

van der Zwaan, Bob; Gerlagh, Reyer

**Working Paper**

## Climate Uncertainty and the Necessity to Transform Global Energy Supply

Nota di Lavoro, No. 95.2004

**Provided in Cooperation with:**

Fondazione Eni Enrico Mattei (FEEM)

*Suggested Citation:* van der Zwaan, Bob; Gerlagh, Reyer (2004) : Climate Uncertainty and the Necessity to Transform Global Energy Supply, Nota di Lavoro, No. 95.2004, Fondazione Eni Enrico Mattei (FEEM), Milano

This Version is available at:

<https://hdl.handle.net/10419/117975>

**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.*

**Climate Uncertainty and the  
Necessity to Transform  
Global Energy Supply**

Bob van der Zwaan and Reyer Gerlagh

NOTA DI LAVORO 95.2004

**JUNE 2004**

CCMP – Climate Change Modelling and Policy

Bob van der Zwaan, *Policies Studies Department, Energy research Centre of the Netherlands  
and John F. Kennedy School of Government, Harvard University*  
Reyer Gerlagh, *IVM, Vrije Universiteit*

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=XXXXXX>

The opinions expressed in this paper do not necessarily reflect the position of  
Fondazione Eni Enrico Mattei

# Climate Uncertainty and the Necessity to Transform Global Energy Supply

## Summary

This paper analyses the policy relevance of the dominant uncertainties in our current scientific understanding of the terrestrial climate system, and provides further evidence for the need to radically transform - this century - our global infrastructure of energy supply, given the global average temperature increase as a result of anthropogenic carbon dioxide emissions. We investigate the effect on required CO<sub>2</sub> emission reduction efforts, both in terms of *how much* and *when*, of our uncertain knowledge today of the climate sensitivity to a doubling in them atmospheric CO<sub>2</sub> concentration. Also the roles of carbon-free energy and energy savings, and their evolutions over time, are researched, as well as their dependence on some of our characteristic modelling features. We use a top-down model in which there are two competing energy sources, fossil and non-fossil. Technological change is represented endogenously through learning curves, and modest but non-zero demand exists for the relatively expensive carbon-free energy resource.

**Keywords:** Global warming, CO<sub>2</sub> emissions, Climate sensitivity, Fossil to non-fossil transition, Carbon-free power, Energy savings

**JEL Classification:** O30, Q25, Q42, Q43, Q48

*The work that lead to this publication has been performed under the EU-funded NEMESIS/ETC project, known at the European Commission under contract No. ENG2-CT- 2001-00538. This EU grant is greatly acknowledged. The authors thank Marty Hoffert for sharing his views on this paper's subject matter with them. The writing of this article has been stimulated by numerous presentations on the subject of climate uncertainty, given at the MIT Global Change Forum XXI, Climate Uncertainty, Long-term Goals, and Current Mitigation Effort, Cambridge MA, 8-10 October 2003.*

*Address for correspondence:*

Bob van der Zwaan  
Energy Research Centre of the Netherlands (ECN)  
Policy Studies Department  
P.O. Box 37154  
1030 AD Amsterdam  
The Netherlands  
E-mail: vanderzwaan@ecn.nl or bob\_vanderzwaan@harvard.edu

## 1. Introduction

The sensitivity of the global mean temperature to increasing levels of atmospheric CO<sub>2</sub> is currently known only to about a factor of three. To be more precise, the climate sensitivity,  $\Delta T_{2X}$  – defined as the global mean climatological temperature change  $\Delta T$  resulting from a doubling of atmospheric carbon dioxide content  $X$  – is thought, today, to lie in a range of about 1.5 to 4.5 C. These numbers have been derived primarily from computer-models, have been reported by the International Panel on Climate Change (IPCC), and have subsequently been used by both scientific and policy-making communities the world over, for almost a decade now (IPCC, 1996 and 2001). In a recent article, Caldeira *et al.* (2003) reported their finding that, in analyses in which scientists attempt to determine the levels of allowable CO<sub>2</sub> emissions, the uncertainty with which we currently know the value of the climate sensitivity,  $\Delta T_{2X}$ , has a larger effect (that is, is more determinant for the calculation of these levels) than the uncertainty in our understanding today of the carbon cycle. Because of the sizeable uncertainties that dominate so many of the scientific results in the field of climatic change studies, and the relevance of these uncertainties for effective and efficient global warming policy-making, the subject of uncertainty analysis has recently been receiving increased attention (as can e.g. be seen from the number of conferences today dedicated to this topic; see, for example, MIT, 2003). This article explores the relation between climate sensitivity uncertainties and the necessity to transform world energy supply. In particular, we put our modelling results into perspective with the findings presented by Caldeira *et al.* (2003) and focus on the desired transition of the global energy system during the 21<sup>st</sup> century.

Today's global energy supply is highly dependent on fossil fuels, and the choice for new and/or renewable sources as the basis of our energy system will undoubtedly require a costly transition. Nonetheless, for the long run, such a transition seems inevitable, given the risks to humankind involved with climate change. Only two main options exist to reduce carbon-dioxide emissions. These are energy savings, on the one hand, and a transition to the use of non-carbon energy, on the other hand. Energy savings are essential for reaching emission reduction targets, especially in the short term, but since energy is essential for economic production (see, for example, Berry *et al.*, 1978), it needs to be complemented by a transformation of the global energy production system. In fact, since the emission intensity of energy production will finally need to fall down to close-to-zero levels (Wigley *et al.*, 1996), a radical energy system overhaul seems imperative. Most scientists and climate specialists today see both an enhanced development of energy-saving technologies and a shift towards non-greenhouse-gas-emitting energy resources as major elements of policies aiming at a

stabilisation of atmospheric carbon-dioxide concentrations. Until recently, however, most top-down integrated assessment models of global warming focused on the energy saving option as the main route to reach emission reductions. Well-known examples of these are CETA, DICE, MERGE, RICE and FUND (Peck and Teisberg, 1992; Nordhaus, 1994; Manne *et al.*, 1995; Nordhaus and Yang, 1996; Tol, 1999).

To address the effect of climate sensitivity uncertainties on policies regarding the control and reduction of carbon emissions, as well as on the required timing of these reductions, we use an integrated assessment model that was specially developed to study policy questions related to global warming, energy supply and technological change. The model, DEMETER, is a general equilibrium model that incorporates a simplified climate change module. DEMETER allows analysing energy savings and energy supply transition processes simultaneously, while it does not display the technological detail of many energy systems-engineering models. Not considering it necessary to describe the model in full detail here again (see Gerlagh *et al.*, 2004, for an extensive description), we highlight four of its main elements. First, it includes two competing energy technologies, one of which has zero net CO<sub>2</sub> emissions. This allows emission reductions to be achievable through a transition towards a carbon-free technology, as an alternative to the substitution of energy by capital and labour. Second, it distinguishes old from new capital, in such a way that substitution possibilities between production factors only apply to new stocks of capital. This so-called ‘vintage’ approach allows for using different substitution elasticities for the short and long term, and can, in particular, describe a slow diffusion process. Third, it includes learning-by-doing, through the use of learning curves. In this way, a transition towards alternative technologies leads to lower energy production costs for these technologies, and thereby enhances their opportunities and accelerates the transition process (see also Messner, 1995). Fourth, it includes substitution elasticities, such that new technologies can spread before they become fully mature – even though their production costs are initially high.

DEMETER has been used successfully already for a few different research subjects (see van der Zwaan *et al.*, 2002; Gerlagh and van der Zwaan, 2003 and 2004; Gerlagh *et al.*, 2004). In this paper, we use DEMETER to investigate the variability of carbon emission reduction efforts, as well as that of their timing, as resulting from uncertainties in climate sensitivity, under the presence of a stringent climate change policy – that is, when constraining the global average temperature increase or applying a stringent constraint to the atmospheric carbon dioxide concentration. We also describe the sensitivity of energy savings and the evolution of the share of non-fossil technologies, to changes in a few of the most relevant model parameters. Below, section 2 concisely describes the main features of DEMETER and its calibration. Section 3 presents the results of our analysis, derives the policy implications of current uncertainties in climate

sensitivity, and underlines the necessity to transform our global energy supply system. Section 4 summarises our findings and concludes.

## 2. Model Description and Calibration

DEMETER is an optimal-growth (welfare maximisation) model of the world economy. It is designed to calculate cost-effective carbon taxes that maximise the discounted value of utility obtained from the consumption of a generic consumer good. Welfare is maximised subject to a number of economic, technological and climatic constraints. The model describes three production sectors, one for the consumer good, and two for energy production. The two energy sectors use different technologies: the first ‘old’ technology uses fossil-fuels ( $F$ ), while the second ‘new’ technology uses backstop energy sources (e.g. solar or wind energy) with assumed zero carbon-dioxide emissions ( $N$ ). DEMETER uses a vintage approach to describe production processes, allowing a differentiation in short-term and long-term elasticities of substitution between various inputs. The production of the consumer good is described by a nested constant-elasticity-of-substitution (CES) function (see Gerlagh *et al.*, 2004). One of our specific assumptions is that production costs decrease *endogenously* as experience increases (see, for example, Chakravorty *et al.*, 1997; Goulder and Schneider, 1999; Carraro *et al.*, 2003), and that production costs converge to a strictly positive floor price. We assume a constant learning rate,  $lr > 0$ , for technologies at the beginning of their learning curve. This means that, initially, production costs decrease by a factor  $(1 - lr)$ , for every doubling of installed vintages.

Another distinguishing feature of DEMETER is that a long-term elasticity of substitution is modelled between the two energy sources,  $F$  and  $N$ , denoted by  $\sigma$ . The CES aggregation of  $F$  and  $N$  marks an important extension of our model compared to existing models. It describes a strictly positive demand for the new technology  $N$ , even if the price of the new technology largely exceeds the price of the old technology  $F$ . Photo-voltaic energy would be an example, since it is used in remote areas irrespective of its high costs, given the local difficulty to connect to a nearby electricity grid. We have chosen a value for the elasticity of substitution  $\sigma$  that is bounded and larger than one. For an extensive justification of this value we refer to Gerlagh and van der Zwaan (2004). Approximately, the parameter  $\sigma$  determines the share of the fossil-fuel based energy source relative to the share of the non-fossil-fuel energy source,  $(F_t / N_t)$ , given their relative production costs,  $(p_t^F / p_t^N)$ , as follows (as a function of time):

$$(F_t / N_t) = (p_t^F / p_t^N)^{-\sigma}. \quad (1)$$

Carbon emissions,  $E_t$ , are proportional to the use of fossil-fuel-based energy  $F_t$ , via the aggregate carbon emission factor  $\varepsilon_t$ :

$$E_t = \varepsilon_t F_t. \quad (2)$$

The factor  $\varepsilon_t$  is assumed to be time-dependent (but exogenous), to account for the decarbonisation process to which the use of fossil fuels has been subject since the early times of industrialisation, by a transition – in chronological order – from wood to coal, from coal combustion to that of oil, and most recently from coal and oil to natural gas. Carbon emissions are linked to the atmospheric carbon-dioxide concentration, which in turn determines the global average surface temperature, through a 1-box representation as in the early DICE model (Nordhaus, 1994). As in Caldeira *et al.* (2003), the stabilisation level of the atmospheric CO<sub>2</sub> concentration,  $P_{stab}$ , and the stabilisation value of the temperature increase,  $\Delta T_{stab}$ , are related through:

$$\frac{P_{stab}}{P_{280}} = 2^{\left(\frac{\Delta T_{stab}}{\Delta T_{2X}}\right)}, \quad (3)$$

in which  $P_{280}$  stands for the pre-industrial atmospheric CO<sub>2</sub> concentration of 280 ppmv, and  $\Delta T_{2X}$ , as above, for the climate sensitivity (with central value of 3 degrees Celsius per doubling of the atmospheric CO<sub>2</sub> concentration).

