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The Environmental Kuznets Curve semi-parametrically revisited

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Abstract

This paper re-examines the existence of an Environmental Kuznets Curve across countries using a semi-parametric regression estimator, which places no restrictions on the functional form. In our specification against a linear model and using bootstrapped values, we are unable to reject a linear relationship.

Keywords: Environmental Kuznets Curve; Semi-parametric kernel regression

JEL classification: O13; Q32; Q56

1. Introduction

Since the seminal paper by Grossman and Krueger (1991), there has been considerable interest in the relationship between economic growth and environmental pollution. Importantly, the authors showed that the link between these follows an inverted U-shaped pattern, now commonly referred to as the Environmental Kuznets Curve (EKC). This finding suggests that lower income regions are 'too poor to be green,' and only when these become rich enough will the benefits from a clean environment outweigh its costs. Much of the subsequent literature has focused on estimating the actual turning point and/or investigated whether the shape may depend on the econometric techniques and assumptions employed. One of the main concerns for the latter has been over the appropriate underlying functional form (see

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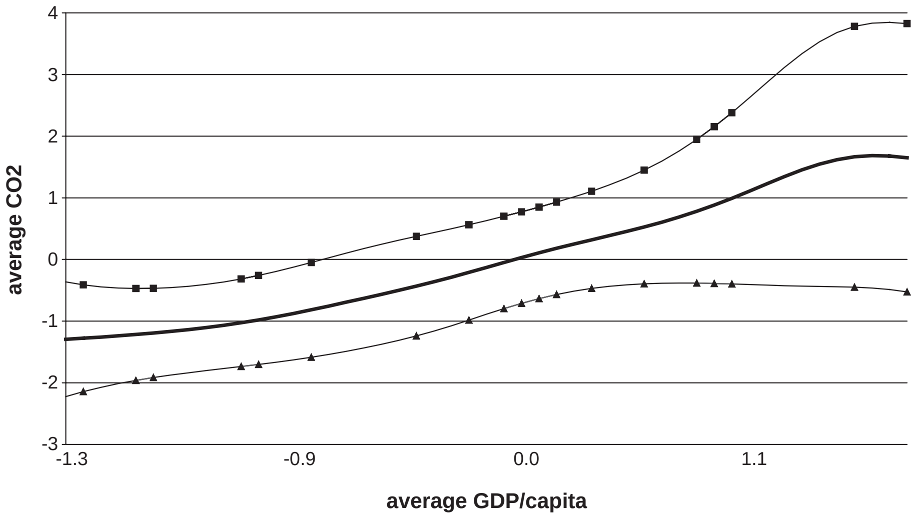

Fig. 1. Sulfur (average 1950–1990).

Dasgupta et al., 2002), where normally researchers allow for the possible non-linearity by introducing higher order terms. However, recently Millimet et al. (2003) have shown with data for US states that such parametric modeling can be rejected in favour of a semi-parametric estimator, which does not impose any a priori restriction on the functional form of the relationship.

In this paper, we employ such a semi-parametric estimator to investigate the existence of the EKC in a cross-country context. So far, results on cross-country studies measuring the relationship between economic growth and pollution have led to rather mixed results concerning the existence of an EKC (see, for instance, Shafik, 1994; Selden and Song, 1994; Grossman and Krueger, 1995; Holtz-Eakin and Selden, 1995; Stern and Common, 2001; Hettige et al., 2000; Harbaugh et al., 2002, among others for recent evidence). However, it must be noted that all of these have imposed relatively restrictive functional forms. Our findings using the semi-parametric estimator suggest that in a cross-country sense, at least in terms of measuring pollution by sulfur and carbon dioxide, the link between environmental pollution and economic growth is actually monotonically increasing for low levels of GDP/capita, and flat thereafter.[1]

2. Methodology and data

Most studies examining the EKC have been concerned with estimating the following equation:

$$P_{it} = \alpha + g(Y_{it}) + Z_{it}\delta + v_i + u_{it} \tag{1}$$

where P_{it} is some proxy of environmental degradation (per capita) in country i at time t, Y_{it} is a measure of wealth, usually real per capita GDP at the start of the period, Z_{it} is a vector of variables that controls for other factors, v_i is a unit-specific residual and u_{it} is a disturbance term.

[1] This result echoes the recent skepticism raised by Stern (2004) over the existence of an EKC internationally in his review of the literature.

