International Energy R&D Spillovers and the Economics of Greenhouse Gas Atmospheric Stabilization

Valentina Bosetti, Carlo Carraro,
Emanuele Massetti, and Massimo Tavoni

NOTA DI LAVORO 82.2007

JULY 2007

CCMP – Climate Change Modelling and Policy

Valentina Bosetti, *Fondazione Eni Enrico Mattei and CMCC*
Carlo Carraro, *Fondazione Eni Enrico Mattei, University of Venice, CEPR, CESifo and CMCC*
Emanuele Massetti and Massimo Tavoni, *Fondazione Eni Enrico Mattei,*
Catholic University of Milan and CMCC

International Energy R&D Spillovers and the Economics of Greenhouse Gas Atmospheric Stabilization

Summary

It is widely recognized that technological change has the potential to reduce GHG emissions without compromising economic growth; hence, any better understanding of the process of technological innovation is likely to increase our knowledge of mitigation possibilities and costs. This paper explores how international knowledge flows affect the dynamics of the domestic R&D sector and the main economic and environmental variables. The analysis is performed using WITCH, a dynamic regional model of the world economy, in which energy technical change is endogenous. The focus is on disembodied energy R&D international spillovers. The knowledge pool from which regions draw foreign ideas differs between High Income and Low Income countries. Absorption capacity is also endogenous in the model. The basic questions are as follows. Do knowledge spillovers enhance energy technological innovation in different regions of the world? Does the speed of innovation increase? Or do free-riding incentives prevail and international spillovers crowd out domestic R&D efforts? What is the role of domestic absorption capacity and of policies designed to enhance it? Do greenhouse gas stabilization costs drop in the presence of international technological spillovers? The new specification of the WITCH model presented in this paper enables us to answer these questions. Our analysis shows that international knowledge spillovers tend to increase free-riding incentives and decrease the investments in energy R&D. The strongest cuts in energy R&D investments are recorded among High Income countries, where international knowledge flows crowd out domestic R&D efforts. The overall domestic pool of knowledge, and thus total net GHG stabilization costs, remain largely unaffected. International spillovers, however, are also an important policy channel. We therefore analyze the implication of a policy mix in which climate policy is combined with a technology policy designed to enhance absorption capacity in developing countries. Significant positive impacts on the costs of stabilising GHG concentrations are singled out. Finally, a sensitivity analysis shows that High Income countries are more responsive than Low Income countries to changes in the parameters and thus suggests to focus additional empirical research efforts on the former.

Keywords: Climate Policy, Energy R&D, International R&D Spillovers, Stabilization

JEL Classification: H0, H2, H3

This paper is part of the research work being carried out by the Climate Change Modelling and Policy Research Programme of the Fondazione Eni Enrico Mattei and by the Climate Impacts and Policy Division of the EuroMediterranean Center on Climate Change. Financial support from the Italian Ministry of the Environment is gratefully acknowledged. The authors are also grateful to participants at the 9th IAEE Conference, Florence, 11-13 June 2007, for helpful comments. The usual disclaimer applies.

Address for correspondence:
Valentina Bosetti
Fondazione Eni Enrico Mattei
C.so Magenta 63
20123 Milano
Italy
Phone: +39 0252036983
Fax: +39 0252036946
E-mail: valentina.bosetti@feem.it

1. Introduction

It is now widely recognized that technological change has the potential to reduce GHG emissions without generating negative feedbacks on economic growth. This is one of the reasons behind the many efforts recently devoted to the development of Integrated Economy-Climate Models, in which technological change is endogenous and responds to market and policy incentives. Significant improvements in the estimate of optimal abatement paths and costs have thus been achieved. In particular, by disentangling the determinants of knowledge accumulation, and linking them to incentives arising from emission targets, it is now possible to measure how climate policy-induced technical change reduces the costs of atmospheric stabilization (Grubb, Carraro and Schellnhuber, 2006). However, despite this encouraging progress, the knowledge accumulation processes are still unclear, and the actual potential of technological innovation is far from being fully understood.

For example, a few studies on the economics of atmospheric stabilization have addressed the role of international knowledge flows in the process of knowledge production and accumulation.[1] The transfer of knowledge across countries is instead crucial in shaping the diffusion of new technologies and in spreading basic scientific developments that gradually foster technological innovation in places different from where they were originally conceived. This is of central importance if we consider that new technologies are created and developed in a handful of countries, and that still greater concentration is recorded for the expenditure on energy R&D. However, despite its concentrated origin, knowledge clearly flows across countries: developing economies import goods and services that embody the technological progress made in the laboratories of richer countries, and are increasingly exposed to the flow of knowledge that circulates among world research laboratories, the so-called disembodied knowledge flows. There is also a rich exchange of knowledge among industrialized countries, that often participate in joint research agreements to share the costs and risks of the most expensive projects.[2] It is therefore crucial to understand how knowledge flows across countries

---

[1] In Buonanno, Carraro e Galeotti (2003) the world stock of knowledge affects productivity of the energy input and reduces the emission output ratio. Gerlagh and Kuik (2003) use a static general equilibrium model to analyze the effect of endogenous technical change and international technology diffusion on carbon leakage. Kemfert (2005) contains some attempts to account for international technology spillovers across countries via capital flows in a general equilibrium model. Some improvements are contained in Gerlagh (2006), again within a CGE framework.

[2] A good example is ITER, a joint international research and development project that aims to demonstrate the scientific and technical feasibility of fusion power. The partners in the project are the European Union, Japan, the People´s Republic of China, India, the Republic of Korea, the Russian Federation and the USA.

in order to correctly assess by how much and at what cost technological change can increase energy efficiency and lower carbon intensity worldwide.

The idea of reducing atmospheric stabilization costs by filling the knowledge gap between countries with more technological cooperation is very attractive indeed, and has been emphasized by several authors (e.g. Barrett, 1994, 2002; Carraro and Siniscalco, 1994; Grubb, Hope and Fouquet, 2002; Philibert, 2004; Buchner et al, 2005). On these grounds, any policy aimed at increasing the circulation of world knowledge should be promoted. For example, favor treatment could be dispensed to knowledge flows, disclosure of sensitive information could be encouraged and joint development programs could be financed to increase knowledge sharing and the productivity of R&D efforts. These proposals have also captivated the interest of policy makers: the basic idea of knowledge transfers is at the core of the recent Asia-Pacific agreement on climate change control.

However, the enhanced circulation of ideas and the free dissemination of technological innovation throughout the world does not necessarily imply that total global innovation will increase and abatement costs decrease. Several obstacles have been identified (Cf. Carraro, 2001 for a survey). For example, a given country may not have the capacity to absorb the flow of ideas and research results coming from other countries. Knowledge from international spillovers may crowd out domestic R&D efforts. Free-riding incentives may induce some countries to reduce their own expenditures in Research and Development. The basic questions are therefore as follows. Do knowledge spillovers enhance energy technological innovation in different regions of the world? Do spillovers increase R&D expenditures? Or do free-riding incentives prevail and international spillovers crowd out domestic R&D efforts? What is the role of domestic absorption capacity and of policies designed to enhance it? And finally, do greenhouse gas stabilization costs drop in the presence of international technological spillovers? The new model specification presented in this paper enables us to answer these questions.

We address both researchers and policy makers by discussing modelling issues and analysing possible cost reductions achievable by greater knowledge diffusion. Our exploration of the role of international knowledge spillovers will be based on a new version of WITCH, a dynamic regional model of the world economy, in which energy technical change is endogenous and free-riding incentives from R&D spillovers and other sources are also accounted for. Although embodied technology transfers play an important role in spreading technical know-how across the world, we focus our analysis on disembodied knowledge spillovers, i.e. on the positive externality that emerges from the exposure to foreign patents, scientists, laboratories and blueprints.[3]

In this paper, we disentangle three main issues that a modeler faces when dealing with international knowledge spillovers: first, the size and the ***characteristics of the international knowledge pool*** from which each country picks ideas to implement at home has to be defined. From another perspective, are knowledge stocks cumulated in different countries heterogeneous or homogeneous, and if they are a mix, to what degree do they overlap? Second, the process of ***knowledge absorption***: are spillovers a "manna from heaven" that indiscriminately falls in each country, regardless of its degree of technological development, or is some domestic effort necessary to absorb foreign knowledge? Third, how do ***spillovers interact with the domestic knowledge*** production sector? Do patents, blueprints produced abroad substitute those discovered at home?

Unfortunately, the limited empirical work on energy efficiency R&D spillovers does not provide us with clear indications on the most appropriate model specification.[4] We therefore make and compare some reasonable assumptions on absorption capacity, on the available international knowledge pool, and on the interactions between international spillovers and the domestic R&D sector. These assumptions are then integrated into the equations of the WITCH model. This is then used to analyze how costs and benefits of GHG stabilisation policy are affected by the presence of international R&D spillovers, to define the impact of international spillovers on domestic R&D efforts, and to determine what policy can be designed to enhance the dissemination of energy-saving technologies.

