods provide heterogeneous estimates of this effect. Third, policy implications arise by examining the effect of spillovers on *TFP* growth; this effect being one factor affecting a state´s environmental behavior. That is, depending on the amount of emissions a state is producing and the magnitude of pollution it receives, estimating the effect of these two on its growth (their combined net effect on growth), can give a measure of how strong (if any) are the incentives towards implementing various environmental policies.

According to the findings, the relationship between pollution spillovers and *TFP* growth is negative. The analysis suggests that a strategic interaction game emerges; states that are relatively low emitters but high receivers of pollution from other states have relatively stronger incentives to cut back on emissions since, *given that all states do the same*, in productivity terms, they will benefit the most from a reduction in emissions. Overall, states alone have no incentive to cut back on their emissions unless all the states follow the same policy; for a successful reduction in interstate pollution spillovers, a federally set and enforced policy is necessary. This reduction will benefit all the states since according to the magnitude of the estimates reducing emissions might not be necessarily too harmful for productivity growth.

The paper is organized as follows. Section 2 presents the model. Section 3 presents the method and the data used for the empirical estimation. Section 4 presents the results. Section 5 discusses the findings and the possible policy implications. Finally, section 6 concludes.

2 Model

The following production function is defined to describe the production process

$$y = F(x, x_e, e, p, t) \tag{1}$$

where y, is the output produced using a vector of non residual generating inputs x, and the input x_e that generates emissions. e stands for emissions that enter directly in the production function and represent the negative externality effect emissions can have on production.[5] p represents pollution spillovers between states. The pollution that a state receives from other states, p, negatively affects the receiver's state environment (e.g deterioration of natural recourses, affects the productivity of agents in the economy and etc). Thus receiving pollution from other states is a pure negative externality and as such it can only have a negative effect on the "receiver's" state output. t is a technology index measured by time trend.

Following Murty and Russell (2002; 2010), the generation of the production residual is described by

---

[5] See Empora & Mamuneas (2011) for details on the use of e directly in the production function.

$$e = g(x_e, t) \qquad (2)$$

where t is a time trend that captures the production technology of emissions[6]. The pollution spillover variable or the pollution received by state i at time t is proxied by “neighbors” emissions. It is the weighted sum of the other states´ emission densities but the state in question

$$p_{it} = p(s_{jt}) = \sum_{i \neq j}^{n} w_{ij} s_{jt} \qquad (3)$$

where w_{ij} is the weight used to define the relationship between states i and j as far as pollution is concerned. When w_{ij} is positive then states i and j are classified as “neighbors”. s_{jt} is the emission density of state j defined as the emissions divided by the area of the state j.[7] More on the construction of spillover pollution variable is provided in the data section of the paper.

Solving (2) for x_e, $x_e = h(e,t)$, and replacing it in (1) the following production function is defined for state i at time t:[8]

$$y_{it} = F(x_{it}, h(e,t), e_{it}, p_{it}, t) = f(x_{it}, e_{it}, p_{it}, t) \qquad (4)$$

That is output, y, depends on x, the vector of traditional inputs (capital, k, and labor inputs, l), the emissions state i is producing, e, the spillover pollution, p, and the time trend t that is now capturing the combined production of output and emissions technology. Total differentiation of (4) with respect to time and division by y along with the definition of *TFP* growth index, results in the following relationship between *TFP* growth, emissions and pollution spillovers (see Empora & Mamuneas (2011) for a detailed derivation), for state i in year t

---

[6] The residual generation mechanism in equation (2) describes the technology of emission production and does not constitute a behavioral relationship.

[7] Once again it is emphasized that “pollution received” does not measure the quantity of *depositions* within a state; it is constructed in order to capture the effect of neighboring states ´emissions.

[8] The function $g(.)$ must be monotonic otherwise is not invertible. The 2nd law of thermodynamics ensures that $\partial e / \partial x_e = g'(.) > 0$ (Baumgartner et al., 2001). Moreover, SO_2 emissions are mainly energy related. In general, emissions can be generated also from materials, in which case x_e will represent an aggregator index of the intermediate inputs.

$$T\hat{F}P_{it} = \hat{\mathrm{A}}_{it} + \varepsilon_{e_{it}} \hat{e}_{it} + \varepsilon_{p_{it}} \hat{p}_{it} \tag{5}$$

The last two terms on the right hand side of (5) capture the unobserved contribution of the emissions state *i* is producing, *e*, and the spillover pollution, *p*, to aggregate production. This unobserved contribution of own emissions and spillover pollution to output growth, is modeled as a general unknown function of both a state's emissions and a state's pollution received, $\theta_1(e,p)\hat{e}$ and $\theta_2(e,p)\,\hat{p},$ respectively

$$T\hat{F}P_{it} = \hat{\mathrm{A}}_{it} + \theta_1(e_{it}, p_{it})\hat{e}_{it} + \theta_2(e_{it}, p_{it})\,\hat{p}_{it} \tag{6}$$

The output elasticity of emissions and the output elasticity of spillover pollution, $\theta_1(.)$ and $\theta_2(.),$ capture the state-specific effect of own emissions and spillover pollution on growth.

3 Data and empirical analysis

Adding the usual error term, $u_{it},$ equation (6) becomes

$$T\hat{F}P_{it} = W_{it}^T \beta +_1 (e_{it}, p_{it})\hat{e}_{it} + \theta_2(e_{it}, p_{it})\,\hat{p}_{it} + u_{it} \tag{7}$$

where $W_{it}^T = (D_i, t, T\hat{F}P_{it-1})$ contains the variables in the linear part of the equation and the error term satisfies $E\left(u_{it} \left| W_{it}, e_{it}, p_{it}, \hat{e}_{it}, \hat{p}_{it}\right.\right) = 0.$[9] The model of equation (7) is estimated using the smooth coefficient semiparametric model. This allows for own emissions and spillover pollution to influence *TFP* growth for each state and each period and in a nonlinear fashion (Fan, 1992; Fan and Zhang, 1999; Li et al., 2002; Kourtellos, 2003; and Mamuneas, et al., 2006). For the estimation of equation (7), the panel dataset with information on the 48 contiguous U.S. states for the years 1965-2002 is employed (see Empora & Mamuneas (2011)

---

[9] Moving from equation (6) to equation (7) $\hat{A}_{it}$ is expressed as a function of state dummies to capture idiosyncratic exogenous technological change and time trend to capture exogenous shifts in technology. The lagged *TFP* growth ($T\hat{F}P_{it-1}$) is used as a regressor to account for the dynamics of *TFP* growth and to capture serial correlation problems.

for details on the construction of the dataset). Emissions and pollution spillovers are measured using the SO_2 pollutant.

One issue to be addressed in order to investigate the relationship between the interstate pollution spillovers and growth is the choice of weights; it is necessary to specify the weights for the construction of the spillover or pollution received variable. Fredriksson and Millimet (2002) when analyzing whether there is strategic interaction between the states as far as environmental stringency, is concerned, they emphasize the importance of the choice of the weight matrix; they use various geographical and/or income/population based weights. States can be interconnected in various ways. The spatial weights matrix (the *w`s* in equation (3)) can use inverse geographical distances between states or indicating which states share a common border. States can be also related due to environmental factors like for example the direction of the wind. Murdoch et al. (1997), Ansuategi (2003) and Maddison (2007) employ scientific information to account for pollution spillovers between European countries; they use a transport (or blame) matrix of coefficients (produced by the EMEP (European Monitoring and Evaluation Program)) that transforms a vector of emissions into a vector of depositions.[10]

In the analysis of this paper various weighting schemes are used but only some of them proved to be functional. The ones discussed in the empirical analysis are the following: the first, is one in which weights are based on the inverse distances between the states, the second is a weight that defines two states as neighbours if the distance between the two states is less than the median distance between two states in the sample. Thus the above two weighting schemes are distance based ones.[11] Two more weighting schemes are used; one that assigns a weight of one if states accept inflows of pollution from the other states (zero otherwise). The information used to construct this weight is obtained by U.S. EPA in the context of the Clean Air Interstate Rule (CAIR) program.[12] The last weighting scheme does not involve the use of weights as such; the unweighted sum of emissions of all other states but the state in question is used as the pollution spillover variable in the estimations. Table 6 of the appendix provides descriptive statistics for the growth of the pollution spillover variables constructed using each of the weighting schemes. In addition to these weighting schemes, for which the results are

---

[10] Currently such information on transport matrices for U.S. states is not available for use in the current paper.
[11] Distance between states is from Wolf (2000).
[12] Source: http://www.epa.gov/cair/where.html.

presented in the next section, experimentation using other weighting schemes was also performed. The search among weights created a list of weighting schemes that have been also used in estimations. Some of them either don't work at all or don't perform well for all states. Some of these weights are listed in table 7 of the appendix.