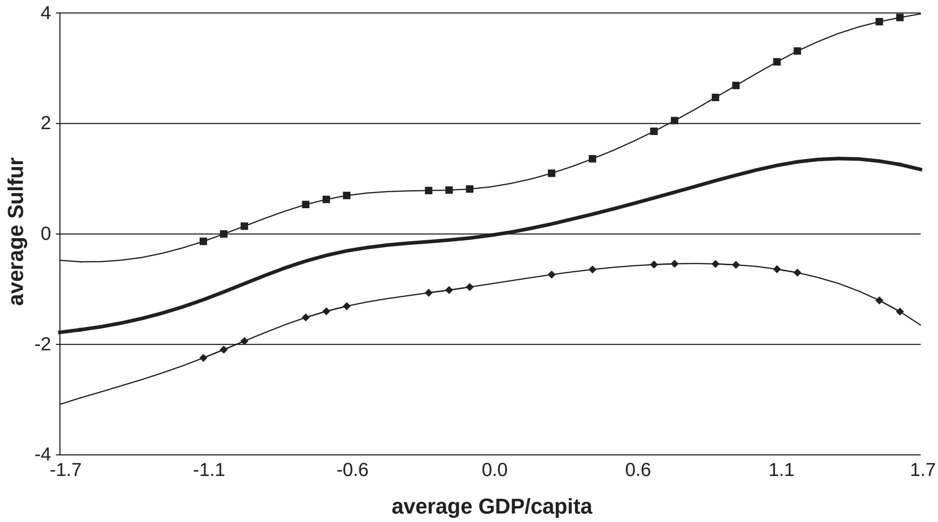

Fig. 2. Carbon dioxide (average 1950–1990).

In order to allow for the possible non-linearity of $g(Y)$, most analyses have simply included a second- and third-order polynomial of Y. As in Millimet et al. (2003), we instead implement Robinson's (1988) semi-parametric Kernel regression estimator (see Blundell and Duncan, 1998, for details and a helpful discussion of the implementation of this method). Accordingly, if we allow $g()$ in (1) to be a smooth and continuous, possibly non-linear, function of Y and assume that the other control variables captured by the vector Z have a linear effect on P, then the estimation of $g(Y)$ can be made by

$$\hat{g}(Y) = \hat{m}_P(Y) - \hat{\delta}\hat{m}_Z(Y) \tag{2}$$

where $\hat{m}_P(Y)$ and $\hat{m}_Z(Y)$ are the (non-parametric) Nadaraya-Watson estimates (Nadarya, 1964; Watson, 1964) of $E(P/Y)$ and $E(Z/Y)$, such that, for a given continuous, bounded, and real shape function, $K_h()$ integrating to one with a smoothing parameter h, $\hat{m}_P(Y)$ (and similarly $\hat{m}_Z(Y)$) is defined as

$$\hat{m}_P(Y) = n^{-1}\frac{\sum_{i=1}^{n} K_h(y - Y_i)P_i}{\sum_{i=1}^{n} K_h(y - Y_i)} \tag{3}$$

and $\hat{\delta}$ is the OLS estimator of

$$P - \hat{m}_P(Y) = \delta(Z - \hat{m}_Z(Y)) + \varepsilon \tag{4}$$

The appeal of the estimator (2) lies in its very flexible approach to non-linearity by allowing the relationship between P and Y to vary over all values of Y after purging the effects of other explanatory variables. Specifically, this technique entails first purging the effect of the other factors Z from the relationship between P and Y and then estimating the regression function of P on Y at a particular point by locally fitting constants to the data via weighted least squares, where those observations closer to the chosen point have more influence on the regression estimate than those further away, as determined by the choice of h.[2]

[2] For all estimations, we use a Gaussian kernel for Kh and the optimal smoothing parameter suggested by Fox (1990).

