

Tarui, Nori; Heal, Geoffrey

Working Paper

Technology diffusion, abatement cost, and transboundary pollution

Nota di Lavoro, No. 96.2008

Provided in Cooperation with:

Fondazione Eni Enrico Mattei (FEEM)

Suggested Citation: Tarui, Nori; Heal, Geoffrey (2008) : Technology diffusion, abatement cost, and transboundary pollution, Nota di Lavoro, No. 96.2008, Fondazione Eni Enrico Mattei (FEEM), Milano

This Version is available at:

<https://hdl.handle.net/10419/53382>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



Fondazione Eni Enrico Mattei

**Technology Diffusion,
Abatement Cost,
and Transboundary Pollution**

Geoffrey Heal and Nori Tarui

NOTA DI LAVORO 96.2008

NOVEMBER 2008

CCMP – Climate Change Modelling and Policy

Geoffrey Heal, *Graduate School of Business, Columbia University*
Nori Tarui, *Department of Economics, University of Hawaii at Manoa*

This paper can be downloaded without charge at:

The Fondazione Eni Enrico Mattei Note di Lavoro Series Index:
<http://www.feem.it/Feem/Pub/Publications/WPapers/default.htm>

Social Science Research Network Electronic Paper Collection:
<http://ssrn.com/abstract=1314754>

The opinions expressed in this paper do not necessarily reflect the position of
Fondazione Eni Enrico Mattei
Corso Magenta, 63, 20123 Milano (I), web site: www.feem.it, e-mail: working.papers@feem.it

Technology Diffusion, Abatement Cost, and Transboundary Pollution

Summary

This paper studies countries' incentives to develop advanced pollution abatement technology when technology may spillover across countries and pollution abatement is a global public good. We are motivated in part by the problem of global warming: a solution to this involves providing a global public good, and will surely require the development and implementation of new technologies. We show that at the Nash equilibrium of a simultaneous-move game with R&D investment and emission abatement, whether the free rider effect prevails and under-investment and excess emissions occur depends on the degree of technology spillovers and the effect of R&D on the marginal abatement costs. There are cases in which, contrary to conventional wisdom, Nash equilibrium investments in emissions reductions exceed the first-best case.

Keywords: International Environmental Agreement, Pollution Abatement Costs, Endogenous Technological Change

JEL Classification: Q50, H87, D70

Address for correspondence:

Geoffrey Heal
Graduate School of Business
Columbia University
616 Uris Hall
New York
NY 10027
USA
E-mail: gmh1@columbia.edu.

1 Introduction

This paper is motivated in part by the problem of global warming: a solution will involve providing a global public good, and will surely require the development of new technologies and their implementation both in the countries that develop them and in others. We examine how the effect of technological innovation on the cost structure of emission abatement influences the countries' incentives to reduce emissions, to invest in R&D, and share new technologies with other countries. To analyze these issues, we use a simultaneous-move game of emissions reduction and R&D investments where each country acts noncooperatively. We hope that the intuitions we develop here can be valuable in managing the R&D process and structuring international agreements on this topic.

In the context of climate change, most studies on emission control and technological innovation predict that scenarios without policy intervention involve excessive emissions and insufficient R&D relative to the first best levels. It is not widely recognized that a crucial assumption behind this prediction is that the marginal abatement cost decreases as technology improves. In fact this need not be the case: we provide examples of technological changes which imply smaller total abatement costs but larger marginal abatement costs. Using a simultaneous-move game of emissions reduction and R&D investments, we find that the equilibrium R&D investment can be larger than the first best level in these examples.

Technological innovation is often induced by an international environmental agreement (IEA). In some cases, IEAs explicitly encourage the signatories to cooperate in R&D.¹ Several studies have examined how technology spillovers influence countries' cooperation in providing global public goods.² Carraro and Siniscalco (1997) analyze the stability of IEAs assuming that the signatories conduct R&D to develop a cleaner technology which is unavailable to non-signatories. Buchner et al. (2002) study the stability of climate change mitigation cooperation across countries when technology spillovers within cooperating countries are larger than spillovers from cooperating countries to non-cooperating countries. Barrett

¹Examples include a six-country pact for developing technology to reduce greenhouse gas emissions. See "Vision Statement of Australia, China, India, Japan, the Republic of Korea, and the U.S. for a New Asia-Pacific Partnership on Clean Development and Climate," available at <http://www.state.gov/g/oes/rls/fs/50335.htm>.

²Heal (1993) and Barrett (2003) argue that abatement efforts and technology change in one country may reduce the marginal abatement costs in other countries and the first-best outcome may be supported once a sufficient number of countries adopt higher environmental standards.

(2003) raises two questions about their approach (pp.309-310). First, it is often difficult to prevent technology diffusion once new technology is developed. Second, given that a cleaner technology is developed and signatories' environmental damage is increasing in non-signatories' emissions, the signatories may have an incentive to allow the non-signatories to use the cleaner technology so that the global emissions decline. Barret (2003) also argues that no existing IEAs prevent the non-signatories from using new technology developed by the signatories. For example, the Montreal Protocol requires that parties cooperate in promoting R&D for a technology that reduces controlled substances, where non-parties are allowed easy access to new technologies by the parties (Barret 2003, pp.309-10.) Indeed, there is a stronger argument against the idea that new technologies will not spill over: this is that the companies that develop them will want to sell them worldwide as part of a profit-maximization strategy. General Electric is aggressively promoting its carbon capture and storage technologies worldwide, though they were developed in the U.S.

To investigate countries' incentive for emission control and investments, we consider a simultaneous-move game where the countries choose investments and emissions simultaneously when both technology and pollution spill over across countries. We find the following (see Table 1).

1. If each country's marginal abatement cost is decreasing in R&D investment, then the Nash equilibrium investments are lower and the equilibrium emissions are larger than the first-best levels. This result holds regardless of the degree of technology spillovers among countries. This is the "conventional wisdom" case.
2. If the marginal abatement costs are increasing in investment, then the equilibrium results in over-(under-)investment when the degree of spillovers is small (large) enough. In this case, emissions may be less than in the first best case. This case is contrary to conventional wisdom.

The first point is consistent with Golombek and Hoel (2004), who have the same finding under the assumptions listed above. The second point implies that whether the first claim holds depends on the relationship between R&D and the marginal abatement costs. Section 2 discusses cases in which marginal abatement costs may increase under a new technology.

Intuitively we can see why the movement of marginal abatement costs (MACs) is important. Suppose that technological development leads to an abatement technology with lower fixed and higher variable costs, and lower average costs - we will suggest below that this accurately describes one of the main technologies now being developed, that of carbon capture and storage. Then the lower fixed costs have an income effect which will typically lead to the choice of more abatement. However the higher MAC produces a substitution effect that acts in the opposite direction. In such a situation it is not clear whether the outcome will be more or less abatement. This is true for both the socially optimal allocation and the Nash equilibrium allocation, but it is stronger for the first best case and so tends to reduce abatement more, reduce emissions less, in this case. This opens up the possibility that Nash emissions may be less than the first best, as Nash abatement is reduced less. We show below that this can happen when spillovers are large: large spillovers tend of course to counteract the standard arguments about free riders and public goods. Large spillovers provide income effects to all countries, similarly to lower fixed costs. This explains why we find counterintuitive outcomes with small income effects.

[Table 1]

The next section discusses examples of technologies where the marginal abatement cost may decrease or increase as a result of technology innovation. Section 3 describes the assumption of our analysis, the result, and discussions regarding alternative assumptions. Section 4 concludes the paper with policy implications.

2 Technology innovation and marginal abatement costs

The relationship between marginal abatement costs and R&D is central to some of our results. We expect, of course, that abatement costs will fall as a result of successful R&D—that is in effect the definition of success in R&D. Presumably we mean the total cost of attaining a given level of abatement falls, but this leaves open the impact of R&D on the fixed and variable costs of reducing emissions. In principle, successful R&D can introduce a new technology whose cost structure is totally different from that of the current technology. The current technology may for example have high fixed and low variable costs, whereas the new one has low fixed costs and high variable costs. In this case the total and average costs

would be lower but the marginal abatement cost might be higher with the new technology. These issues are discussed to some degree in Baker et al. (2006, 2008), who consider the effect of uncertainty about the costs of climate change on the optimal spending on R&D: they find that the abatement cost curve can change in many different ways as a result of R&D, depending on the parameters of the model. Bauman (2003) and Brechet and Jouvett (2006) also present theoretical models which demonstrate that the marginal abatement cost may be higher with new technology. *The Economics of Climate Change* (Stern Review, 2006) also notes that “step-change improvements in a technology might accelerate progress [of declining marginal costs], while constraints such as the availability of land or materials could result in increasing marginal costs” (Executive Summary, p.xx).

