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Thierry Bréchet and Pierre-André Jouvet

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METHODS

Environmental innovation and the cost of pollution abatement revisited

Thierry Bréchet[a,*], *Pierre-André Jouvet*[b,c]

[a]*Center for Operations Research and Econometrics, Chair Lhoist Berghmans in Environmental Economics and Management, Louvain School of Management, Université catholique de Louvain, Voie du Roman Pays 34, B-1348 Louvain-la-Neuve, Belgium*
[b]*EconomiX, Université de Nanterre, France*
[c]*Center for Operations Research and Econometrics, Université catholique de Louvain, Belgium*

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A B S T R A C T

It is widely assumed in the literature that environmental innovation reduces the marginal cost of pollution abatement. In this paper we show that this is not necessarily the case and we provide some unexpected outcomes.

1. Introduction

It is widely assumed in the literature that environmental innovation reduces marginal pollution abatement costs. For example, Palmer et al. (1995) claim that new pollution abatement technology reduces the marginal abatement cost at all pollution levels. More recently, Jaffe et al. (2005) wrote that "technology innovations (...) typically reduce the marginal cost of achieving a given unit of pollution reduction". The same argument can also be found in Fischer et al. (2003), Montero (2002) or Xepapadeas (1997), among others. Graphically, this is reflected by a decrease of the slope of the marginal abatement cost function (see Fig. 1a in the next section). Requate and Unod (2003) do the same assumption, but they also explain that innovation shifts the marginal abatement cost function to the left, which is only part of the overall real impact, as we will show.

In all this literature it is intuitively and unambiguously expected that, when an emission fee is imposed the innovator will pay a lower tax amount and bear a lower total abatement cost. These two arguments provide a clear incentive for polluters to adopt environmentally friendly technologies. There exists an extensive literature comparing policy instruments with regard to their relative incentive to innovate, taking for granted the assumption that innovation reduces marginal abatement costs. The objective of our paper is to question this

* *Corresponding author.* Center for Operations Research and Econometrics (CORE), Université catholique de Louvain, Voie du Roman Pays 34, B-1348 Louvain-la-Neuve, Belgium. Tel.: +32 10 47 43 40.
E-mail address: Thierry.Brechet@uclouvain.be (T. Bréchet).

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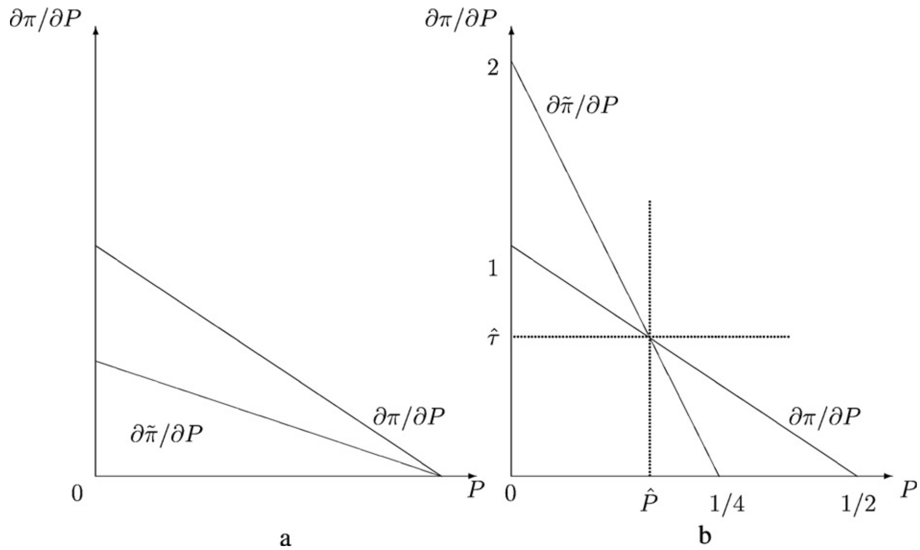

Fig. 1 – The effect of innovation on the MAC function a: according to Palmer et al. (1995) b: the adequate representation.

assumption. Actually, environmental innovation does not necessarily reduce the marginal cost of pollution abatement.