The rest of the paper is structured as follows: Section 2 briefly introduces the WITCH model and discusses our modeling of R&D spillovers. Section 3 presents the calibration results, a new baseline, and analyses the dynamics of stabilization investments in R&D when international spillovers are explicitly modeled. In this section, we also present our new results on the costs and benefits of GHG stabilization policy. Section 4 discusses a policy mix in which climate policy is combined with an R&D incentive scheme designed to enhance the absorption capacity in developing countries, and thus the dissemination of new energy technologies. Section 5 shows the main outputs of our sensitivity analysis. A concluding section summarizes our results.

---

[3] For the role of trade in spreading technological knowledge see Keller (1997), Coe and Helpman (1995), Eaton and Kortum (1996).

[4] See Lanjouw and Mody (1996) for an analysis of innovation and international diffusion of environmental responsive technology.

2. The WITCH model

2.1 Short model description

WITCH – World Induced Technical Change Hybrid – is a regional integrated assessment model structured to provide normative information on the optimal responses of world economies to climate damages. It is a hybrid model because it combines features of both top-down and bottom-up modeling: the top-down component consists of an inter-temporal optimal growth model in which the energy input of the aggregate production function has been integrated into a bottom-up like description of the energy sector. World countries are grouped in 12 regions that strategically interact when determining their optimal policies. A game theoretic framework is adopted to capture these strategic interactions. A climate module and a damage function provide the feedback on the economy of carbon dioxide emissions into the atmosphere.

WITCH top-down framework guarantees a coherent, fully intertemporal allocation of investments that have an impact on the level of mitigation – R&D effort, investments in energy technologies, fossil fuel expenditures. The regional specification of the model and the presence of interdependencies among regions – through CO_2, exhaustible natural resources, trade and technological spillovers – allows us to account for the incentives to free-ride. By solving an open-loop Nash game, the investment strategies are optimized taking into account both economic and environmental externalities.

WITCH contains a detailed representation of the energy sector, which allows the model to produce a reasonable characterization of future energy and technological scenarios and an assessment of their compatibility with the goal of stabilizing greenhouse gases concentrations. In addition, by endogenously modeling fuel (oil, coal, natural gas, uranium) prices, as well as the cost of storing the CO_2 captured, the model can be used to evaluate the implication of mitigation policies on the energy system in all its components. In the next subsections, we focus on the representation of technical change; for a thorough description of the model, see Bosetti *et al.* (2006) and Bosetti, Massetti and Tavoni (2007).

2.2 Endogenous Technical Change (ETC) in the WITCH model

Energy-related technical change is endogenous in WITCH. Thanks to the hybrid nature of the model, we portray endogenous technological change both in its bottom-up and top-down dimensions: R&D investments designed to enhance energy-efficiency increase the productivity of energy inputs in generating energy services; growing expertise driven by Learning-by-Doing (LbD) reduces the cost of power generation plants.

Following Popp (2004), in country *n* at time *t*, technological advances are captured by a stock of knowledge, *HE*(n,t), combined with energy, *EN*(n,t), in a constant elasticity of substitution (CES) function that simulates the production of energy services, *ES*(n,t), demanded by the final good production sector:

$$ES(n,t) = \left[\alpha_H HE(n,t)^{\rho} + \alpha_{EN} EN(n,t)^{\rho}\right]^{1/\rho} . \tag{1}$$

The R&D sector exhibits intertemporal spillovers and the production of new "ideas" follows an innovation possibility frontier (Kennedy, 1964): knowledge is produced "standing on the shoulders" of the nation's giants: investment in R&D is combined with the stock of ideas already discovered and produces new knowledge which will be the base for new discoveries in the following years. A similar description of the R&D sector can be found in the seminal paper by Romer (1990), in which the research sector productivity increases proportionally with the stock of knowledge cumulated in the past, giving rise to endogenous growth. Using data on patent citations, Jaffe, Trajtenberg and Henderson (1993), Trajtenberg, Henderson and Jaffe (1992) and Caballero and Jaffe (1993), have found evidence of state dependence at the industry level.[5] In the specific narrower scope of our analysis, Popp (2002) finds that the energy R&D sector exhibits diminishing returns. Denoting R&D Investments with *I*, the production of new ideas in country *n* at time *t*, Z, is modelled as follows:

$$Z(n,t) \; = \; aI(n,t)^{b} HE(n,t)^{c} , \tag{2}$$

where $b + c < 1$ so as to account for diminishing returns. Assuming that obsolescence makes a fraction δ of past ideas not fruitful for the purpose of current innovation activity, the law of motion of the R&D stock is as follows:

$$HE(n,t+1) \; = \; HE(n,t)(1-\delta) + Z(n,t) . \tag{3}$$

Since in the present specification of the model we do not explicitly model non-energy R&D, we assume an exogenous crowding out effect between energy and non-energy R&D.[6] Empirical

---

[5] According to Rosenberg (1994), not only does technological progress in one nation shows *state* dependence, but also *path* dependence. This interpretation of technological progress will be used in the next section to justify one of our modelling formulations.

[6] For a study on R&D crowding out in the short and medium term see Goolsbee (1998).

studies have shown that the returns to higher investments in R&D are four times higher than those for general investment, thus the total cost of energy R&D investments is as in equation (4):

$$COST_{R\&D}(t,n) = I(n,t) + 4\psi\ I(nt)\ . \tag{4}$$

Where ψ is the crowding out parameter which measures how many dollars of generic R&D investment are lost per each dollar of energy R&D investment. We set $\psi = 0.5$ as in Popp (2004).

2.3. International R&D Spillovers

Researchers do not only stand on the shoulders of their predecessors but also on those of their neighbours.[7] Knowledge flows across countries, either embodied in traded goods or disembodied, in blueprints, patents, exchange of ideas between researchers, and imitation. We concentrate here on disembodied knowledge spillovers. Being WITCH a multiregional model, we can accommodate for the effect of disembodied knowledge spillovers by introducing a transmission channel across energy R&D sectors in each region. Thus, the implications of these spillovers for investments in the creation of new ideas, climate policy costs and energy demand can all be analysed.

Unfortunately, the empirical analysis of international spillovers induced by energy-saving R&D investments is almost nonexistent and it is thus not possible to derive useful modeling insights from the available empirical research. After comparing several alternative specifications of the equations representing technology spillovers in the model, here is the one that we propose as the most reliable. Countries/regions are exposed to a pool of world knowledge that can be considered as a global public good. A fraction of this knowledge is absorbed by each country and is available for use in the domestic R&D sector. Different assumptions can be made on (1) the characteristics of world knowledge, on (2) the process of absorption and on (3) the way in which countries use this available information. We follow this three-step approach to highlight the most relevant issues and to illustrate our modelling choices.

---

[7] See Chapter 11 in Rosenberg (1982).

2.4 International Knowledge Pool

We consider two distinct views of the pool of international knowledge. In the first, technological development is seen as a process in which all countries move upwards on the same knowledge ladder, with the least technologically advanced lying at the bottom and the technological innovator at the top; each region has a distinct position along the ladder at any time. Only knowledge still not possessed (in its possess) is attractive. Innovators receive scarce or no benefit from exposure to international knowledge while laggards harvest substantial gains. This was the view of technological progress put forward by Gerschenkron (1962) in his famous essay *Economic Backwardness in Historical Perspective*: by adopting frontier technologies, backward countries could catch up with advanced economies at a relatively fast pace. More recently, the idea of knowledge that trickles down from the technological frontier to the technological laggards was explored by Acemoglu, Aghion and Zilibotti (2006).

In our second description of world knowledge, we assume that countries move, at least partially, along independent technological patterns, and thus all external knowledge adds new insights to the domestic knowledge capital. Rosenberg (1994), in his second exploration of technological development, argues that indeed the technological development of countries tends to follow specific patterns influenced by the sequence of particular events which constitutes the history of the system. According to this view, the very same history of countries, their different regulatory regimes, and their economic and social environments, are drivers of technological differentiation. Indeed, for energy technologies we record a similar pattern of R&D and technology discoveries, and a clear example of path-dependent technological progress is the success of the wind industry in Europe. When technologies tend to diverge, spillovers are a great source of benefit because they fill in important gaps that might otherwise remain unexplored.

According to the first view, the knowledge pool accessible to each region is provided by the technology that lies unexplored between its own and the *innovator*'s knowledge stock, whereas according to the second view, the knowledge pool equals the overall amount of *world knowledge* detained by other countries. Both these two representations of the pool of ideas available to each country capture some interesting and important features of the process of technology diffusion. In our analysis, we assume that the first view prevails in Low Income countries. Therefore, for Low Income countries, the absorption of knowledge from the *innovator* is the prevailing effect to model, i.e. the Gerschenkron effect. The second view, i.e.

the situation described by Rosenberg with heterogeneous capital stocks, is to be preferred for High Income countries.