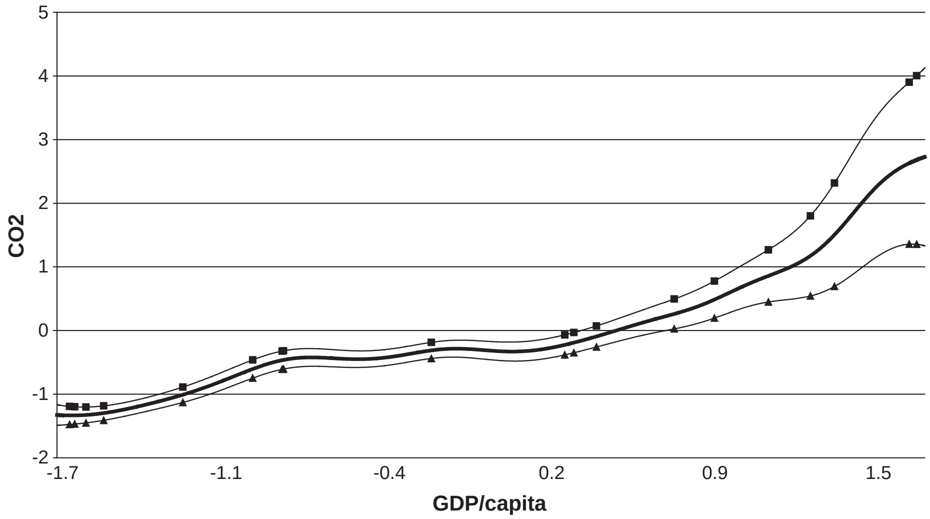

Fig. 3. Sulfur (1950–1990).

One should note that, given its semi-parametric nature, the estimate of $\hat{g}(Y)$ cannot be subjected to the kind of standard statistical tests (such as an F-test or a t-test) of parametric regressions. However, it is possible to calculate upper and lower point-wise confidence intervals, as suggested by Haerdle (1990). Specifically, we calculated bands at the 1st and 99th percentiles along the range of initial income and at every fifth percentile in between. Choosing points according to the distribution of observations also allows one to gauge how the density of the sample affects the approximation bias, since these are inversely related. It should also be noted that the use of the semi-parametric estimator just described leads to a problem of non-identification of an unrestricted intercept term, which leads to a scaling issue when

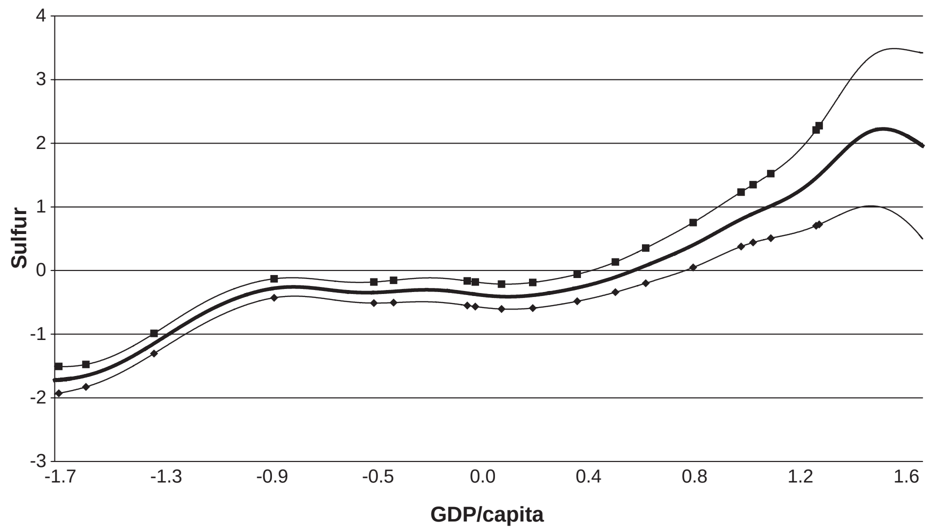

Fig. 4. Carbon dioxide (1950–1990).

Table 1
Im, Pesaran and Shin (IPS, 2003) test for panel unit roots

	Level	First difference
	(1)	(2)
GDP/capita	−1.202 (0.989)	−5.266 (0.000)
Sulfur	−1.026 (1.000)	−5.196 (0.000)
Carbon dioxide	0.515 (1.000)	−4.207 (0.000)

(1) Reported values are the t-bar statistics (Im, Pesaran and Shin (IPS, 2003)); (2) p-values in parentheses.

comparing our semiparametric results with any parametric alternative. As in Millimet et al. (2003), we deal with this issue by standardising our data (relative to the full sample).

The data used for our analysis consists of annual information on sulfur emissions taken from the Historical Global Sulfur Emissions database (Lefohn et al., 1999), carbon dioxide emissions taken from World Resource Institute (People and Ecosystems CD-ROM), and GDP per capita figures (real GDP per capita in constant dollars, base year 1985) taken from the World Penn Tables 6.1. As other explanatory variables, Z, we included time- and country-specific dummies.[3] Together, this provides us with a total sample size of 3976 observations consisting of 122 countries (of which 95 are LDCs), and 3336 observations for 108 countries (of which 81 are LDCs) for the carbon dioxide sample and the sulfur sample respectively, over the period 1950–1990.[4]

3. Results

In Figs. 1 and 2, we depict the graph for $\hat{g}(\overline{Y})$ and corresponding confidence bands for sulfur and carbon dioxide, respectively, where $\overline{Y}$ is the across-period average of GDP/capita, i.e., we have estimated specification (1) by averaging the two variables of interest (pollution and GDP/capita) over the 40-year period under scrutiny. Accordingly, there is little evidence of a bell-shaped link between either sulfur or carbon dioxide emissions and GDP/capita. Rather, in contrast to an 'EKC,' our estimate appears to be decidedly linear, environmental pollution increasing with country wealth for low levels of GDP/capita, and becoming flat thereafter.