Researchers are currently investigating many different technologies for CO₂ abatement. Integrated combined cycle coal gasification (ICCCG) with carbon capture and storage is one possibility: coal combustion with cryogenic oxygen and carbon capture and storage is another, and the use of renewable energy sources and nuclear power represent yet more alternatives. If we think of renewable energy and nuclear as the current abatement technologies, and ICCCG with C-capture and storage as a possible new technology, then the change in cost structures in going from the old to the new technologies is instructive. Renewable energy sources and nuclear have high fixed costs but almost no variable costs, so that the marginal cost of abatement along this route is close to zero even though the average is high. ICCCG with C-capture and storage, by contrast, would have high marginal costs: each ton of CO₂ has to be captured (perhaps \$5 per ton) and then transported (perhaps \$10 per ton) and stored (perhaps \$5 per ton). We would not use this technology unless its average cost were less than renewables, but if we used it we would face a higher marginal cost.³

3 A game with emissions and technology externality

3.1 Assumptions, the optimal outcome, and the symmetric Nash equilibrium

Suppose N countries choose R&D investments and emissions for developing abatement technology. Let $(k_i, e_i) \geq 0$ be country i 's investment and emissions choice. Country i 's cost of

³We are grateful to Klaus Lackner for an instructive discussion of these issues.

investing k_i is given by $G(k_i) \geq 0$ where $G' > 0, G'' \geq 0$. When the countries' investment profile is $k = (k_1, \dots, k_N)$, country i 's cost of reducing emissions from its status-quo level $\bar{e} > 0$ to a level $e_i \geq 0$ is given by $C(e_i, z_i(k)) \geq 0$ where

$$z_i(k) = k_i + \lambda \sum_{j \neq i} k_j.$$

The function z_i represents the effective amount of abatement capital available to country i given investment profile k . The exogenous parameter $\lambda \in [0, 1]$ represents the extent of innovation spillovers across countries. There is no technology diffusion and R&D is a private good if $\lambda = 0$. With complete spillovers, λ is equal to one. The abatement cost function C is twice continuously differentiable and convex with $C_e < 0, C_z < 0, C_{ee} > 0, C_{zz} > 0$ for all $e < \bar{e}$. (Subscripts stand for partial derivatives.) We assume C_{ez} is positive, zero, or negative. The marginal abatement cost $-C_e$ is decreasing in investment if $C_{ez} > 0$. Given total emissions $E = \sum_j e_j$, country i 's damage is $D(E) \geq 0$ where $D' > 0$ and $D'' > 0$.

We assume that the countries choose investment and emissions simultaneously. The main result of the paper will hold if the countries choose investment and emissions sequentially (i.e. they choose investment simultaneously first, and then emissions simultaneously).

The first-best investment emission and allocation $\{k_i^*, e_i^*\}$ minimizes the social cost of emissions $\sum_i [G(k_i) + C(e_i, z_i(k)) + D(E)]$. The first order condition for an interior solution is

$$\begin{aligned} G'(k_i^*) + C_z(e_i^*, k_i^* + \lambda \sum_{j \neq i} k_j^*) + \sum_{j \neq i} \lambda C_z(e_j^*, k_j^* + \lambda \sum_{l \neq j} k_l^*) &= 0, \\ C_e(e_i^*, k_i^* + \sum_{j \neq i} k_j^*) + ND'(\sum_j e_j^*) &= 0 \end{aligned}$$

for $i = 1, \dots, N$. The symmetric solution where $(k_i^*, e_i^*) = (k_j^*, e_j^*) \equiv (k^*, e^*)$ for all $i, j \in I$ satisfies

$$G'(k^*) + f(\lambda)C_z(e^*, f(\lambda)k^*) = 0, \tag{1}$$

$$C_e(e^*, f(\lambda)k^*) + ND'(Ne^*) = 0 \tag{2}$$

where $f(\lambda) \equiv 1 + (N - 1)\lambda$. Similarly, an interior Nash equilibrium $\{\hat{k}_i, \hat{e}_i\}$ satisfies

$$G'(\hat{k}_i) + C_z(\hat{e}_i, \hat{k}_i + \lambda \sum_{j \neq i} \hat{k}_j) = 0, \quad C_e(\hat{e}_i, \hat{k}_i + \lambda \sum_{j \neq i} \hat{k}_j) + D'(\sum_j \hat{e}_j) = 0$$

for all i . The symmetric Nash equilibrium (\hat{e}, \hat{k}) where $(\hat{k}_i, \hat{e}_i) = (\hat{k}, \hat{e})$ for all i satisfies

$$G'(\hat{k}) + C_z(\hat{e}, f(\lambda)\hat{k}) = 0, \tag{3}$$

$$C_e(\widehat{e}, f(\lambda)\widehat{k}) + D'(N\widehat{e}) = 0. \quad (4)$$

Under the assumptions on C and D , we can solve conditions (2) and (4) for emissions as a function of investment in the first best allocation and in the Nash equilibrium. Call these functions e^f and e^n . (Superscript f stands for the first best and n for Nash equilibrium. Note that $e^f(k^*) = e^*$ and $e^n(\widehat{k}) = \widehat{e}$.) These functions satisfy the following property. (See the appendix for the proofs.)

Lemma 1 $e^n(k) > e^f(k)$ for all $k > 0$.

Lemma 2 If $C_{ez} \gtrless 0$, then $\frac{de^f}{dk} \lesseqgtr 0$ and $\frac{de^n}{dk} \lesseqgtr 0$.

Lemma 3 The equilibrium investment by each country is decreasing in the degree of technology spillovers λ (i.e. $\frac{\partial \widehat{k}}{\partial \lambda} < 0$). The first-best investment by each country may be decreasing or increasing in technology spillovers. The equilibrium and the first best emissions are non-increasing (nondecreasing) in λ if $C_{ez} > (<)0$.

Given the same investment level, the Nash equilibrium emission is larger than the first best level (Lemma 1). Both the equilibrium and the first best emissions are decreasing (increasing) in investment if the marginal abatement cost is decreasing (increasing) in investment (Lemma 2). See figure 3 for an example where the first-best investment may decrease when the degree of technology spillovers increases.

3.2 Main results

The following proposition is based on the three lemmas and compares the first best solution and the Nash equilibrium outcome of the game where countries choose investment and emissions simultaneously.

Proposition 1 Let $\{k^*, e^*\}$ be the first best investment and emission of each country and $\{\widehat{k}, \widehat{e}\}$ be the symmetric Nash equilibrium.

- (i) If $C_{ez} > 0$, then $\widehat{e} > e^*$ and $\widehat{k} < k^*$ for all $\lambda \in [0, 1]$.
- (ii) If $C_{ez} = 0$ and $\lambda = 0$, then $\widehat{e} > e^*$ and $\widehat{k} = k^*$. If $C_{ez} = 0$ and $\lambda > 0$, then $\widehat{e} > e^*$ and $\widehat{k} < k^*$.

(iii) If $C_{ez} < 0$ and $(N - 1)\lambda < \frac{C_z(e^n(\hat{k}), f(\lambda)\hat{k})}{C_z(e^f(k), f(\lambda)k)} - 1$, then $\hat{e} > e^*$ and $\hat{k} > k^*$. If $C_{ez} < 0$ and $(N - 1)\lambda > \frac{C_z(e^n(\hat{k}), f(\lambda)\hat{k})}{C_z(e^f(k), f(\lambda)k)} - 1$, then $\hat{k} < k^*$.