We combine these two different representations in one single formulation by assuming that the *technological frontier* is set not only by a single *innovator* but by the whole group of High Income countries, i.e. that the *technological frontier* is measured by the sum of the stocks of R&D capital detained by these countries. High Income countries may draw from the knowledge stock of all other High Income countries, while the Low Income countries' knowledge pool consists of the knowledge accumulated in the more advanced economies (those setting the world's *technological frontier*). For Low Income countries, we describe the process of technological advancement as an upward movement along a technology ladder; the gap to fill is measured by the difference between each country's R&D capital stock and the *technological frontier* capital. At high levels of technological development, however, countries specialize in different energy R&D paths and thus they have the opportunity to benefit from all other High Income countries' R&D stocks, which constitute the knowledge pool. By assuming a *technological frontier* determined by more than one country, we avoid the case of one single world leader, which cannot absorb any valuable knowledge from its followers, which is highly unrealistic when not dealing with a specific industry. If we define *HI* as the set of High Income Countries, equation (5) describes the knowledge pool for all *n* countries:

$$KP(n,t) = \sum\nolimits_{n \in HI} HE(n,t) - HE(n,t) \ , \tag{5}$$

where HE is the regional stock of knowledge as defined in equation (3).

2.5 Knowledge Absorption

Moving to the second logical step, we assume that only a fraction $\gamma(n,t)$ of the world's available pool of knowledge is absorbed by each country. The absorption parameter γ might be an indicator of industrial policy or of the legal environment, or a measure of some effort to absorb international knowledge. We consider γ as being primarily a function of domestic knowledge. In this we follow Cohen and Levinthal (1989), who were the first to suggest that the process of learning, far from being free, is costly and that most of this cost is borne by a stock of knowledge cumulated in the receiving country. Keller (2004) reinforces this position in his survey of international knowledge spillovers by showing that an R&D effort is needed to absorb international knowledge. By means of an empirical analysis of spillovers across OECD manufacturing industries, Kneller (2005) finds that absorptive capacity, rather than physical distance, plays an important role in determining the amount of knowledge transfers at the international level. Also Griffith, Redding and Van Reenen (2003) find that R&D increases the absorption of knowledge spillovers and that neglecting this "second face" of knowledge investments necessarily leads to an underestimation of R&D's social rate of return. Accordingly, we assume that the absorption capacity $\gamma(n,t)$ is a function of the distance of R&D capital accumulated in the region with respect to the *technological frontier*. We use the ratio of one country’s capital stock to the *technological frontier* as an indicator of this distance, as shown in equation (6):

$$\gamma(n,t)=\frac{HE(n,t)}{\sum_{n\in HI} HE(n,t)}. \qquad (6)$$

The further one country lies from the *technological frontier,* the lesser this country is able to absorb knowledge from the potentially available international knowledge pool. In words, the lack of laboratories, scientific bodies, investments in R&D in Low Income countries is a serious obstacle to the profitable use of the knowledge that circulates in the world. The low absorptive capacity of Low Income countries realistically reduces the potentially very large inflow of knowledge from the *technological frontier* in determining the overall amount of knowledge spillovers. More in general, also High Income Countries may see their absorptive capacity decline over time if they do not innovate at the same pace of their advanced partners. This is indeed true for all technological breakthroughs that completely change the paradigms in a discipline: even if close to the frontier, countries lagging behind might fail to reap any benefit from these new discoveries.

Accordingly, the spillover of international knowledge in region *n* at time *t*, $SPILL(n,t)$, is obtained by multiplying the Knowledge Pool and the absorption capacity:

$$\begin{aligned} SPILL(n,t) &= \gamma(n,t)\cdot KP(n,t) \\ &= \frac{HE(n,t)}{\sum_{n\in HI} HE(j,t)}\left[\sum_{n\in HI} HE(n,t) - HE(n,t)\right] \end{aligned} \qquad (7)$$

Notice that spillovers are a bell-shaped function of the country’s R&D capital stock. For Low Income countries, the peak of the curve lies halfway from the *technological frontier*. Spillovers are thus first increasing and then decreasing along the transition from low to high level of technological progress. For High Income countries, spillovers are increasing until the capital stock of one country is equal to the sum of the capital stocks of all the other High Income countries.

2.6 Spillover Use

The third and final step consists in defining how countries use the spillover in their process of knowledge generation. We assume that spillovers enter the domestic R&D sector as an input in the innovation possibility frontier. Thanks to this highly standardized aggregation of different production inputs we can control for the elasticity of the production of new ideas to international R&D spillover, i.e. the coefficient *d* in equation (8) below:[8]

$$Z(n,t) \;=\; a(n) I_{R\&D}(n,t)^{b}\, HE(n,t)^{c}\, SPILL(n,t)^{d}\,. \tag{8}$$

2.7 Synthesis

In the previous sub-sections, we described the logical steps that have been followed to introduce international energy R&D spillovers in the WITCH model. There is a variety of other available options that were considered and explored. However, the one chosen is the strongest from a theoretical point of view, and it has the advantage of being tractable and easily understandable, while capturing the most interesting effects at work.

Notice that in our framework the public good features of the knowledge pool are somehow mitigated. Were knowledge a fully global public good, the incentive to free-riding would dominate, regions would invest less in technology R&D and the overall production of knowledge would shrink.[9] On the contrary, by giving knowledge a role in the process of knowledge absorption and by letting international R&D spillover augment the productivity of domestic investment, we have introduced forces that work against the free-riding incentive. This is in accordance with the literature on knowledge spillovers. As an example, Cohen and Levinthal (1989) have shown that when domestic R&D increases absorption capacity and some general conditions hold, the incentive to invest more in R&D offsets the disincentive represented by free-riding, and world investments in R&D eventually increase.

---

[8] For an analogous aggregation of spillovers to domestic investment and capital stock see Acemoglu (2002), p. 793.

[9] The standard result that sees free-riding effects to dominate has also been questioned by D'Aspremont and Jacquemin (1988), who show how, in a cooperative setting with strong knowledge flows, spillovers induce higher overall investment in R&D due to the full internalization of positive externalities.

3. Calibration, New Baseline and the Effects of Spillovers on GHG Stabilization

Summing up, the new equation that describes the process of technology creation in country n at time t is as follows:

$$Z(n,t) = aI_{R\&D}(n,t)^{b}\,HE(n,t)^{c}\left\{\frac{HE(n,t)}{\sum_{n\in HI}HE(n,t)}\left[\sum_{n\in HI}HE(n,t)-HE(n,t)\right]\right\}^{d} \qquad (9)$$

We set the parameter d to be equal to 0.15, i.e. an increase of 1% of international spillovers increases the output of domestic ideas by 0.15%. Since, to our knowledge, there is no empirical evidence that attributes the value of the elasticity of knowledge generation to international spillovers, we have chosen here a value slightly lower than the elasticity of knowledge production to domestic investments (equal to 0.18), and about one third of the elasticity with respect to past capital stock, which is equal to 0.53 in the model without spillovers. Thus, we give priority to domestic investments in generating new discoveries, and we assume that intertemporal knowledge spillovers are stronger than the international ones. The effects and the robustness of this choice will be tested through an appropriate sensitivity analysis (see Section 5).

We calibrated the new production function so as to reproduce the same time path of the R&D capital stock without international spillovers; this also yields exactly equal paths for output and all energy variables and a very similar time path for R&D investments. Calibration was performed by reducing c in equation (9) so as to accommodate for the new input. By explicitly modelling international spillovers, we can separate the two "standing on shoulders" effects and attribute a correct nationality to the "giants" on which present researchers stand. Decreasing returns to scale are preserved. New values for parameter c are country- and time-specific.

We tested the above modeling choices by computing the costs and benefits of a 450 stabilization policy, i.e. a policy aimed at stabilizing atmospheric CO_2 concentrations at 450ppmv (550ppmv when considering all gases) at the end of the 21st century. We computed the effects of this stabilization policy both with and without international energy R&D spillovers.

In the WITCH model, the group of High Income countries is composed by USA, OLDEURO, NEWEURO, KOSAU (Korea, South Africa and Australia), CAJANZ (Canada, Japan, New

Zeland), while all other regions are labeled as Low Income.[10] A world ceiling on emissions across the century is derived consistently from the stabilization target and emission allowances are distributed across world regions according to the Sovereignty rule, i.e. each year regions receive a fraction of permits equal to their share of world emissions in the base year 2002. This distribution scheme is, of course, highly questionable, but it offers the grounds for studying policies to redistribute the effort of stabilization from Low Income to High Income countries. The latter may design policies to compensate Low Income countries for any distribution of permits that is considered inequitable, as will be shown in Section 4. A world carbon market equalizes marginal abatement costs worldwide.[11]

Table 1 shows a first important result: although our modeling choices rule out strong free-riding effects, world investments in R&D are always lower when spillovers are accounted for. The gap is about 3.5% in the first decades of the century and then progressively declines to 1.5% at the end of the century. Greater discrepancies are recorded if we look at more disaggregated data. High Income countries reduce investments the most, by cutting 4.1% of their R&D effort at the beginning of the century. This figure then decreases gradually to 1.5% at the end of the simulation period. For Low Income countries we record only a mild 1.7% reduction in the first decades, then a slightly greater gap at the middle of the century when they cut their efforts by 2.1%, and finally a decline to a 1.6% reduction at the end of the century. The difference in behaviour between High and Low Income countries during the first decades of the century is explained by the fact that, for Low Income countries, spillovers increase at a faster rate as they augment their capital stocks and move along the bell-shaped curve that governs knowledge inflows, as explained in the previous section.