The spillover pollution variable is constructed using the weight matrix (with the leading diagonal terms equal to zero) along with the data on the emission density of each state. Emissions and not ambient concentration rates are used for this calculation. Ansuategi (2003) argues that ambient concentration rates measure the local impact of polluting activities but the source of the polluting activities, that is, the origin of emissions, is not taken into account. In a framework that accounts for transboundary pollution spillovers, the choice of the pollution measure to be used becomes even more important. That is, a state can produce low (high) quantity of emissions but to exhibit high (low) reported ambient concentration rates due to transboundary pollution transfers between states. There are of course other factors like chemical transformation of the pollutant in the ambient air. So using ambient concentration rates is not the best measure for calculating pollution transfers between states because it already contains, or is net from, any interstate pollution spillovers that have taken place. Using emissions, although it accounts for the origin of the polluting activities, which is important in defining pollution spillovers between states, it does not account for the area in which they are released nor for the location of the impact. The first issue is dealt with by using emission density for the calculation of spillover pollution; emissions transferred outside a state's border may diminish as the size of the state increases. That is, bigger states typically absorb more of their own emissions.[13] By dividing emissions by the state size, the emissions that the states that are assigned a nonzero weight (the "neighboring" states; states from which pollution can be transferred to other states), are able to spill out is adjusted according to the size of area in which they are released. The unknown probable location of the impact of emissions is then dealt with by calculating the pollution spillovers using specific weighting schemes.

Before proceeding to the results, it should be noted that NO_x spillovers were also constructed but it seems that in this case the model does not perform well. One reason might be that NO_x causes much less damage on the environment than SO_2. Muller and Mendelsohn (2007),

---

[13] This is true if one assumes that the polluting activities take place in the center of a state (which is a circle). But even if it is not, this assumption is not restrictive.

measure the damages of air emissions in the U.S. in 2002 using six air pollutants. They find that SO_2 emissions generate considerable more damage than NO_x; SO_2 produces 26% of total damages while NO_x emissions generate only 8% of total damages. Also, the differences in sources for the two pollutants may be another reason for why the model does not work well for NO_x emissions. According to the U.S. EPA, National emissions Inventory (2002), 70% of SO_2 comes from stationary sources while only 22% of NO_x comes from these sources. The major source for NO_x is mobile sources (59% and only 5% for SO2). Since NO_x emissions come mainly from mobile sources, the relationship between the origin and receptor states, as far as pollution spillovers is concerned, might need more precise (in terms of environmental engineering) weights between states in order to be modeled. Further investigation of the effect of transboundary nature of NO_x emissions and is effect in growth is left as a future research[14].

4 Empirical results

The results of the semiparametric model are presented in figures 1-3 and tables 1-3 and 4. Figure 1 and table 1 present the results on two distance based weighting schemes. Figure 2 and table 2 present the results of the CAIR weighting scheme and that of the unweighted measure of spillover pollution. Figure 3 plots the results for the marginal effect of own emissions on growth. Table 3 offers the 15 states with the highest effect of spillover pollution on their growth, for all weighting schemes. Table 4 presents the estimates of the exogenous rate of technological change for all weighting schemes. The average estimated exogenous rate of technological change ranges from 0.008, for the CAIR weighting scheme, to 0.04 when the weighting scheme used is the one with the inverse distances between states. Table 5 presents the estimates of the linear parametric model for each of the weighting scheme.[15]

The nonparametric results are based on standard local kernel estimation using the standard Gaussian density as the kernel. The bandwidth is chosen by cross-validation. Figures 1 and 2 plot the output elasticity of spillover pollution, $\theta_2(.)$, on the vertical axis and spillover

---

[14] To see if the difference between SO_2 and NO_x holds before 1990, when the Clean Air Act amendments were released by EPA and generated the cap-and-trade system for SO_2, the analysis was also performed for the period 1965-1990; the difference remains but the nonparametric estimates for NO_x are now statistically incignificant.

[15] In the literature people also use standardized weights; the elements of the row of the matrix sum to unity and have zeros in the leading diagonal. Standardized weights are not essential; they are usually used for the ease of interpretation.

pollution on the horizontal axis, for the different weights.[16] Figure 3 plots the output elasticity of emissions, $\theta_1(.)$, on the vertical axis and emission levels on the horizontal axis. For each figure the estimates are drawn along with the 95% confidence intervals for these estimates. The straight line is the estimated parameter of pollution received and emissions, respectively, from a parametric linear specification, where $\theta_1(.)$ and $\theta_2(.)$ are constants and therefore the contribution of pollution to *TFP* growth is linear (see table 5 for the parametric estimates).

Two specification tests are performed. First, the Li and Wang (1998) test; it tests the null hypothesis of a parametric linear specification against a general nonlinear specification. The test results show rejection of the null. This holds for all the estimated models that use all the different weighting schemes presented in this paper (the p-value is 0.0001 for each one of them). Second, a serial correlation test is also performed. This test is (also) used as a specification test because if serial correlation is present to the parametric linear specification and not in the semiparametric one, this might be an indication that nonlinear effects, and not error dependency, are probably present and are not captured by the regression function in the linear parametric formulation (Li and Hsiao, 1998, and Li and Stengos, 2003). The null hypothesis is no-first order serial correlation. The Lagrange Multiplier test employed for the parametric model shows that 1st order serial correlation is present (the null hypothesis is rejected in all cases/all weighting schemes with a p-value equal to zero). The testing for serial correlation in the semiparametric specification is conducted using the test proposed by Li and Stengos (2003). In terms of implementation this test is the same as the LM test used in the case of the parametric model. For the standard errors in the smooth coefficient function, these are obtained with block "wild" bootstrapping to account for dependent data. The results indicate that 1st order serial correlation is also present (for all weighting schemes) in the semiparametric specification (with zero p-values). Including the lagged *TFP* growth as a regressor and re-applying the test, shows that in the linear model first order serial correlation is still (strongly) persistent (the p-value is less than 0.0005 for all weighting schemes) while in the semiparametric is not (the p-value is greater than 0.77 for all weighting schemes). The tests results support the use of the semiparametric model since nonlinear effects seem to be present. This nonlinear relationship is also evident by observing the linear estimate in the

---

[16] $\theta_1(.)$ is evaluated at the mean of spillover pollution. $\theta_2(.)$ is evaluated at the mean of own emissions. This is necessary because otherwise the graphical analysis would require a three dimensional graph.

graphs; apart from certain ranges, the linear estimate lies outside the 95% upper and lower bands. Finally, the point estimates from the semiparametric model seem to be statistically different from zero since the 95% bands do not include zero for most of the estimates.

The results show that the effect of spillover pollution, as expected, negative.[17] The pollution that a state receives from other states is a negative externality and as such it has a negative effect on the "receiver's" state growth. The heterogeneous estimates show that the negative marginal effect on growth is higher the higher the spillover pollution is. In the case of emissions that the states are producing, the effect on *TFP* growth is positive.[18] As far as the magnitude of these estimates is concerned, on average the output elasticity of spillover pollution ranges from -0.01 to -0.03 depending on the weight used (see tables 1 and 2)[19]. The average output elasticity of own emissions ranges from 0.006 to 0.007. The average output elasticity of spillover pollution is large relatively to the average output elasticity of emissions. Muller and Mendelsohn (2007), found that in the U.S., the 2002 14.8 million tons of SO_2 emissions (19% of the total emissions by weight ($PM_{2.5}$, NH_3, SO_2, VOC's PM_{10} NO_x) generated $19.5 billion in damages (26% of total damages) and is considered to be amongst the four pollutants ($PM_{2.5}$, NH_3, SO_2, VOC's) that cause the greatest damage. According to their results, most of the damages are attributed to effects on human health. This means that the negative externality effect of spillover pollution, coming from factors like the worsening of the productivity and quality of the inputs (mostly labor inputs), is well captured by the model as the relatively large impact on the production indicates.

Comparing the results between the different weighting schemes, the results on the effect of spillover pollution on growth show a lot of similarities as far as the average magnitude of the effect on growth as well as the distribution of states is concerned. Table 3 reports the 15 states with the highest negative output elasticity from spillover pollution. Ohio is always, no matter the weight used for the construction of spillover pollution, the state that has the biggest

---

[17] In order to account for the possible lag of the effect of the spillover pollution on the economy, the lagged values of spillover pollution are used in the estimation.

[18] In this paper emission levels are used as a measure of own emissions. According to the results in Empora & Mamuneas (2011), using emissions or emission density does not differentiate the pattern of their effect on growth, in the case of SO_2. The robustness of this is also verified in this paper. Moreover the results, of the effect of spillover pollution on growth, are not much differentiated between the two measures of own emissions. Since the focus of the paper is the effect of spillover pollution, to conserve space the results shown and discussed in this paper are only for the case in which emission levels are used as the variable for a state´s "own emissions".

[19] The estimates before 1990 do not change the results qualitatively. Quantitatively the estimated elasticities are three times larger relatively to the full sample estimates (for all weighting schemes).

negative output elasticity of spillover pollution (and the biggest positive output elasticity of own emissions); Ohio is among the states that receive the highest, on average, pollution from other states (see table 8 of the appendix for rankings of the states as far as the level of pollution they receive, is concerned).[20] Also, overall, the states with the biggest negative elasticity of pollution spillovers are the eastern states. A comparison of the R^2 values, although the differences are minor, favors the last weighting scheme (when using the sum of emission densities – unweighted – of all states but the state in question as the spillover variable in the estimations). Nevertheless, because this weight ignores factors that define and shape the relationship between states, all the other weights, with the next best being the weight defining as neighbors the states that are less than 1091 miles (median distance) far from each other, are preferable. A similar weighting scheme also performs the best in Maddison (2006); he specifies countries as neighbors if the distance between them is less than 1750 miles. Lin (2010) also uses a similar weight, which takes the value of one if a site is located between 1 and 500km from another site.