The equilibrium emission is larger than the first best level if the marginal abatement cost is nonincreasing in R&D or if the spillover effect is small. If the marginal abatement cost is decreasing in investment ($C_{ez} > 0$), then the equilibrium investment is smaller than the first best level regardless of the spillover effect λ . If $C_{ez} = 0$, then the equilibrium investment is the same as the first best level under no spillover and under-investment occurs under spillovers. If the marginal abatement cost is increasing in investment ($C_{ez} < 0$), then over-investment occurs when spillovers and the number of countries are small while under-investment occurs when spillovers or the number of countries are large. Larger marginal abatement costs imply larger ex-post optimal emissions and hence larger damages to each country. With small technology spillovers and the marginal abatement costs increasing in investments, each country's privately optimal investment exceeds the socially optimal investment.

Part (i) has been demonstrated in literature (e.g. Golombek and Hoel 2004) and perhaps not surprising. We explain part (iii) graphically by assuming $C_{ez} < 0$. Figure 1 contrasts a representative country's optimal and equilibrium emission and investment choice. The figure also assumes $\lambda = 0$, and hence the only source of externality is emissions. While the marginal abatement cost of each country equals the social (aggregate) marginal damages of all countries under the optimal outcome, the equilibrium emission equates the marginal abatement cost and the private marginal damages for each country (panel b). The assumption $C_{ze} \equiv C_{ez} < 0$ implies that the marginal benefit of investment (i.e. the marginal reduction in abatement cost due to investment) is smaller under smaller emissions (see panel a), and hence the equilibrium investment exceeds the first best level. Figure 2 illustrates a case where the equilibrium emission is lower than the first best level. Given $\lambda > 0$, technology spillover is an additional source of externality. The spillovers tend to lower the equilibrium investment relative to the first best level. With λ sufficiently large, the equilibrium investment \hat{k} exceeds the first best level k^* and hence the marginal abatement cost curve given \hat{k} lies to the left of the marginal abatement cost curve given k^* . Therefore, as in Figure 2, the equilibrium emission (given by the intersection of the marginal abatement cost given \hat{k} and the private marginal damage) can fall below the first best emission (given by the intersection

of the marginal abatement cost given k^* and the social marginal damage) as in panel (b).⁴

[Figure 1]

[Figure 2]

3.3 Example

The following example illustrates the result of Proposition 1:

$$G(k) = rk, \quad C(e, z) = f(z) + a(z)(\bar{e} - e) + \frac{b(z)}{2}(\bar{e} - e)^2, \quad D(E) = \frac{d}{2}E^2, \quad (5)$$

where the quantity \bar{e} represents the emission level in the absence of abatement, and $\bar{e} - e$ the abatement level. The function f represents the fixed cost of emission abatement. As explained in the previous section, f may be decreasing or increasing in the effective capital z . We assume f is strictly convex. At an emission level $e \in [0, \bar{e}]$, the marginal abatement cost is given by $a(z) + b(z)(\bar{e} - e)$ and its derivative with respect to investment is $a'(z) + b'(z)(\bar{e} - e)$. For simplicity, assume

$$f(z) = f_0 + f_1z + \frac{f_2}{2}z^2, \quad a(z) = az, \quad b(z) \equiv b, \quad (6)$$

for all $z \geq 0$ where f_2 and b are positive while f_1 and a may be positive or negative. New technology results in either lower marginal abatement cost, lower fixed cost of abatement, or both. If $f_1 > 0$ and $a > 0$, then investment results in technologies with lower fixed costs and larger marginal abatement cost. If $a < 0$, then investment results in smaller marginal abatement cost. Convexity of C requires $bf_2 - a^2 \geq 0$.

[Figure 3]

Figure 3 illustrates the result of Proposition 1 using the above example with $a = 1, b = 1, d = .75, N = 2, r = 1.5, f_1 = 2, f_2 = 1, \bar{e} = .5$. (Note that $a > 0$ implies $C_{ez} < 0$, i.e. the marginal abatement cost is increasing in investment.) This example illustrates part (iii) of Proposition 1:

- With small technology spillovers, the equilibrium emissions are larger than the optimal level. The equilibrium investment level is larger than the optimal level.

⁴Though the figure assumes that $G'' = 0$, the argument is also valid when $G'' > 0$.

- With large technology spillovers, the equilibrium emissions are smaller than the optimal level. The equilibrium investment level is smaller than the optimal level.

As discussed in section 1, this example corresponds to the case where the current technology is renewable energy and the new technology is ICCCG with carbon capture. When the spillover effect is small, the equilibrium may result in over-investment. When the spillover effect is large, the equilibrium may result in under-emissions.

Proposition 1 states that the equilibrium emission exceeds the optimal level whenever the equilibrium investment is larger than the optimal level. Figure 3 demonstrates that the equilibrium emissions can exceed the first best level when the equilibrium investment is smaller than the optimal level. As in Lemma 2, both the equilibrium and optimal emissions are increasing in investment when the marginal abatement cost is increasing in investment. Hence, when under-investment occurs at the equilibrium, the equilibrium emissions may fall below the optimal level. However, as Figure 4 illustrates, the equilibrium emissions are not necessarily smaller than the optimal level when λ is large.

[Figure 4]

3.4 Investment and emissions under alternative assumptions

We discuss the results under alternative assumptions.

We assumed that the countries choose investment and emissions simultaneously. It might be more natural to assume that the countries choose investment first and then emissions. The result about over-investment under increasing marginal abatement cost holds under the alternative assumption of sequential move.

Though we present our result in the context of transboundary pollution with countries as players, our analysis has an implication to domestic environmental regulation with a regulator and regulated firms as players. A large number of studies have compared regulated firms' incentive for technology innovation and adoption under alternative emission regulation (such as emissions quantity standards, emissions taxes, and emissions trading, see Milliman and Prince 1989, Requate et al. 2003, Newell and Jaffe et al. 2003). A number of studies have found that, when the regulator sets emissions standards or emissions taxes after the firms conduct investment, the regulated firms have an incentive to over-invest (relative to

the optimal level) under taxes and under-invest under standards (Malik 1991, Kennedy and Laplante 1999, Karp and Zhang 2002, Moledina et al. 2003, Tarui and Polasky 2006). They assume that the marginal abatement costs are decreasing in investment. If the marginal abatement costs are increasing investment, then the opposite incentive will work under taxes and standards. Baker et al. (2008) present a thorough summary of the implications of the increasing marginal abatement costs and provide a ranking of alternative emission policy instruments under the assumption.

The analysis in this section assumed that the countries are identical. A more realistic model would assume that countries differ in abatement costs and pollution damage functions. With heterogeneity, the equilibrium investment (emission) of some countries may be larger (lower) than the first best level even if the marginal abatement cost is decreasing in investment. This possibility is analogous to the free-rider problem associated with the private provision of public goods: with heterogeneous players, those who would benefit most (less) from public goods may contribute more (less) to the supply of public goods.

4 Discussion

This paper studied countries' incentives to reduce emissions of pollutants and develop a new emission abatement technology when technology diffusion across countries may occur and emission reduction is a global public good. If the marginal abatement cost of each country is decreasing in investment, then the Nash equilibrium results in excessive emissions and under-investment in innovation relative to the first-best under any degree of technology spillovers. The equilibrium results in over-investment when spillovers are small enough and if the marginal abatement cost is increasing in investment.

Our study is motivated in part by the problem of global climate change: it is clear that a comprehensive solution needs new technologies, that solving the problem is providing a global public good, and that the trade-offs we model here are central to policy choices about funding R&D and about treaty formats. Our finding implies that the direction to which the incentives for investments and emission reduction are biased depends on the types of technologies involved and the degree of technology spillovers. In particular, the transitions from one pollution abatement technology to another do not necessarily justify subsidizing

it even if the emission causes a negative externality. Though the model applies to trans-boundary pollution and technology spillovers across countries, the implication extends to environmental regulation on industries in a domestic context as well (see section 3.4).

We did not consider several important aspects of investments and emission reduction in international and national contexts such as government-industry interactions (firms' incentive to innovate given costly R&D and/or patenting or licensing opportunities given imperfect appropriability of innovation), heterogeneity among countries, and dynamics (changes in technology, atmospheric CO₂ concentration, and treaty participation over time). We assumed deterministic innovation.⁵ Though some of these issues are discussed in the previous section, further analysis is left for future research.