It is also worth noting that among High Income countries the greatest reductions are recorded in USA, OLDEUROPE and CAJANZ, with the greatest difference found in USA, the smallest for CAJANZ, and OLDEUROPE in the middle. Investments decrease less in KOSAU and NEWEUROPE, the other two High Income countries, than in the top three countries/regions and for both, the share of investments at the frontier, i.e. the share of all High Income countries' investments, increases by 4% and 2.2%, respectively, in the first decades of the century. Thus,

---

[10] The aggregation of countries into twelve world regions is described in Bosetti, Massetti and Tavoni (2006).

[11] A distribution of emission allowances according to the "Equal per Capita" rule has also been tested. There are only very minor differences in R&D investments and all the results illustrated in this section are confirmed. The reason is that the carbon price is independent of the distribution of permits, as expected from the theoretical prediction of the Coase theorem, and income effects have only mild impacts on investment choices.

our results show that spillovers enhance convergence among countries at the frontier, as detailed in Table 2.

	2022	*2042*	*2062*	*2082*	*2102*
USA	-5.2%	-4.2%	-3.3%	-2.6%	-1.8%
OLDEURO	-3.8%	-3.2%	-2.6%	-2.1%	-1.4%
NEWEURO	-0.3%	-0.5%	-0.5%	-0.5%	-0.4%
KOSAU	-2.0%	-1.9%	-1.7%	-1.4%	-1.0%
CAJAZ	-3.3%	-2.8%	-2.2%	-1.8%	-1.2%
TE	-1.0%	-1.3%	-1.3%	-1.2%	-0.9%
MENA	-2.2%	-2.5%	-2.5%	-2.4%	-2.0%
SSA	0.6%	-0.3%	-0.4%	-0.4%	-0.4%
SASIA	-1.2%	-1.7%	-1.8%	-1.7%	-1.3%
CHINA	-1.8%	-2.4%	-2.4%	-2.2%	-1.7%
EASIA	-1.4%	-1.9%	-2.0%	-1.9%	-1.5%
LACA	-2.0%	-2.2%	-2.1%	-1.9%	-1.4%
WORLD	-3.5%	-2.9%	-2.5%	-2.0%	-1.5%
HIGH INCOME	-4.1%	-3.4%	-2.7%	-2.1%	-1.5%
LOW INCOME	-1.7%	-2.1%	-2.1%	-2.0%	-1.6%

Table 1.
Reduction of R&D Investments when Spillovers are Modeled.

	2022	*2042*	*2062*	*2082*	*2102*
USA	-1.2%	-0.9%	-0.7%	-0.5%	-0.3%
OLDEURO	0.3%	0.2%	0.1%	0.1%	0.0%
NEWEURO	4.0%	3.0%	2.2%	1.6%	1.1%
KOSAU	2.2%	1.5%	1.0%	0.7%	0.4%
CAJAZ	0.8%	0.6%	0.4%	0.3%	0.2%

Table 2.
Variation of Share of High Income Countries Investments.

Among Low Income countries, we record reductions in investments for all countries except for SSA (Sub-Saharan Africa) that slightly increases its investments when spillovers are introduced. However, as shown in Table 3, during the first decades of the century, reductions are inferior to those recorded for High Income countries and thus their share of world R&D between 2002 and 2032 increases, ranging from 4.3% for SSA to 1.3% for MENA (Middle East and North Africa). As a group, Low Income countries increase their share of world investments between 2002 and 2082 and slightly invert the trend at the end of the century.

Summing up, our results show some convergence in R&D investments shares among High Income countries. As a group, these countries lose grounds in favour of Low Income countries in the first decades of the century. Hence, our formulation of international R&D Spillovers captures the convergence process from multiple perspectives. It must also be stressed that these results are obtained within a stabilization scenario in which, even without spillovers, there is a high degree of convergence in R&D investments and capital stocks across world regions. International spillovers thus reinforce an already strong underlying convergence process.[12]

Changes in the stock of R&D are instead negligible. International knowledge inflows substitute domestic investments and the cuts are spread across the economy. In addition, energy R&D expenditures at the end of the century, when they are at their highest level, range from 0.12% to 0.02% of GDP, respectively, for USA and SSA. Therefore, the change induced by spillovers is small in absolute terms. As a consequence, gains in terms of stabilization costs are also negligible. As an example, over the whole century, the USA save 72 USD Billions over a cumulated GDP of more than 2100 Trillions in our stabilization scenario, i.e. a modest 0.003%.

Given that the stock of domestic R&D changes only slightly, and that we do not record any significant effect of spillovers on the available income, there is also no adjustment in the investment in all energy technologies, and the price of emissions permits does not vary when spillovers are introduced.

	2022	*2042*	*2062*	*2082*	*2102*
USA	-1.8%	-1.3%	-0.9%	-0.6%	-0.3%
OLDEURO	-0.3%	-0.3%	-0.1%	0.0%	0.1%
NEWEURO	3.4%	2.6%	2.0%	1.6%	1.1%
KOSAU	1.6%	1.1%	0.8%	0.6%	0.5%
CAJANZ	0.2%	0.2%	0.2%	0.3%	0.3%
TE	2.6%	1.7%	1.1%	0.8%	0.6%
MENA	1.3%	0.4%	-0.1%	-0.3%	-0.5%
SSA	4.3%	2.8%	2.1%	1.7%	1.2%
SASIA	2.4%	1.3%	0.6%	0.3%	0.2%
CHINA	1.7%	0.6%	0.1%	-0.1%	-0.2%
EASIA	2.2%	1.1%	0.4%	0.1%	0.0%
LACA	1.6%	0.8%	0.4%	0.2%	0.1%
HI	-0.6%	-0.4%	-0.2%	-0.1%	0.0%
LI	1.9%	0.9%	0.3%	0.1%	-0.1%

Table 3.
Variation of Share of World Investments in Energy R&D.

---

[12] In order to control for differences between the two stabilization scenarios that might arise from small discrepancies between the baselines with and without spillovers, we have also compared the changes in investments in R&D induced by the stabilization policy with and without spillovers and we are able to confirm the results illustrated in the text.

4. GHG Stabilisation and Technology Diffusion. A Policy Exercise

Even though spillovers have a major impact on the amount and distribution of R&D investments, but only a minor impact on energy investments and overall stabilization costs, they may play an important role to shape investment and emission strategies. Assume indeed that a set of countries decide to adopt an energy R&D policy to stimulate the development of a new low-carbon energy technology. The overall effects of this policy can be properly assessed only in a model with international spillovers, where the benefits of R&D investments are not limited to the country where investments are made. As another example, consider a policy aimed at increasing the circulation of world knowledge, indistinctly among regions or with a special focus on some areas. This kind of policy intervention is frequently debated (Cf. Barrett, 2001) and could be the core of a future GHG stabilization treaty (this is recommended, for example, in the June 2007 Heiligendamm Summit Declaration). Again, the overall effects of such policy can only be studied in models in which knowledge flows are explicitly modeled.

Let us analyse, in this paper, a third case, in which a 450 ppm stabilization policy, based on the introduction of a global permit market, is coupled to a policy to foster knowledge dissemination. Let us assume that emission permits are distributed according to the Sovereignty rule as in the previous stabilization exercise. With such a distribution of emission permits – rather extreme but often debated in the policy arena – complementary policies to alleviate the burden falling on Low Income countries would be needed to redistribute the cost of stabilizing GHG concentrations. R&D cooperation policies are certainly among the most promising tools to attain this objective.

We consider here an R&D cooperation policy in which High Income countries use a fraction of the revenues from emission permit sales to build absorption capacity in Low Income countries. This is shown in equation (10), which modifies equation (9):

$$Z(n,t) = aI_{R\&D}(n,t)^{b}\, HE(n,t)^{c} \left\{ \left[\frac{HE(n,t)+ABS(n,t)}{\sum_{n\in HI} HE(n,t)} \right] \left[\sum_{n\in HI} HE(n,t) - HE(n,t) \right] \right\}^{d} \quad \forall n \in LI \qquad (10)$$

where $ABS(n,t)$ is the Low Income countries absorption capacity stock, which derives from the flow of R&D cooperation aid, $AID(t)$, coming from High Income countries. $ABS(n,t)$ evolves as shown in equation (11):

$$ABS(n,t+1) = ABS(n,t)(1-\delta) + AID(t) \tag{11}$$

The fraction of revenues from emission permits sales devoted to fund R&D technology transfers and cooperation declines across time as shown in Table 4. The world fund devoted to increase absorption capacity in Low Income countries ranges between 2 and 105 billion USD. These revenues are equally shared among Low Income countries.