Averaging pollution and GDP/capita over the whole period, however, reduces considerably the information contained in inter-annual changes. We thus also show in Figs. 3 and 4 plots of $\hat{g}(\overline{Y})$ for annual sulfur and carbon dioxide emissions. As for our averaged data, there is little support for a bell-shaped link between pollution and GDP/capita., but instead, a linear relationship emerges.[5] The only exception of linearity is for very high GDP per capita values, but as the distance between the confidence intervals suggests, this portion of both curves is likely to be very poorly estimated because of the lower number of observations around it and the fact that it is near the endpoint.[6]

[3] We also experimented with other controls, such as openness and population growth rate. However, these made little qualitatively or quantitative difference and only reduced sample size.

[4] A list of all the countries can be found in Bertinelli and Strobl (2004).

[5] One should note that our panel is unbalanced. However, 80% of the countries had more than three quarters of the observations in the carbon dioxide sample (70% for the sulfur sample). Missing data are essentially concentrated in former colonial countries for years before 1960.

[6] The accuracy of the estimate of $g(Y)$ at Y is positively related to the density of other observations around that point. Furthermore, the approximation bias is larger at the boundaries (see Wand and Jones, 1995).

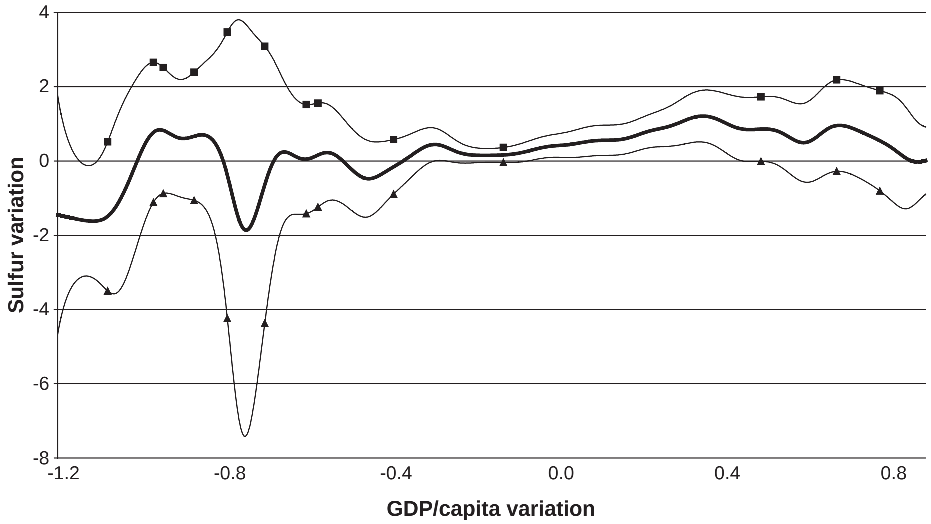

Fig. 5. Sulfur (first-differenced series; 1950–1990).

One issue to be considered with regard to using annual data is the potential time series component in the data. In particular, pollutant emissions and GDP/capita are unlikely to be stationary over time and this is confirmed by the Im et al.'s (2003) *t*-test statistics for unit roots in heterogeneous panels shown in Table 1. We thus first-differenced our series so that, as confirmed by the test-statistics in the same table, these are difference stationary, although not surprisingly, more volatile plots of the semi-parametric estimates of these, depicted in Figs. 5 and 6, are similarly roughly linear.