Appendix

Proof of Lemma 1

We have

$$C_e(e^n(k), f(\lambda)k) + ND'(Ne^n(k)) = C_e(e^n(k), f(\lambda)k) + D'(Ne^n(k)) + (N-1)D'(Ne^n(k)) > 0$$

for all $k > 0$ by condition (4). Because $C_e + ND'$ is increasing in emissions, it follows that $e^n(k) > e^f(k)$ for all $k > 0$. ■

Proof of Lemma 2

Totally differentiate condition (2) with respect to e^* and k^* to obtain

$$C_{ee}de^* + f(\lambda)C_{ez}dk^* + N^2D''de^* = 0, \quad \text{i.e.} \quad \frac{de^f}{dk} = \frac{-f(\lambda)C_{ez}}{C_{ee} + N^2D''}$$

which is positive if $C_{ez} < 0$ and negative if $C_{ez} > 0$. Similarly, total differentiation of condition (4) yields

$$C_{ee}d\hat{e} + f(\lambda)C_{ez}dk + ND''d\hat{e} = 0, \quad \text{i.e.} \quad \frac{de^n}{dk} = \frac{-f(\lambda)C_{ez}}{C_{ee} + ND''}$$

which is positive if $C_{ez} < 0$ and negative if $C_{ez} > 0$. ■

⁵For the analysis of IEAs with stochastic technological change, see Kolstad (2007).

Proof of Lemma 3

Differentiate the equations (3) and (4) with respect to λ and obtain

$$\begin{pmatrix} G'' + f(\lambda)C_{zz} & C_{ze} \\ f(\lambda)C_{ez} & C_{ee} + ND'' \end{pmatrix} \begin{pmatrix} \frac{\partial \hat{k}}{\partial \lambda} \\ \frac{\partial \hat{e}}{\partial \lambda} \end{pmatrix} = \begin{pmatrix} -f'(\lambda)\hat{k}C_{zz} \\ -f'(\lambda)\hat{k}C_{ez} \end{pmatrix}.$$

Applying Cramer's Rule, we have

$$\frac{\partial \hat{e}}{\partial \lambda} = \frac{-f'(\lambda)\hat{k}G''C_{ez}}{A}, \quad \frac{\partial \hat{k}}{\partial \lambda} = \frac{-f'(\lambda)\hat{k} \{C_{ee}C_{zz} - C_{ez}^2\} + NC_{zz}D''}{A}$$

where

$$A \equiv G''(C_{ee} + ND'') + f(\lambda)\{C_{ee}C_{zz} - C_{ez}^2\} + Nf(\lambda)C_{zz}D'' > 0.$$

Therefore, $\frac{\partial \hat{e}}{\partial \lambda} \leq (\geq) 0$ if $C_{ez} \geq (\leq) 0$. The equilibrium investment is decreasing in λ ($\frac{\partial \hat{k}}{\partial \lambda} < 0$) regardless of the sign of C_{ez} .

Similarly, differentiate the equations (1) and (2) with respect to λ and obtain

$$\begin{pmatrix} G'' + f^2C_{zz} & fC_{ze} \\ fC_{ez} & C_{ee} + N^2D'' \end{pmatrix} \begin{pmatrix} \frac{\partial k^*}{\partial \lambda} \\ \frac{\partial e^*}{\partial \lambda} \end{pmatrix} = \begin{pmatrix} -f'C_z - ff'k^*C_{zz} \\ -f'k^*C_{ez} \end{pmatrix}.$$

Solving for $\frac{\partial k^*}{\partial \lambda}$ and $\frac{\partial e^*}{\partial \lambda}$, we have

$$\frac{\partial e^*}{\partial \lambda} = \frac{-f'C_{ez}[G''k^* - fC_z]}{B}, \quad \frac{\partial k^*}{\partial \lambda} = \frac{-f'C_z(C_{ee} + N^2D'') - ff'k^* \{C_{ee}C_{zz} - C_{ez}^2\} + N^2C_{zz}D''}{B}$$

where

$$B \equiv G''(C_{ee} + N^2D'') + f^2\{C_{ee}C_{zz} - C_{ez}^2\} + f^2N^2C_{zz}D'' > 0.$$

Therefore, $\frac{\partial e^*}{\partial \lambda} < (>) 0$ if $C_{ez} > (<) 0$. The sign of $\frac{\partial k^*}{\partial \lambda}$ is indeterminate. ■

Proof of Proposition 1

To show (i), suppose $C_{ez} > 0$. As in the proof of lemma 3, the first best investment k^* satisfies

$$F^*(k^*) \equiv G'(k^*) + f(\lambda)C_z(e^f(k^*), f(\lambda)k^*) = 0.$$

Similarly, the equilibrium investment \hat{k} satisfies

$$F(\hat{k}) \equiv G'(\hat{k}) + C_z(e^n(\hat{k}), f(\lambda)\hat{k}) = 0.$$

Note that $\frac{de^f}{dk} < 0$ and $\frac{de^n}{dk} < 0$ by lemma 2 and $C_{ez} > 0$. For any $k \geq 0$ we have

$$\begin{aligned} F^*(k) - F(k) &= f(\lambda)C_z(e^f(k), f(\lambda)k) - C_z(e^n(k), f(\lambda)k) \\ &\leq C_z(e^f(k), f(\lambda)k) - C_z(e^n(k), f(\lambda)k) \end{aligned}$$

where the last inequality follows from $C_z < 0$ and $f(\lambda) \geq 1$ for all $\lambda \in [0, 1]$. Because $C_{ze} > 0$ by assumption and $e^f(k) < e^n(k)$ by lemma 1, we have $C_z(e^f(k), f(\lambda)k) - C_z(e^n(k), f(\lambda)k) < 0$. Hence, \hat{k} (that satisfies $F(\hat{k}) = 0$) must be smaller than k^* (that satisfies $F^*(k^*) = 0$) regardless of the value of λ . Finally, $\hat{k} < k^*$ implies $\hat{e} = e^n(\hat{k}) > e^n(k^*) > e^f(k^*) = e^*$.

To show (ii), suppose $C_{ez} = 0$. Then conditions (1) and (2) are equivalent to

$$G'(k^*) + f(\lambda)\phi_k(f(\lambda)k^*) = 0, \quad (7)$$

$$\phi_e(e^*) + ND'(Ne^*) = 0$$

where $\phi_k(z) \equiv C_z(e, z)$ for all e, z and $\phi_e(e) \equiv C_e(e, z)$ for all e, z . These two conditions determine the first best invest and emission independently. Similarly, conditions (3) and (4) for the Nash equilibrium are equivalent to

$$G'(\hat{k}) + \phi_k(f(\lambda)\hat{k}) = 0, \quad (8)$$

$$\phi_e(\hat{e}) + D'(N\hat{e}) = 0.$$

Lemma 1 implies $\hat{e} > e^*$ for any λ . If $\lambda = 0$, then conditions (7) and (8) are identical and hence $\hat{k} = k^*$. If $\lambda > 0$, then

$$G'(k) + \phi_k(f(\lambda)k) = G'(k) + f(\lambda)\phi_k(f(\lambda)k) - (f(\lambda) - 1)\phi_k(f(\lambda)k) > G'(k) + f(\lambda)\phi_k(f(\lambda)k)$$

for all k because $\phi_k < 0$. It follows from $G'' + \phi'_k > 0$ that $\hat{k} < k^*$.

To show (iii), suppose $C_{ez} < 0$. If $\lambda = 0$, then

$$F^*(k) - F(k) = C_z(e^f(k), k) - C_z(e^n(k), k)$$

where $e^f(k) < e^n(k)$ for all k by lemma 1. Because $C_{ze} < 0$, we have

$$C_z(e^f(k), k) > C_z(e^n(k), k)$$

for all k . Hence, $F^*(k) - F(k) > 0$ for all k . This implies that $\widehat{k} > k^*$. Emissions satisfy $\widehat{e} = e^n(\widehat{k}) > e^f(\widehat{k}) > e^f(k^*) = e^*$ where the last inequality follows from lemma 2 and the assumption $C_{ez} < 0$.