	2007	**2022**	**2042**	**2062**	**2082**	**2102**
Share of Carbon Permits Sales	78%	37%	14%	5%	2%	1%
Billions per year (1995 USD)	2	35	87	105	70	37

Table 4.
Financial Aid for R&D Absorption Capacity.

Table 5 shows the impact of this stabilization and R&D cooperation policy-mix on GHG stabilization costs. R&D cooperation policy reduces stabilization costs in Low Income countries by 2.2% with respect to the standard stabilization policy examined in Section 3. High Income stabilization costs increase by 11.3% (but their quota of world stabilization costs remains fairly low because of the application of the sovereignty principle in allocating permits). Overall, we record a reduction of world GHG stabilization costs.[13]

In order to test the validity of our exercise we also simulated a redistribution policy in which High Income countries transfer to Low Income ones the same amount of resources that they spend for building the extra absorption capacity. In this case, there are gains both for Low Income countries and for the World as a whole. However, these gains are smaller than when the policy is targeted to enhance R&D absorption capacity.

Table 6 shows that by intervening on the absorption capacity the knowledge stock available to Low Income countries increases by more than 50% by the end of the century. Instead investments, as also shown in Table 6, only marginally increase. The reason is that, as time goes by, new ideas developed in Low Income countries are more and more based on external

---

[13] The variation is very high for OLDEUROPE because the initially very low level of costs magnifies, in percentage terms, the change due to the introduction of an international transfer scheme for building absorption capacity in Low Income countries.

knowledge than on domestic effort. The economic gains are induced by this increased free flow of knowledge, which comes at no cost for Low Income countries.

	450 + R&D Absorption	*450 + Transfer*
USA	13.06%	12.00%
OLDEURO	210.76%	193.66%
NEWEURO	0.39%	0.83%
KOSAU	1.99%	2.38%
CAJAZ	10.28%	9.55%
TE	-2.04%	-2.43%
MENA	-2.72%	-1.21%
SSA	-1.90%	-5.10%
SASIA	-2.34%	-1.43%
CHINA	-2.02%	-1.11%
EASIA	-2.24%	-1.21%
LACA	-2.46%	-1.47%
WORLD	-0.67%	-0.09%
HIGH INCOME	11.33%	10.63%
LOW INCOME	-2.30%	-1.55%

Table 5. Change of Stabilization Costs.

	R&D Capital at 2102		R&D Investments (Cumulative, 2002-2102)	
	450 + R&D Absorption	*450 + Transfer*	*450 + R&D Absorption*	*450 + Transfer*
USA	0%	0%	-1%	0%
OLDEURO	0%	0%	-1%	0%
NEWEURO	0%	0%	-1%	0%
KOSAU	0%	0%	-1%	0%
CAJAZ	0%	0%	-1%	0%
TE	56%	0%	6%	0%
MENA	46%	0%	3%	0%
SSA	93%	0%	13%	0%
SASIA	53%	0%	4%	0%
CHINA	46%	0%	3%	0%
EASIA	53%	0%	4%	0%
LACA	47%	0%	3%	0%
WORLD	25%	0%	1%	0%
HIGH INCOME	0%	0%	-1%	0%
LOW INCOME	52%	0%	4%	0%

Table 6.
Change of R&D Capital and R&D Investments
when Absorption Capacity Building Policy is Implemented.

The above analysis of the combined stabilization and R&D policy should be considered as a realistic proxy of any policy under which the distribution of emission permits, or the abatement effort, favours High Income countries and a set of re-distribution measures is therefore necessary. Our analysis clearly shows that absorption capacity is a powerful channel through which the capital stocks in LI countries can be enhanced, and through this channel it is possible to increase equity and achieve higher efficiency.

5. Sensitivity Analysis.

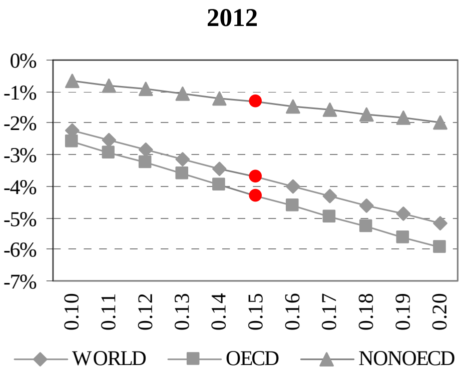
As previously discussed, there is some uncertainty over the value to assign to the elasticity of knowledge creation to international R&D spillovers. Therefore, we tested the robustness of our findings to different values of this elasticity. We used a symmetric interval around the central value of 0.15 by setting 0.20 and 0.10 as upper and lower bounds, respectively. With the upper bound value, the elasticity of knowledge creation to international spillovers is greater than that of domestic investments, whose value is 0.18. 0.20 is thus a considerably high level for the parameter d. With the lower bound, instead, we allow for a sufficiently low relevance of international R&D spillovers by assuming that a one percent increase of foreign knowledge is almost half as powerful as a one percent increase in domestic investment in creating new ideas.

Sensitivity analysis shows that for all values of the parameter d that were considered, investments in energy R&D in a 450ppmv stabilization scenario decline in almost all countries when spillovers are explicitly modeled (the only exception is SSA). This confirms the results described in the previous section.

Figures 1 to 4 show, for different years, the relationship found between the parameter d and the magnitude of cuts in energy R&D investments, with respect to the stabilization scenario without spillovers. The strongest responses are recorded from High Income countries, but the sensitivity of Low Income countries progresses over time, reaches its maximum before the end of the century, and then regresses to converge towards values similar to those found for High Income countries. For these countries we find instead a constantly declining responsiveness to spillovers across time.

This implies that our model yields different reactions to spillovers as a function of the degree of economic development (the level of knowledge accumulation). Initially, Low Income countries find it difficult to reap the benefits of the internationally available pool of technologies due to their low absorption capacity; however, as their cumulated stock of knowledge increases, they substitute more and more easily foreign to domestic investments and become more reactive to the foreign flows of knowledge.

Consider now the responsiveness of domestic investments to international spillovers in the first half of the century. In case of "standing-on-shoulders" effects, as in WITCH, investments in the next decades will be crucial to determine future knowledge stocks and energy intensities in the subsequent decades. It is thus important to understand the effect of knowledge spillovers on these early investments. We have seen that while Low Income countries investments' decisions are relatively rigid with respect to the degree of international spillovers, High Income countries show a higher margin of variation, that ranges from -2.8% to -6% in 2012. This result bears some meaningful implications: empirical research should above all be addressed to estimate the impact of energy R&D spillovers in High Income countries and the lack of reliable data on Low Income countries should not be considered as a serious obstacle to perform model simulations.



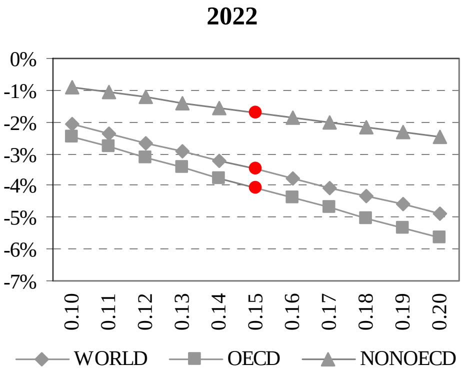
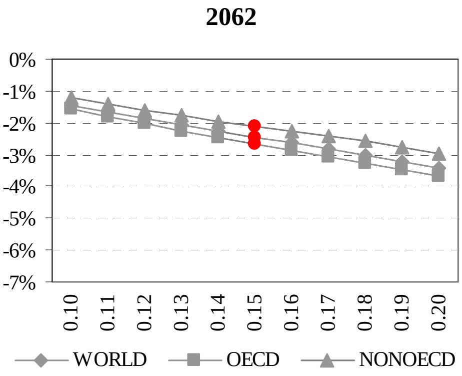


Figure 1.

Figure 2.



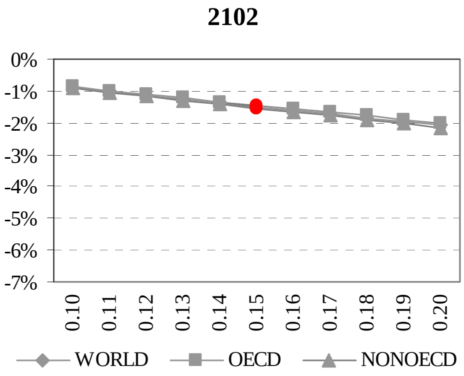


Figure 3.

Figure 4.