The inclusion of a temperature or atmospheric carbon concentration constraint in the model results in a positive shadow price for carbon emissions. This emissions shadow price can be interpreted as the tax required on carbon emissions to meet the temperature or concentration constraint that we impose in our model. Additional to the carbon tax, the model calculates an efficient subsidy on investments in new/renewable energy production. Since investments in non-fossil-fuel energy production lower future costs of energy production, through the learning mechanism, the shadow price (or social costs) for such investments lies below the immediate costs, that is, below the consumption foregone. The gap between this investment shadow price and the immediate costs can be interpreted as the subsidy on investments that internalises the learning effect.

For this paper's purpose, we have basically analysed two kinds of scenarios. The first kind of scenario, 'business-as-usual' (BAU), assumes no control on carbon-dioxide emissions. It also assumes that there is no policy stimulating the use of the non-fossil-fuel energy source, that is, it abstracts from both taxes and subsidies. The second kind of scenario sets a ceiling on the average global temperature increase, or, roughly equivalently, a constraint on the atmospheric carbon dioxide concentration. In this study, the average temperature increase is not allowed to rise above 2 degrees Celsius,

compared to its pre-industrial value. This is an ambitious scenario that involves taking drastic emission reduction steps (see Schneider and Azar, 2001). In contrast to the first type of scenario, in the temperature-constrained scenario it is assumed that both taxes on carbon emissions are applied, and subsidies are available for investments in the non-fossil-fuel energy source.

DEMETER has been calibrated in order to obtain modelling results that mimic real-world phenomena as closely as possible. The world population is assumed to grow from 5.89 billion in 1997 at a rate of 1.45 % per year, levelling off and reaching 11.4 billion by 2100 (World Bank, 1999, and Nakicenovic *et al.*, 1998). Gross World Product (GWP) in 1997 is assumed to have been 25.1 trillion US\$1990 (World Bank, 1999) and its future annual per capita growth rate is assumed to be 1.5 %. The value assumed for the autonomous energy services efficiency improvement (AESEI) is 1.0 % per year. The AESEI measures the productivity increase of our CES aggregate. The combined assumptions on population growth, GWP growth and the value of AESEI result in an energy consumption growth rate of 1.9 % per year in 2000, which decreases to 0.6 % per year in 2100.

The aggregation of final energy supply over various energy sources such as electricity and heat is facilitated by conversion of all final energy data in primary energy equivalents. Specifically, for electricity, energy flows measured in ExaJoule per year (EJ/yr) are divided by 0.33, the typical conversion efficiency from heat to electricity, while electricity prices, measured in US dollars per GigaJoule (\$/GJ), are multiplied by 0.33, to arrive at volumes and prices, respectively, in primary energy equivalents. Over the year 1997, commercial final energy supply (in primary energy equivalents) based on fossil-fuel energy sources is estimated to have been some 307 EJ, and related carbon emissions are assumed to have been 6.3 GtC. Carbon emissions related to land-use changes and industrial processes are around 1.3 GtC, and are assumed constant over time. By dividing the fossil-fuel carbon emissions of 6.3 GtC by the fossil-fuel commercial final energy (services) supply of 307 EJ, one obtains the carbon emission intensity of fossil-fuel commercial final energy (services) supply,  $\bullet_t$ , which amounts to 0.021 gC/kJ in 1997. The fossil-fuel technology is assumed to be subject to a ‘decarbonisation’ of 0.2 % per year, which continues until a floor is reached of 0.016 gC/kJ.

On the basis of the database developed for the IIASA-WEC study (Nakicenovic *et al.*, 1998), final commercial energy consumption in 1997 is estimated to be (in primary energy equivalents) 320 EJ.<sup>1</sup> From the same database, the share of fossil-fuel

---

<sup>1</sup> This excludes non-commercial biomass use, as well as ‘traditional’ carbon-free sources such as nuclear and hydropower. However important these may be, we do not consider these energy resources in this analysis for ease of exposition.



technologies in energy production (in 1997) is estimated to be 96 %. This corresponds to the 307 EJ mentioned above. The remaining share of 13 EJ is non-fossil-fuel energy. Thus, in equation (1), the ratio at the left-hand-side is about 24. Prices, in primary energy equivalents, for energy derived from natural gas technologies vary in a range from 2 to 3 \$(1990)/GJ (IEA/OECD, 1999, p.41). Since coal, oil and natural gas are more or less competitive, a good reference price in our calculations for the average fossil-fuel energy resource is 2.5 \$/GJ, in the model start-off year 1997 (this price in primary energy equivalents corresponds to a price of  $2.5 \times 3.33 = 8.3$  \$/GJ in final electricity units). A large spread exists in production costs for energy from e.g. wind and solar energy (electricity) options. Prices, in primary energy equivalents, for commercial final electricity from wind turbines varied in 1995 between 2 and 7 \$(1990)/GJ, in the highest-cost and lowest-cost production cases, respectively (IEA/OECD, 2000, p.54; Gerlagh and van der Zwaan, 2004). Electricity production costs for photo-voltaic systems are still significantly higher than those for wind energy (IEA/OECD, 2000, p.21). We consider a realistic range for the ratio of production costs (non-fossil vs. fossil) to be a factor varying from 2 to 5, consistent with an elasticity of substitution ranging from about  $\sigma=2$  to  $\sigma=4$ . As central value, we take  $\sigma=3$ . Given fossil-fuel energy prices of 2.5 \$/GJ, this value for  $\sigma$  is consistent – see equation (1) – with production costs for the non-fossil-fuel energy source of 7.2 \$/GJ, in the year 1997 (this latter price in primary energy equivalents corresponds to a price of  $7.2 \times 3.33 = 24$  \$/GJ in final electricity units). For the basis parameter values, in 1997, energy production accounts for about 2.7 % of GWP. As lower bound for  $\sigma$  we take  $\sigma=2$ , and we adjust the initial production costs for the non-fossil-fuel energy source accordingly, to 12.2 \$/GJ. As upper bound we take  $\sigma=4$ , and we adjust initial non-fossil-fuel prices to 5.5 \$/GJ.

The learning rate for non-fossil-fuel energy resources is assumed to be 20% per doubling of installed vintages, in line with the empirical evidence on this variable for e.g. solar power and wind suggesting that the learning rate ranges from 8 to 35% (McDonald and Schrattenholzer, 2000). The fossil-fuel energy technology is assumed to have used most of its learning potential already. The cumulative capacity of installed vintages up to the year 1997 is estimated to be about 1200 EJ and 32 EJ for the fossil-fuel energy option and the non-fossil-fuel energy alternative, respectively.<sup>2</sup> Under the baseline scenario, the cumulative capacity of installed vintages for the carbon-free energy technology is doubled by 2020. Consequently, under the central parameter choice, production costs have decreased by 20%, and for  $\sigma=3$  the market share will have

---

<sup>2</sup> For how we derived these figures for the cumulative installed capacity of past vintages, we refer to Gerlagh and van der Zwaan (2004).

increased by approximately 75%, corresponding to an increase of 3% in total energy supply, from 4% to 7%.

### 3. Results

We have calculated the optimal carbon emission path under three different climate sensitivities. Figure 1 shows the carbon dioxide emission evolutions both under a business-as-usual scenario (BAU, in solid squares) and under five different scenarios in which global warming is controlled through some policy intervention - in modelling terms through the imposition of an exogenous constraint on our simulations. Among the five climate-constrained scenarios, the first three cases involve a limitation of the average global temperature increase to 2 degrees Celsius, each under a different climate sensitivity assumption.

The central climate sensitivity we use is a 3 degrees Celsius temperature increase resulting from a doubling of the atmospheric concentration of carbon dioxide (C/doubling). We have varied this climate sensitivity from 3 C/doubling down to 2 C/doubling and up to 4 C/doubling. A 4 C/doubling climate sensitivity involves, naturally, a more stringent climate policy than the case in which we use a 3 C/doubling, so that more radical emission reductions are called for in the former case, compared to those needed in the latter. A 2 C/doubling climate sensitivity clearly involves less stringent policy measures, as demonstrated in Figure 1. We point out that our sensitivity analysis regarding the climate sensitivity parameter can also be interpreted as one regarding the temperature constraint used in our policy scenarios, with temperature increase targets of 1.5, 2 and 3 degrees Celsius, respectively. To put it more precisely, varying the climate sensitivity from a central value of 3 C/doubling down to a lower value of 2 C/doubling, under a 2 degrees Celsius stabilisation constraint, is equivalent to keeping the climate sensitivity at 3 C/doubling, but increasing the temperature target from 2 to 3 degrees Celsius. Inversely, varying the climate sensitivity from a central value of 3 C/doubling up to a value of 4 C/doubling, under a 2 degrees Celsius stabilisation constraint, is equivalent to keeping the climate sensitivity at 3 C/doubling, but decreasing the temperature target from 2 to 1.5 degrees Celsius.

We have generated two additional policy scenarios, as an extra check regarding the sensitivity of our results to different climate change targets. We have changed our 2 degrees Celsius constraint into an atmospheric CO<sub>2</sub> concentration constraint, of 450 ppmv and 550 ppmv (CO<sub>2</sub>) respectively, the results of which are shown in Figure 1. As can be seen, for the long-term, a constraint on the atmospheric carbon dioxide concentration of 450 ppmv is slightly more flexible than a 2 degrees Celsius constraint with a 3 C/doubling climate sensitivity. But for (more than) the first half of the century,

it is a more stringent constraint. The 550 ppmv carbon dioxide concentration scenario resembles the 2 degrees Celsius constraint scenario with 2 C/doubling climate sensitivity.

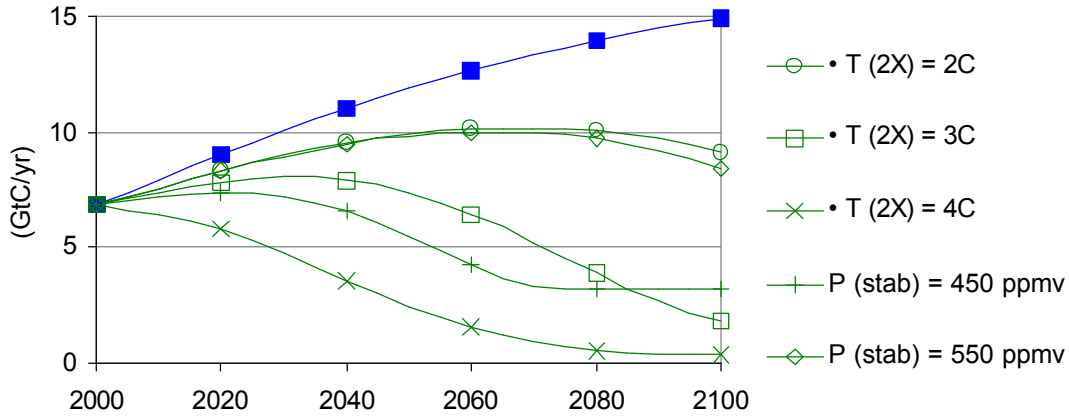


FIGURE 1. Carbon dioxide emissions under various climate sensitivities and policy scenarios.