For $\lambda > 0$, suppose $F^*(\widehat{k}) > 0$. Then we have $\widehat{k} > k^*$ because

$$F^{*'} = G'' + f(\lambda)C_{ze}\frac{de^f}{dk} + (f(\lambda))^2C_{zz} = G'' + \frac{(f(\lambda))^2[C_{ee}C_{zz} - C_{ze}^2 + N^2C_{zz}D'']}{C_{ee} + N^2D''} > 0.$$

Inequality $\widehat{k} > k^*$ also implies $\widehat{e} = e^n(\widehat{k}) > e^f(\widehat{k}) > e^f(k^*) = e^*$. It follows from $F(\widehat{k}) = 0$ that $F^*(\widehat{k}) - F(\widehat{k}) > 0$, i.e.

$$f(\lambda)C_z(e^f(\widehat{k}), f(\lambda)\widehat{k}) - C_z(e^n(\widehat{k}), f(\lambda)\widehat{k}) > 0.$$

Because $C_z < 0$ and $f(\lambda) = 1 + (N - 1)\lambda$, this inequality is equivalent to

$$(N - 1)\lambda < \frac{C_z(e^n(\widehat{k}), f(\lambda)\widehat{k})}{C_z(e^f(\widehat{k}), f(\lambda)\widehat{k})} - 1. \quad (9)$$

Because $C_z < 0$, $C_{ze} < 0$ and $e^n > e^k$, the right hand side is positive. The inequality (9) implies $\widehat{k} > k^*$ and $\widehat{e} > e^*$. We have $\widehat{k} \leq k^*$ if (9) does not hold. ■

References

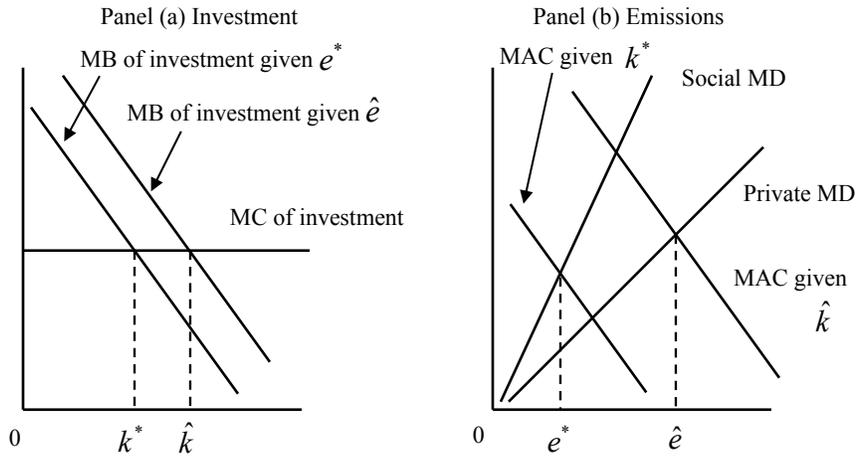
- [1] Baker, E., Clarke, L., Weyant, J., 2006. Optimal Technology R&D in the Face of Climate Uncertainty. *Climatic Change* 75, 157-180.
- [2] Baker, E., Clarke, L., Shittu, E., 2008. Technical Change and the Marginal Cost of Abatement. *Energy Economics*, forthcoming.
- [3] Barrett, S., 2003. *Environment and Statecraft*. Oxford University Press, Oxford, UK.
- [4] Bauman, Y. K. 2003. *The Effects of Environmental Policy on Technological Change in Pollution Control*. PhD Dissertation, University of Washington.
- [5] Brechet, T., Jouvet, P.-A. 2006. Environmental Innovation and the Cost of Pollution Abatement. Presented at the Third World Congress of Environmental and Resource Economists, July 2006.

- [6] Buchner, B., Carraro, C. Cersosimo, I., Marchiori, C. 2002. Back to Kyoto? US Participation and the Linkage between R&D and Climate Cooperation. FEEM Working Paper 22.2002, Fondazione Eni Enrico Mattei.
- [7] Carraro, C., Siniscalco, D. 1997. R&D Cooperation and the Stability of International Environmental Agreements. In C. Carraro ed. International Environmental Negotiations, Edward Elgar Publishing, Cheltenham.
- [8] Golombek, R., Hoel, M. 2004. The Kyoto Agreement and Technology Spillovers. University of Oslo, Working paper.
- [9] Heal, G. 1993. Formation of International Environmental Agreements, in C. Carraro ed. Trade, Innovation, Environment, Kluwer, Dordrecht.
- [10] Jaffe, A.B., Newell, R. G., Stavins, R. N., 2003. Technology change and the environment, in K.G. Mäler, J. Vincent (Eds.), Handbook of Environmental Economics, North Holland/Elsevier Science, Amsterdam.
- [11] Karp,L., Zhang, J., 2002. Controlling a stock pollutant with endogenous investment and asymmetric information, Working Paper, Department of Agricultural and Resource Economics, University of California, Berkeley, CA
- [12] Kennedy, P. W., Laplante, B., 1999. Environmental policy and time consistency: emission taxes and emissions trading, in Petrakis, E., Sartzetakis, E. S., Xepapadeas, A. (Eds.), Environmental Regulation and Market Power, Edward Elgar, Cheltenham, pp.116–144.
- [13] Kolstad, C., 2007. Systematic uncertainty in self-enforcing international environmental agreements. Journal of Environmental Economics and Management, 53, 1, 68–79.
- [14] Malik, A.S., 1991. Permanent versus interim regulations: A game-theoretic analysis. Journal of Environmental Economics and Management, 21, 2, 127–139.
- [15] Milliman,S.R., Prince, R., 1989. Firm incentives to promote technological change in pollution, Journal of Environmental Economics and Management, 17, 292–296.

- [16] Moledina, A. A., Coggins, J. S., Polasky, S., Costello, C., 2003. Dynamic environmental policy with strategic firms: prices versus quantities, *Journal of Environmental Economics and Management*, 45, 356–376.
- [17] Requate, T., Unold, W., 2003. Environmental policy incentives to adopt advanced abatement technology: Will the true ranking please stand up? *European Economic Review*, 47, 125–146.
- [18] Stern, N., 2006. *The Economics of Climate Change: The Stern Review*. H.M. Treasury, U.K.

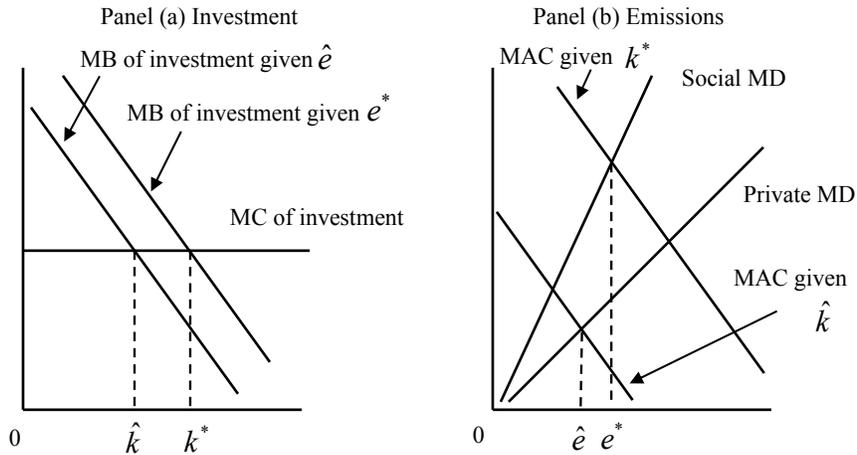
Table 1: Equilibrium outcome of simultaneous-move games

| Technology spillovers | <u>Marginal abatement costs</u> | | | |
|--------------------------|---------------------------------|------------|------------------------------|------------|
| | <u>Decreasing in R&D</u> | | <u>Increasing in R&D</u> | |
| | Emissions | Investment | Emissions | Investment |
| Small | Too large | Too small | Too large | Too large |
| Large | Too large | Too small | ? | Too small |