Our estimates for both sulfur and carbon dioxide emissions suggest that the relationship between pollution and wealth is in fact linear. To test this more rigorously, we employ the test suggested by

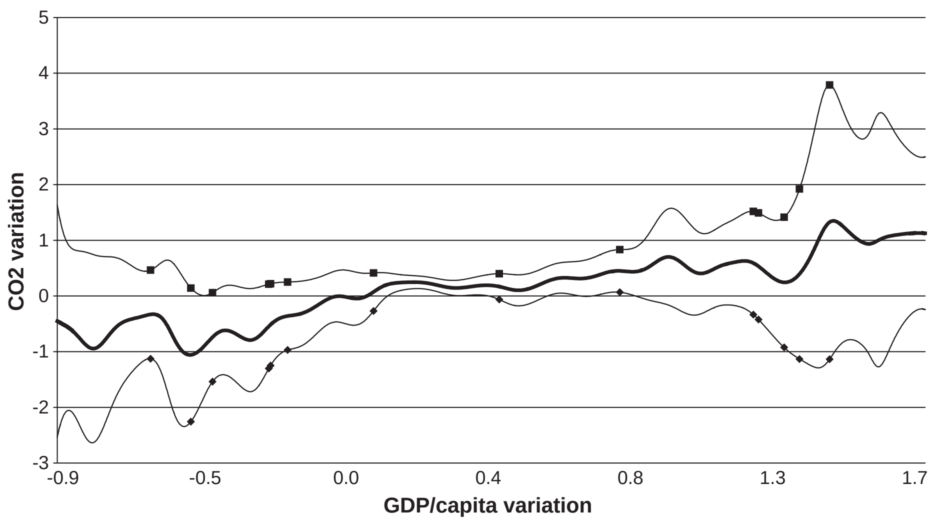

Fig. 6. Carbon dioxide (first-differenced series; 1950–1990).

Table 2
Tests against linearity

	Sulfur			Carbon dioxide		
	Average	Level	First difference	Average	Level	First difference
T	0.918	0.911	0.339	0.505	0.989	0.619
p-values	0.243	1.00	0.66	0.312	1.00	0.58

Ullah (1985), which allows one to test our semi-parametric estimate (SP) against some linear parametric estimate (P) of a regression curve by using their residual sum of squares $\mathrm{RSS}^{\mathrm{SP}}$ and $\mathrm{RSS}^{\mathrm{P}}$, respectively:

$$T = \frac{\left(\mathrm{RSS}^{\mathrm{P}} - \mathrm{RSS}^{\mathrm{SP}}\right)}{\mathrm{RSS}^{\mathrm{SP}}} \tag{5}$$

The test is based on the null hypothesis that there is a relationship of interest that is linear. Given that $\sqrt{nT}$ has an analytically intractable distribution under the null hypothesis, we implement the bootstrap procedure suggested by Lee and Ullah (2001) to obtain p-values using 100 replications.[7] The resultant test statistics for both pollutants in cross-country average, levels and first-difference, as well as bootstrapped p-values, are reported in Table 2. As can be seen, results suggest that we are in all cases unable to reject the linearity of the relationship between wealth and pollution.[8]

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References

Ait-Sahalia, Y., Bickel, P.J., Stoker, T.M., 2001. Goodness-of-fit tests for kernel regression with an application to option implied volatilities. Journal of Econometrics 105 (2), 363–412.

Bertinelli, L., Strobl, E., 2004. The Environmental Kuznets Curve semi-parametrically revisited, Core Discussion Papers, 2004/51.

Blundell, R., Duncan, A., 1998. Kernel regression in empirical microeconomics. Journal of Human Resources 33 (1), 62–87.

Dasgupta, S., Laplante, B., Wang, H., Wheeler, D., 2002. Confronting the Environmental Kuznets Curve. Journal of Economic Perspectives 16, 147–168.

Fox, J., 1990. Describing univariate distributions. In: Fox, J., Long, J.S. (Eds.), Modern Methods of Data Analysis. Sage.

Grossman, G.M., Krueger, A.B., 1991. Environmental Impacts of a North American Free Trade Agreement. National Bureau of Economic Research Working Paper, vol. 3914. NBER, Cambridge, MA.

Grossman, G.M., Krueger, A.B., 1995. Economic growth and the environment. Quarterly Journal of Economics 110, 353–377.

Haerdle, W., 1990. Applied Nonparametric Regression. Cambridge University Press.

[7] This admittedly small number of replications was chosen in consideration of the considerable amount of computational time for each procedure.

[8] The 5% and 10% critical values are 1.64 and 1.28, respectively; see Ait-Sahalia et al. (2001).

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.

Hettige, H., Mani, M., Wheeler, D., 2000. Industrial pollution in economic development: the Environmental Kuznets Curve revisited. Journal of Development Economics 62, 445–476.

Holtz-Eakin, D., Selden, T.M., 1995. Stoking the fires? CO_2 emissions and economic growth. Journal of Public Economics 57, 85–101.