The paper is organized as follows. It is enlightening to first show the impact of innovation on the abatement costs in a simple linear example (actually, the one used in many papers). This is done in the first section. Section 3 generalizes the result and the conclusion follows.

2. A simple counter-example

Most of the articles referred to in the introduction use linear marginal abatement costs and assume that environmental innovation reduces the marginal abatement cost for all pollution levels, which boils down to reduce the slope of the function, as shown in Fig. 1a taken from Palmer et al. (1995). In this particular case, showing that innovation actually does not necessarily reduce the marginal abatement cost is straightforward, just by going back to the theoretical model.

A firm produces an output y with a single input x; the production function writes $y = \sqrt{x}$. Polluting effluents are given by $e = \alpha y$, with $\alpha > 0$. All markets are competitive and prices equal to unity. The firm's profit function is given by $\pi = y - x$, which can be expressed, by substitution, in terms of pollution, $\pi = \frac{1}{\alpha} e - \frac{1}{\alpha^2} e^2$. The marginal benefit to the firm of emitting one more unit of pollution is given by the first derivative of this profit function.

What is the cost of reducing pollution for the firm? The cost is a profit loss. The profit loss is given by the variation of profit in response to a decrease of pollution level, *i.e.*, reducing one unit of pollution yields a marginal profit loss. The marginal abatement cost function is thus defined as the first derivative of the profit function with respect to polluting effluents (see for example Pearce and Turner (1990) or McKitrick (1999)). It writes,

$$\mathrm{MAC}(e) \equiv \frac{\partial \pi}{\partial e} = \frac{1}{\alpha} - \frac{2}{\alpha^2} e \tag{1}$$

Taking $\alpha = 1$ gives the decreasing function displayed in Fig. 1a. Assume now that environmental innovation reduces the pollution – output ratio, so that, for example, $\alpha = 0.5$. This technological effect may represent different kinds of innovations: end-of-pipe devices (like scrubbers for dust in the cement industry, material particles in transportation, carbon dioxide or sulfur dioxide emissions in combustion processes) or process improvements or new machines yielding higher pollution efficiency. For example, scrubbers have played a key role for curbing SO_2 emissions when the market for tradable permits was implemented in the U.S. power sector (see Ellerman et al., 2000). From Eq. (1) it is clear that the MAC function shifts left and that its slope increases after innovation. So, the marginal abatement cost is not necessarily lower after innovation for every pollution level. Actually, this marginal cost is higher after innovation for pollution levels smaller than $\bar{p}$, the point where the two functions cross each others.

Two implications may be stressed out from this example. First, a motive generally advocated for a firm to innovate is to pay less environmental taxes. It is clear from Fig. 1b that, for any proportional tax imposed on pollution above $\bar{\tau}$, the firm pollutes more after innovation than before and, consequently, pays more environmental taxes.[1] Second, part of the literature devoted to the rankings of policy instruments in terms of incentive to innovate relies on the assumption that innovation reduces the marginal abatement cost (see Xepapadeas (1997), Montero (2002), Requate and Unod (2003) or Fischer et al. (2003) for example). One may question whether these rankings still hold when, as we have just shown, innovation increases the marginal abatement cost.

3. Generalization

Let us consider a firm producing a desired output y by using a set of inputs $\mathbf{x} = \{x_1, \ldots x_N\}$ and a technology represented by a *production function* $f(\mathbf{x}) : \mathbb{R}^N_+ = \rightarrow \mathbb{R}_+$. This function is increasing, strictly concave and verifies the Inada conditions. The firm also generates a set $\mathbf{e} = \{e_1, \ldots e_P\}$ of undesired outputs, namely polluting effluents. Some inputs may pollute (*e.g.*, the use of fossil fuels), some may not (*e.g.*, human knowledge) and some

[1] This questions the issue of environmental performance. See Bréchet and Michel (2007) for a specific discussion on that point.