As a final remark, according to Anselin (2002) a number of issues concerning the specification of weights should be taken into account but in general the choice of the correct weighting scheme is a matter of the application in hand. For example, the distance based weights generally place more weight to states that belong to a neighborhood of small states. This feature of the distance based weights, although is a drawback in general, is appropriate in the application of this study because the states more heavily weighted are the east states; the middle-east states are generally small and therefore have more neighbors. These states are also high emitters, therefore states located near these states, will have, according to the distance based weights, higher spillover pollution. Since the eastern states are, according to U.S. EPA the ones receiving the highest pollution spillins due to prevailing winds, and also these high "receiver" states the same with the high "giver" states, the distance based weights used in this study are therefore correctly capturing the status of the east U.S. states by defining this neighborhood of states as being the high receivers of spillover pollution.[21] The distance based

---

[20] The statement that Ohio receives the highest pollution from other states, captures not the quantity of depositions within the Ohio, but the neighboring states´ (as these are defined as such when the weight between Ohio and other states is positive) emission density. Higher levels of pollution received means that a state has either more "neighbors" or the neighbors are high polluters, or both.

[21] The U.S EPA performed the so-called State-by-State zero-out modeling to quantify the contribution from emissions in each state to future PM2.5 nonattainment in other states. According to the resulting PM2.5

weights would have produced misleading results if, for example, the high polluters were the big states, these states were located to the east and small states were located to the west. Then the selection of these distanced based weights will have been inappropriate because they would have not been able to capture the correct relationships between states (since they would have been placing a lot of weight on the small states, thus producing false spillover effects).

5 Discussion

The results lead to some interesting conjectures. First, the average output elasticity of pollution spillovers, for all states, and for all weighting schemes, is higher in absolute value than that of emissions the state is producing. This means that, all else equal, on average the marginal net effect on productivity growth is negative; if a state reduces its emissions but other states don't then this reduction will cause a decrease in its productivity growth. Assuming that the growth rate of states' emissions and that of the pollution they receive are the same, then if all states reduce their emissions by 1%, the net effect on output will be positive; using the nearest neighbor weighting scheme, on average output will go down by 0.006% but also increase by 0.03% from a 1% reduction in spillover pollution. The net effect on output will be positive (increase by 0.02%). That is, it seems that reducing emissions might not be necessarily so harmful for productivity growth.

The results also suggest a grouping of the states based on the difference between the estimated elasticities, $|\hat{\theta}_2| - |\hat{\theta}_1|$. This difference shows which states will benefit the most from a reduction in spillover pollution. For example, states like Ohio, Maryland, Delaware, New Jersey and West Virginia show high estimated difference between the marginal effect on growth of the pollution they receive and the emissions they produce. These (east) states are highly affected by the emissions of neighboring states, i.e. they receive relatively high levels of pollution from other states. This group of states has relatively stronger incentives to cut back on emissions since, *given that all states do the same*, they will benefit the most. For

---

contribution matrix (available at http://www.epa.gov/CAIR/pdfs/iaqr_pm25_contributions.xls), the high receiver states of P.M2.5 are the same with the states having the highest spillover pollution in this study. The biggest contributors are, according to the same matrix, the same as the high receivers; the middle-eastern states. Since this indicative PM2.5 contribution matrix classifies the "receivers" and "givers" all being in the same area i.e. they are neighbors, provides further support that the distance based weights, used in the paper and classify the same states as neighbors, are appropriate in the application of this study.

states like, Arizona, Washington, California, Nevada and Montana the estimated difference, $\left|\hat{\theta}_2\right| - \left|\hat{\theta}_1\right|$, is low. These states have weaker incentives to cut back on their emissions. For the rest of the states the difference, $\left|\hat{\theta}_2\right| - \left|\hat{\theta}_1\right|$, is average relatively to the two aforementioned extremes.

Overall, states will benefit from a reduction in the spillover pollution, some more and some less, and therefore the incentives to cut on their emissions are also higher for some and lower for others. But no matter the degree of the benefit, left on their own to set their environmental policy, they do not have incentive to cut back on their emissions because they will only benefit if other states do the same. Reducing emissions in order to reduce spillovers is not a credible strategy because of the free riding behavior of the states. A state has the incentive to free ride since if the other states reduce their emissions, the state in question will gain the most if it does not; pollution spillovers and their negative effect on growth will be reduced and at the same time the positive effect of its own emissions will, at the least, be the same. This is common knowledge, which means that if all states assume the same then none of the states will be willing to reduce its emissions in order to reduce spillovers. That is unless the states are assured that there will be a reduction in the pollution spillovers, they don't have incentives for reducing their emissions. Thus the states will engage in a prisoner's dilemma-type game and reach a sub-optimal equilibrium. Because of the public nature of spillovers, that is if a state reduces its emissions then some others benefit, states can only rely on governments for the provisions of pollution spillover reduction; to get to the optimal solution, a federal policy towards an overall reduction of emissions is necessary. Ansuategi (2003) calls this game "open-loop Nash equilibrium" where each country takes the other countries 'policies as given when maximizing their objective function.

Most of the papers dealing with transboundary pollution, measure the outcome of strategic interaction, if any. They do not provide estimates of the possible channels for why for example a country affected by the emissions of other countries is reducing (or increasing or does not change) its emissions. For the latter to be addressed it usually requires, among others, an environmental damage function. The estimates provided by this paper, on the effect of the pollution spillovers together with the effect of the emissions a state is producing, on *TFP* growth, is one indicator of why possible strategic interaction games can take place. The game is based on the states' incentives to change their emissions policy. This paper provides, in productivity terms alone, estimates of these incentives.

U.S. states act, to a significant extent, independently as far as their environmental policy is concerned; this gives states the liberty to act strategically. Policies that are determined at the level of the state are likely to ignore the air pollution spillovers. In order for a policy to be credible, is, for this policy to be set at the federal level. So it seems that to ensure the control of spillovers and reduce their negative effect on growth, federal policies, is a superior (or, as it looks like, the only) choice. This is also acknowledged by the U.S. EPA, which issued the Clean Air Interstate Rule on March 10, 2005, to reduce interstate pollution movements.[22] Summarizing, in terms of productivity only, ceteris paribus, it seems that this type of action (if it is a collective one), will benefit all states (some more, some less) since, according to the estimates, the reduction in productivity growth from reducing emissions comes with the benefit from a reduction in pollution spillovers.

6 Conclusion

This paper takes into account the transboundary nature of SO_2 emissions and measures the effect of pollution spillovers on the Total Factor Productivity (*TFP*) growth among the U.S. states. The effect of pollution spillovers on productivity growth is negative for each one of the states in the sample and is also larger in magnitude than the positive effect of a state's own emissions. As far as policy implications is concerned, it seems that the incentives for a state-level policy towards emissions cut backs (in order to reduce overall spillovers) differs among states (or among group of states) depending on the levels of the emissions a state is producing, the level of pollution it receives from other states and their (combined) effect on *TFP* growth. Although some states will gain from the reduction is spillovers, it holds that no state is willing to reduce its emissions unless all states do the same.

Although the intention of this paper is not to model and estimate strategic interaction effects between the U.S. states, but to provide estimates of the effect of pollution spillovers on one

---

[22] Because the Clean Air Interstate Rule was first issued in 2005, the effect of this policy cannot be accounted for since it falls outside the time period of the dataset in this paper.

very important economic indicator, the *TFP* growth, nevertheless, these estimates provide some insights about the states´ behavior. That is, in productivity terms alone, the estimates of pollution spillovers on growth, quantify the incentives of the states; states with high negative output elasticities of the pollution spillovers relativity to the output elasticities of their own emissions have higher incentives to cooperate for reducing emissions. But because, unless *all* states follow a reduction of emissions policy, no state is willing to do so, points towards a federally set policy in order for a reduction in pollution spillovers to be achieved. This reduction will (for some sates more and for some other less) benefit all the states since according to the estimates reducing emissions might not be necessarily too harmful for productivity.

This paper integrates different areas of research that have developed independently. Unlike previous work, it provides estimates of the effect of transboundary pollution on the state level productivity growth. In productivity terms, this effect can be used as another measure of “damage” of the transboundary pollution spillovers and can be taken into account in policy setting situations. The pollution spillover variable is constructed using various weighting schemes. The results are not much differentiated among weights thus providing confidence for the robustness of the results. Nonetheless, future work could focus on finding alternative and more detailed weighting matrices for the measurement of pollution spillovers among the U.S. states. Overall this work can have a broader applicability. It can be applied to other air pollutants and/or other types of pollution, like water pollution. It can be also applied to a set of other countries (like the European countries) or areas within countries that are linked with each other because of the spatial dispersion of pollution, and provide measures of the spillover effect on their productivity growth.