Lee, T., Ullah, A., 2001. Nonparametric bootstrap tests for neglected nonlinearity in time series regression models. Journal of Nonparametric Statistics 13, 425–451.

Lefohn, A.S., Husar, J.D., Husar, R.B., 1999. Estimating historical anthropogenic global sulfur emission patterns for the period 1850–1990. Atmospheric Environment 33, 3435–3444.

Millimet, D.L., List, J.A., Stengos, T., 2003. The Environmental Kuznets Curve: real progress or misspecified models? Review of Economics and Statistics 85 (4), 1038–1047.

Nadarya, E., 1964. On estimating regression. Theory of Probability and Its Applications 10, 186–190.

Robinson, P., 1988. Root-N-consistent semiparametric regression. Econometrica 56, 931–954.

Selden, T.M., Song, D., 1994. Environmental quality and development: is there a Kuznets curve for air pollution? Journal of Environmental Economics and Management 27, 147–162.

Shafik, N., 1994. Economic development and environmental quality: an econometric analysis. Oxford Economic Papers 46, 757–773.

Stern, D.I., 2004. The Environmental Kuznets Curve. In: Cleveland, C.J. (Ed.), Encyclopedia of Energy. Academic Press, San Diego, CA.

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

Ullah, A., 1985. Specification analysis of econometric models. Journal of Quantitative Economics 1, 187–209.

Wand, M.P., Jones, M.C., 1995. Kernel Smoothing. Chapman and Hall.

Watson, G.S., 1964. Smooth regression analysis. Sankhya, Series A 26, 337–359.

Environmental Economics & Management Memoranda

99. Rabah AMIR, Marc GERMAIN, Vincent VAN STEENBERGHE. On the impoact of innovation on the marginal abattement cost curve. *Journal of Public Economic Theory*, 10 (6), 985-1010.

98. Maria Eugenia SANIN, Skerdilajda ZANAJ. Clean technology adoption and its influence on tradeable emission permit prices. April 2009 (also CORE DP 2009/29).

97. Jerzy A. FILAR, Jacek B. KRAWCZYK, Manju AGRAWAL. On production and abatement time scales in sustainable development. Can we loose the *sustainability screw* ? April 2009 (also CORE DP 2009/28).

96. Giorgia OGGINI, Yves SMEERS. Evaluating the impact of average cost based contracts on the industrial sector in the European emission trading scheme. *CEJOR* (2009) 17: 181-217.

95. Marc GERMAIN, Henry TULKENS, Alphonse MAGNUS. Dynamic core-theoretic cooperation in a two-dimensional international environmental model, April 2009 (also CORE DP 2009/21).

94. Henry TULKENS, Vincent VAN STEENBERGHE. "Mitigation, Adaptation, Suffering" : In search of the right mix in the face of climate change, June 2009.

93. Luisito BERTINELLI, Eric STROBL. The environmental Kuznets curve semi-parametrically revisited. *Economics Letters,* 88 (2005) 350-357.

92. Maria Eugenia SANIN, Francesco VIOLANTE. Understanding volatility dynamics in the EU-ETS market: lessons from the future, March 2009 (also CORE DP 2009/24)

91. Thierry BRECHET, Henry TULKENS. Beyond BAT : Selecting optimal combinations of available techniques, with an example from the limestone industry. *Journal of Environmental Management*, 90 (2009) :1790-1801.

90. Giorgia OGGIONI, Yves SMEERS. Equilibrium models for the carbon leakage problem. December 2008 (also CORE DP 2008/76)

89. Giorgia OGGIONI, Yves SMEERS. Average power contracts can mitigate carbon leakage. December 2008 (also CORE DP 2008/62)

88. Thierry BRECHET, Johan EYCKMANS, François GERARD, Philippe MARBAIX, Henry TULKENS, Jean-Pascal van YPERSELE. The impact of the unilateral EU commitment on the stability of international climate agreements. (also CORE DP 2008/61)

87. Raouf BOUCEKKINE, Jacek B. KRAWCZYK, Thomas VALLEE. Towards an understanding of tradeoffs between regional wealth, tightness of a common environmental constraint and the sharing rules. (also CORE DP 2008/55)

86. Thierry BRECHET, Tsvetomir TSACHEV, Vladimir VELIOV. Prices versus quantities in a vintage capital model. March 2009 (also CORE DP 2009/15).

85. David DE LA CROIX, Davide DOTTORI. Easter Island's collapse : a tale of a population race. *Journal of Economic Growth*, 13 :27-55, 2008.