Table 1 displays the variability of emissions, the share of energy savings in total emission reductions, and the share of carbon-free energy sources in total energy supply, in 2020, under three different climate sensitivities and two different concentration constraints. As can be seen, the emission reduction effort (first results-column) strongly depends on the assumed climate sensitivity, and also varies over the carbon concentration constraint employed. The extent to which energy savings are used as instrument to reach the climate objective is little dependent on the value of either the sensitivity or constraint. In formal terms, the savings vs. total emission reductions share can be expressed as:

$$\frac{(E_t^{BAU} - E_t^{2C})}{E_t^{BAU}} \bigg/ \frac{(Em_t^{BAU} - Em_t^{2C})}{Em_t^{BAU}}, \quad (4)$$

where  $E_t^{BAU}$  is the energy level in the BAU scenario,  $E_t^{2C}$  the energy level in the 2 C climate-constrained scenario,  $Em_t^{BAU}$  are the emissions in the BAU scenario, and  $Em_t^{2C}$  the emissions in the 2 C scenario (all dependent on time  $t$ ). By 2020, about half of the emission reductions are attained through savings.

The non-fossil share of energy supply, in 2020 - hence the extent to which a transition towards non-fossil fuels is realised by then - displays a significant dependence on the parameter values used, especially in case of the climate sensitivity parameter.

TABLE 1. *Emissions, energy savings share in emission reductions, and carbon-free share in energy supply, under different climate sensitivities and climate constraints.*

	Lower value	Basis value	Upper value	Emissions in 2020 (GtC/yr)	Energy Savings / Emission Reduction in 2020 (%)	Non-Fossil share in 2020 (%)
Basis (with 2 C climate constraint)				7.8	52	12
Climate sensitivity (C/doubling)	(4,	3,	2)	<b>(5.8, 8.3)</b>	<b>(48, 49)*</b>	<b>(9, 27)*</b>
CO <sub>2</sub> concentration constraint (ppmv)	(450		550)	(7.4, <b>8.3)</b>	(49, <b>53)*</b>	<b>(9, 14)*</b>
<b>Overall range</b>				<b>(5.8, 8.3)</b>	<b>(48, 53)</b>	<b>(9, 27)</b>

N.B. The largest extremities reached are in bold and are indicated in the last row as 'overall range'.

\* Asterics denote intervals where the lower bound of the sensitivity result is associated with the upper value of the corresponding parameter.

How do these results compare with those found in the literature? Table 2 juxtaposes our findings, for two (rather extreme) climate sensitivity values, next to the ones presented in Caldeira *et al.* (2003), and indicates that, apart from a number of similarities, a few seemingly important differences exist. With a 2 C/doubling climate sensitivity, 2020 emissions in our study are found to be roughly the same as those in Caldeira *et al.* (2003); increasing this sensitivity to 4 C/doubling induces considerable decreases in emissions, of 30% and 39% in the two cases respectively. As for the carbon-free share in total energy supply, in 2020, we find that its value triples, from 9% to 27%, when changing the climate sensitivity from 2 to 4 C/doubling. In Caldeira *et al.* (2003), it is found that this value almost doubles, from 34% to 60%. For the non-fossil energy share, their results differ less from ours than it may seem from quick examination. Closer scrutiny points out that we express non-fossil shares with respect to total energy supply, while they do so in comparison to total electric power generation. This explains that the numbers displayed differ by a factor of about 4 (9 compared to 34, in the 2 C/doubling case) to 2 (27 compared to 60, in the 4 C/doubling case). The difference in results between these two factors, 4 and 2 respectively, can be explained as well. Increasing the share of power production in energy supply proves the most efficient way to increase the share of (mostly electric) non-fossil energy in total supply. With a high (4 C/doubling) climate sensitivity, reaching the 2 C climate constraint is much more ambitious than in the 2 C/doubling case, that is, much more carbon-free energy needs to be employed (in a rather short time). Hence, in the 4 C/doubling case the electricity-to-total-energy ratio is likely to be significantly higher than in the 2 C/doubling case, explaining why the numbers 27 and 60 lie closer in each other's

vicinity (that is, differ by 'only' about a factor of two) than 9 and 34 (off by a factor of almost 4). Overall, the results prove thus consistent.

TABLE 2. *Emissions and carbon-free share in total energy supply, in 2020, under different climate sensitivities.*

			Climate sensitivity	
			2	4
Emissions in 2020 (GtC/yr)		This study	8.3	5.8
		Caldeira <i>et al.</i> (2003)	8.0	4.8
Non-Fossil Share in 2020 (%)	(energy)	This study	9	27
	(electricity)	Caldeira <i>et al.</i> (2003)	34	60

N.B. The quoted Caldeira *et al.* (2003) data are obtained through inspection of their figures 1 and 2.

We observe, with Caldeira *et al.* (2003), that even under central assumptions for the climate constraint and sensitivity, a massive transition towards non-fossil energy is called for. By the end of the century, between 75% and 100% of total power demand will need to be provided by non-CO<sub>2</sub> releasing energy sources (Caldeira *et al.* 2003), or, in between 80% and 90% of total energy supply (our analysis).

In this article we go a few steps further and exploit the advantages of using a top-down model like DEMETER: we have calculated the relative importance of energy savings versus the transition from fossil-fuel towards non-fossil-fuel energy sources for reaching the climate stabilisation objective. In Gerlagh and van der Zwaan (2004), we reported our findings regarding the share of emission reductions, relative to the BAU benchmark, reached through energy savings measures (the first policy option, as also displayed in the second results-column of Table 1). The remainder of the emission reductions, we concluded, is reached through the second policy option (a transition to non-fossil-fuel energy sources). Let's here expand on the mechanisms through which emission reductions take place. In Figure 2, we present the trade-off between energy savings and the decarbonisation of energy supply. That is, for reaching the climate stabilisation target, the model chooses between decreasing the energy intensity of total output, on the horizontal axis, versus decreasing the emissions per energy output by shifting energy supply to non-carbon energy sources, on the vertical axis. The figure presents the relative use of these two options for the period 2000-2050. The figure shows that the path is almost entirely independent of the climate change target or the climate sensitivity used, although the extent of progression along the path depends significantly on the stringency of the climate change target or the value of the climate sensitivity. The figure shows that energy savings constitute mainly an option for moderate and medium emission reductions. The first part of emission reductions is

reached through both energy savings and energy decarbonisation, both in approximately equal shares, consistent with the reporting in Table 1. When energy savings exceed the level of 20%, it becomes an expensive option, in relative terms, and the development of the non-carbon energy source becomes more favourable. The curve thus bends backwards. For a substantial cut in emissions, the policy option of energy savings is then used to only a limited extent at most. The explanation is that, when the non-fossil-fuel energy source has reached a substantial share in total energy supply, it has become sufficiently competitive to take over the role of the fossil-fuel energy source as the main contributor to total energy supply.<sup>3</sup>

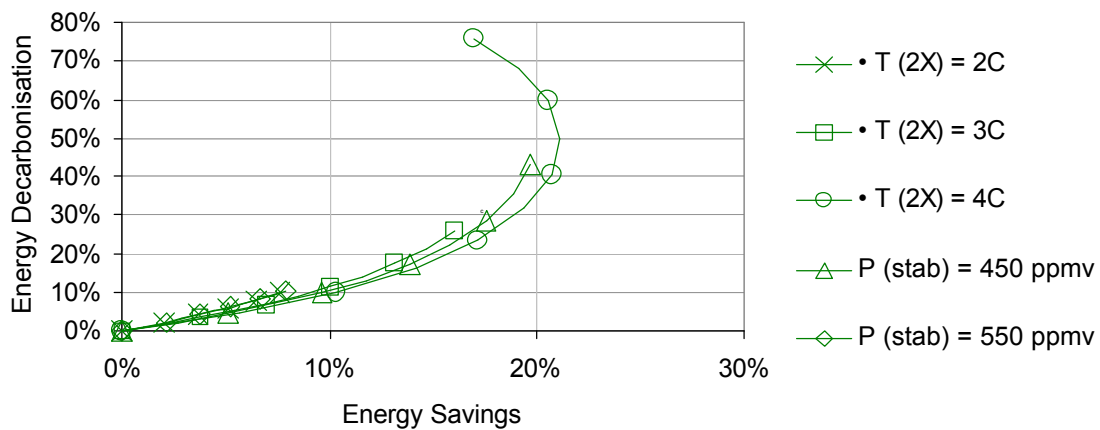


FIGURE 2. *Relative importance of energy savings and energy decarbonisation in total emissions reduction under different climate change parameters.*

Apart from showing the savings vs. decarbonisation dependence on the value adopted for the climate change sensitivity, we present a similar figure for the central climate change parameters, but now with different *economic* parameters. Figure 3 depicts four additional (2 C) scenarios in which the learning rate (LR) and energy substitutability ( $\bullet$ ) are changed to other-than-central values, to demonstrate the impact of certain important parameter modifications. It can be seen from Figure 2 that if the non-fossil-fuel energy source has sufficient potential to replace the fossil-fuelled one, that is, if the learning rate is 30% or the substitution elasticity  $\bullet$  has value 4, the transition to the non-fossil-fuel energy source is the main mechanism for emissions reduction, even in early periods. These cases correspond to the curves on the left-hand side of the graph. Alternatively, when the non-fossil-fuel energy source possesses no good capacity to replace fossil fuels, that is, when we assume a low learning rate,

<sup>3</sup> The value of the relative importance of energy savings in the total amount of emissions reduction may fall below zero: a very successful transition to non-fossil-fuel energy permits an expansion of total future energy use.

LR=10%, or a low substitution elasticity,  $\sigma=2$ , energy savings remain the most important window for emissions reduction in both the short and medium term.

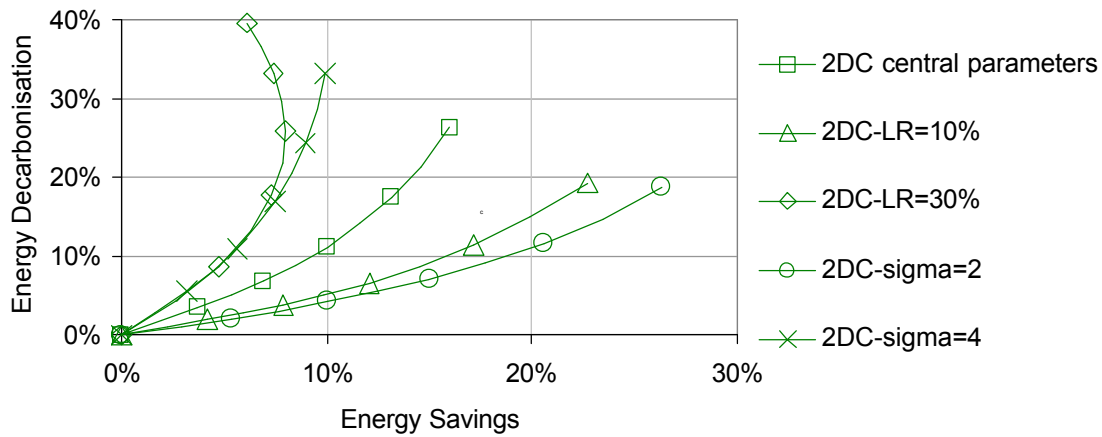


FIGURE 3. *Relative importance of energy savings and energy decarbonisation in total emissions reduction under different economic parameters.*

Nonetheless, in the long-term, the transition to the non-carbon energy source remains the dominant strategy. Figure 4 shows the share of the non-fossil-fuel energy source in total energy supply for 2 C temperature-constrained scenarios. While in the short term the transition to (and thus the share in total supply of) non-fossil energy remains sensitive to economic parameter values, in the longer run the transition becomes the predominant method to reach climate objectives, and becomes almost insensitive to choices for the values of parameters LR and  $\sigma$ . For the central parameter choice, the non-fossil share increases by nearly 1% per year, to a share of about 95% in 2100. This finding portrays a substantial acceleration in the transition of the energy system to non-fossil-fuel energy sources in comparison to the BAU reference scenario (not plotted in the figure). In the BAU scenario, under central parameter values, the share of the non-fossil-fuel energy source increases from 4% in 2000 to 33% in 2100.