Figure 1 Output elasticities of spillover pollution, $\theta_2(\bar{e}, p_{it})$, distance based weights

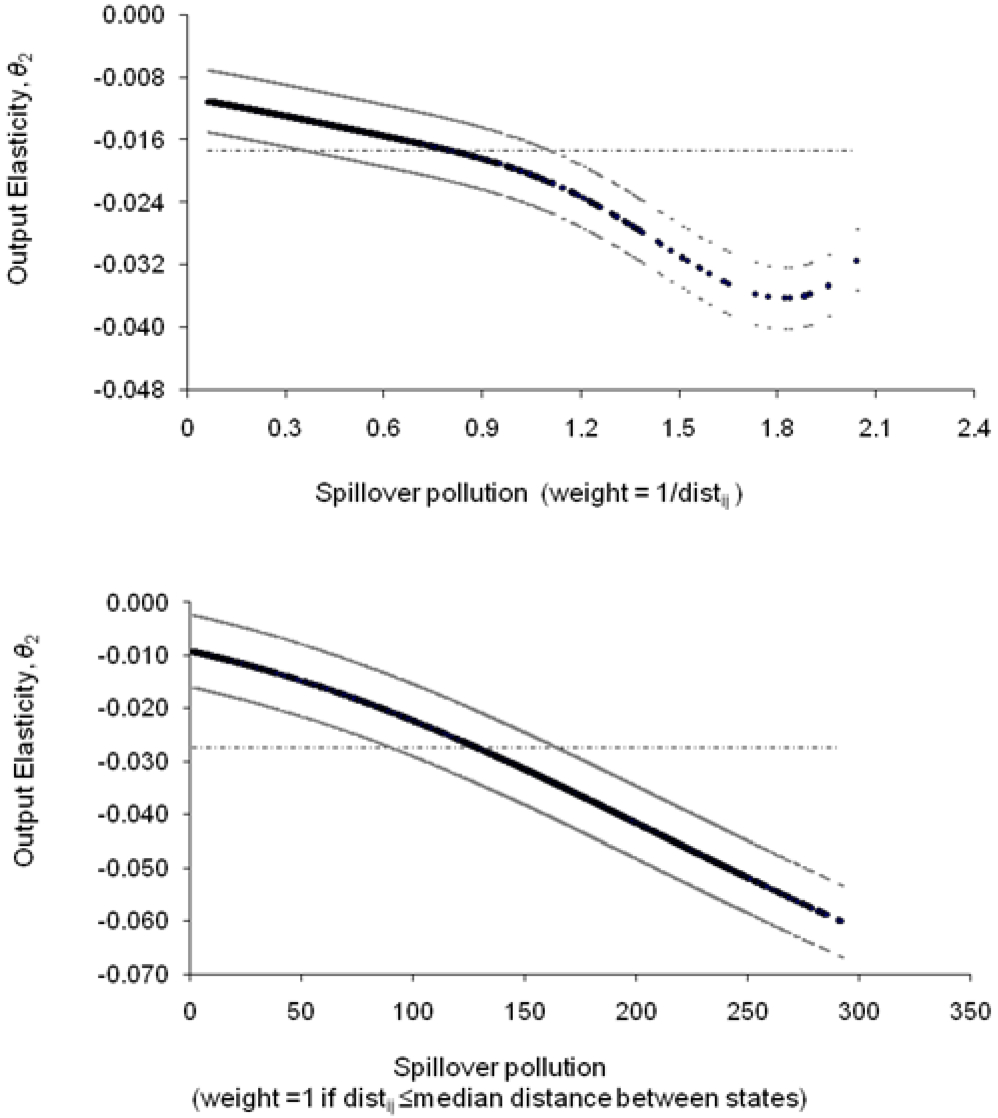


Figure 2 Output elasticities of spillover pollution, $\theta_2(\bar{e}, p_{it})$, other weights

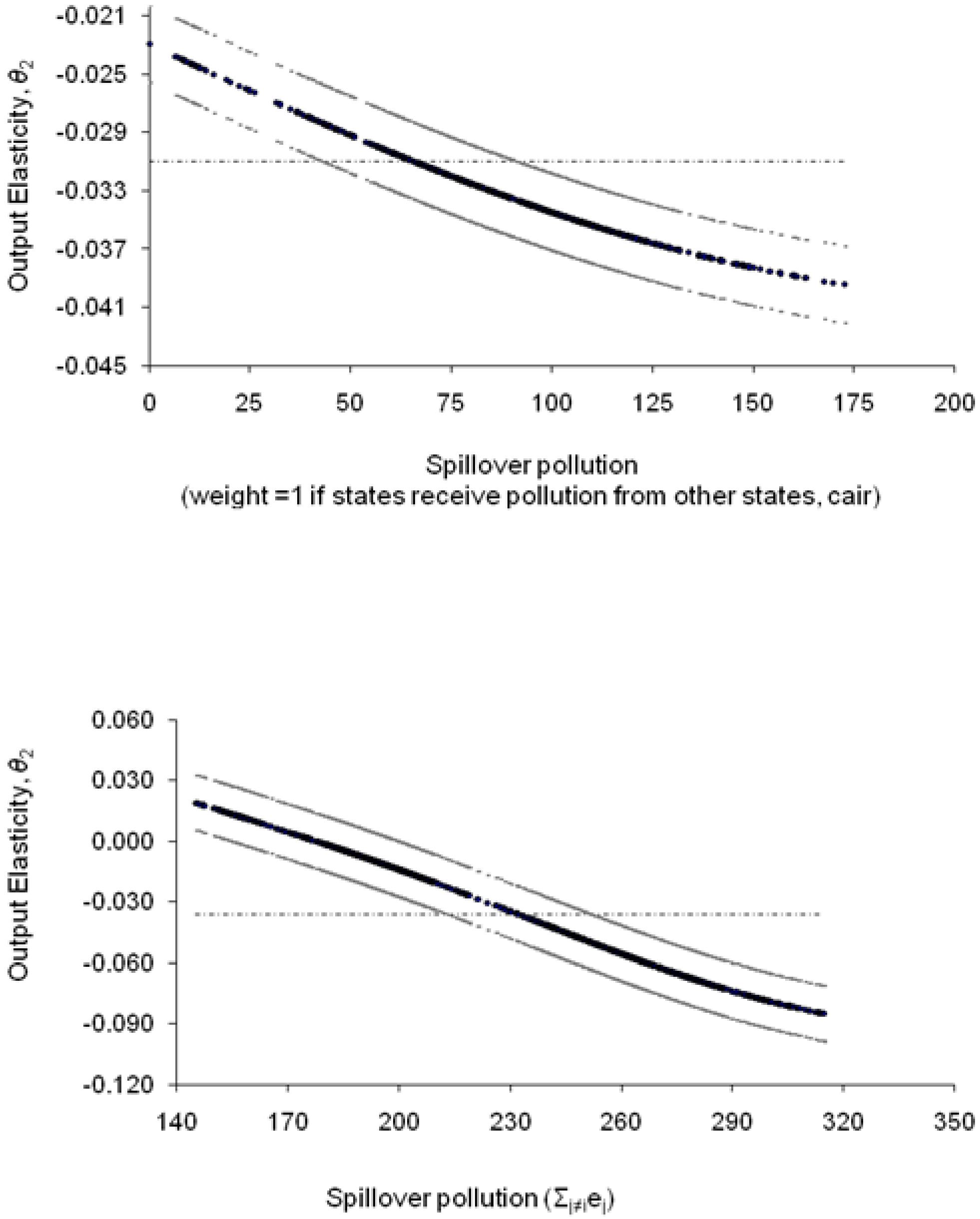
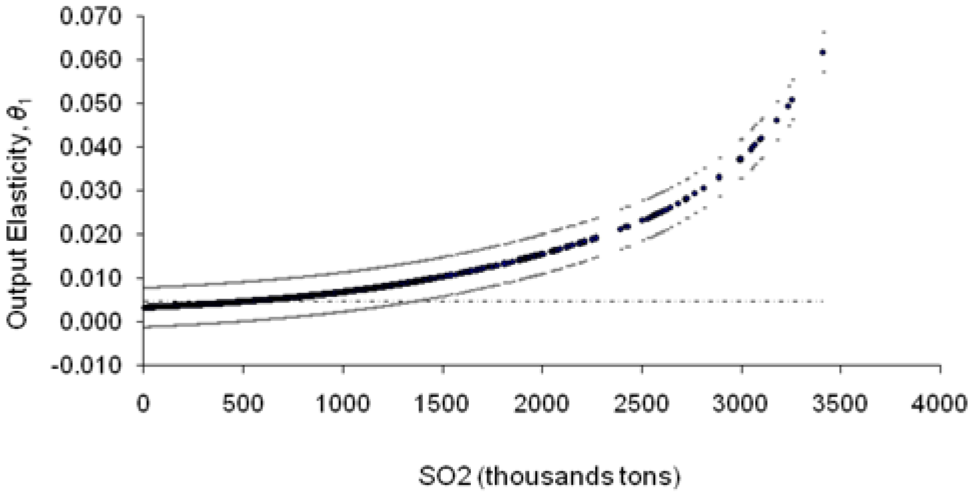


Figure 3 Output elasticities of emissions (own), $\theta_1(e_{it}, \overline{p})$ [23]



---

[23] The shapes of the figures of the output elasticity of own emissions are the same between the different models that use the different weighting schemes for the construction of the spillover pollution variable.