may reduce pollution (*e.g.*, the use of an environmental management system). Moreover, each input may give rise to many pollutants and each pollutant may flow from many inputs.[2] Let i be the index of inputs and j be the index of pollutant effluents. The amount of effluents e_j coming from input x_i is noted e_{ij}. Thus, we have that $e_j = \sum_i e_{ij}$. The amount of effluent e_{ij} is given by a *pollution function* $h_{ij}(x_i): \mathbb{R}_+ \to \mathbb{R}$, such that $e_{ij}=h_{ij}(x_i)$. For a polluting input this function has the following properties: it is inversible, $h_{ij}(0)=0$, $h_{ij}(x_i)>0$ and $h'_{ij}(x_i)>0$.[3]

The output is the numeraire. The price vector for the inputs is $\mathbf{q}=\{q_1, \ldots q_N\}$. All markets are competitive. Without pollution constraint the program of the firm writes

$$\max_{\{\mathbf{x}\}} \pi(\mathbf{x}) = f(\mathbf{x}) - \mathbf{qx} \tag{2}$$

which results in a unique solution $\mathbf{x}^o$ and $\mathbf{e}^o h(\mathbf{x}^o)$, where "o" stands for the *laissez-faire*.

Let us note $\Omega_{ij}(e_{ij})$ the marginal abatement cost function related to pollutant e_{ij}. This function is defined for all $e_{ij} \in (0, e^o_{ij})$, where e^o_{ij} stands for the firm's optimal level of pollution under *laissez-faire*. This function gives the profit loss incurred when pollutant e_{ij} has to be reduced by one unit, all other things being equal. By substituting x_i by the inverse function $h^{-1}_{ij}(e_{ij})$ in the firm's program we obtain the profit level as a function of e_{ij}, $\forall e_{ij} \in (0, e^o_{ij})$. The marginal abatement cost function $\Omega_{ij}(e_{ij})$ is given by the derivative of this profit function and it writes:

$$\Omega_{ij}(e_{ij}) \equiv \frac{\partial \pi}{\partial e_{ij}} = \frac{\frac{\partial f(\mathbf{x})}{\partial x_i} - q_i}{\frac{\partial h_{ij}(x_i)}{\partial x_i}} \tag{3}$$

At the firm's optimum under *laissez-faire*, Eq. (3) implies that $\Omega_{ij}(e_{ij})=0$ since $\frac{\partial f(\mathbf{x})}{\partial x_i} = q_i$, $\forall i$, which results in a pollution level $e_{ij}=e^o_{ij}$. If a restriction $\bar{e}_{ij}$ was imposed on pollution such that $0<\bar{e}_{ij}<e^o_{ij}$, then the maximization problem would lead to an optimal input level x^*_i such that $x^*_i<x^o_i$. As a consequence, $\frac{\partial f(\mathbf{x})}{\partial x_i}>q_i$ and the firm would experience a profit loss, the marginal abatement cost being given by Eq. (3).

We can now define environmental innovation when applied to polluting inputs.

Definition. Environmental innovation leads to a new pollution function, $\tilde{h}_{ij}(x_i)$. This function has the same properties as $h_{ij}(x_i)$, except that $0<\tilde{h}'_{ij}(x_i)<h'_{ij}(x_i)$, for all polluting input x_i.

Environmental innovation reduces the marginal pollution intensity of the production process. In other words, an increase in output will lead to a lower increase in pollution after innovation. This also means that the marginal productivity of pollution is higher after innovation. Under our definition of environmental innovation, the assumption that $\tilde{h}_{ij}(0)=h_{ij}(0)=0$ yields $\tilde{h}_{ij}(x_i)<h_{ij}(x_i)$, for all polluting input. So, innovation also reduces the total amount of pollution. Stemming from the definition of the *pollution function*, this definition of environmental innovation is also a general one. It encompasses all the kinds of innovations considered in the linear case (see Section 2 above) but also input substitutions, like the possibility to use cleaner fuels (for example, clean coal *vs* dirty coal in terms of SO_2 emissions, biomass or gas *vs* oil or coal in terms of CO_2 and particles).