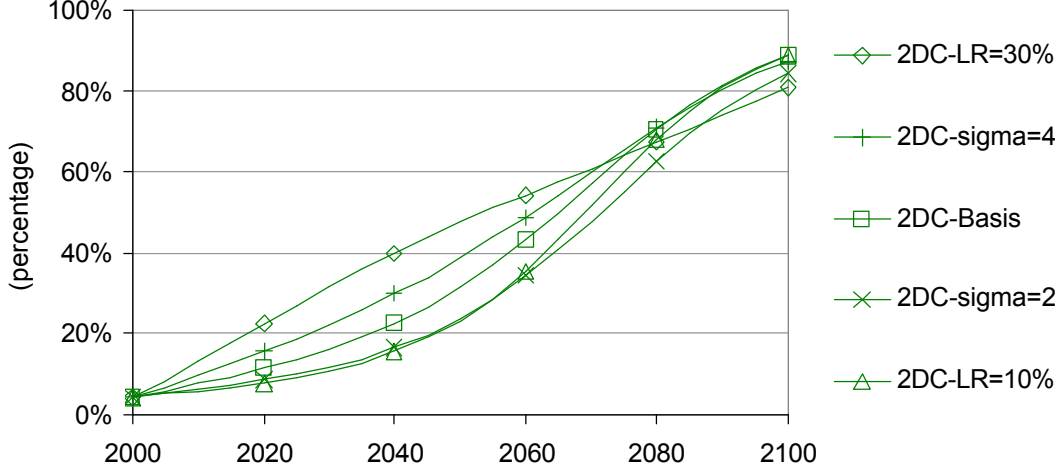


FIGURE 4. *Fraction of energy supply produced by the carbon-free technology.*

We end by turning to the main subject of this paper, the effect of assuming different climate sensitivities on long-term temperature-constrained energy supply scenarios, in particular the impact on the timing of required emission reductions. In particular, we want to confirm the acclaimed necessity of realising early carbon emission reductions. For this purpose, we need a more precise meaning of emissions abatement timing that constitutes a common measure of timing applicable to scenarios defined by different parameter values and/or climate constraints. We define the emissions reduction effort in period  $t$  under a climate-constrained (e.g. 2 C) scenario as the amount of emissions reduced relative to the emissions level in the BAU scenario. The timing of abatement can be presented as the development over time of the emissions reduction effort, relative to this same effort in 2050, formally calculated by:

$$\frac{(Em_t^{BAU} - Em_t^{2C})}{Em_t^{BAU}} \bigg/ \frac{(Em_{2050}^{BAU} - Em_{2050}^{2C})}{Em_{2050}^{BAU}}, \quad (5)$$

where  $Em_t^{BAU}$  are emissions in the BAU scenario, and  $Em_t^{2C}$  are emissions in the 2 C scenario (the subscripts  $t$  and 2050 indicating the particular moments in time under consideration). The results are presented in Figure 5 for scenarios with the three earlier different climate sensitivity values (with a 2 C temperature constraint) and the two carbon concentration constraint values. The figure shows that the emissions reduction effort is almost linearly increasing in time, and is almost unaffected by either changes in the climate sensitivity assumed or the CO<sub>2</sub> concentration constraint imposed. This is a remarkable finding, first of all because the calculated emission paths vary widely among different climate sensitivities and targets, as we have seen in Figure 1. Furthermore, due to the vintage structure of DEMETER, emission intensities are fixed for old vintages.



Thus, the linear path of the emissions reduction effort has to be reached through a substantial cut in the emission intensity of new vintages. We hence observe that although the overall emissions reduction effort (obviously) depends strongly on both the climate sensitivity and objective, the timing of the effort is almost independent of either this sensitivity or policy target.

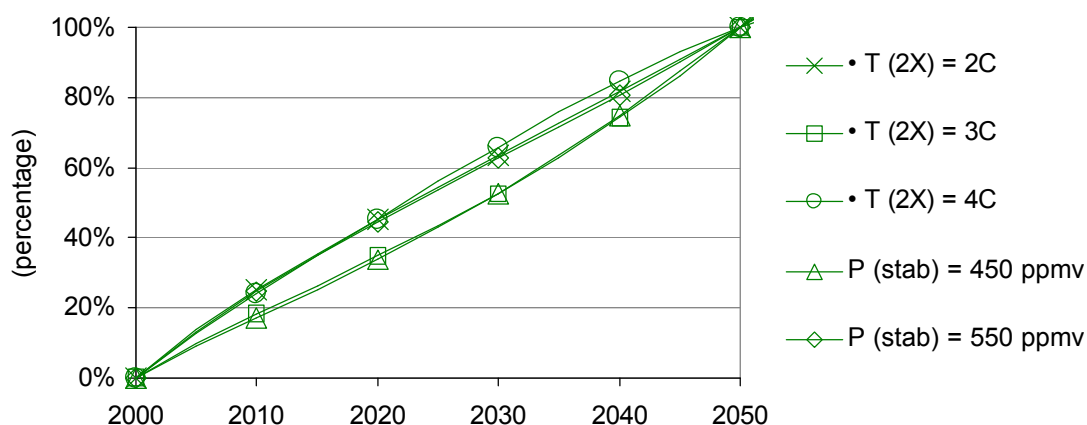


FIGURE 5. *Timing of emission reduction efforts.*

#### 4. Conclusions

In this paper we have, first of all, provided further evidence of the claim brought forward in one of our recent publications (Gerlagh and van der Zwaan, 2004) that by playing around with the values of some of the parameters used in climate change models one loses significance in the findings derived from them. In particular, in the analysis presented in this paper we have done so regarding the climate sensitivity parameter. We have demonstrated that whether one assumes 2, 3 or 4 C temperature increase per doubling of the atmospheric carbon dioxide concentration matters a lot for the calculated emission path during the 21<sup>st</sup> century. Meanwhile, however, we have pointed out that irrespective of the climate sensitivity assumed, many results continue to hold. Regarding carbon emissions we have seen that substantial reductions are called for, under whatever climate sensitivity, and that, sooner or later, the emission path should be pushed downwards in order to reach climate change objectives. Indeed, the overall obliged energy transformation that follows from our model continues to hold, even under large variations of the value of the sensitivity parameter: by the end of the century the vast majority of energy production should be non-fossil based.

We have seen that the emission reductions that ought to be reached in 2020 are strongly dependent on the value of the climate sensitivity, as is the non-fossil share in total energy supply realised in that year. The extent to which energy savings are used to meet reasonable climate requirements, however, depends little on this sensitivity: by

2020 around half of emission reductions should be attained through savings. We have paid particular attention to compare our results with those of Caldeira *et al.* (2003). A number of numerical differences appeared to exist between their and our analysis results, but most of these were more or less explainable, or merely resulted from the difference in nature between the respective models used. Most importantly, we have confirmed one of their main conclusions. As stated by the IPCC, the temperature increase resulting from a doubling in carbon dioxide concentration is probably known only to about a factor of three. This uncertainty propagates from climate stabilisation objectives, to allowable carbon concentrations and emissions, and finally to non-fossil based energy production. Uncertainties in our understanding of climate sensitivity introduces the largest possible uncertainties in allowable CO<sub>2</sub> emission paths, as can be seen from Figure 1. It is thus not surprising that these uncertainties exceed those induced by the uncertainty with which we understand the complexity of the carbon cycle (Caldeira *et al.*, 2003). But, and this is the central thrust of our research, even if climate sensitivity is at the low end of the currently accepted range (or other modelling parameters are chosen such so as to obtain the most optimistic climate results possible), by the end of the century over three-quarters of mankind's total energy supply will need to come from sources that do not emit CO<sub>2</sub> in the terrestrial atmosphere.

The results reported here have been obtained with the integrated assessment climate model DEMETER, which includes two energy sources and learning-by-doing for both of these (fossil and non-fossil) energy sources. This top-down model allows us to study the two main options for achieving substantial reductions in carbon dioxide emissions. The first is the energy savings option, in which the substitution of capital and labour for energy is allowed for. The second is the energy transformation option, in which emission reductions can be achieved through a transition from a carbon energy technology towards a carbon-free technology. The first option turns out to be of most importance in the short run, whereas the second option is needed to reach substantial emission reductions in the long run. The finding that the transformation from carbon to non-carbon energy technologies starts to play a major role only after a few decades should not create the impression that little action is called for today. On the contrary, the emission paths determined by DEMETER clearly show that in order to stabilize climate change at an increase of the atmospheric temperature of 2 C, substantial emission reductions are also called for in the short and medium term.

This analysis has also shown that the main results regarding the required global energy transformation are robust against changes in the values of even the most sensitive economic and technological parameters. The numerical results on the role of energy savings and the carbon-free technology appear most sensitive to the learning rate of the non-fossil-fuel energy source, on the one hand, and the substitution possibilities

between this energy source and the fossil-fuelled technology, on the other hand. The sensitivity of our results to the learning rate is understandable, since this rate determines the intensity of the mechanism that promotes accelerated price decreases. The learning rate contributes to determining the speed with which the transition towards a large-scale use of non-fossil-fuel energy – and thus the reduction of carbon emission – takes place. It is not surprising either that our findings are sensitive to the value of elasticity  $\sigma$ , describing the substitution potential between the two energy sources. Increasing the value of this substitution elasticity increases the potential of a transition policy and reduces the role played by energy savings. The levels of carbon taxes and subsidies for the non-fossil-fuel energy source, required to reach the temperature change stabilisation objective, were reported on in earlier publications (see e.g. van der Zwaan *et al.* 2002): they remain relatively independent of the value of these two parameters. We also spent time analysing the important policy-relevant subject of emissions reduction timing, for which we defined a common emission abatement timing measure. We conclude that although the overall emission reduction effort depends strongly on the climate sensitivity assumed, the timing of the effort is almost independent of this sensitivity.

With our findings, we have further backed the acclaimed importance of non-carbon energy resources gradually taking over, during the 21<sup>st</sup> century, currently cheaply available conventional fossil fuels. Not only for the sciences occupied with solving the global warming problem, but also for those engaged in apprehending how to establish sustainable development at large (including, for example, the problem of how to preserve global biodiversity; see van der Zwaan and Petersen, 2003), providing an understanding of how to materialise such a transition is fundamental. This paper points out once again – like done by many other studies – the need for mankind to make a substantial transition, over the decades to come, from fossil to non-fossil energy use.