84. Thierry BRECHET, Stéphane LAMBRECHT, Fabien PRIEUR. Intertemporal transfers of emission quotas in climate policies. *Economic Modelling*, 26(1) : 126-143, 2009.

83. Thierry BRECHET, Stéphane LAMBRECHT. Family altruism with renewable resource and population growth. *Mathematical Population Studies*, 16 :60-78, 2009.

82. Thierry BRECHET, Alexis GERARD, Giordano MION. Une évaluation objective des nuisances subjectives de l'aéroport de Bruxelles-National. *Regards Economiques*, N° 66, Février 2009.

81. Thierry BRECHET, Johan EYCKMANS. Coalition theory and integrated assessment modeling : Lessons for climate governance. In E. Brousseau, P.A. Jouvet and T. Tom Dedeurwaerder (eds). Governing Global Environmental Commons: Institutions, Markets, Social Preferences and Political Games, Oxford University Press, 2009.

80. Parkash CHANDER and Henry TULKENS. Cooperation, stability, and self-enforcement in international environmental agreements : A conceptual discussion. In R. Guesnerie and H. Tulkens (eds). The Design of Climate Policy, CESifo Seminar Series, The MIT Press, 2008.

79. Mirabelle MUULS. The effect of investment on bargaining positions. Over-investment in the case of international agreements on climate change. September 2008

78. Pierre-André JOUVET, Philippe MICHEL, Pierre PESTIEAU. Public and private environmental spending : a political economy approach. *Environmental Economics and Policy Studies*, Vol 9 (3) : 177-191 2008.

77. Fabien PRIEUR. The environmental Kuznets curve in a world of irreversibility. *Economic Theory*, 2009.

76. Raouf BOUCEKKINE, Natali HRITONENKO and Yuri YATSENKO. Optimal firm behavior under environmental constraints. April 2008. (also CORE DP 2008/24).

75. Giorgia OGGIONI and Yves SMEERS. Evaluating the impact of average cost based contracts on the industrial sector in the European emission trading scheme. January 2008 (also CORE DP 2008/1).

74. Thierry BRECHET and Pierre-André JOUVET. Environmental innovation and the cost of pollution abatement revisited. *Ecological Economics*, 65 : 262-265, 2008.

73. Ingmar SCHUMACHER and Benteng ZOU. Pollution perception : A challenge for intergenerational equity. *Journal of Environmental Economics and Management*, 55, 296-309, 2008.

72. Thierry BRECHET et Patrick VAN BRUSSELEN. Le pic pétrolier: un regard d'économiste. *Reflets et Perspectives de la vie économique*, Tome XLVI, n° 4, 63-81, 2007.

71. Thierry BRECHET. L'énergie : mutations passées et mutations en cours. *Reflets et Perspectives de la vie économique*, Tome XLVI, n° 4, 5-11, 2007.

70. Marc GERMAIN, Alphonse MAGNUS and Vincent VAN STEENBERGHE. How to design and use the clean development mechanism under the Kyoto Protocol? A developing country perspective. *Environmental & Resource Economics*, 38(1) : 13-30, 2007.

69. Thierry BRECHET en Pierre PICARD. Economische instrumenten voor de regulering van de geluidshinder in de omgeving van luchthavens? *Brussels Studies*, nummer 12, 3 december 2007

68. Thierry BRECHET et Pierre PICARD. Des instruments économiques pour la régulation des nuisances sonores autour des aéroports? *Brussels Studies*, numéro 12, 3 décembre 2007, www.brusselsstudies.be.

67. Thierry BRECHET and Pierre PICARD. Can economic instruments regulate noise pollution in locations near airports? *Brussels Studies*, issue 12, 2007 december the 3rd , www.brusselsstudies.be

66. Pierre-André JOUVET, Pierre PESTIEAU and Gregory PONTHIERE. Longevity and Environmental quality in an OLG model. September 2007 (also available as CORE DP 2007/69).

65. Raouf BOUCEKKINE and Marc GERMAIN. Impacts of emission eduction policies in a multi-regional multi-sectoral small open economy with endogenous growth. February 2007 (also available CORE DP 2007/11).

64. Parkash CHANDER and Subhashini MUTHUKRISHNAN. Green consumerism and collective action. June 2007 (also available as CORE DP 2007/58).

63. Jakub GROWIEC and Ingmar SCHUMACHER. Technological opportunity, long-run growth and convergence. July 2007 (also available as CORE DP 2007/57).