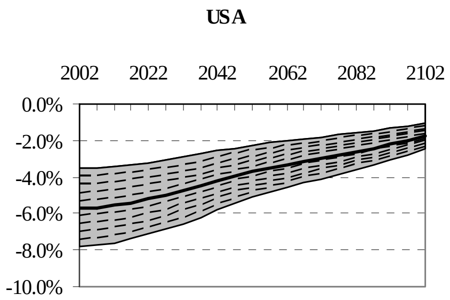


Figure 5.

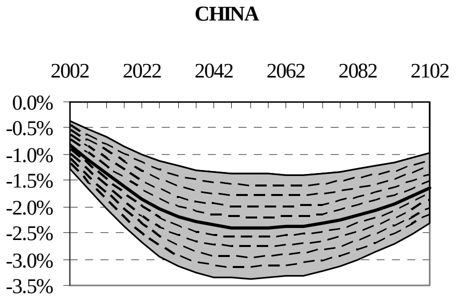


Figure 6.

The shadowed areas in Figures 5 and 6 show the range of reductions in R&D investments for USA and CHINA, with respect to the stabilization scenario without spillovers. The area included between the two extreme parameter values of 0.10 and 0.20 has been shadowed to highlight the range of values found; the dotted lines correspond to intermediate values assigned to the parameter *d* and the solid line corresponds to the central value 0.15. As noted above, the widest range is recorded for the country with the highest level of capital per capita.[14] CHINA starts from low ranges, but as income per capita and knowledge increase, and spillovers become more important, the range increases as well. This is due to the bell-shaped curve that governs spillovers, as explained in Section 2.

6. Conclusions

In order to achieve the emission reductions needed for stabilizing concentrations of GHG in the atmosphere at safe levels, new technologies must be developed to soften the link between economic/demographic growth and carbon emissions. The development of technologies that allow for a more efficient use of energy is part of this effort and will certainly play a substantial role in any future stabilization policy. New technologies like hybrid engines, for example, allow for a substantial reduction of energy consumption, while delivering the same services. More efficient air conditioning systems would cut energy consumption in a significant manner, while preserving unaltered comfort conditions.

The discovery of new technologies and the development of new ideas is, at least partially, a public good that freely flows across different firms, industries and world regions. Thanks to this

---

[14] A similar behaviour is found for Old Europe (OLDEURO) and Canada, Japan and New Zealand (CAJANZ).

flow of ideas, the development of new technologies spreads across firms, industries and world regions from an initially very narrow set of innovators. The development of new technologies is concentrated in a few world regions, and international spillovers have a potential role to play in assuring a wider diffusion of new discoveries. Greater knowledge flows will make it easier and less costly to achieve energy efficiency gains.

This paper contributes to the literature on the costs of GHG stabilization by providing a first assessment of the potential role of international knowledge flows in fostering the development of new energy technologies. Disembodied international energy R&D spillovers are modeled in the WITCH model. The amount of spillovers entering each world region depends on a pool of freely available knowledge and on the ability of each country to benefit from it, i.e. on its absorption capacity. Knowledge acquired from abroad combines with domestic capital stock and investments and thus contributes to the production of new technologies at home.

We focused on the stabilization of world CO_2 concentrations in the atmosphere at 450ppmv by the end of the 21st century (550 ppmv when considering all gases) and showed that, when international knowledge spillovers are explicitly modeled, optimal energy R&D investments are lower than previously estimated. In particular, the strongest free-riding effects are recorded among High Income countries. The reason lies in the higher exposure of these economies to the international exchange of ideas, and thus on greater benefits in terms of potential investment savings. However, thanks to spillovers, total knowledge stocks remain unchanged and the main gain for each country is a lower expenditure in energy R&D. These savings are not negligible in absolute terms, but are only a small share of the overall stabilization bill. The result is that stabilization costs are slightly changed by endogenising international energy R&D spillovers.

Sensitivity analysis revealed that these findings are robust to a range of parameter values. High income countries are more sensitive to variations of the parameters than Low Income countries, especially in the first decades of the century. Given the lack of empirical evidence on the actual role of international spillovers in the development of domestic technologies, it is worth concentrating the efforts in studying knowledge dynamics in High Income countries.

Despite the above conclusions, this paper has achieved some policy relevant results. International spillovers are indeed an important policy channel. This is why we focused our analysis on a policy-mix in which a stabilization policy based on a global permit market is coupled with a technology policy based on transfers designed to enhance the absorption capacity in Low Income countries. The new model that we developed enabled us to assess the implications of such policy-mix. Our results show that this policy-mix can reduce the costs of stabilizing GHG emissions (and is more cost-effective than a stabilization policy alone). More specifically, without policies targeted to enhance absorption capacity, the dissemination of knowledge does not appear to contribute significantly to the achievement of ambitious stabilization targets. Low Income countries have barriers that prevent them from absorbing international knowledge spillovers. Hence, exchanges of ideas remains confined to High Income countries, were the overwhelming majority of R&D investments takes place. However, even with greater absorption capacity, the main effect is a substitution of foreign to domestic efforts, as has been found optimal for High Income countries. Therefore, greater knowledge flows and higher investments in absorption capacity in Low Income countries must necessarily be combined with specific measures aimed at reducing free-riding incentives.

It is worth noting that during the 2007 G8 Summit at Heiligendamm, in Germany, complementary-technology-agreement for contrasting climate change and increasing energy security have been strongly advocated. The final Summit Declaration explicitly asks for "unprecedented international cooperation" in developing new technologies.[16] Our policy exercise shows a previously disregarded possible area of policy intervention in the spirit of the Heiligendamm Declaration.

---

[16] Heiligendamm Summit Declaration, June 7, 2007, at Para. 43.

References

Acemoglu, D. (2002), "Directed Technical Change," *Review of Economic Studies*, 69(4), 781—809.

Acemoglu, D., P. Aghion and F. Zilibotti (2006), "Distance to Frontier, Selection, and Economic Growth," *Journal of the European Economic Association*, 4(1), 37—74.

Barrett, S. (1994), "Self-enforcing International Environmental Agreements," *Oxford Economic Papers*, Special Issue on Environmental Economics, 46(3), 878—94.

Barrett, S. (2001), Towards a Better Climate Treaty. *Policy Matters* 01-29, Washington, DC: AEI-Brookings Joint Center for Regulatory Studies.

Barrett, S. (2002), *Environment and Statecraft*. Oxford, Oxford University Press.

Bosetti, V., C. Carraro, M. Galeotti, E. Massetti and M. Tavoni, (2006), "WITCH: A World Induced Technical Change Hybrid Model," *The Energy Journal*, Special Issue on Hybrid Modeling of Energy-Environment Policies: Reconciling Bottom-up and Top-down, 13—38.

Bosetti, V., E. Massetti and M. Tavoni (2007), "FEEM’s WITCH Model: Structure, Baseline, Solutions," FEEM Working Paper No 10/2007.

Buchner, B., Carraro, C., Cersosimo, I. and C. Marchiori (2005), “Back to Kyoto? US Participation and the Linkage between R&D and Climate Cooperation”, in A. Haurie and L. Viguier, eds., *Coupling Climate and Economic Dynamics*, Kluwer Academic Publishers, pp. 173-204.

Buonanno, P., C. Carraro and M. Galeotti (2003), "Endogenous Induced Technical Change and the Costs of Kyoto," *Resource and Energy Economics*, 25(1), 11—34.

Caballero, R.J and A.B. Jaffe (1993), "How High are Giants’ Shoulders: An Empirical Assessment of Knowledge Spillovers and Creative Destruction in a Model of Economic Growth," *NBER Macroeconomics Annual 1993*, Cambridge (MA), MIT Press, 15—74.

Carraro, C. (2001) “Environmental Technological Innovation and Diffusion”, in H. Folmer, L. Gabel, S. Gerking and A. Rose, eds., *Frontiers of Environmental Economics,* E. Elgar: Cheltenham.

Carraro, C. and D. Siniscalco (1994), “Environmental Policy Re-considered: The Role of Technological Innovation", *European Economic Review*, 38, 545—554.

Coe, D. and E. Helpman (1995), "International R&D Spillovers," *European Economic Review*, 39(5), 859—887.

Cohen, W. and D. Levinthal (1989), "Innovation and Learning: the Two Faces of R&D," *Economic Journal*, 99(397), 569—596.

D’Aspremont, C. and A. Jacquemin (1988), "Cooperative and Noncooperative R&D in Duopoly with Spillovers," *The American Economic Review*, 78(5), 1133—1137.

Eaton, J. and S. Kortum (1996), "Trade in Ideas: Patenting & Productivity in the OECD," *Journal of International Economics*, 40(3-4), 251—278.

Eaton, J. and S. Kortum (1999), "International Technology Diffusion: Theory and Measurement," *International Economic Review*, 1999.

Gerlagh, R. (2006), "International Carbon Leakage. Interpreting CGE's and assessing the implications of international technology spillovers", paper presented at the 2nd Meeting of the Transust Project, Vienna, 10 October, 2006.