### **Acknowledgements**

The work that lead to this publication has been performed under the EU-funded NEMESIS/ETC project, known at the European Commission under contract No. ENG2-CT-2001-00538. This EU grant is greatly acknowledged. The authors thank Marty Hoffert for sharing his views on this paper's subject matter with them. The writing of this article has been stimulated by numerous presentations on the subject of climate uncertainty, given at the MIT Global Change Forum XXI, *Climate Uncertainty, Long-term Goals, and Current Mitigation Effort*, Cambridge MA, 8-10 October 2003.

## References

- Berry, R.S., G. Heal, and P. Salomon (1978), 'On a relation between economic and thermodynamic optima', *Resources and Energy* **1**, 125-137.
- Caldeira, K., A.K. Jain, M.I. Hoffert, 'Climate sensitivity uncertainty and the need for energy without CO<sub>2</sub> emission', *Science*, Vol. 299, 28 March 2003, 2052-2054.
- Carraro, C., R. Gerlagh, and B van der Zwaan (2003), 'Endogenous technical change in environmental macroeconomics', Editorial, *Resource and Energy Economics* **25**, 1-10.
- Chakravorty, U., J. Roumasset, and K. Tse (1997), 'Endogenous substitution among energy resources and global warming', *Journal of Political Economy* **105**, 1201-1234.
- Gerlagh, R., B.C.C. van der Zwaan, M.W. Hofkes, and G. Klaassen (2004), 'Impacts of CO<sub>2</sub>-taxes in an economy with niche markets and learning-by-doing', *Environmental and Resource Economics*, forthcoming.
- Gerlagh, R. and B.C.C. van der Zwaan (2003), 'Gross World Product and Consumption in a Global Warming Model with Endogenous Technological Change', *Resource and Energy Economics* **25**, 35-57.
- Gerlagh, R. and B.C.C. van der Zwaan (2004), 'A sensitivity analysis of timing and costs of greenhouse gas emission reductions under learning effects and niche markets', *Climatic Change*, forthcoming.
- Goulder, L.H. and S.H. Schneider (1999), 'Induced technological change and the attractiveness of CO<sub>2</sub> abatement policies', *Resource and Energy Economics* **21**, 211-253.
- IEA/OECD (1999), *Key World Energy Statistics*, International Energy Agency, OECD, Paris.
- IEA/OECD (2000), *Experience curves for energy technology policy*, International Energy Agency, OECD, Paris.
- IPCC (1996), *Climate Change 1995: The Science of Climate Change*, J. T. Houghton *et al.* (eds.), Cambridge University Press, Cambridge, UK.
- IPCC (2001), *Climate Change 2001: The Scientific Basis*, U. Cubasch *et al.*, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, J. T. Houghton *et al.* (eds.), Cambridge University Press, Cambridge, UK.
- Manne, A.S., R. Mendelsohn, and R. Richels (1995), 'MERGE, A model for evaluating regional and global effects of GHG reduction policies', *Energy Policy* **23**, 17-34.
- McDonald, A., Schratzenholzer, L. (2001), Learning rates for energy technologies, *Energy Policy*, 29 (4), 255-261.
- Messner, S. (1995), *Endogenized technological learning, an energy systems model*, WP-95-114, IIASA, Laxenburg, Austria.

- MIT (2003), MIT Global Change Forum XXI, Cambridge MA, *Climate Uncertainty, Long-term Goals, and Current Mitigation Effort*, 8-10 October 2003.
- Nakicenovic, N. A. Grübler and A. McDonald, eds. (1998), *Global energy perspectives*, IIASA-WEC, Cambridge University Press, Cambridge, UK.
- Nordhaus, W.D. (1994), *Managing the global commons*, MIT Press, Cambridge, Massachusetts.
- Nordhaus, W.D. and Z. Yang (1996), 'A regional dynamic general equilibrium model of alternative climate-change strategies', *American Economic Review* **86**, 741-765.
- Peck, S.C. and T.J. Teisberg (1992), 'CETA, a model for carbon emissions trajectory assessment', *Energy Journal* **13**, 55-77.
- Schneider, S.H., C. Azar (2001), 'Are uncertainties in climate and energy systems a justification for stronger near-term mitigation policies?', Pew Center on Global Climate Change, [www.pewclimate.org/events](http://www.pewclimate.org/events), workshop paper, October 2001.
- Tol, R.S.J. (1999), 'Spatial and temporal efficiency, climate policy, applications of FUND', *Environmental and Resource Economics* **14**, 33-49.
- van der Zwaan, B.C.C., R. Gerlagh, G. Klaassen, and L. Schrattenholzer (2002), 'Endogenous technological change in climate change modelling', *Energy Economics* **24**, 1.
- van der Zwaan, B.C.C. and A.C. Petersen, eds., (2003), *Sharing the Planet: Population – Consumption – Species*, Eburon, Delft, 2003.
- Wigley, T.M.L., R. Richels, and J.A. Edmonds (1996), 'Economic and environmental choices, the stabilization of atmospheric CO<sub>2</sub> concentrations', *Nature* **379**, 240-379.
- World Bank (1999), *1999 World development indicators*, World Bank, Washington DC, USA.

## 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.html>

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

### NOTE DI LAVORO PUBLISHED IN 2003

PRIV	1.2003	<i>Gabriella CHIESA and Giovanna NICODANO</i> : <u>Privatization and Financial Market Development: Theoretical Issues</u>
PRIV	2.2003	<i>Ibolya SCHINDELE</i> : <u>Theory of Privatization in Eastern Europe: Literature Review</u>
PRIV	3.2003	<i>Wietze LISE, Claudia KEMFERT and Richard S.J. TOL</i> : <u>Strategic Action in the Liberalised German Electricity Market</u>
CLIM	4.2003	<i>Laura MARSILIANI and Thomas I. RENSTRÖM</i> : <u>Environmental Policy and Capital Movements: The Role of Government Commitment</u>
KNOW	5.2003	<i>Reyer GERLAGH</i> : <u>Induced Technological Change under Technological Competition</u>
ETA	6.2003	<i>Efrem CASTELNUOVO</i> : <u>Squeezing the Interest Rate Smoothing Weight with a Hybrid Expectations Model</u>
SIEV	7.2003	<i>Anna ALBERINI, Alberto LONGO, Stefania TONIN, Francesco TROMBETTA and Margherita TURVANI</i> : <u>The Role of Liability, Regulation and Economic Incentives in Brownfield Remediation and Redevelopment: Evidence from Surveys of Developers</u>
NRM	8.2003	<i>Elissaios POPYRAKIS and Reyner GERLAGH</i> : <u>Natural Resources: A Blessing or a Curse?</u>
CLIM	9.2003	<i>A. CAPARRÓS, J.-C. PEREAU and T. TAZDAÏT</i> : <u>North-South Climate Change Negotiations: a Sequential Game with Asymmetric Information</u>
KNOW	10.2003	<i>Giorgio BRUNELLO and Daniele CHECCHI</i> : <u>School Quality and Family Background in Italy</u>
CLIM	11.2003	<i>Efrem CASTELNUOVO and Marzio GALEOTTI</i> : <u>Learning By Doing vs Learning By Researching in a Model of Climate Change Policy Analysis</u>
KNOW	12.2003	<i>Carole MAIGNAN, Gianmarco OTTAVIANO and Dino PINELLI (eds.)</i> : <u>Economic Growth, Innovation, Cultural Diversity: What are we all talking about? A critical survey of the state-of-the-art</u>
KNOW	13.2003	<i>Carole MAIGNAN, Gianmarco OTTAVIANO, Dino PINELLI and Francesco RULLANI (lix)</i> : <u>Bio-Ecological Diversity vs. Socio-Economic Diversity. A Comparison of Existing Measures</u>
KNOW	14.2003	<i>Maddy JANSSENS and Chris STEYAERT (lix)</i> : <u>Theories of Diversity within Organisation Studies: Debates and Future Trajectories</u>
KNOW	15.2003	<i>Tuzin BAYCAN LEVENT, Enno MASUREL and Peter NIJKAMP (lix)</i> : <u>Diversity in Entrepreneurship: Ethnic and Female Roles in Urban Economic Life</u>
KNOW	16.2003	<i>Alexandra BITUSIKOVA (lix)</i> : <u>Post-Communist City on its Way from Grey to Colourful: The Case Study from Slovakia</u>
KNOW	17.2003	<i>Billy E. VAUGHN and Katarina MLEKOV (lix)</i> : <u>A Stage Model of Developing an Inclusive Community</u>
KNOW	18.2003	<i>Selma van LONDEN and Arie de RUIJTER (lix)</i> : <u>Managing Diversity in a Globalizing World</u>
Coalition		
Theory	19.2003	<i>Sergio CURRARINI</i> : <u>On the Stability of Hierarchies in Games with Externalities</u>
Network		
PRIV	20.2003	<i>Giacomo CALZOLARI and Alessandro PAVAN (lx)</i> : <u>Monopoly with Resale</u>
PRIV	21.2003	<i>Claudio MEZZETTI (lx)</i> : <u>Auction Design with Interdependent Valuations: The Generalized Revelation Principle, Efficiency, Full Surplus Extraction and Information Acquisition</u>
PRIV	22.2003	<i>Marco LiCalzi and Alessandro PAVAN (lx)</i> : <u>Tilting the Supply Schedule to Enhance Competition in Uniform-Price Auctions</u>
PRIV	23.2003	<i>David ETTINGER (lx)</i> : <u>Bidding among Friends and Enemies</u>
PRIV	24.2003	<i>Hannu VARTIAINEN (lx)</i> : <u>Auction Design without Commitment</u>
PRIV	25.2003	<i>Matti KELOHARJU, Kjell G. NYBORG and Kristian RYDQVIST (lx)</i> : <u>Strategic Behavior and Underpricing in Uniform Price Auctions: Evidence from Finnish Treasury Auctions</u>
PRIV	26.2003	<i>Christine A. PARLOUR and Uday RAJAN (lx)</i> : <u>Rationing in IPOs</u>
PRIV	27.2003	<i>Kjell G. NYBORG and Ilya A. STREBULAIEV (lx)</i> : <u>Multiple Unit Auctions and Short Squeezes</u>
PRIV	28.2003	<i>Anders LUNANDER and Jan-Eric NILSSON (lx)</i> : <u>Taking the Lab to the Field: Experimental Tests of Alternative Mechanisms to Procure Multiple Contracts</u>
PRIV	29.2003	<i>TangaMcDANIEL and Karsten NEUHOFF (lx)</i> : <u>Use of Long-term Auctions for Network Investment</u>
PRIV	30.2003	<i>Emiel MAASLAND and Sander ONDERSTAL (lx)</i> : <u>Auctions with Financial Externalities</u>
ETA	31.2003	<i>Michael FINUS and Bianca RUNDSHAGEN</i> : <u>A Non-cooperative Foundation of Core-Stability in Positive Externality NTU-Coalition Games</u>
KNOW	32.2003	<i>Michele MORETTO</i> : <u>Competition and Irreversible Investments under Uncertainty</u>
PRIV	33.2003	<i>Philippe QUIRION</i> : <u>Relative Quotas: Correct Answer to Uncertainty or Case of Regulatory Capture?</u>
KNOW	34.2003	<i>Giuseppe MEDA, Claudio PIGA and Donald SIEGEL</i> : <u>On the Relationship between R&amp;D and Productivity: A Treatment Effect Analysis</u>
ETA	35.2003	<i>Alessandra DEL BOCA, Marzio GALEOTTI and Paola ROTA</i> : <u>Non-convexities in the Adjustment of Different Capital Inputs: A Firm-level Investigation</u>