Table 1 Output elasticity of own and spillover pollution: nonparametric estimates. Average by state, 1965-2002, distance based weights

	Weighting scheme			
State	$1/dist_{ij}$ (1)		$=1$ if $dist_{ij} \leq$ median (2)	
	Own	Spillover	Own	Spillover
Alabama	0.00819	-0.01445	0.00538	-0.03693
Arizona	0.01234	-0.01491	0.01065	-0.01087
Arkansas	0.00531	-0.01052	0.00333	-0.02831
California	0.00820	-0.00921	0.00728	-0.00935
Colorado	0.00675	-0.00860	0.00515	-0.01527
Connecticut	0.00293	-0.01448	0.00287	-0.03477
Delaware	0.00068	-0.02870	0.00261	-0.03688
Florida	0.00855	-0.01395	0.00532	-0.03447
Georgia	0.00777	-0.01433	0.00507	-0.03770
Idaho	0.00706	-0.00746	0.00652	-0.00941
Illinois	0.01484	-0.01898	0.01254	-0.05193
Indiana	0.01430	-0.01789	0.01340	-0.05152
Iowa	0.00628	-0.01121	0.00390	-0.02801
Kansas	0.00626	-0.00981	0.00379	-0.02534
Kentucky	0.00698	-0.01590	0.00652	-0.04178
Louisiana	0.00706	-0.01092	0.00434	-0.02560
Maine	0.00414	-0.01208	0.00308	-0.03097
Maryland	0.00292	-0.01655	0.00340	-0.03769
Massachusetts	0.00423	-0.01409	0.00375	-0.03136
Michigan	0.00798	-0.01495	0.00632	-0.04346
Minnesota	0.00637	-0.01013	0.00423	-0.02260
Mississippi	0.00586	-0.01078	0.00345	-0.02999
Missouri	0.01008	-0.01480	0.00686	-0.02786
Montana	0.00727	-0.00843	0.00660	-0.01005
Nebraska	0.00568	-0.00971	0.00367	-0.02435
Nevada	0.00731	-0.00816	0.00677	-0.00936
New Hampshire	0.00296	-0.01472	0.00300	-0.03248
New Jersey	0.00108	-0.02174	0.00340	-0.03541
New Mexico	0.00764	-0.00945	0.00651	-0.01152
New York	0.00366	-0.01668	0.00578	-0.03687
North Carolina	0.00595	-0.01386	0.00394	-0.04015
North Dakota	0.00672	-0.00920	0.00482	-0.01770
Ohio	0.03282	-0.03142	0.03063	-0.07320
Oklahoma	0.00628	-0.00945	0.00372	-0.02513
Oregon	0.00719	-0.00734	0.00669	-0.00894

Table 1 (continued)

State	Weighting scheme			
	$1/dist_{ij}$ (1)		$=1$ if $dist_{ij} \leq$ median (2)*	
	Own	Spillover	Own	Spillover
Pennsylvania	0.00541	-0.01812	0.01231	-0.04636
Rhode Island	0.00212	-0.01611	0.00276	-0.03338
South Carolina	0.00513	-0.01215	0.00296	-0.03959
South Dakota	0.00657	-0.00815	0.00595	-0.01129
Tennessee	0.00993	-0.01528	0.00667	-0.03522
Texas	0.01208	-0.01600	0.00860	-0.01953
Utah	0.00721	-0.00819	0.00665	-0.00967
Vermont	0.00444	-0.01101	0.00275	-0.03335
Virginia	0.00530	-0.01296	0.00340	-0.03824
Washington	0.00765	-0.00806	0.00701	-0.00888
West Virginia	0.00849	-0.01600	0.00681	-0.04030
Wisconsin	0.00588	-0.01382	0.00410	-0.03925
Wyoming	0.00693	-0.00874	0.00554	-0.01387
Average (all states)	0.00722	-0.01332	0.00606	-0.02909
Std. Error	0.00541	0.00568	0.00508	0.01550
Obs.	1824		1824	
R^2	0.07699		0.07997	

*sample median distance between states is 1091 miles (mean distance is 1194.5 miles). The 48 contiguous states are included in the dataset. The states of Alaska, Hawaii and the District of Columbia are excluded from the sample.

Table 2 Output elasticity of own and spillover pollution: nonparametric estimates. Average by state, 1965-2002, other weights

State	Weighting scheme			
	CAIR (1)		$\sum_{j \neq i} e_j$ (2)	
	Own	Spillover	Own	Spillover
Alabama	0.00354	-0.02851	0.00673	-0.02902
Arizona	0.01067	-0.02095	0.00875	-0.03342
Arkansas	0.00658	-0.02684	0.00409	-0.02754
California	0.00724	-0.02428	0.00490	-0.02894
Colorado	0.00661	-0.02670	0.00413	-0.02781
Connecticut	0.00136	-0.03604	0.00415	-0.02330
Delaware	0.00156	-0.03597	0.00399	-0.02219
Florida	0.00879	-0.01992	0.00651	-0.02965
Georgia	0.00245	-0.03110	0.00638	-0.02940
Idaho	0.00645	-0.02749	0.00396	-0.02762
Illinois	0.01160	-0.02687	0.01404	-0.03719
Indiana	0.01161	-0.02648	0.01480	-0.03513
Iowa	0.00711	-0.02456	0.00470	-0.02777
Kansas	0.00674	-0.02611	0.00428	-0.02786
Kentucky	0.00429	-0.02787	0.00802	-0.02883
Louisiana	0.00730	-0.02399	0.00486	-0.02774
Maine	0.00652	-0.02716	0.00403	-0.02738
Maryland	0.00322	-0.03078	0.00476	-0.02238
Massachusetts	0.00717	-0.02438	0.00474	-0.02151
Michigan	0.00504	-0.02799	0.00800	-0.03210
Minnesota	0.00686	-0.02560	0.00444	-0.02803
Mississippi	0.00684	-0.02565	0.00438	-0.02750
Missouri	0.00975	-0.01885	0.00775	-0.03119
Montana	0.00674	-0.02617	0.00432	-0.02814
Nebraska	0.00652	-0.02715	0.00403	-0.02765
Nevada	0.00669	-0.02636	0.00426	-0.02799
New Hampshire	0.00655	-0.02697	0.00405	-0.02566
New Jersey	0.00132	-0.03480	0.00473	-0.02029
New Mexico	0.00711	-0.02464	0.00473	-0.02854
New York	0.00314	-0.03019	0.00718	-0.02947
North Carolina	0.00157	-0.03295	0.00545	-0.02814
North Dakota	0.00674	-0.02614	0.00424	-0.02773
Ohio	0.02954	-0.04024	0.03304	-0.05157
Oklahoma	0.00665	-0.02650	0.00417	-0.02769
Oregon	0.00647	-0.02741	0.00398	-0.02766

Table 2 (continued)

	Weighting scheme			
State	CAIR (1)		$\sum_{j\neq i} e_j$ (2)	
	Own	Spillover	Own	Spillover
Pennsylvania	0.00911	-0.02898	0.01357	-0.03559
Rhode Island	0.00166	-0.03623	0.00393	-0.02467
South Carolina	0.00695	-0.02520	0.00447	-0.02688
South Dakota	0.00645	-0.02749	0.00396	-0.02761
Tennessee	0.00435	-0.02777	0.00791	-0.02905
Texas	0.01002	-0.01867	0.00868	-0.03552
Utah	0.00667	-0.02649	0.00423	-0.02784
Vermont	0.00638	-0.02787	0.00388	-0.02737
Virginia	0.00323	-0.03069	0.00485	-0.02736
Washington	0.00677	-0.02596	0.00432	-0.02781
West Virginia	0.00380	-0.02915	0.00804	-0.02475
Wisconsin	0.00557	-0.02608	0.00566	-0.02871
Wyoming	0.00670	-0.02629	0.00423	-0.02788
Average (all states)	0.00658	-0.02751	0.00634	-0.02865
Std. Error	0.00497	0.00468	0.00556	0.02905
Obs.	1824		1824	
R^2	0.07720		0.08514	

The 48 contiguous states are included in the dataset. The states of Alaska, Hawaii and the District of Columbia are excluded from the sample.

Table 3 Ranking of states as far as the average magnitude of the estimated output elasticity of spillover pollution

States with the highest output elasticity*			
Weighting scheme			
1/dist$_{ij}$	=1 if dist$_{ij}$ ≤ median	CAIR	$\sum_{j \neq i} e_j$
Ohio	Ohio	Ohio	Ohio
Delaware	Illinois	Rhode Island	Illinois
New Jersey	Indiana	Connecticut	Pennsylvania
Illinois	Pennsylvania	Delaware	Texas
Pennsylvania	Michigan	New Jersey	Indiana
Indiana	Kentucky	North Carolina	Arizona
New York	West Virginia	Georgia	Michigan
Maryland	North Carolina	Maryland	Missouri
Rhode Island	South Carolina	Virginia	Florida
Texas	Wisconsin	New York	New York
West Virginia	Virginia	West Virginia	Georgia
Kentucky	Georgia	Pennsylvania	Tennessee
Tennessee	Maryland	Alabama	Alabama
Michigan	Alabama	Michigan	California
Arizona	Delaware	Kentucky	Kentucky

* The first state is the one with the *highest* (in absolute terms) average output elasticity of spillover pollution.