Gerlagh and Kuik (2003), "Trade Liberalization and Carbon Leakage," *The Energy Journal*, 24(3), 97—120.

Gerschenkron, A. (1962), *Economic Backwardness in Historical Perspective*. Harvard University Press.

Goolsbee, A. (1998), "Does Government R&D Policy Mainly Benefit Scientists and Engineers?" *The American Economic Review*, 88(2), 298—302.

Griffith, R., S. Redding and J. Van Reenen (2003), "R&D and Absorptive Capacity: Theory and Empirical Evidence", *Scandinavian Journal of Economics*, 105(1), 99—118.

Grubb, M., C. Carraro and J. Schellnhuber (2006), "Technological Change for Atmospheric Stabilization: Introductory Overview to the Innovation Modeling Comparison Project," *The Energy Journal*, Special Issue on Endogenous Technological Change and the Economics of Atmospheric Stabilisation, March, pp. 1—8.

Grubb, M., C. Hope and R. Fouquet (2002), "Climatic Implications of the Kyoto Protocol: The Contribution of International Spillover," *Climatic Change*, 54(1-2), 11—28.

Jaffe, A.B., M. Trajtenberg and R. Henderson (1993), "Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations," *Quarterly Journal of Economics*, 108(3), 577—598.

Keller, W. (1997), "Trade and the Transmission of Technology," NBER Working Paper No 6113.

Keller, W. (2004), "International Technology Diffusion," *Journal of Economic Literature*, 42(3), 752—782.

Kemfert, C. (2005), "Induced Technological Change in a Multi-Regional, Multi-Sectoral, Integrated Assessment Model (WIAGEM). Impact assessment of climate policy strategies," *Ecological Economics*, 54(2-3), 293–305.

Kennedy, C. (1964), "Induced Bias in Innovation and the Theory of Distribution", *Economic Journal*, 74(295), 541—547.

Kneller, R. (2005), "Frontier Technology, Absorptive Capacity and Distance", *Oxford Bulletin of Economics and Statistics*, 67(1), 1—23.

Lanjouw, J.O. and A. Mody (1996), "Innovation and the International Diffusion of Environmentally Responsive Technology," *Research Policy*, 25, 549—571.

Philibert, C. (2004), "International Energy Technology Collaboration and Climate Change Mitigation," OECD Environment Directorate and International Energy Agency, Paris.

Popp, D. (2002), “Induced Innovation and Energy Prices”, *The American Economic Review*, 92(1), 160—180.

Popp, D. (2004), "ENTICE: Endogenous Technological Change in the DICE Model of Global Warming", *Journal of Environmental Economics and Management*, 48(1), 742—768.

Romer, P. (1990), "Endogenous Technical Change," *Journal of Political Economy*, 98, S71—S102.

Rosenberg, N. (1982), *Inside the Black Box: Technology and Economics*, Cambridge University Press, Cambridge.

Rosenberg, N. (1994), *Exploring the Black Box: Technology, Economics, and History*. Cambridge University Press, Cambridge.

Trajtenberg, M., R. Henderson, A.B. Jaffe (1992), "Ivory Tower vs Corporate Lab: An Empirical Study of Basic Research and Appropriability," NBER Working Paper No. 4146.

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 2007

NRM	1.2007	*Rinaldo Brau, Alessandro Lanza, and Francesco Pigliaru*: How Fast are Small Tourism Countries Growing? The 1980-2003 Evidence
PRCG	2.2007	*C.V. Fiorio, M. Florio, S. Salini and P. Ferrari:* Consumers' Attitudes on Services of General Interest in the EU: Accessibility, Price and Quality 2000-2004
PRCG	3.2007	*Cesare Dosi and Michele Moretto*: Concession Bidding Rules and Investment Time Flexibility
IEM	4.2007	*Chiara Longo, Matteo Manera, Anil Markandya and Elisa Scarpa*: Evaluating the Empirical Performance of Alternative Econometric Models for Oil Price Forecasting
PRCG	5.2007	*Bernardo Bortolotti, William Megginson and Scott B*. Smart: The Rise of Accelerated Seasoned Equity Underwritings
CCMP	6.2007	*Valentina Bosetti and Massimo Tavoni*: Uncertain R&D, Backstop Technology and GHGs Stabilization
CCMP	7.2007	*Robert Küster, Ingo Ellersdorfer, Ulrich Fahl* (lxxxi): A CGE-Analysis of Energy Policies Considering Labor Market Imperfections and Technology Specifications
CCMP	8.2007	*Mònica Serrano* (lxxxi): The Production and Consumption Accounting Principles as a Guideline for Designing Environmental Tax Policy
CCMP	9.2007	*Erwin L. Corong* (lxxxi): Economic and Poverty Impacts of a Voluntary Carbon Reduction for a Small Liberalized Developing Economy: The Case of the Philippines
CCMP	10.2007	*Valentina Bosetti, Emanuele Massetti, and Massimo Tavoni*: The WITCH Model. Structure, Baseline, Solutions
SIEV	11.2007	*Margherita Turvani, Aline Chiabai, Anna Alberini and Stefania Tonin*: Public Policies for Contaminated Site Cleanup: The Opinions of the Italian Public
CCMP	12.2007	*M. Berrittella, A. Certa, M. Enea and P. Zito*: An Analytic Hierarchy Process for The Evaluation of Transport Policies to Reduce Climate Change Impacts
NRM	13.2007	*Francesco Bosello, Barbara Buchner, Jacopo Crimi, Carlo Giupponi and Andrea Povellato*: The Kyoto Protocol and the Effect of Existing and Planned Measures in the Agricultural and Forestry Sector in the EU25
NRM	14.2007	*Francesco Bosello, Carlo Giupponi and Andrea Povellato*: A Review of Recent Studies on Cost Effectiveness of GHG Mitigation Measures in the European Agro-Forestry Sector
CCMP	15.2007	*Massimo Tavoni, Brent Sohngen, and Valentina Bosetti*: Forestry and the Carbon Market Response to Stabilize Climate
ETA	16.2007	*Erik Ansink and Arjan Ruijs*: Climate Change and the Stability of Water Allocation Agreements
ETA	17.2007	*François Gusdorf and Stéphane Hallegatte*: Compact or Spread-Out Cities: Urban Planning, Taxation, and the Vulnerability to Transportation Shocks
NRM	18.2007	*Giovanni Bella*: A Bug's Life: Competition Among Species Towards the Environment
IEM	19.2007	*Valeria Termini and Laura Cavallo*: "Spot, Bilateral and Futures Trading in Electricity Markets. Implications for Stability"
ETA	20.2007	*Stéphane Hallegatte and Michael Ghil*: Endogenous Business Cycles and the Economic Response to Exogenous Shocks
CTN	21.2007	*Thierry Bréchet, François Gerard and Henry Tulkens*: Climate Coalitions: A Theoretical and Computational Appraisal
CCMP	22.2007	*Claudia Kettner, Angela Köppl, Stefan P. Schleicher and Gregor Thenius*: Stringency and Distribution in the EU Emissions Trading Scheme –The 2005 Evidence
NRM	23.2007	*Hongyu Ding, Arjan Ruijs and Ekko C. van Ierland*: Designing a Decision Support System for Marine Reserves Management: An Economic Analysis for the Dutch North Sea
CCMP	24.2007	*Massimiliano Mazzanti, Anna Montini and Roberto Zoboli*: Economic Dynamics, Emission Trends and the EKC Hypothesis New Evidence Using NAMEA and Provincial Panel Data for Italy
ETA	25.2007	*Joan Canton*: Redealing the Cards: How the Presence of an Eco-Industry Modifies the Political Economy of Environmental Policies
ETA	26.2007	*Joan Canton*: Environmental Taxation and International Eco-Industries
CCMP	27.2007	*Oscar Cacho and Leslie Lipper* (lxxxii): Abatement and Transaction Costs of Carbon-Sink Projects Involving Smallholders
CCMP	28.2007	*A. Caparrós, E. Cerdá, P. Ovando and P. Campos* (lxxxii): Carbon Sequestration with Reforestations and Biodiversity-Scenic Values
CCMP	29.2007	*Georg E. Kindermann, Michael Obersteiner, Ewald Rametsteiner and Ian McCallcum* (lxxxii): Predicting the Deforestation–Trend Under Different Carbon–Prices