GG	36.2003	<i>Matthieu GLACHANT</i> : <u>Voluntary Agreements under Endogenous Legislative Threats</u>
PRIV	37.2003	<i>Narjess BOUBAKRI, Jean-Claude COSSET and Omrane GUEDHAMI</i> : <u>Postprivatization Corporate Governance: the Role of Ownership Structure and Investor Protection</u>
CLIM	38.2003	<i>Rolf GOLOMBEK and Michael HOEL</i> : <u>Climate Policy under Technology Spillovers</u>
KNOW	39.2003	<i>Slim BEN YOUSSEF</i> : <u>Transboundary Pollution, R&amp;D Spillovers and International Trade</u>
CTN	40.2003	<i>Carlo CARRARO and Carmen MARCHIORI</i> : <u>Endogenous Strategic Issue Linkage in International Negotiations</u>
KNOW	41.2003	<i>Sonia OREFFICE</i> : <u>Abortion and Female Power in the Household: Evidence from Labor Supply</u>
KNOW	42.2003	<i>Timo GOESCHL and Timothy SWANSON</i> : <u>On Biology and Technology: The Economics of Managing Biotechnologies</u>
ETA	43.2003	<i>Giorgio Busetti and Matteo MANERA</i> : <u>STAR-GARCH Models for Stock Market Interactions in the Pacific Basin Region, Japan and US</u>
CLIM	44.2003	<i>Katrin MILLOCK and Céline NAUGES</i> : <u>The French Tax on Air Pollution: Some Preliminary Results on its Effectiveness</u>
PRIV	45.2003	<i>Bernardo BORTOLOTTI and Paolo PINOTTI</i> : <u>The Political Economy of Privatization</u>
SIEV	46.2003	<i>Elbert DIJKGRAAF and Herman R.J. VOLLEBERGH</i> : <u>Burn or Bury? A Social Cost Comparison of Final Waste Disposal Methods</u>
ETA	47.2003	<i>Jens HORBACH</i> : <u>Employment and Innovations in the Environmental Sector: Determinants and Econometrical Results for Germany</u>
CLIM	48.2003	<i>Lori SNYDER, Nolan MILLER and Robert STAVINS</i> : <u>The Effects of Environmental Regulation on Technology Diffusion: The Case of Chlorine Manufacturing</u>
CLIM	49.2003	<i>Lori SNYDER, Robert STAVINS and Alexander F. WAGNER</i> : <u>Private Options to Use Public Goods. Exploiting Revealed Preferences to Estimate Environmental Benefits</u>
CTN	50.2003	<i>László Á. KÓCZY and Luc LAUWERS</i> (Ixi): <u>The Minimal Dominant Set is a Non-Empty Core-Extension</u>
CTN	51.2003	<i>Matthew O. JACKSON</i> (Ixi): <u>Allocation Rules for Network Games</u>
CTN	52.2003	<i>Ana MAULEON and Vincent VANNETELBOSCH</i> (Ixi): <u>Farsightedness and Cautiousness in Coalition Formation</u>
CTN	53.2003	<i>Fernando VEGA-REDONDO</i> (Ixi): <u>Building Up Social Capital in a Changing World: a network approach</u>
CTN	54.2003	<i>Matthew HAAG and Roger LAGUNOFF</i> (Ixi): <u>On the Size and Structure of Group Cooperation</u>
CTN	55.2003	<i>Taiji FURUSAWA and Hideo KONISHI</i> (Ixi): <u>Free Trade Networks</u>
CTN	56.2003	<i>Halis Murat YILDIZ</i> (Ixi): <u>National Versus International Mergers and Trade Liberalization</u>
CTN	57.2003	<i>Santiago RUBIO and Alistair ULPH</i> (Ixi): <u>An Infinite-Horizon Model of Dynamic Membership of International Environmental Agreements</u>
KNOW	58.2003	<i>Carole MAIGNAN, Dino PINELLI and Gianmarco I.P. OTTAVIANO</i> : <u>ICT, Clusters and Regional Cohesion: A Summary of Theoretical and Empirical Research</u>
KNOW	59.2003	<i>Giorgio BELLETTINI and Gianmarco I.P. OTTAVIANO</i> : <u>Special Interests and Technological Change</u>
ETA	60.2003	<i>Ronnie SCHÖB</i> : <u>The Double Dividend Hypothesis of Environmental Taxes: A Survey</u>
CLIM	61.2003	<i>Michael FINUS, Ekko van IERLAND and Robert DELLINK</i> : <u>Stability of Climate Coalitions in a Cartel Formation Game</u>
GG	62.2003	<i>Michael FINUS and Bianca RUNDSHAGEN</i> : <u>How the Rules of Coalition Formation Affect Stability of International Environmental Agreements</u>
SIEV	63.2003	<i>Alberto PETRUCCI</i> : <u>Taxing Land Rent in an Open Economy</u>
CLIM	64.2003	<i>Joseph E. ALDY, Scott BARRETT and Robert N. STAVINS</i> : <u>Thirteen Plus One: A Comparison of Global Climate Policy Architectures</u>
SIEV	65.2003	<i>Edi DEFRANCESCO</i> : <u>The Beginning of Organic Fish Farming in Italy</u>
SIEV	66.2003	<i>Klaus CONRAD</i> : <u>Price Competition and Product Differentiation when Consumers Care for the Environment</u>
SIEV	67.2003	<i>Paulo A.L.D. NUNES, Luca ROSSETTO, Arianne DE BLAEIJ</i> : <u>Monetary Value Assessment of Clam Fishing Management Practices in the Venice Lagoon: Results from a Stated Choice Exercise</u>
CLIM	68.2003	<i>ZhongXiang ZHANG</i> : <u>Open Trade with the U.S. Without Compromising Canada's Ability to Comply with its Kyoto Target</u>
KNOW	69.2003	<i>David FRANTZ</i> (Iix): <u>Lorenzo Market between Diversity and Mutation</u>
KNOW	70.2003	<i>Ercole SORI</i> (Iix): <u>Mapping Diversity in Social History</u>
KNOW	71.2003	<i>Ljiljana DERU SIMIC</i> (Ixi): <u>What is Specific about Art/Cultural Projects?</u>
KNOW	72.2003	<i>Natalya V. TARANOVA</i> (Ixi): <u>The Role of the City in Fostering Intergroup Communication in a Multicultural Environment: Saint-Petersburg's Case</u>
KNOW	73.2003	<i>Kristine CRANE</i> (Ixi): <u>The City as an Arena for the Expression of Multiple Identities in the Age of Globalisation and Migration</u>
KNOW	74.2003	<i>Kazuma MATOBA</i> (Ixi): <u>Glocal Dialogue- Transformation through Transcultural Communication</u>
KNOW	75.2003	<i>Catarina REIS OLIVEIRA</i> (Ixi): <u>Immigrants' Entrepreneurial Opportunities: The Case of the Chinese in Portugal</u>
KNOW	76.2003	<i>Sandra WALLMAN</i> (Ixi): <u>The Diversity of Diversity - towards a typology of urban systems</u>
KNOW	77.2003	<i>Richard PEARCE</i> (Ixi): <u>A Biologist's View of Individual Cultural Identity for the Study of Cities</u>
KNOW	78.2003	<i>Vincent MERK</i> (Ixi): <u>Communication Across Cultures: from Cultural Awareness to Reconciliation of the Dilemmas</u>
KNOW	79.2003	<i>Giorgio BELLETTINI, Carlotta BERTI CERONI and Gianmarco I.P. OTTAVIANO</i> : <u>Child Labor and Resistance to Change</u>
ETA	80.2003	<i>Michele MORETTO, Paolo M. PANTEGHINI and Carlo SCARPA</i> : <u>Investment Size and Firm's Value under Profit Sharing Regulation</u>