Table 4 Exogenous rate of technological change

	Weighting scheme			
State	$1/dist_{ij}$ (1)	$=1$ if $dist_{ij} \leq$ median (2)	CAIR (3)	$\sum_{j \neq i} e_j$ (4)
Alabama	0.03805	0.00574	0.00802	0.03696
Arizona	0.04621	0.01408	0.01623	0.04466
Arkansas	0.04077	0.00878	0.01084	0.03975
California	0.03853	0.00637	0.00869	0.03737
Colorado	0.04222	0.01005	0.01236	0.04110
Connecticut	0.03625	0.00415	0.00604	0.03561
Delaware	0.03830	0.00577	0.00807	0.03725
Florida	0.04263	0.01036	0.01280	0.04152
Georgia	0.04344	0.01108	0.01366	0.04230
Idaho	0.04110	0.00893	0.01122	0.03982
Illinois	0.03411	0.00167	0.00403	0.03297
Indiana	0.03779	0.00561	0.00769	0.03674
Iowa	0.03758	0.00551	0.00779	0.03653
Kansas	0.03704	0.00501	0.00720	0.03603
Kentucky	0.03750	0.00516	0.00743	0.03649
Louisiana	0.03308	0.00114	0.00326	0.03209
Maine	0.03694	0.00460	0.00721	0.03596
Maryland	0.03676	0.00444	0.00678	0.03593
Massachusetts	0.03639	0.00425	0.00690	0.03569
Michigan	0.03476	0.00233	0.00452	0.03378
Minnesota	0.03912	0.00699	0.00932	0.03803
Mississippi	0.03841	0.00636	0.00852	0.03735
Missouri	0.03632	0.00430	0.00654	0.03519
Montana	0.03381	0.00181	0.00394	0.03258
Nebraska	0.03680	0.00478	0.00699	0.03577
Nevada	0.04412	0.01194	0.01425	0.04289
New Hampshire	0.04236	0.01006	0.01259	0.04140
New Jersey	0.03560	0.00344	0.00543	0.03494
New Mexico	0.03558	0.00353	0.00573	0.03442
New York	0.03193	-0.00010	0.00185	0.03128
North Carolina	0.04329	0.01088	0.01339	0.04220
North Dakota	0.03525	0.00324	0.00543	0.03435
Ohio	0.03508	0.00290	0.00509	0.03395
Oklahoma	0.03637	0.00433	0.00654	0.03532
Oregon	0.04079	0.00864	0.01092	0.03964

Table 4 (continued)

State	Weighting scheme 1/dist$_{ij}$ (1)	 =1 if dist$_{ij}$ ≤ median (2)	 CAIR (3)	 $\sum_{j\neq i} e_j$ (4)
Pennsylvania	0.03428	0.00220	0.00430	0.03344
Rhode Island	0.03483	0.00263	0.00420	0.03410
South Carolina	0.04276	0.01034	0.01285	0.04167
South Dakota	0.03970	0.00759	0.00985	0.03866
Tennessee	0.04132	0.00910	0.01127	0.04016
Texas	0.04111	0.00918	0.01163	0.03993
Utah	0.04096	0.00883	0.01108	0.03967
Vermont	0.03900	0.00664	0.00929	0.03800
Virginia	0.04042	0.00807	0.01044	0.03942
Washington	0.04090	0.00873	0.01103	0.03974
West Virginia	0.03012	-0.00219	0.00016	0.02916
Wisconsin	0.03825	0.00589	0.00808	0.03728
Wyoming	0.03205	-0.00001	0.00222	0.03107
Average (all states)	0.03812	0.00594	0.00820	0.03709
Std. Error	0.00382	0.00399	0.00401	0.00369
Obs.	1824	1824	1824	1824

The 48 contiguous states are included in the dataset. The states of Alaska, Hawaii and the District of Columbia are excluded from the sample.

Table 5 Parametric estimation results (1965-2002). Dependent variable: TFP growth

	Weighting scheme			
	$1/dist_{ij}$	$=1$ if $dist_{ij} \leq$ median	CAIR	$\sum_{j \neq i} e_j$
Variable	(1)	(2)	(3)	(4)
Growth of spillover pollution	-0.01732	-0.02732	-0.03102	-0.03598
	(0.02730)	(0.03054)	(0. 02372)	(0.05710)
Growth of emissions	0.00479*	0.00486*	0.00475*	0.00494*
	(0.00266)	(0.00259)	(0.02372)	(0.00252)
Lagged *TFP* growth	0.19249**	0.19740**	0.19289**	0.19698**
	(0.07676)	(0.07439)	(0.07611)	(0.07880)
Year	-0.00016	-0.00018	-0.00017	-0.00018
	(0.00018)	(0.00019)	(0.00018)	(0.00020)
Constant	0.33406	0.36654	0.35067	0.37159
	(0.37872)	(0.39367)	(0.37521)	(0.40504)
Obs.	1,824	1,824	1,824	1,824
R^2	0.073	0.074	0.073	0.074

Robust standard errors in parentheses. These are the Driscoll and Kraay (1998) standard errors which are robust to both heteroskedasticity and serial correlation of unknown form as well as cross sectional dependence.

*** p<0.01, ** p<0.05, * p<0.1.

The estimated model includes state specific effects.

The 48 contiguous states are included in the dataset. The states of Alaska, District of Columbia and Hawaii are excluded from the sample.

7 Appendix

Table 6 Descriptive statistics (1965-2002)

Growth of	Mean	Std.Dev.	Min	Max
SO_2 emissions	-0.00893	0.21333	-2.54625	2.66449
Spillover pollution				
1/$dist_{ij}$	-0.01261	0.05997	-0.55752	0.62535
=1 if $dist_{ij} \leq$ median	-0.01390	0.05504	-0.57531	0.18984
CAIR	-0.00409	0.04035	-0.33305	0.17460
$\sum_{j \neq i} e_j$	-0.01255	0.04252	-0.13126	0.06634
Obs.	1824			

Table 7 Some other weighting schemes

weight*	Source and information
Border=1 if states share a common border, zero otherwise	The source of information about which states share a common border is: http://www.enchantedlearning.com/usa/states/
Border/radius_distance$_{ij}$	This weight uses the radius of each state to calculated the distance between states; it is assumed that states are circles and the distance between two *neighbouring* states is the sum if their radius (radius_ distance$_{ij}$). Radius is calculated as: $r = \sqrt{area / \pi}$, $\pi = 3.14$. Source for area of states: U.S. Census Bureau, 2000 Census of Population and Housing, Summary Population and Housing Characteristics (http://www.census.gov/population/www/censusdata/density.html)
DW=1 if the direction of the wind affects a state, zero otherwise	This weight is constructed based on information on prevailing wind directions. Wind directions is from specific sites in each U.S. state and are given in compass points; mean wind speeds (SPD) and peak gust (PGU) are in miles per hour (mph). Source: National climatic data center, U.S. Department of Commerce (http://www.ncdc.noaa.gov).
(DW x speed)/dist$_{ij}$	The source for the direction and speed of the wind is the same as above. The speed of the wind is also used in this weight in order to calculate how fast a particle can travel. It is then divided by distance between states to account for the distance it travels to get to another state. Distance between states is from Wolf (2000).
S_W_SW=1 if a state is located to the south, west or southwest of other states, zero otherwise.	This weight is constructed according to information obtained from Lin (2010). According to Lin, who uses information on the direction that the winds blow, a state *i* is considered a neighbour of state *j* if it located to the South, West or Southwest of state *j*.
(S_W_SW)/dist$_{ij}$	Same as above but is now divided by the distance between states (obtain by Wolf, 2000).

*Variants of the weights in this table are also used in estimations.

Table 8 Ranking of states as far as the levels of spillover pollution

15 States with the highest level of spillovers*		
weight 1 ($1/dist_{ij}$)	weight 2 ($=1$ if $dist_{ij} \leq$ median)	weight (CAIR)
Delaware	Michigan	Pennsylvania
Pennsylvania	North Carolina	West Virginia
New Jersey	South Carolina	New York
New York	Illinois	Georgia
Maryland	Kentucky	North Carolina
Rhode Island	Wisconsin	Ohio
New Hampshire	Virginia	New Jersey
Connecticut	Indiana	Kentucky
Kentucky	Maryland	Tennessee
Indiana	West Virginia	Alabama
Massachusetts	Delaware	Connecticut
Ohio	Georgia	Delaware
West Virginia	Ohio	Michigan
Michigan	Alabama	Rhode Island
Wisconsin	New Jersey	Indiana

* The first state is the one with the *highest levels* of "pollution received".

The last "weighting scheme" used in the estimations, the sum of all states´ emissions but the state´s emissions in question, $\sum_{j \neq i} e_j$, is not a weight as such and it is therefore not presented in this table.

Bibliography

Aldy, J.E. (2005), An environmental Kuznets curve analysis of U.S. state-level carbon dioxide emissions, *Environment and Development Economics,* 14, 48–72.

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

Anselin, L. (1988), Spatial Econometrics: Methods and Models, Dordrecht: Kluwer Academic Publishers, Dordrecht, The Netherlands.

Anselin, L. (2002), Under the Hood: Issues in the Specification and Interpretation of Spatial Regression Models, *Agricultural Economics*, 17, 247-267.

Ansuategi, A. (2003), Economic growth and transboundary pollution in Europe: an empirical analysis, *Environmental and Resource Economics*, 26, 305-328.

Ansuategi, A., Barbier, E., Perrings, C. (1998), The Environmental Kuznets Curve, In: van den Bergh, J.C.J.M. and Hofkes, M.W., (eds.), *Theory and Implementation of Sustainable Development Modelling*, Kluwer Academic, Dordrecht.

Aslanidis, N., Xepapadeas, A. (2006), Smooth transition pollution-income paths, *Ecological Economics*, 57, 182-189.

Aslanidis, N., Xepapadeas, A. (2008), Regime switching and the shape of the emission-income relationship, *Economic Modelling*, 25, 731-739.

Ayres, R.U., Kneese, A.V. (1969), Production, Consumption, and Externalities, *American Economic Review*, 59, 282-97.