In order to focus on the incentive to innovate we assume that innovation has no fixed cost.

We are now able to analyze how environmental innovation shapes the marginal abatement cost function. Let us note the marginal abatement cost function after environmental innovation $\tilde{\Omega}_{ij}(e_{ij})$. The issue is to check whether $\tilde{\Omega}_{ij}(e_{ij})$ is smaller or greater than $\Omega_{ij}(e_{ij})$, $\forall e_{ij} \in (0, e^o_{ij})$. This is done by comparing Eq. (3) before and after environmental innovation. It leads to the following proposition.

Proposition. *For every pollution level below the optimal one after innovation, environmental innovation decreases (resp. increases) the marginal pollution abatement cost if the decrease of the pollution intensity is large enough (resp. small enough) compared to the increase of the marginal productivity of pollution.*

Proof. We want to compare $\Omega_{ij}(e_{ij})$ and $\tilde{\Omega}_{ij}(e_{ij})$ for a given $e_{ij} \in (0, \tilde{e}^o_{ij})$. We know that $\tilde{e}_{ij}=\tilde{h}_{ij}(x_i)<e_{ij}=h_{ij}(x_i), \forall i$. It follows that, for any given $e_{ij} \in (0, \tilde{e}^o_{ij})$, $\tilde{x}_i=\tilde{h}_{ij}^{-1}(e_{ij})>x_i=h_{ij}^{-1}(e_{ij})$. So the numerator of $\tilde{\Omega}_{ij}(e_{ij})$ is smaller than the one of $\Omega_{ij}(e_{ij})$. As for the denominator, the one of $\tilde{\Omega}_{ij}(e_{ij})$ is smaller or greater than the one of $\Omega_{ij}(e_{ij})$ depending on whether $h'_{ij}(\tilde{x}_i(e_{ij}))$ is greater or smaller than $h'_{ij}(x_i(e_{ij}))$, $\forall e_{ij} \in (0, \tilde{e}^o_{ij})$. □

The impact of innovation on the abatement cost is twofold. On the one hand, it reduces the pollution intensity of production in the *laissez-faire* (since $\tilde{e}^o_{ij}=\tilde{h}_{ij}(x^o_i)<e^o_{ij}=h_{ij}(x^o_i)$), and for any output levels below, but, on the other hand, it increases the marginal productivity of pollution, thus making the MAC function steeper. The linear example presented in the previous section clearly shows that, the smaller the first effect, the smaller the possibility that the marginal abatement cost is reduced after innovation. In the general case, however, one cannot be sure that the slope is always higher after innovation for every pollution levels: it also depends on how innovation alters the second derivative of the pollution function. Finally, in the general case it may happen, as in the example, that the innovating firm pollutes more when a tax is imposed on pollution.

4. Conclusion

In this paper we have shown that, as assumed in the literature, environmental innovation does not necessarily reduce the marginal cost of pollution abatement. Actually, environmental innovation increases the slope of the marginal abatement cost function (instead of decreasing it as widely assumed) and shifts it left. In the linear quadratic case, environmental innovation reduces the marginal abatement cost only if the abatement level is not too strong. Otherwise, innovation increases the marginal abatement cost.

This result may have many implications on major policy issues. For example, if a pollution fee is set above some threshold, the firm pollutes more after innovation than before,

[2] As an example, coal combustion gives rise, among other pollutants, to the emission of CO_2, SO_2, NO_x and dust. Carbon emissions come from the combustion of all fossil fuels (liquid, gaseous and solid) but also, in some industries, from the process itself (e.g. cement, lime, steel…).

[3] For the other productive inputs this function has the following properties. If the input is non-polluting, $h_{ij}(x_i)=0$. If the input is depolluting, $h_{ij}(x_i)<0$ and $h'_{ij}(x_i)<0$.

and thus pays more tax. In this case, maybe a command-and-control regulation could be more appropriate to avoid such adverse effects. Nevertheless, a quantity-based regulation expressed in relative terms (*e.g.* a 10% reduction) or in absolute terms (*e.g.* x-ton reduction) would be more detrimental to the firm after innovation, because of a higher abatement cost. The usual assumption would yield the reverse. These examples suggest to revisit the ranking of environmental policy instruments (permits, taxes and standard) in terms of incentive to innovate.