IEM	81.2003	<i>Alessandro LANZA, Matteo MANERA and Massimo GIOVANNINI: <u>Oil and Product Dynamics in International Petroleum Markets</u></i>
CLIM	82.2003	<i>Y. Hossein FARZIN and Jinhua ZHAO: <u>Pollution Abatement Investment When Firms Lobby Against Environmental Regulation</u></i>
CLIM	83.2003	<i>Giuseppe DI VITA: <u>Is the Discount Rate Relevant in Explaining the Environmental Kuznets Curve?</u></i>
CLIM	84.2003	<i>Reyer GERLAGH and Wietze LISE: <u>Induced Technological Change Under Carbon Taxes</u></i>
NRM	85.2003	<i>Rinaldo BRAU, Alessandro LANZA and Francesco PIGLIARU: <u>How Fast are the Tourism Countries Growing? The cross-country evidence</u></i>
KNOW	86.2003	<i>Elena BELLINI, Gianmarco I.P. OTTAVIANO and Dino PINELLI: <u>The ICT Revolution: opportunities and risks for the Mezzogiorno</u></i>
SIEV	87.2003	<i>Lucas BRETSCGHER and Sjak SMULDERS: <u>Sustainability and Substitution of Exhaustible Natural Resources. How resource prices affect long-term R&amp;D investments</u></i>
CLIM	88.2003	<i>Johan EYCKMANS and Michael FINUS: <u>New Roads to International Environmental Agreements: The Case of Global Warming</u></i>
CLIM	89.2003	<i>Marzio GALEOTTI: <u>Economic Development and Environmental Protection</u></i>
CLIM	90.2003	<i>Marzio GALEOTTI: <u>Environment and Economic Growth: Is Technical Change the Key to Decoupling?</u></i>
CLIM	91.2003	<i>Marzio GALEOTTI and Barbara BUCHNER: <u>Climate Policy and Economic Growth in Developing Countries</u></i>
IEM	92.2003	<i>A. MARKANDYA, A. GOLUB and E. STRUKOVA: <u>The Influence of Climate Change Considerations on Energy Policy: The Case of Russia</u></i>
ETA	93.2003	<i>Andrea BELTRATTI: <u>Socially Responsible Investment in General Equilibrium</u></i>
CTN	94.2003	<i>Parkash CHANDER: <u>The <math>\gamma</math>-Core and Coalition Formation</u></i>
IEM	95.2003	<i>Matteo MANERA and Angelo MARZULLO: <u>Modelling the Load Curve of Aggregate Electricity Consumption Using Principal Components</u></i>
IEM	96.2003	<i>Alessandro LANZA, Matteo MANERA, Margherita GRASSO and Massimo GIOVANNINI: <u>Long-run Models of Oil Stock Prices</u></i>
CTN	97.2003	<i>Steven J. BRAMS, Michael A. JONES, and D. Marc KILGOUR: <u>Forming Stable Coalitions: The Process Matters</u></i>
KNOW	98.2003	<i>John CROWLEY, Marie-Cecile NAVES (Ixxiii): <u>Anti-Racist Policies in France. From Ideological and Historical Schemes to Socio-Political Realities</u></i>
KNOW	99.2003	<i>Richard THOMPSON FORD (Ixxiii): <u>Cultural Rights and Civic Virtue</u></i>
KNOW	100.2003	<i>Alaknanda PATEL (Ixxiii): <u>Cultural Diversity and Conflict in Multicultural Cities</u></i>
KNOW	101.2003	<i>David MAY (Ixxiii): <u>The Struggle of Becoming Established in a Deprived Inner-City Neighbourhood</u></i>
KNOW	102.2003	<i>Sébastien ARCAND, Danielle JUTEAU, Sirma BILGE, and Francine LEMIRE (Ixxiii) : <u>Municipal Reform on the Island of Montreal: Tensions Between Two Majority Groups in a Multicultural City</u></i>
CLIM	103.2003	<i>Barbara BUCHNER and Carlo CARRARO: <u>China and the Evolution of the Present Climate Regime</u></i>
CLIM	104.2003	<i>Barbara BUCHNER and Carlo CARRARO: <u>Emissions Trading Regimes and Incentives to Participate in International Climate Agreements</u></i>
CLIM	105.2003	<i>Anil MARKANDYA and Dirk T.G. RÜBBELKE: <u>Ancillary Benefits of Climate Policy</u></i>
NRM	106.2003	<i>Anne Sophie CRÉPIN (Ixiv): <u>Management Challenges for Multiple-Species Boreal Forests</u></i>
NRM	107.2003	<i>Anne Sophie CRÉPIN (Ixiv): <u>Threshold Effects in Coral Reef Fisheries</u></i>
SIEV	108.2003	<i>Sara ANIYAR (Ixiv): <u>Estimating the Value of Oil Capital in a Small Open Economy: The Venezuela's Example</u></i>
SIEV	109.2003	<i>Kenneth ARROW, Partha DASGUPTA and Karl-Göran MÄLER(Ixiv): <u>Evaluating Projects and Assessing Sustainable Development in Imperfect Economies</u></i>
NRM	110.2003	<i>Anastasios XEPAPADEAS and Catarina ROSETA-PALMA(Ixiv): <u>Instabilities and Robust Control in Fisheries</u></i>
NRM	111.2003	<i>Charles PERRINGS and Brian WALKER (Ixiv): <u>Conservation and Optimal Use of Rangelands</u></i>
ETA	112.2003	<i>Jack GOODY (Ixiv): <u>Globalisation, Population and Ecology</u></i>
CTN	113.2003	<i>Carlo CARRARO, Carmen MARCHIORI and Sonia OREFFICE: <u>Endogenous Minimum Participation in International Environmental Treaties</u></i>
CTN	114.2003	<i>Guillaume HAERINGER and Myrna WOODERS: <u>Decentralized Job Matching</u></i>
CTN	115.2003	<i>Hideo KONISHI and M. Utku UNVER: <u>Credible Group Stability in Multi-Partner Matching Problems</u></i>
CTN	116.2003	<i>Somdeb LAHIRI: <u>Stable Matchings for the Room-Mates Problem</u></i>
CTN	117.2003	<i>Somdeb LAHIRI: <u>Stable Matchings for a Generalized Marriage Problem</u></i>
CTN	118.2003	<i>Marita LAUKKANEN: <u>Transboundary Fisheries Management under Implementation Uncertainty</u></i>
CTN	119.2003	<i>Edward CARTWRIGHT and Myrna WOODERS: <u>Social Conformity and Bounded Rationality in Arbitrary Games with Incomplete Information: Some First Results</u></i>
CTN	120.2003	<i>Gianluigi VERNASCA: <u>Dynamic Price Competition with Price Adjustment Costs and Product Differentiation</u></i>
CTN	121.2003	<i>Myrna WOODERS, Edward CARTWRIGHT and Reinhard SELTEN: <u>Social Conformity in Games with Many Players</u></i>
CTN	122.2003	<i>Edward CARTWRIGHT and Myrna WOODERS: <u>On Equilibrium in Pure Strategies in Games with Many Players</u></i>
CTN	123.2003	<i>Edward CARTWRIGHT and Myrna WOODERS: <u>Conformity and Bounded Rationality in Games with Many Players</u></i>
	<b>1000</b>	<b>Carlo CARRARO, Alessandro LANZA and Valeria PAPPONETTI: <u>One Thousand Working Papers</u></b>



## NOTE DI LAVORO PUBLISHED IN 2004

IEM	1.2004	<i>Anil MARKANDYA, Suzette PEDROSO and Alexander GOLUB: <u>Empirical Analysis of National Income and So2 Emissions in Selected European Countries</u></i>
ETA	2.2004	<i>Masahisa FUJITA and Shlomo WEBER: <u>Strategic Immigration Policies and Welfare in Heterogeneous Countries</u></i>
PRA	3.2004	<i>Adolfo DI CARLUCCIO, Giovanni FERRI, Cecilia FRALE and Ottavio RICCHI: <u>Do Privatizations Boost Household Shareholding? Evidence from Italy</u></i>
ETA	4.2004	<i>Victor GINSBURGH and Shlomo WEBER: <u>Languages Disenfranchisement in the European Union</u></i>
ETA	5.2004	<i>Romano PIRAS: <u>Growth, Congestion of Public Goods, and Second-Best Optimal Policy</u></i>
CCMP	6.2004	<i>Herman R.J. VOLLEBERGH: <u>Lessons from the Polder: Is Dutch CO2-Taxation Optimal</u></i>
PRA	7.2004	<i>Sandro BRUSCO, Giuseppe LOPOMO and S. VISWANATHAN (lxv): <u>Merger Mechanisms</u></i>
PRA	8.2004	<i>Wolfgang AUSSENEGG, Pegaret PICHLER and Alex STOMPER (lxv): <u>IPO Pricing with Bookbuilding, and a When-Issued Market</u></i>
PRA	9.2004	<i>Pegaret PICHLER and Alex STOMPER (lxv): <u>Primary Market Design: Direct Mechanisms and Markets</u></i>
PRA	10.2004	<i>Florian ENGLMAIER, Pablo GUILLEN, Loreto LLORENTE, Sander ONDERSTAL and Rupert SAUSGRUBER (lxv): <u>The Chopstick Auction: A Study of the Exposure Problem in Multi-Unit Auctions</u></i>
PRA	11.2004	<i>Bjarne BRENDSTRUP and Harry J. PAARSCH (lxv): <u>Nonparametric Identification and Estimation of Multi-Unit, Sequential, Oral, Ascending-Price Auctions With Asymmetric Bidders</u></i>
PRA	12.2004	<i>Ohad KADAN (lxv): <u>Equilibrium in the Two Player, k-Double Auction with Affiliated Private Values</u></i>
PRA	13.2004	<i>Maarten C.W. JANSSEN (lxv): <u>Auctions as Coordination Devices</u></i>
PRA	14.2004	<i>Gadi FIBICH, Arieh GAVIOUS and Aner SELA (lxv): <u>All-Pay Auctions with Weakly Risk-Averse Buyers</u></i>
PRA	15.2004	<i>Orly SADE, Charles SCHNITZLEIN and Jaime F. ZENDER (lxv): <u>Competition and Cooperation in Divisible Good Auctions: An Experimental Examination</u></i>
PRA	16.2004	<i>Marta STRYSZOWSKA (lxv): <u>Late and Multiple Bidding in Competing Second Price Internet Auctions</u></i>
CCMP	17.2004	<i>Slim Ben YOUSSEF: <u>R&amp;D in Cleaner Technology and International Trade</u></i>
NRM	18.2004	<i>Angelo ANTOCI, Simone BORGHESI and Paolo RUSSU (lxvi): <u>Biodiversity and Economic Growth: Stabilization Versus Preservation of the Ecological Dynamics</u></i>
SIEV	19.2004	<i>Anna ALBERINI, Paolo ROSATO, Alberto LONGO and Valentina ZANATTA: <u>Information and Willingness to Pay in a Contingent Valuation Study: The Value of S. Erasmo in the Lagoon of Venice</u></i>
NRM	20.2004	<i>Guido CANDELA and Roberto CELLINI (lxvii): <u>Investment in Tourism Market: A Dynamic Model of Differentiated Oligopoly</u></i>
NRM	21.2004	<i>Jacqueline M. HAMILTON (lxvii): <u>Climate and the Destination Choice of German Tourists</u></i>
NRM	22.2004	<i>Javier Rey-MAQUIEIRA PALMER, Javier LOZANO IBÁÑEZ and Carlos Mario GÓMEZ GÓMEZ (lxvii): <u>Land, Environmental Externalities and Tourism Development</u></i>
NRM	23.2004	<i>Pius ODUNGA and Henk FOLMER (lxvii): <u>Profiling Tourists for Balanced Utilization of Tourism-Based Resources in Kenya</u></i>
NRM	24.2004	<i>Jean-Jacques NOWAK, Mondher SAHLI and Pasquale M. SGRO (lxvii): <u>Tourism, Trade and Domestic Welfare</u></i>
NRM	25.2004	<i>Riaz SHAREEF (lxvii): <u>Country Risk Ratings of Small Island Tourism Economies</u></i>
NRM	26.2004	<i>Juan Luis EUGENIO-MARTÍN, Noelia MARTÍN MORALES and Riccardo SCARPA (lxvii): <u>Tourism and Economic Growth in Latin American Countries: A Panel Data Approach</u></i>
NRM	27.2004	<i>Raúl Hernández MARTÍN (lxvii): <u>Impact of Tourism Consumption on GDP. The Role of Imports</u></i>
CSRM	28.2004	<i>Nicoletta FERRO: <u>Cross-Country Ethical Dilemmas in Business: A Descriptive Framework</u></i>
NRM	29.2004	<i>Marian WEBER (lxvi): <u>Assessing the Effectiveness of Tradable Landuse Rights for Biodiversity Conservation: an Application to Canada's Boreal Mixedwood Forest</u></i>
NRM	30.2004	<i>Trond BJORN DAL, Phoebe KOUNDOURI and Sean PASCOE (lxvi): <u>Output Substitution in Multi-Species Trawl Fisheries: Implications for Quota Setting</u></i>
CCMP	31.2004	<i>Marzio GALEOTTI, Alessandra GORIA, Paolo MOMBRINI and Evi SPANTIDAKI: <u>Weather Impacts on Natural, Social and Economic Systems (WISE) Part I: Sectoral Analysis of Climate Impacts in Italy</u></i>
CCMP	32.2004	<i>Marzio GALEOTTI, Alessandra GORIA, Paolo MOMBRINI and Evi SPANTIDAKI: <u>Weather Impacts on Natural, Social and Economic Systems (WISE) Part II: Individual Perception of Climate Extremes in Italy</u></i>
CTN	33.2004	<i>Wilson PEREZ: <u>Divide and Conquer: Noisy Communication in Networks, Power, and Wealth Distribution</u></i>
KTHC	34.2004	<i>Gianmarco I.P. OTTAVIANO and Giovanni PERI (lxviii): <u>The Economic Value of Cultural Diversity: Evidence from US Cities</u></i>
KTHC	35.2004	<i>Linda CHAIB (lxviii): <u>Immigration and Local Urban Participatory Democracy: A Boston-Paris Comparison</u></i>
KTHC	36.2004	<i>Franca ECKERT COEN and Claudio ROSSI (lxviii): <u>Foreigners, Immigrants, Host Cities: The Policies of Multi-Ethnicity in Rome. Reading Governance in a Local Context</u></i>
KTHC	37.2004	<i>Kristine CRANE (lxviii): <u>Governing Migration: Immigrant Groups' Strategies in Three Italian Cities – Rome, Naples and Bari</u></i>
KTHC	38.2004	<i>Kiflemariam HAMDE (lxviii): <u>Mind in Africa, Body in Europe: The Struggle for Maintaining and Transforming Cultural Identity - A Note from the Experience of Eritrean Immigrants in Stockholm</u></i>
ETA	39.2004	<i>Alberto CAVALIERE: <u>Price Competition with Information Disparities in a Vertically Differentiated Duopoly</u></i>
PRA	40.2004	<i>Andrea BIGANO and Stef PROOST: <u>The Opening of the European Electricity Market and Environmental Policy: Does the Degree of Competition Matter?</u></i>
CCMP	41.2004	<i>Micheal FINUS (lxix): <u>International Cooperation to Resolve International Pollution Problems</u></i>