Azomahou, T., Laisney, F., Nguyen Van, P. (2006), Economic development and CO_2 emissions: a nonparametric panel approach, *Journal of Public Economics*, 90, 1347-1363.

Ball, V.E., Lovell, C.A.K., Nehring, R.F., Somwaru, A. (1994), Incorporating Undesirable Outputs into Models of Production: An Application to US Agricultural, *Cahiers d'Economique et Sociologie Rurales*, 31, 59-73.

Baumgartner, St., Dyckhoff, H., Faber, M., Proops, J., Schiller, J. (2001), The Concept of Joint Production and Ecological Economics, *Ecological Economics*, 36, 365-72.

Baumol, W.J., Oates, W.E. (1988), *The Theory of Environmental Policy*, Second Edition, Cambridge, Cambridge University Press.

Bertinelli, L., Strobl, E. (2005), The Environmental Kuznets Curve Semi-Parametrically Revisited, *Economics Letters*, 88, 350–357.

Bovenberg, A.L., Smulders, S. (1995), Environmental quality and pollution augmenting technological change in a two-sector endogenous growth model, *Journal of Public Economics*, 57, 369-391.

Brock, W., Taylor, M.S. (2005), Economic growth and the environment: A Review of Theory and Empirics, in Aghion, P., Durlauf, S. (eds.), *Handbook of Economic Growth II*, Chap. 28, Elsevier, 1749-1821.

Carson, R.T., Jeon, Y., McCubbin, D. (1997), The relationship between air pollution and emissions: U.S. data, *Environment and Development Economics*, 2, 433–50.

Case, A.C., Rosen, H.S., Hines, J.R. (1993), Budget Spillovers and Fiscal Policy Interdependence: Evidence from the States, *Journal of Public Economics*, 52, 285-307.

Chay, K., Dobkin, C., Greenstone, M. (2003), Air quality, adult mortality, and the clean air act of 1970, *Journal of Risk and Uncertainty*, 27, 279–300.

Chay, K., Greenstone, M. (2003), Air quality, infant mortality, and the clean air act of 1970, NBER Working Paper 10053.

Chimeli, A.B., Braden, J.B. (2005), Total factor productivity and the environmental Kuznets curve, *Journal of Environmental Economics and Management*, 49, 366-380.

Christensen, L.R., Jorgenson, D.W., Lau, L.J. (1973), Transcendental logarithmic production frontiers. *The Review of Economics and Statistics*, 55, 28–45.

Cole, M. (2003), Development, trade and the environment: how robust is the environmental Kuznets curve?, *Environment and Development Economics*, 8, 557-80.

Cropper, M.L., Oates, W.E. (1992), Environmental Economics: A Survey, *Journal of Economic Literature*, 30, 675-740.

Dasgupta, P. (1982), The Control of Resources. Cambridge, Massachusetts, Harvard University Press.

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

Dinda, S. (2004), Environmental Kuznets curve hypothesis: a survey, *Ecological Economics*, 49, 431-455.

Dockery, D.W., et al., (1993), An association between air pollution and mortality in six US cities, *New England J. Med*, 329, 1753–1759.

Driscoll, J. C., Kraay. A. C. (1998), Consistent Covariance Matrix Estimation with Spatially Dependent Panel Data, *Review of Economics and Statistics*, 80, 549–560.

Ecological Economics, 1998, Special issue on the environmental Kuznets curve 25, 143–229.

Empora, N., Mamuneas, T. (2011), The Effect of Emissions on U.S. State Total Factor Productivity Growth, *Review of Economic Analysis*, 3(2), 149-172.

Fan, J. (1992), Design-adaptive nonparametric regression, *Journal of the American Statistical Association*, 87, 998-1004.

Fan, J., Zhang, W. (1999), Statistical estimation in varying-coefficient models, *Annals of Statistics*, 27, 1491-1518.

Fare, R., Grosskopf, S., Lovell, C.A.K., Yaisawarng, S. (1993), Derivation of shadow prices for undesirable outputs: a distance function approach, *Review of Economics and Statistics*, 75, 375-380.

Fare, R., Grosskopf, S., Pasurka, C. (1986), Effects of Relative Efficiency in Electric Power Generation Due to Environmental Controls, *Resources and Energy*, 8, 167-184.

Fare, R., Grosskopf, S., Pasurka, C. (2001), Accounting for air pollution emissions in measures of state manufacturing productivity growth, *Journal of Regional Science*, 41, 381- 409.

Fare, R., Grosskopf, S., Noh, D.W., Weber, W. (2005), Characteristics of a Polluting Technology: Theory and Practice, *Journal of Econometrics*, 126, 469-492.

Fernandez, C., Koop, G., Steel, M.F.J. (2005), Alternative efficiency measures for multiple-output production, *Journal of Econometrics*, Elsevier 126, 411-444.

Førsund, F., Strøm, S. (1994), Miljøøkonomi (in Norwegian) (Environmental Economics), Second edition, Universitetsforlaget AS, Oslo, Norway.

Førsund, F. (2009), Good Modelling of Bad Outputs: Pollution and Multiple-Output Production, *International Review of Environmental & Recourse Economics*, 3, 1-38.

Fredriksson, P.G., Millimet, D.L. (2002), Strategic Interaction and the Determinants of Environmental Policy across US States, *Journal of Urban Economics*, 51, 101-122.

Freeman III, A.M. (1993), The Measurement of Environmental and Resource Values: Theory and Methods, Resources for the Future (RfF), Washington D.C.

Gradus, R., Smulders, S. (1993), The trade-off between environmental care and long-term growth: pollution in three prototype growth models, *Journal of Economics*, 58, 25-51.

Grossman, G.M., Krueger, A.B. (1991), Environmental Impacts of a North American Free Trade Agreement, NBER Working Papers 3914, National Bureau of Economic Research, Inc.

Grossman, G.M., Krueger, A.B. (1993), Environmental Impacts of a North American Free Trade Agreement, in Garber, P. (ed.), *The US-Mexico Free Trade Agreement*, Cambridge, MIT Press.

Grossman, G.M., Krueger, A.B. (1995), Economic Growth and the Environment, *Quarterly Journal of Economics*, 110, 353-377.

Hansen, B.E. (2000), Sample splitting and threshold estimation, *Econometrica*, 68, 575-603.

Harbaugh, W., Levinson, A., Wilson, D.M. (2002), Reexamining the empirical evidence for an environmental Kuznets curve, *Review of Economics and Statistics*, 84, 541-551.

Hazardous Substances Data Bank (HSDB). (2002), Hazardous Substances Data Bank Sulfur Dioxide (HSN 228). Toxicology and Environmental Health Information Program, National Library of Medicine, Bethesda, MD (http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB).

Hauer, G., Runge, C.F. (2000), Transboundary Pollution and the Kuznet's Curve in the Global Commons, Working paper WP00-4, University of Minnesota.

Helland, E., Whitford, A.B. (2003), Pollution Incidence and Political Jurisdiction: Evidence from TRI, *Journal of Environmental Economics and Management*, 46, 403-24.

Hettige, H., Mani, M., Wheeler, D. (2000), Industrial pollution in economic development: the environmental Kuznets curve revisited, *Journal of Development Economics*, 62, 445-476.

Hidy, G.M. (1994), Atmospheric Sulfur and Nitrogen Oxides: Eastern North America Source-receptor Relationships, Academic Press Inc., San Diego, California.

Hoover, D.R., Rice, C., Wu, C.O., Yang, L.P. (1998), Nonparametric Smoothing Estimates of Time-Varying Coefficient Models with Longitudinal Data, *Biometrica*, 85, 809-822.

Im, K. S., Pesaran, M. H. and Shin, Y. (2003), Testing for unit roots in heterogeneous panels, *Journal of Econometrics*, 115, 53–74.

Jones, L. E., Manuelli, R. E. (2001), Endogenous Policy Choice: The Case of Pollution and Growth, *Review of Economic Dynamics*, 4, 369-405.

Jorgenson, D.W. (1990), Productivity and Economic Growth, in Berndt, E. and J. Triplett, (eds.), *Fifty Years of Economic Measurement*, NBER Studies in Income and Wealth 54, Chicago, The University of Chicago Press.

Jorgenson, D.W., Stiroh, K.J. (2000), Raising the Speed Limit: U.S. Economic Growth in the Information Age, *Brookings Papers on Economic Activity*, 1, 125-211.

Kalaitzidakis, P., Mamuneas, T.P, Stengos, T. (2010), The Contribution of Greenhouse Pollution to Productivity Growth, working Papers, Department of Economics, University of Guelph.

Katz, M. (1977), The Canadian Sulphur Problem. *Sulphur and Its Inorganic Derivatives in the Canadian Environment*, NRCC No. 15015, Associate Committee on Scientific Criteria for

Environmental Quality, National Research Council of Canada, Ottawa, ON, 21-67.

Koop, G. (1998), Carbon Dioxide emissions and economic growth a structural approach, *Journal of Applied Statistics*, 25, 489-515.

Kourtellos, A. (2003), Modeling parameter heterogeneity in cross-country growth regression models, mimeo, University of Cyprus.

Laffont, J.J. (1988), *Fundamentals of Public Economics*. Cambridge: MIT Press.

Lauwers, L. (2009), Justifying the incorporation of the materials balance principle into frontier-based eco-efficiency models, *Ecological Economics*, 68, 1605-1614.