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REFERENCES

Bréchet, Th., Michel, Ph., 2007. Environmental performance and equilibrium. Canadian Journal of Economics 40 (4), 1078–1099.

Ellerman, A.D., Joskow, P.L., Schalensee, R., Montero, J.-P., 2000. Markets for Clean Air — The U.S. Acid Rain Program Cambridge University Press.

Fischer, C., Parry, W.H., Pizer, W.A., 2003. Instrument choice for environmental protection when technological innovation is endogenous. Journal of Environmental Economics and Management 45, 523–545.

Jaffe, A.B., Newell, R.G., Stavins, R.N., 2005. A tale of two market failures: technology and environmental policy. Ecological Economics 54, 164–174.

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

Montero, J.-P., 2002. Permits, standards and technology innovation. Journal of Environmental Economics and Management 44, 23–77.

Palmer, K., Oates, W.E., Portney, P.R., 1995. Tightening the environmental standards: the benefit-cost or the no-cost paradigm? Journal of Economic Perspectives 9, 119–132.

Pearce, D., Turner, K., 1990. Economics of Natural Resources and the Environment. Harvester Wheatsheaf, London.

Requate, T., Unod, W., 2003. Environmental policy incentives to adopt advanced abatement technology: will the true ranking please stand up? European Economic Review 47, 125–146.

Xepapadeas, A., 1997. Advanced Principles in Environmental Policy. Edward Elgar Publishing.

Environmental Economics & Management Memoranda

77. Fabien PRIEUR. The environmental Kuznets curve in a world of irreversibility. May 2008.

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)

35. Vincent VAN STEENBERGHE. The impact of banking on permits prices and compliance costs. 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)

34. Johan EYCKMANS, Denise VAN REGEMORTER and Vincent VAN STEENBERGHE. Kyoto-permit prices and compliance costs: an analysis with MacGEM. 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)

33. Johan EYCKMANS, Bert WILLEMS and Jean-Pascal VAN YPERSELE. Climate Change: Challenges for the World. 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)

32. Marc GERMAIN, Stef PROOST and Bert SAVEYN. The Belgian Burden Sharing. 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)

31. Ingmar SCHUMACHER. Reviewing Social Discounting within Intergenerational Moral Intuition. June 2005.

30. Stéphane LAMBRECHT. The effects of a demographic shock in an OLG economy with pay-as-you-go pensions and property rights on the environment: the case of selfish households. January 2005.

29. Stéphane LAMBRECHT. Maintaining environmental quality for overlapping generations: Some Reflections on the US Sky Trust Initiative. May 2005.

28. Thierry BRECHET, Benoît LUSSIS. The contribution of the Clean Development Mechanism to national climate policies. April 2005.

27. Thierry BRECHET, Stéphane LAMBRECHT, Fabien PRIEUR. Intergenerational transfers of pollution rights and growth. May 2005 (also availabe as CORE DP 2005/42).

26. Maryse LABRIET, Richard LOULOU. From non-cooperative CO_2 abatement strategies to the optimal world cooperation: Results from the integrated MARKAL model. April 2005.

25. Marc GERMAIN, Vincent VAN STEENBERGHE, Alphonse MAGNUS. Optimal Policy with Tradable and Bankable Pollution Permits : Taking the Market Microstructure into Account.*Journal of Public Economy Theory*, 6(5), 2004, 737-757.

24. Marc GERMAIN, Stefano LOVO, Vincent VAN STEENBEGHE. De l'impact de la microstructure d'un marché de permis de polluer sur la politique environnementale. *Annales d'Economie et de Statistique*, n° 74 – 2004, 177-208.

23. Marc GERMAIN, Alphonse MAGNUS, Vincent VAN STEENBERGHE. Should developing countries participate in the Clean Development Mechanism under the Kyoto Protocol ? The low-hanging fruits and baseline issues. December 2004.