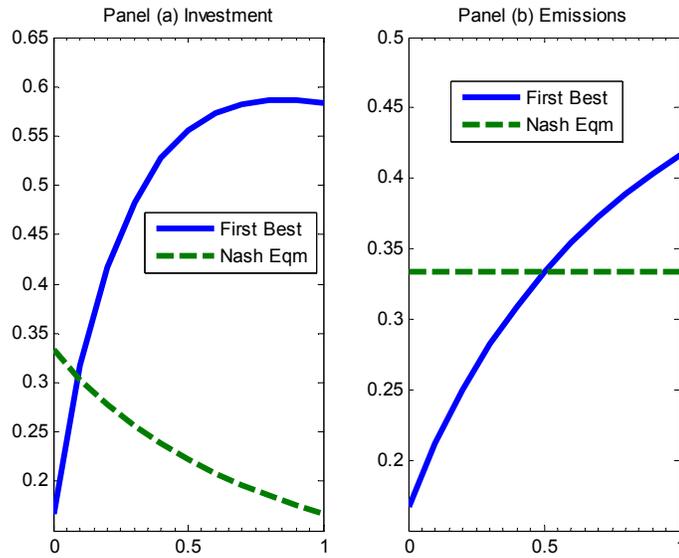
MB of investment is the negative of the partial derivative of abatement cost with respect to investment. MC of investment is the derivative of investment cost. MAC is the negative of the partial derivative of abatement cost with respect to emissions. Private and social MD refer to the marginal damage at a country level and at the aggregate, global level.

Figure 1: The equilibrium and the first best when $C_{ez} < 0$ and $\lambda = 0$.



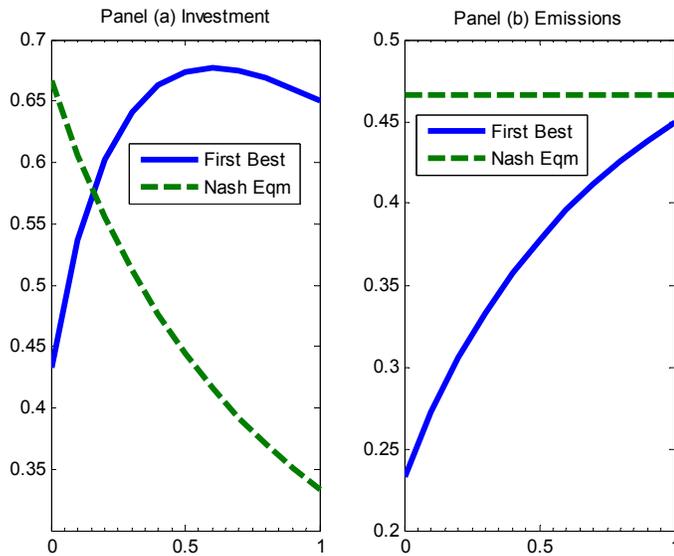
MB of investment is the negative of the partial derivative of abatement cost with respect to investment. MC of investment is the derivative of investment cost. MAC is the negative of the partial derivative of abatement cost with respect to emissions. Private and social MD refer to the marginal damage at a country level and at the aggregate, global level.

Figure 2: The equilibrium and the first best when $C_{ez} < 0$ and a large λ .



The figure is based on a linear quadratic example (equations 5, 6) with $a = 1$, $b = 1$, $d = .75$, $N = 2$, $r = 1.5$, $f_1 = 2$, $f_2 = 1$, $\bar{e} = .5$. In the two panels, the horizontal axes measure the degree of spillovers (0: no spillovers, 1: highest degree of spillovers).

Figure 3: The equilibrium and the first best when $C_{ez} < 0$.



The figure is based on a linear quadratic example (equations 5, 6) with $a = 1$, $b = 1$, $d = .75$, $N = 2$, $r = 1.3$, $f_1 = 2$, $f_2 = 1$, $\bar{e} = .5$. In the two panels, the horizontal axes measure the degree of spillovers (0: no spillovers, 1: highest degree of spillovers).

Figure 4: The equilibrium and the first best when $C_{ez} < 0$ (2).

NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI

Fondazione Eni Enrico Mattei Working Paper Series

Our Note di Lavoro are available on the Internet at the following addresses:

<http://www.feem.it/Feem/Pub/Publications/WPapers/default.htm>

<http://www.ssrn.com/link/feem.html>

<http://www.repec.org>

<http://agecon.lib.umn.edu>

<http://www.bepress.com/feem/>

NOTE DI LAVORO PUBLISHED IN 2008

| | | |
|------|---------|--|
| CCMP | 1.2008 | <i>Valentina Bosetti, Carlo Carraro and Emanuele Massetti</i> : <u>Banking Permits: Economic Efficiency and Distributional Effects</u> |
| CCMP | 2.2008 | <i>Ruslana Palatnik and Mordechai Shechter</i> : <u>Can Climate Change Mitigation Policy Benefit the Israeli Economy? A Computable General Equilibrium Analysis</u> |
| KTHC | 3.2008 | <i>Lorenzo Casaburi, Valeria Gattai and G. Alfredo Minerva</i> : <u>Firms' International Status and Heterogeneity in Performance: Evidence From Italy</u> |
| KTHC | 4.2008 | <i>Fabio Sabatini</i> : <u>Does Social Capital Mitigate Precariousness?</u> |
| SIEV | 5.2008 | <i>Wisdom Akpalu</i> : <u>On the Economics of Rational Self-Medication</u> |
| CCMP | 6.2008 | <i>Carlo Carraro and Alessandra Sgobbi</i> : <u>Climate Change Impacts and Adaptation Strategies In Italy. An Economic Assessment</u> |
| ETA | 7.2008 | <i>Elodie Rouvière and Raphaël Soubeyran</i> : <u>Collective Reputation, Entry and Minimum Quality Standard</u> |
| IEM | 8.2008 | <i>Cristina Cattaneo, Matteo Manera and Elisa Scarpa</i> : <u>Industrial Coal Demand in China: A Provincial Analysis</u> |
| IEM | 9.2008 | <i>Massimiliano Serati, Matteo Manera and Michele Plotegher</i> : <u>Modeling Electricity Prices: From the State of the Art to a Draft of a New Proposal</u> |
| CCMP | 10.2008 | <i>Bob van der Zwaan and Reyer Gerlagh</i> : <u>The Economics of Geological CO₂ Storage and Leakage</u> |
| KTHC | 11.2008 | <i>Maria Francesca Cracolici and Teodora Erika Uberti</i> : <u>Geographical Distribution of Crime in Italian Provinces: A Spatial Econometric Analysis</u> |
| KTHC | 12.2008 | <i>Victor Ginsburgh, Shlomo Weber and Sheila Weyers</i> : <u>Economics of Literary Translation. A Simple Theory and Evidence</u> |
| NRM | 13.2008 | <i>Carlo Giupponi, Jaroslav Mysiak and Alessandra Sgobbi</i> : <u>Participatory Modelling and Decision Support for Natural Resources Management in Climate Change Research</u> |
| NRM | 14.2008 | <i>Yaella Depietri and Carlo Giupponi</i> : <u>Science-Policy Communication for Improved Water Resources Management: Contributions of the Nostrum-DSS Project</u> |
| CCMP | 15.2008 | <i>Valentina Bosetti, Alexander Golub, Anil Markandya, Emanuele Massetti and Massimo Tavoni</i> : <u>Abatement Cost Uncertainty and Policy Instrument Selection under a Stringent Climate Policy. A Dynamic Analysis</u> |
| KTHC | 16.2008 | <i>Francesco D'Amuri, Gianmarco I.P. Ottaviano and Giovanni Peri</i> : <u>The Labor Market Impact of Immigration in Western Germany in the 1990's</u> |
| KTHC | 17.2008 | <i>Jean Gabszewicz, Victor Ginsburgh and Shlomo Weber</i> : <u>Bilingualism and Communicative Benefits</u> |
| CCMP | 18.2008 | <i>Benno Torgler, María A.GarcíaValiñas and Alison Macintyre</i> : <u>Differences in Preferences Towards the Environment: The Impact of a Gender, Age and Parental Effect</u> |
| PRCG | 19.2008 | <i>Gian Luigi Albano and Berardino Cesi</i> : <u>Past Performance Evaluation in Repeated Procurement: A Simple Model of Handicapping</u> |
| CTN | 20.2008 | <i>Pedro Pintassilgo, Michael Finus, Marko Lindroos and Gordon Munro (lxxxiv)</i> : <u>Stability and Success of Regional Fisheries Management Organizations</u> |
| CTN | 21.2008 | <i>Hubert Kempf and Leopold von Thadden (lxxxiv)</i> : <u>On Policy Interactions Among Nations: When Do Cooperation and Commitment Matter?</u> |
| CTN | 22.2008 | <i>Markus Kinaterer (lxxxiv)</i> : <u>Repeated Games Played in a Network</u> |
| CTN | 23.2008 | <i>Taiji Furusawa and Hideo Konishi (lxxxiv)</i> : <u>Contributing or Free-Riding? A Theory of Endogenous Lobby Formation</u> |
| CTN | 24.2008 | <i>Paolo Pin, Silvio Franz and Matteo Marsili (lxxxiv)</i> : <u>Opportunity and Choice in Social Networks</u> |
| CTN | 25.2008 | <i>Vasileios Zikos (lxxxiv)</i> : <u>R&D Collaboration Networks in Mixed Oligopoly</u> |
| CTN | 26.2008 | <i>Hans-Peter Weikard and Rob Dellink (lxxxiv)</i> : <u>Sticks and Carrots for the Design of International Climate Agreements with Renegotiations</u> |
| CTN | 27.2008 | <i>Jingang Zhao (lxxxiv)</i> : <u>The Maximal Payoff and Coalition Formation in Coalitional Games</u> |
| CTN | 28.2008 | <i>Giacomo Pasini, Paolo Pin and Simon Weidenholzer (lxxxiv)</i> : <u>A Network Model of Price Dispersion</u> |
| CTN | 29.2008 | <i>Ana Mauleon, Vincent Vannetelbosch and Wouter Vergote (lxxxiv)</i> : <u>Von Neumann-Morgenstern Farsightedly Stable Sets in Two-Sided Matching</u> |
| CTN | 30.2008 | <i>Rahmi İlkiliç (lxxxiv)</i> : <u>Network of Commons</u> |
| CTN | 31.2008 | <i>Marco J. van der Leij and I. Sebastian Buhai (lxxxiv)</i> : <u>A Social Network Analysis of Occupational Segregation</u> |
| CTN | 32.2008 | <i>Billand Pascal, Frachisse David and Massard Nadine (lxxxiv)</i> : <u>The Sixth Framework Program as an Affiliation Network: Representation and Analysis</u> |
| CTN | 33.2008 | <i>Michèle Breton, Lucia Sbragia and Georges Zaccour (lxxxiv)</i> : <u>Dynamic Models for International Environmental Agreements</u> |