Levin, A., Lin, C.F., Chu, C.S.J. (2002), Unit root tests in panel data: Asymptotic and finite-sample properties, *Journal of Econometrics* 108, 1–24.

Levinson, A. (1999), An Industry-Adjusted Index of State Environmental Compliance Costs. NBER Working Papers 7297, Cambridge, MA: National Bureau of Economic Research.

Levinson, A. (2002), The ups and downs of the environmental Kuznets curve. In Recent advances in environmental economics, J. List and A. De Zeeuw (eds.), Northhampton. MA: Edward Elgar Publishing.

Li, Q., Hsiao, C. (1998), Testing Serial Correlation in Semiparametric Panel Data Models, *Journal of Econometrics*, 87, 207-237.

Li, Q., Huang, C., Li, D., Fu, T. (2002), Semiparametric smooth coefficient models. *Journal of Business Economics and Statistics*, 20, 412-422.

Li, D.D., Stengos, T. (2003), Testing serial correlation in semiparametric time series models, *Journal of Time Series Analysis*, 24, 311-335.

Li, Q., Wang, S. (1998), A simple consistent bootstrap test for a parametric regression function, *Journal of Econometrics*, 87, 145-165.

Lieb, C.M. (2002), The Environmental Kuznets Curve and satiation: a simple static model, *Environment and Development Economics*, **7**, 429–448.

Lieb, C.M. (2003), The Environmental Kuznets Curve: A Survey of the Empirical Evidence and of Possible Causes. University of Heidelberg, Department of Economics, Discussion Paper No. 391.

Lin, C.Y.C. (2010), A spatial econometric approach to measuring pollution externalities: An Application to Ozone Smog, *The Journal of Regional Analysis & Policy*, 40, 1-19.

List, J., Gallet, C. (1999), The environmental Kuznets curve: Does one size fit all, *Ecological Economics*, 31, 409–23.

Lucas, R.E. (1988), On the Mechanics of Economic Development, *Journal of Monetary Economics*, 22, 3-42.

Maddala, G. S., Wu, S. (1999), A Comparative Study of Unit Root Tests with Panel Data and New Simple Test, *Oxford Bulletin of Economics and Statistics*, 61, 631-652

Maddison, D. (2006), Environmental Kuznets curves: A spatial econometric approach, *Journal of Environmental Economics and management*, 51, 218-230.

Maddison, D. (2007), Modelling sulphur in Europe: A spatial econometric approach, *Oxford Economics Paper*, 59, 726-743.

Mamuneas, T.P., Savvides, A., Stengos, T. (2006), Economic development and the return to human capital: a smooth coefficient semiparametric approach, *Journal of Applied Econometrics*, 21, 111-132.

Managi, S. (2006), Are there Increasing Returns to Pollution Abatement? Empirical analytics of the Environmntal Kuznets Curve in pesticides, *Ecological Economics*, 58, 617-636.

Margulis, S. (1991), A Guide to Back of the Envelope Estimates of Environmental Damage Costs: An Application to Mexico, mimeo, World Bank.

McKitrick, R. (1999), A derivation of the marginal abatement cost curve, *Journal of Environmental Economics and Management*, 37, 306-314.

McKitrick, R. (2006), Why Did US Air Pollution Decline After 1970? *Empirical Economics*, 33, 491-513.

Millimet, D., List, J.A., Stengos, T. (2003), The environmental Kuznets curve: Real progress or misspecified models?, *Review of Economics and Statistics*, 85, 1038-1047.

Muller, N.Z., Mendelsohn, R. (2007), Measuring the damages of air pollution in the United States, *Journal of Environmental Economics and Management*, 54, 1–14.

Murdoch, J.C., Sandler, T., Sargent, K. (1997), A tale of two collectives: sulphur versus nitrogen oxide emission reduction in Europe, *Economica*, 64, 281–301.

Murty, M.N., Kumar, S. (2002), Measuring Cost of Environmentally Sustainable Industrial Development in India: A Distance Function Approach, *Environment and Development Economics*, 7, 467-86.

Murty, M.N., Kumar, S. (2003), Win-Win Opportunities and Environmental Regulation:
Testing of Porter Hypothesis for Indian Manufacturing Industries, *Journal of Environmental Management*, 67, 139-44.

Murty, S., Russell, R.R. (2002), On modelling pollution-generating technologies, mimeo, Department of Economics, University of California, Riverside (revised version April 2010, Department of Economics, University of Warwick).

National climatic data center, U.S. Department of Commerce (http://www.ncdc.noaa.gov).

Pollution Abatement Cost and Expenditures (PACE), US Bureau of the Census, *Current Industrial Reports*, MA-200.

Perman, R., Stern, D. I. (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, 325-347.

Pethig, R. (2003), The 'Materials Balance Approach' to Pollution: Its Origin, Implications and Acceptance, Economics Discussion Paper No. 105–03, University of Siegen.

Pethig, R. (2006), Nonlinear Production, Abatement, Pollution and Materials Balance Reconsidered, *Journal of Environmental Economics and Management*, 51, 185–204.

Plassmann, F., Khanna, N. (2006), A note on the simple analytics of the Environmental Kuznets Curve, *Environment and Development Economics*, 11, 697-707.

Ransom, M.R., Pope III, C.A. (1995), External health costs of a steel mill, *Contemporary Econ. Pol*., 8, 86–97.

Reinhard, S., Lovell, C.A.K., Thijssen, G. (1999), Econometric Estimation of Technical and Environmental Efficiency: An Application to Dutch Dairy Farms, *American Journal of Agricultural Economics*, 81, 44-60.

Robinson, P. M. (1988), Root-N-Consistent semiparametric regression, *Econometrica*, 56, 931-954.

Roy, N., Van Kooten, G.C. (2004), Another Look at the Income Elasticity of Non-point Source Air Pollutants: A Semiparametric Approach, *Economics Letters*, 85, 17–22.

Rupasingha, A., Goetz, S.J., Debertin, D.L., Pagoulatos, A. (2004), The environmental Kuznets curve for US counties: a spatial econometric analysis with extensions, *Papers in Regional Science*, 83, 407–424.

Selden, T., Song, D. (1994), Environmental quality and development: is there a Kuznets Curve for air pollution emissions?, *Journal of Environmental Economics and management*, 27, 147-162.

Sigman, H. (2005), Transboundary spillovers and decentralization of environmental policies, *Journal of Environmental Economics and Management*, 50, 82–101.

Shafik, N. (1994), Economic Development and Environmental Quality: An Econometric Analysis, *Oxford Economic Papers*, 46, 757–773.

Stern, D.I. (1998), Progress on the environmental Kuznets curve?, *Environment and Development Economics*, 3, 175–98.

Stern, D.I. (2000), Applying recent developments in time series econometrics to the spatial domain, *Professional Geographer*, 52, 37–49.

Stern, D.I., Common, M.S. (2001), Is there an environmental Kuznets curve for sulfur?, *Journal of Environmental Economics and Management*, 41, 162–178.

Stern, D.I., Common, M.S., Barbier, E.B. (1996), Economic growth and environmental degradation: The environmental Kuznets curve and sustainable development, *World Development*, 24, 1151–60.

Stern, D.I. (2004), The rise and fall of the environmental Kuznets curve, *World Development*, 32, 1419–1439.

Stokey, N. (1998), Are there Limits to Growth?, *International Economic Review*, 39, 1-31.

Taskin, F., Zaim, O. (2000), Searching for a Kuznets Curve in Environmental Efficiency Using Kernel Estimation, *Economics Letters*, 68, 217–223.

Temple J. (1999), The new growth evidence. *Journal of Economic Literature*, 37, 112–156.

Tzouvelekas, E., Vouvaki, D., Xepapadeas, A. (2007), Total factor productivity and the environment: a case for green growth accounting, FEEM working Paper No. 38.2007.

U.S. Bureau of Economic Analysis (2009), Regional Economic Accounts. (http://www.bea.gov/regional/).

U.S. Census Bureau (2000) Census of Population and Housing, Summary Population and Housing Characteristics (http://www.census.gov/population/www/censusdata/density.html).

U.S. Environmental Protection Agency, National Air Pollutant Emission Trends and National Emissions Inventory (NEI), Emissions Inventory & Analysis Group; Air Quality Assessment Division, Office of Air Quality Planning and Standards.

Vouvaki, D., Xepapadeas, A. (2008), Total Factor Productivity Growth when Factors of Production Generate Environmental Externalities, MPRA Paper 10237, University Library of Munich, Germany.

WBK & Associates Inc. (2003). Sulphur Dioxide: Environmental Effects, Fate and Behaviour, *Alberta Environment* (http://www.environment.gov.ab.ca/info/library/6615.pdf).

Weber, W.L., Domazlicky, B. (2001), Productivity Growth and Pollution in State Manufacturing, *Review of Economics and Statistics*, 83, 195-199.

Wolf, H. C. (2000), Intranational home bias in trade, *Review of Economics and Statistics*, 82, 555–63.

Yandle, B., Bjattarai, M., Vijayaraghavan, M. (2004), Environmental kuznets curves: a review of findings, methods, and policy implications, Research Study 02.1. Property and Environment Research Center, Montana.

Zhang, W., Lee, S.Y., Song, X. (2002), Local polynomial fitting in semivarying coefficient model, *Journal of Multivariate Analysis*, 82, 166-188.