62. Maria Eugenia SANIN and Skerdilajda ZANAJ. Environmental innovation under Cournot competition. June 2007. (also available as CORE DP 2007/50)

61. Thierry BRECHET and Stéphane LAMBRECHT. Family altruism with a renewable resource and population growth. October 2006 (also available as CORE DP 2006/35).

60. Thierry BRECHET, François GERARD and Henry TULKENS. Climate Coalitions: a theoretical and computational appraisal. February 2007 (also available as CORE DP 2007/3).

59. Thierry BRECHET. L'environnement dans tous ses états. *Regards Economiques*, n° 50, 26-32, Avril 2007.

58. Thierry BRECHET and Susana PERALTA. The race for polluting permitsThierry. March 2007 (also available as CORE DP 2007/27).

57. Giorgia OGGIONI, Ina RUMIANTSEVA and Yves SMEERS. Introduction of CO_2 emission certificates in a simplified model of the Benelux electricity network with small and industrial consumers. Reprint from *Proceedings of the International Conference on Clean Electrical Power*, Capri, Italy, May 21-23, 2007.

56. Agustin PEREZ-BARAHONA. The problem of non-renewable energy resource in the production of physical capital. January 2007 (also available as CORE DP 2007/8).

55. Thierry BRECHET, Benoît LUSSIS. The contribution of the clean development mechanism to national climate policies. *Journal of Policy Modelling*, 28(9), 981-994, December 2006.

54. Ingmar SCHUMACHER. Endogenous discounting via wealth, twin-peaks and the role of technology. November 2006 (also available as CORE DP 2006/104).

53. Ingmar SCHUMACHER. On optimality, endogenous discounting and wealth accumulation. October 2006 (also available as CORE DP 2006/103).

52. Jakub GROWIEC, Ingmar SCHUMACHER. On technical change in the elasticities of resource inputs. November 2006. (also available as CORE DP 2006/63).

51. Maria Eugenia SANIN. Market Design in Wholesale Electricity Markets. October 2006 (also available as CORE DP 2006/100).

50. Luisito BERTINELLI, Eric STROBL and Benteng ZOU. Polluting technologies and sustainable economic development. June 2006 (also available as CORE DP 2006/52).

49. Marc GERMAIN, Alphonse MAGNUS. Prices versus quantities: Stock pollution control with repeated choice of the instrument. October 2005. *Journal of Computational and Applied Mathematics*, 197 (2006) 437-445.

48. Agustin PEREZ-BARAHONA. Capital accumulation and exhaustible energy resources: a special functions case. September 2006 (also available as CORE DP 2007/9).

47. Philippe TULKENS, Henry TULKENS. The White House and the Kyoto Protocol: Double standards on uncertainties and their consequences. May 2006 (also TERI School of Advanced Studies WP Series #1).

46. Thierry BRECHET, Pierre-André JOUVET. Environmental innovation and the cost of pollution abatement. January 2006 (also available as CORE DP 2006/40).

45. Fabien PRIEUR. The implication of irreversible pollution on the relation between growth and the environment: The degenerate Kuznets curve. February 2006.

44. Thierry BRECHET, Marc GERMAIN, Philippe MONTFORT. Allocation des efforts de dépollution dans des économies avec spécialisation internationale. *Revue Economique*, 57(2), Mars 2006.

43. Ingmar SCHUMACHER and Benteng ZOU. Habit in Pollution, A Challenge for Intergenerational Equity. March 2006 (also available as CORE DP 2006/6).

42. Jean-Charles HOURCADE, P.R. SHUKLA and Sandrine MATHY. Cutting the Climate-Development Gordian Knot – Economic options in a politically constrained world. September 2005.

41. Urs LUTERBACHER. Climate Change, the Kyoto Protocol, and Transatlantic Relations. November 2005.

40. Parkash CHANDER and Henry TULKENS. Cooperation, Stability and Self-Enforcement in International Environmental Agreements: A Conceptual Discussion. July 2005.

39. Paul-Marie BOULANGER et Thierry BRECHET. Le Mécanisme pour un Développement Propre tiendra-t-il ses promesses ? *Reflets et Perspectives de la Vie Economique*, Tome XLIV – 2005 – N° 3, 5-27.

38. Paul-Marie BOULANGER and Thierry BRECHET. Models for policy-making in sustainable development: The state of the art and perspectives for research. *Ecological Economics*, 55, 337-350, 2005.

37. Johan EYCKMANS an Henry TULKENS. Optimal and Stable International Climate Agreements. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)

36. Thierry BRECHET and Benoît LUSSIS. The Clean Development Mechanism in Belgian Climate Policy. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)

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