22. Thierry BRECHET et Paul-Marie BOULANGER. Le Mécanisme pour un Développement Propre, ou comment faire d'une pierre deux coups. *Regards Economiques*, Ires n° 27, janvier 2005.

21. Sergio CURRARINI & Henry TULKENS. Stable international agreements on transfrontier pollution with ratification constraints. In C. Carrarro and V. Fragnelli (eds.), *Game Practice and the Environment*. Cheltenham, Edward Elgar Publishing, 2004, 9-36. (also available as CORE Reprint 1715).

20. Agustin PEREZ-BARAHONA & Benteng ZOU. A comparative study of energy saving technical progress in a vintage capital model. December 2004.

19. Agustin PEREZ-BARAHONA & Benteng ZOU. Energy saving technological progress in a vintage capital model. December 2004.

18. Matthieu GLACHANT. Voluntary agreements under endogenous legislative threats and imperfect enforcement. November 2004.

17. Thierry BRECHET, Stéphane LAMBRECHT. Puzzling over sustainability: an equilibrium analysis. November 2004.

16. Vincent VAN STEENBERGHE. Core-stable and equitable allocations of greenhouse gas emission permits. October 2004. (also available as CORE DP 2004/75).

15. Pierre-André JOUVET Philippe MICHEL, Pierre PESTIEAU. Public and private environmental spending. A political economy approach. September 2004. (also available as CORE DP 2004/68).

14. Thierry BRECHET, Marc GERMAIN, Vincent VAN STEENBERGHE. The clean development mechanism under the Kyoto protocol and the 'low-hanging fruits' issue. July 2004. (also available as CORE DP 2004/81).

13. Thierry BRECHET, Philippe MICHEL. Environmental performance and equilibrium. July 2004. (also available as CORE DP 2004/72).

12. Luisito BERTINELLI, Eric STROBL. The Environmental Kuznets Curve semi-parametrically revisited. July 2004. (also available as CORE DP 2004/51).

11. Axel GOSSERIES, Vincent VAN STEENBERGHE. Pourquoi des marchés de permis de polluer ? Les enjeux économiques et éthiques de Kyoto. April 2004. (also available as IRES discussion paper n° 2004-21).

10. Vincent VAN STEENBERGHE. CO_2 Abatement costs and permits price : Exploring the impact of banking and the role of future commitments. December 2003. (also available as CORE DP 2003/98).

9. Katheline SCHUBERT. Eléments sur l'actualisation et l'environnement. March 2004.

8. Marc GERMAIN. Modélisations de marchés de permis de pollution. July 2003.

7. Marc GERMAIN. Le Mécanisme de Développement Propre : Impacts du principe d'additionalité et du choix de la baseline. January 2003.

6. Thierry BRECHET et Marc GERMAIN. Les affres de la modélisation. May 2002.

5. Marc GERMAIN and Vincent VAN STEENBERGHE. Constraining equitable allocations of tradable CO_2 emission quotas by acceptability, *Environmental and Resource Economics*, (26) 3, 2003.

4. Marc GERMAIN, Philippe TOINT, Henry TULKENS and Aart DE ZEEUW. Transfers to sustain dynamic core-theoretic cooperation in international stock pollutant control, *Journal of Economic Dynamics & Control*, (28) 1, 2003.

3. Thierry BRECHET, Marc GERMAIN et Philippe MONTFORT. Spécialisation internationale et partage de la charge en matière de réduction de la pollution. (also available as IRES discussion paper n°2003-19).

2. Olivier GODARD. Le risque climatique planétaire et la question de l'équité internationale dans l'attribution de quotas d'émission échangeable. May 2003.

1. Thierry BRECHET. Entreprise et environnement : des défis complémentaires ? March 2002. Revue Louvain.

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Chair Lhoist Berghmans in Environmental Economics and Management
Center for Operations Research & Econometrics (CORE)
Université catholique de Louvain (UCL)
Voie du Roman Pays 34
B-1348 Louvain-la-Neuve, Belgium

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