| | | |
|------|---------|--|
| PRCG | 34.2008 | <i>Carmine Guerriero</i> : <u>The Political Economy of Incentive Regulation: Theory and Evidence from US States</u> |
| IEM | 35.2008 | <i>Irene Valsecchi</i> : <u>Learning from Experts</u> |
| PRCG | 36.2008 | <i>P. A. Ferrari and S. Salini</i> : <u>Measuring Service Quality: The Opinion of Europeans about Utilities</u> |
| ETA | 37.2008 | <i>Michele Moretto and Gianpaolo Rossini</i> : <u>Vertical Integration and Operational Flexibility</u> |
| CCMP | 38.2008 | <i>William K. Jaeger and Van Kolpin</i> : <u>The Environmental Kuznets Curve from Multiple Perspectives</u> |
| PRCG | 39.2008 | <i>Benno Torgler and Bin Dong</i> : <u>Corruption and Political Interest: Empirical Evidence at the Micro Level</u> |
| KTHC | 40.2008 | <i>Laura Onofri, Paulo A.L.D. Nunes, Jasone Cenoz and Durk Gorter</i> : <u>Language Diversity in Urban Landscapes: An econometric study</u> |
| CTN | 41.2008 | <i>Michel Le Breton, Valery Makarov, Alexei Savvateev and Shlomo Weber</i> (lxxxiv): <u>Multiple Membership and Federal Structures</u> |
| NRM | 42.2008 | <i>Gideon Kruseman and Lorenzo Pellegrini</i> : <u>Institutions and Forest Management: A Case Study from Swat, Pakistan</u> |
| SIEV | 43.2008 | <i>Pietro Caratti and Ludovico Ferraguto</i> : <u>Analysing Regional Sustainability Through a Systemic Approach: The Lombardy Case Study</u> |
| KTHC | 44.2008 | <i>Barbara Del Corpo, Ugo Gasparino, Elena Bellini and William Malizia</i> : <u>Effects of Tourism Upon the Economy of Small and Medium-Sized European Cities. Cultural Tourists and “The Others”</u> |
| CTN | 45.2008 | <i>Dinko Dimitrov and Emiliya Lazarova</i> : <u>Coalitional Matchings</u> |
| ETA | 46.2008 | <i>Joan Canton, Maia David and Bernard Sinclair-Desgagné</i> : <u>Environmental Regulation and Horizontal Mergers in the Eco-industry</u> |
| ETA | 47.2008 | <i>Stéphane Hallegatte</i> : <u>A Proposal for a New Prescriptive Discounting Scheme: The Intergenerational Discount Rate</u> |
| KTHC | 48.2008 | <i>Angelo Antoci, Paolo Russu and Elisa Ticci</i> : <u>Structural Change, Environment and Well-being: Interactions Between Production and Consumption Choices of the Rich and the Poor in Developing Countries</u> |
| PRCG | 49.2008 | <i>Gian Luigi Albano, Federico Dini Roberto Zampino and Marta Fana</i> : <u>The Determinants of Suppliers’ Performance in E-Procurement: Evidence from the Italian Government’s E-Procurement Platform</u> |
| CCMP | 50.2008 | <i>Inmaculada Martínez-Zarzoso</i> : <u>The Impact of Urbanization on CO2 Emissions: Evidence from Developing Countries</u> |
| KTHC | 51.2008 | <i>Michele Moretto and Sergio Vergalli</i> : <u>Managing Migration through Quotas: an Option-theory Perspective</u> |
| KTHC | 52.2008 | <i>Ugo Gasparino, Elena Bellini, Barbara Del Corpo and William Malizia</i> : <u>Measuring the Impact of Tourism Upon Urban Economies: A Review of Literature</u> |
| ETA | 53.2008 | <i>Reyer Gerlagh, Snorre Kverndokk and Knut Einar Rosendahl</i> : <u>Linking Environmental and Innovation Policy</u> |
| KTHC | 54.2008 | <i>Oguzhan C. Dincer and Burak Gunalp</i> : <u>Corruption, Income Inequality, and Poverty in the United States</u> |
| PRCG | 55.2008 | <i>Carmine Guerriero</i> : <u>Accountability in Government and Regulatory Policies: Theory and Evidence</u> |
| KTHC | 56.2008 | <i>Tanmoyee Banerjee (Chatterjee) and Nilanjana Mitra</i> : <u>Export, Assembly-line FDI or FDI with the Possibility of Technology Diffusion: Optimal Entry Mode for Multinationals</u> |
| ETA | 57.2008 | <i>Xavier Pautrel</i> : <u>Environmental Policy, Education and Growth: A Reappraisal when Lifetime Is Finite</u> |
| CCMP | 58.2008 | <i>Natalia Zugravu, Katrin Millock and Gérard Duchene</i> : <u>The Factors Behind CO2 Emission Reduction in Transition Economies</u> |
| NRM | 59.2008 | <i>Benno Torgler, María A.García-Valiñas and Alison Macintyre</i> : <u>Justifiability of Littering: An Empirical Investigation</u> |
| SIEV | 60.2008 | <i>Paolo Rosato, Anna Alberini, Valentina Zanatta and Margaretha Breil</i> : <u>Redeveloping Derelict and Underused Historic City Areas: Evidence from a Survey of Real Estate Developers</u> |
| CTN | 61.2008 | <i>Ricardo Nieva</i> : <u>Networks with Group Counterproposals</u> |
| CTN | 62.2008 | <i>Michael Finus and Dirk T.G. Rübhelke</i> : <u>Coalition Formation and the Ancillary Benefits of Climate Policy</u> |
| SIEV | 63.2008 | <i>Elisabetta Strazzera, Elisabetta Cerchi and Silvia Ferrini</i> : <u>A Choice Modelling Approach for Assessment of Use and Quasi-Option Values in Urban Planning for Areas of Environmental Interest</u> |
| SIEV | 64.2008 | <i>Paolo Rosato, Lucia Rotaris, Margaretha Breil and Valentina Zanatta</i> : <u>Do We Care about Built Cultural Heritage? The Empirical Evidence Based on the Veneto House Market</u> |
| KTHC | 65.2008 | <i>Luca Petruzzellis and Antonia Rosa Guerrieri</i> : <u>Does Network Matter in International Expansion? Evidence from Italian SMEs</u> |
| NRM | 66.2008 | <i>Sheila M. Olmstead and Robert N. Stavins</i> : <u>Comparing Price and Non-price Approaches to Urban Water Conservation</u> |
| CCMP | 67.2008 | <i>Robert N. Stavins</i> : <u>Addressing Climate Change with a Comprehensive U.S. Cap-and-Trade System</u> |
| CCMP | 68.2008 | <i>Geoffrey J. Blanford, Richard G. Richels and Thomas F. Rutherford</i> : <u>Impact of Revised CO₂ Growth Projections for China on Global Stabilization Goals</u> |
| CCMP | 69.2008 | <i>Valentina Bosetti, Carlo Carraro, Alessandra Sgobbi and Massimo Tavoni</i> : <u>Delayed Action and Uncertain Targets. How Much Will Climate Policy Cost?</u> |
| CCMP | 70.2008 | <i>Valentina Bosetti, Carlo Carraro and Massimo Tavoni</i> : <u>Delayed Participation of Developing Countries to Climate Agreements: Should Action in the EU and US be Postponed?</u> |
| SIEV | 71.2008 | <i>Massimiliano Mazzanti, Anna Montini and Francesco Nicoli</i> : <u>Embedding Landfill Diversion in Economic, Geographical and Policy Settings Panel based evidence from Italy</u> |
| ETA | 72.2008 | <i>Reyer Gerlagh and Matti Liski</i> : <u>Strategic Resource Dependence</u> |
| CCMP | 73.2008 | <i>Sonia Ben Kheder and Natalia Zugravu</i> : <u>The Pollution Haven Hypothesis: A Geographic Economy Model in a Comparative Study</u> |
| SIEV | 74.2008 | <i>Jérôme Massiani and Paolo Rosato</i> : <u>The Preferences of Trieste Inhabitants for the Re-use of the Old Port: A Conjoint Choice Experiment</u> |
| SIEV | 75.2008 | <i>Martin F. Quaas and Sjak Smulders</i> : <u>Pollution and the Efficiency of Urban Growth</u> |
| CCMP | 76.2008 | <i>Anil Markandya and Dirk T.G. Rübhelke</i> : <u>Impure Public Technologies and Environmental Policy</u> |