CCMP	30.2007	*Raul Ponce-Hernandez* (lxxxii): A Modelling Framework for Addressing the Synergies between Global Conventions through Land Use Changes: Carbon Sequestration, Biodiversity Conservation, Prevention of Land Degradation and Food Security in Agricultural and Forested Lands in Developing Countries
ETA	31.2007	*Michele Moretto and Gianpaolo Rossini*: Are Workers' Enterprises Entry Policies Conventional
KTHC	32.2007	*Giacomo Degli Antoni*: Do Social Relations Affect Economic Welfare? A Microeconomic Empirical Analysis
CCMP	33.2007	*Reyer Gerlagh and Onno Kuik*: Carbon Leakage with International Technology Spillovers
CCMP	34.2007	*Richard S.J. Tol*: The Impact of a Carbon Tax on International Tourism
CCMP	35.2007	*Reyer Gerlagh, Snorre Kverndokk and Knut Einar Rosendahl*: Optimal Timing of Environmental Policy; Interaction Between Environmental Taxes and Innovation Externalitie
SIEV	36.2007	*Anna Alberini and Alberto Longo*: Valuing the Cultural Monuments of Armenia: Bayesian Updating of Prior Beliefs in Contingent Valuation
CCMP	37.2007	*Roeland Bracke, Tom Verbeke and Veerle Dejonckheere*: What Distinguishes EMAS Participants? An Exploration of Company Characteristics
CCMP	38.2007	*E. Tzouvelekas, D. Vouvaki and A. Xepapadeas*: Total Factor Productivity Growth and the Environment: A Case for Green Growth Accounting
CCMP	39.2007	*Klaus Keller, Louise I. Miltich, Alexander Robinson and Richard S.J. Tol*: How Overconfident are Current Projections of Anthropogenic Carbon Dioxide Emissions?
CCMP	40.2007	*Massimiliano Mazzanti and Roberto Zoboli*: Environmental Efficiency, Emission Trends and Labour Productivity: Trade-Off or Joint Dynamics? Empirical Evidence Using NAMEA Panel Data
PRCG	41.2007	*Veronica Ronchi*: Populism and Neopopulism in Latin America: Clientelism, Trade Union Organisation and Electoral Support in Mexico and Argentina in the '90s
PRCG	42.2007	*Veronica Ronchi*: The Neoliberal Myth in Latin America: The Cases of Mexico and Argentina in the '90s
CCMP	43.2007	*David Anthoff, Cameron Hepburn and Richard S.J. Tol*: Equity Weighting and the Marginal Damage Costs of Climate Change
ETA	44.2007	*Bouwe R. Dijkstra and Dirk T.G. Rübbelke*: Group Rewards and Individual Sanctions in Environmental Policy
KTHC	45.2007	*Benno Torgler*: Trust in International Organizations: An Empirical Investigation Focusing on the United Nations
CCMP	46.2007	*Enrica De Cian, Elisa Lanzi and Roberto Roson*: The Impact of Temperature Change on Energy Demand: A Dynamic Panel Analysis
CCMP	47.2007	*Edwin van der Werf*: Production Functions for Climate Policy Modeling: An Empirical Analysis
KTHC	48.2007	*Francesco Lancia and Giovanni Prarolo*: A Politico-Economic Model of Aging, Technology Adoption and Growth
NRM	49.2007	*Giulia Minoia*: Gender Issue and Water Management in the Mediterranean Basin, Middle East and North Africa
KTHC	50.2007	*Susanna Mancinelli and Massimiliano Mazzanti*: SME Performance, Innovation and Networking Evidence on Complementarities for a Local Economic System
CCMP	51.2007	*Kelly C. de Bruin, Rob B. Dellink and Richard S.J. Tol*: AD-DICE: An Implementation of Adaptation in the DICE Model
NRM	52.2007	*Frank van Kouwen, Carel Dieperink, Paul P. Schot and Martin J. Wassen*: Interactive Problem Structuring with ICZM Stakeholders
CCMP	53.2007	*Valeria Costantini and Francesco Crespi*: Environmental Regulation and the Export Dynamics of Energy Technologies
CCMP	54.2007	*Barbara Buchner, Michela Catenacci and Alessandra Sgobbi*: Governance and Environmental Policy Integration in Europe: What Can We learn from the EU Emission Trading Scheme?
CCMP	55.2007	*David Anthoff and Richard S.J. Tol*: On International Equity Weights and National Decision Making on Climate Change
CCMP	56.2007	*Edwin van der Werf and Sonja Peterson*: Modeling Linkages Between Climate Policy and Land Use: An Overview
CCMP	57.2007	*Fabien Prieur*: The Environmental Kuznets Curve in a World of Irreversibility
KTHC	58.2007	*Roberto Antonietti and Giulio Cainelli*: Production Outsourcing, Organizational Governance and Firm's Technological Performance: Evidence from Italy
SIEV	59.2007	*Marco Percolo*: Urban Transport Policies and the Environment: Evidence from Italy
ETA	60.2007	*Henk Folmer and Pierre von Mouche*: Linking of Repeated Games. When Does It Lead to More Cooperation and Pareto Improvements?
CCMP	61.2007	*Arthur Riedacker* (lxxxi): A Global Land Use and Biomass Approach to Reduce Greenhouse Gas Emissions, Fossil Fuel Use and to Preserve Biodiversity
CCMP	62.2007	*Jordi Roca and Mònica Serrano*: Atmospheric Pollution and Consumption Patterns in Spain: An Input-Output Approach
CCMP	63.2007	*Derek W. Bunn and Carlo Fezzi* (lxxxi): Interaction of European Carbon Trading and Energy Prices
CTN	64.2007	*Benjamin Golub and Matthew O. Jackson* (lxxxiii): Naïve Learning in Social Networks: Convergence, Influence and Wisdom of Crowds
CTN	65.2007	*Jacob K. Goeree, Arno Riedl and Aljaž Ule* (lxxxiii): In Search of Stars: Network Formation among Heterogeneous Agents
CTN	66.2007	*Gönül Doğan, M.A.L.M. van Assen, Arnout van de Rijt, and Vincent Buskens* (lxxxiii): The Stability of Exchange Networks
CTN	67.2007	*Ben Zissimos* (lxxxiii): Why are Trade Agreements Regional?
CTN	68.2007	*Jacques Drèze, Michel Le Breton, Alexei Savvateev and Shlomo Weber* (lxxxiii): «Almost» Subsidy-free Spatial Pricing in a Multi-dimensional Setting
CTN	69.2007	*Ana Babus* (lxxxiii): The Formation of Financial Networks

CTN	70.2007	*Andrea Galeotti and Sanjeev Goyal* (lxxxiii): A Theory of Strategic Diffusion
IEM	71.2007	*Francesco Bosello, Enrica De Cian and Roberto Roson*: Climate Change, Energy Demand and Market Power in a General Equilibrium Model of the World Economy
ETA	72.2007	*Gastón Giordana and Marc Willinger*: Fixed Instruments to Cope with Stock Externalities An Experimental Evaluation
KTHC	73.2007	*Oguzhan Dincer and Eric Uslaner*: Trust and Growth
CCMP	74.2007	*Fei Teng and Alun Gu*: Climate Change: National and Local Policy Opportunities in China
KTHC	75.2007	*Massimiano Bucchi and Valeria Papponetti*: Research Evaluation as a Policy Design Tool: Mapping Approaches across a Set of Case Studies
SIEV	76.2007	*Paolo Figini, Massimiliano Castellani and Laura Vici*: Estimating Tourist Externalities on Residents: A Choice Modeling Approach to the Case of Rimini
IEM	77.2007	*Irene Valsecchi*: Experts and Non-experts
CCMP	78.2007	*Giuseppe Di Vita*: Legal Families and Environmental Protection: is there a Causal Relationship?
KTHC	79.2007	*Roberto Antonietti and Giulio Cainelli*: Spatial Agglomeration, Technology and Outsourcing of Knowledge Intensive Business Services Empirical Insights from Italy
KTHC	80.2007	*Iacopo Grassi*: The Music Market in the Age of Download
ETA	81.2007	*Carlo Carraro and Alessandra Sgobbi*: Modelling Negotiated Decision Making: a Multilateral, Multiple Issues, Non-Cooperative Bargaining Model with Uncertainty
CCMP	82.2007	*Valentina Bosetti, Carlo Carraro, Emanuele Massetti and Massimo Tavoni*: International Energy R&D Spillovers and the Economics of Greenhouse Gas Atmospheric Stabilization

(lxxxi) This paper was presented at the EAERE-FEEM-VIU Summer School on "Computable General Equilibrium Modeling in Environmental and Resource Economics", held in Venice from June 25th to July 1st, 2006 and supported by the Marie Curie Series of Conferences "European Summer School in Resource and Environmental Economics".

(lxxxii) This paper was presented at the Workshop on “Climate Mitigation Measures in the Agro-Forestry Sector and Biodiversity Futures”, Trieste, 16-17 October 2006 and jointly organised by The Ecological and Environmental Economics - EEE Programme, The Abdus Salam International Centre for Theoretical Physics - ICTP, UNESCO Man and the Biosphere Programme - MAB, and The International Institute for Applied Systems Analysis - IIASA.

(lxxxiii) This paper was presented at the 12th Coalition Theory Network Workshop organised by the Center for Operation Research and Econometrics (CORE) of the Université Catholique de Louvain, held in Louvain-la-Neuve, Belgium on 18-20 January 2007.

2007 SERIES

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