| | | |
|------|---------|--|
| KTHC | 77.2008 | <i>Gianmarco I P Ottaviano and Giovanni Peri: <u>Immigration and National Wages: Clarifying the Theory and the Empirics</u></i> |
| CCMP | 78.2008 | <i>Vivekananda Mukherjee, Dirk T.G. Rübbelke and Tilak Sanyal: <u>Technology Transfer in the Non-traded Sector as a Means to Combat Global Warming</u></i> |
| SIEV | 79.2008 | <i>A. Ghermandi, J.C.J.M. van den Bergh, L.M. Brander, H.L.F. de Groot, and P.A.L.D. Nunes: <u>The Economic Value of Wetland Conservation and Creation: A Meta-Analysis</u></i> |
| CCMP | 80.2008 | <i>Snorre Kverndokk and Adam Rose: <u>Equity and Justice in Global Warming Policy</u></i> |
| ETA | 81.2008 | <i>Sonia Oreffice: <u>Sexual Orientation and Household Decision Making. Same-Sex Couples' Balance of Power and Labor Supply Choices</u></i> |
| CCMP | 82.2008 | <i>Robert N. Stavins: <u>A Meaningful U.S. Cap-and-Trade System to Address Climate Change</u></i> |
| NRM | 83.2008 | <i>Ruben N. Lubowski, Andrew J. Plantinga and Robert N. Stavins: <u>What Drives Land-Use Change in the United States? A National Analysis of Landowner Decisions</u></i> |
| CSRM | 84.2008 | <i>Forest L. Reinhardt, Robert N. Stavins, and Richard H. K. Vietor: <u>Corporate Social Responsibility Through an Economic Lens</u></i> |
| CCMP | 85.2008 | <i>Valentina Bosetti, Carlo Carraro, Alessandra Sgobbi and Massimo Tavoni: <u>Modelling Economic Impacts of Alternative International Climate Policy Architectures. A Quantitative and Comparative Assessment of Architectures for Agreement</u></i> |
| PRCG | 86.2008 | <i>Gian Luigi Albano, Federico Dini and Roberto Zampino: <u>Bidding for Complex Projects: Evidence From the Acquisitions of IT Services</u></i> |
| SIEV | 87.2008 | <i>Dennis Guignet and Anna Alberini: <u>Voluntary Cleanups and Redevelopment Potential: Lessons from Baltimore, Maryland</u></i> |
| IEM | 88.2008 | <i>Louis-Gaëtan Giraudet and Philippe Quirion: <u>Efficiency and Distributional Impacts of Tradable White Certificates Compared to Taxes, Subsidies and Regulations</u></i> |
| CCMP | 89.2008 | <i>Damien Demailly and Philippe Quirion: <u>Changing the Allocation Rules in the EU ETS: Impact on Competitiveness and Economic Efficiency</u></i> |
| CCMP | 90.2008 | <i>Judson Jaffe and Robert N. Stavins: <u>Linkage of Tradable Permit Systems in International Climate Policy Architecture</u></i> |
| SIEV | 91.2008 | <i>Silvio Giove, Paolo Rosato and Margaretha Breil: <u>A Multicriteria Approach for the Evaluation of the Sustainability of Re-use of Historic Buildings in Venice</u></i> |
| CCMP | 92.2008 | <i>Corrado Di Maria, Sjak Smulders and Edwin van derWerf: <u>Absolute Abundance and Relative Scarcity: Announced Policy, Resource Extraction, and Carbon Emissions</u></i> |
| CCMP | 93.2008 | <i>Dirk T.G. Rübbelke and Nathan Rive: <u>Effects of the CDM on Poverty Eradication and Global Climate Protection</u></i> |
| SIEV | 94.2008 | <i>Massimiliano Mazzanti and Roberto Zoboli: <u>Waste Generation, Incineration and Landfill Diversion. Decoupling Trends, Socio-Economic Drivers and Policy Effectiveness in the EU</u></i> |
| CCMP | 95.2008 | <i>Benno Torgler, María A. García Valiñas and Alison Macintyre: <u>Environmental Participation and Environmental Motivation</u></i> |
| CCMP | 96.2008 | <i>Geoffrey Heal and Nori Tarui: <u>Technology Diffusion, Abatement Cost, and Transboundary Pollution</u></i> |

(lxxxiv) This paper was presented at the 13th Coalition Theory Network Workshop organised by the Fondazione Eni Enrico Mattei (FEEM), held in Venice, Italy on 24-25 January 2008.

| 2008 SERIES | |
|--------------------|--|
| CCMP | <i>Climate Change Modelling and Policy</i> (Editor: Carlo Carraro) |
| SIEV | <i>Sustainability Indicators and Environmental Valuation</i> (Editor: Carlo Carraro) |
| NRM | <i>Natural Resources Management</i> (Editor: Carlo Giupponi) |
| KTHC | <i>Knowledge, Technology, Human Capital</i> (Editor: Gianmarco Ottaviano) |
| IEM | <i>International Energy Markets</i> (Editor: Matteo Manera) |
| CSRM | <i>Corporate Social Responsibility and Sustainable Management</i> (Editor: Giulio Sapelli) |
| PRCG | <i>Privatisation Regulation Corporate Governance</i> (Editor: Bernardo Bortolotti) |
| ETA | <i>Economic Theory and Applications</i> (Editor: Carlo Carraro) |
| CTN | <i>Coalition Theory Network</i> |