KTHC	42.2004	<i>Francesco CRESPI</i> : <u>Notes on the Determinants of Innovation: A Multi-Perspective Analysis</u>
CTN	43.2004	<i>Sergio CURRARINI and Marco MARINI</i> : <u>Coalition Formation in Games without Synergies</u>
CTN	44.2004	<i>Marc ESCRHUELA-VILLAR</i> : <u>Cartel Sustainability and Cartel Stability</u>
NRM	45.2004	<i>Sebastian BERVOETS and Nicolas GRAVEL</i> (lxvi): <u>Appraising Diversity with an Ordinal Notion of Similarity: An Axiomatic Approach</u>
NRM	46.2004	<i>Signe ANTHON and Bo JELLESMARK THORSEN</i> (lxvi): <u>Optimal Afforestation Contracts with Asymmetric Information on Private Environmental Benefits</u>
NRM	47.2004	<i>John MBURU</i> (lxvi): <u>Wildlife Conservation and Management in Kenya: Towards a Co-management Approach</u>
NRM	48.2004	<i>Ekin BIROL, Ágnes GYOVAI and Melinda SMALE</i> (lxvi): <u>Using a Choice Experiment to Value Agricultural Biodiversity on Hungarian Small Farms: Agri-Environmental Policies in a Transitional Economy</u>
CCMP	49.2004	<i>Gernot KLEPPER and Sonja PETERSON</i> : <u>The EU Emissions Trading Scheme. Allowance Prices, Trade Flows, Competitiveness Effects</u>
GG	50.2004	<i>Scott BARRETT and Michael HOEL</i> : <u>Optimal Disease Eradication</u>
CTN	51.2004	<i>Dinko DIMITROV, Peter BORM, Ruud HENDRICKX and Shao CHIN SUNG</i> : <u>Simple Priorities and Core Stability in Hedonic Games</u>
SIEV	52.2004	<i>Francesco RICCI</i> : <u>Channels of Transmission of Environmental Policy to Economic Growth: A Survey of the Theory</u>
SIEV	53.2004	<i>Anna ALBERINI, Maureen CROPPER, Alan KRUPNICK and Nathalie B. SIMON</i> : <u>Willingness to Pay for Mortality Risk Reductions: Does Latency Matter?</u>
NRM	54.2004	<i>Ingo BRÄUER and Rainer MARGGRAF</i> (lxvi): <u>Valuation of Ecosystem Services Provided by Biodiversity Conservation: An Integrated Hydrological and Economic Model to Value the Enhanced Nitrogen Retention in Renaturated Streams</u>
NRM	55.2004	<i>Timo GOESCHL and Tun LIN</i> (lxvi): <u>Biodiversity Conservation on Private Lands: Information Problems and Regulatory Choices</u>
NRM	56.2004	<i>Tom DEDEURWAERDERE</i> (lxvi): <u>Bioprospection: From the Economics of Contracts to Reflexive Governance</u>
CCMP	57.2004	<i>Katrin REHDANZ and David MADDISON</i> : <u>The Amenity Value of Climate to German Households</u>
CCMP	58.2004	<i>Koen SMEKENS and Bob VAN DER ZWAAN</i> : <u>Environmental Externalities of Geological Carbon Sequestration Effects on Energy Scenarios</u>
NRM	59.2004	<i>Valentina BOSETTI, Mariaester CASSINELLI and Alessandro LANZA</i> (lxvii): <u>Using Data Envelopment Analysis to Evaluate Environmentally Conscious Tourism Management</u>
NRM	60.2004	<i>Timo GOESCHL and Danilo CAMARGO IGLIORI</i> (lxvi): <u>Property Rights Conservation and Development: An Analysis of Extractive Reserves in the Brazilian Amazon</u>
CCMP	61.2004	<i>Barbara BUCHNER and Carlo CARRARO</i> : <u>Economic and Environmental Effectiveness of a Technology-based Climate Protocol</u>
NRM	62.2004	<i>Elissaios POPYRAKIS and Reyer GERLAGH</i> : <u>Resource-Abundance and Economic Growth in the U.S.</u>
NRM	63.2004	<i>Györgyi BELA, Györgyi PATAKI, Melinda SMALE and Mariann HAJDÚ</i> (lxvi): <u>Conserving Crop Genetic Resources on Smallholder Farms in Hungary: Institutional Analysis</u>
NRM	64.2004	<i>E.C.M. RUIJGROK and E.E.M. NILLESEN</i> (lxvi): <u>The Socio-Economic Value of Natural Riverbanks in the Netherlands</u>
NRM	65.2004	<i>E.C.M. RUIJGROK</i> (lxvi): <u>Reducing Acidification: The Benefits of Increased Nature Quality. Investigating the Possibilities of the Contingent Valuation Method</u>
ETA	66.2004	<i>Giannis VARDAS and Anastasios XEPAPADEAS</i> : <u>Uncertainty Aversion, Robust Control and Asset Holdings</u>
GG	67.2004	<i>Anastasios XEPAPADEAS and Constadina PASSA</i> : <u>Participation in and Compliance with Public Voluntary Environmental Programs: An Evolutionary Approach</u>
GG	68.2004	<i>Michael FINUS</i> : <u>Modesty Pays: Sometimes!</u>
NRM	69.2004	<i>Trond BJØRNDAL and Ana BRASÃO</i> : <u>The Northern Atlantic Bluefin Tuna Fisheries: Management and Policy Implications</u>
CTN	70.2004	<i>Alejandro CAPARRÓS, Abdelhakim HAMMOUDI and Tarik TAZDAÏT</i> : <u>On Coalition Formation with Heterogeneous Agents</u>
IEM	71.2004	<i>Massimo GIOVANNINI, Margherita GRASSO, Alessandro LANZA and Matteo MANERA</i> : <u>Conditional Correlations in the Returns on Oil Companies Stock Prices and Their Determinants</u>
IEM	72.2004	<i>Alessandro LANZA, Matteo MANERA and Michael MCALEER</i> : <u>Modelling Dynamic Conditional Correlations in WTI Oil Forward and Futures Returns</u>
SIEV	73.2004	<i>Margarita GENIUS and Elisabetta STRAZZERA</i> : <u>The Copula Approach to Sample Selection Modelling: An Application to the Recreational Value of Forests</u>
CCMP	74.2004	<i>Rob DELLINK and Ekko van IERLAND</i> : <u>Pollution Abatement in the Netherlands: A Dynamic Applied General Equilibrium Assessment</u>
ETA	75.2004	<i>Rosella LEVAGGI and Michele MORETTO</i> : <u>Investment in Hospital Care Technology under Different Purchasing Rules: A Real Option Approach</u>
CTN	76.2004	<i>Salvador BARBERÀ and Matthew O. JACKSON</i> (lxx): <u>On the Weights of Nations: Assigning Voting Weights in a Heterogeneous Union</u>
CTN	77.2004	<i>Àlex ARENAS, Antonio CABRALES, Albert DÍAZ-GUILERA, Roger GUIMERA and Fernando VEGA-REDONDO</i> (lxx): <u>Optimal Information Transmission in Organizations: Search and Congestion</u>
CTN	78.2004	<i>Francis BLOCH and Armando GOMES</i> (lxx): <u>Contracting with Externalities and Outside Options</u>

CTN	79.2004	<i>Rabah AMIR, Effrosyni DIAMANTOUDI and Licun XUE</i> (lxx): <u>Merger Performance under Uncertain Efficiency Gains</u>
CTN	80.2004	<i>Francis BLOCH and Matthew O. JACKSON</i> (lxx): <u>The Formation of Networks with Transfers among Players</u>
CTN	81.2004	<i>Daniel DIERMEIER, Hülya ERASLAN and Antonio MERLO</i> (lxx): <u>Bicameralism and Government Formation</u>
CTN	82.2004	<i>Rod GARRATT, James E. PARCO, Cheng-ZHONG QIN and Amnon RAPOPORT</i> (lxx): <u>Potential Maximization and Coalition Government Formation</u>
CTN	83.2004	<i>Kfir ELIAZ, Debraj RAY and Ronny RAZIN</i> (lxx): <u>Group Decision-Making in the Shadow of Disagreement</u>
CTN	84.2004	<i>Sanjeev GOYAL, Marco van der LEIJ and José Luis MORAGA-GONZÁLEZ</i> (lxx): <u>Economics: An Emerging Small World?</u>
CTN	85.2004	<i>Edward CARTWRIGHT</i> (lxx): <u>Learning to Play Approximate Nash Equilibria in Games with Many Players</u>
IEM	86.2004	<i>Finn R. FØRSUND and Michael HOEL</i> : <u>Properties of a Non-Competitive Electricity Market Dominated by Hydroelectric Power</u>
KTHC	87.2004	<i>Elissaios POPYRAKIS and Reyer GERLAGH</i> : <u>Natural Resources, Investment and Long-Term Income</u>
CCMP	88.2004	<i>Marzio GALEOTTI and Claudia KEMFERT</i> : <u>Interactions between Climate and Trade Policies: A Survey</u>
IEM	89.2004	<i>A. MARKANDYA, S. PEDROSO and D. STREIMIKIENE</i> : <u>Energy Efficiency in Transition Economies: Is There Convergence Towards the EU Average?</u>
GG	90.2004	<i>Rolf GOLOMBEK and Michael HOEL</i> : <u>Climate Agreements and Technology Policy</u>
PRA	91.2004	<i>Sergei IZMALKOV</i> (lxx): <u>Multi-Unit Open Ascending Price Efficient Auction</u>
KTHC	92.2004	<i>Gianmarco I.P. OTTAVIANO and Giovanni PERI</i> : <u>Cities and Cultures</u>
KTHC	93.2004	<i>Massimo DEL GATTO</i> : <u>Agglomeration, Integration, and Territorial Authority Scale in a System of Trading Cities. Centralisation versus devolution</u>
CCMP	94.2004	<i>Pierre-André JOUVET, Philippe MICHEL and Gilles ROTILLON</i> : <u>Equilibrium with a Market of Permits</u>
CCMP	95.2004	<i>Bob van der ZWAAN and Reyer GERLAGH</i> : <u>Climate Uncertainty and the Necessity to Transform Global Energy Supply</u>

- (lix) This paper was presented at the ENGIME Workshop on “Mapping Diversity”, Leuven, May 16-17, 2002
- (lx) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications”, organised by the Fondazione Eni Enrico Mattei, Milan, September 26-28, 2002
- (lxi) This paper was presented at the Eighth Meeting of the Coalition Theory Network organised by the GREQAM, Aix-en-Provence, France, January 24-25, 2003
- (lxii) This paper was presented at the ENGIME Workshop on “Communication across Cultures in Multicultural Cities”, The Hague, November 7-8, 2002
- (lxiii) This paper was presented at the ENGIME Workshop on “Social dynamics and conflicts in multicultural cities”, Milan, March 20-21, 2003
- (lxiv) This paper was presented at the International Conference on “Theoretical Topics in Ecological Economics”, organised by the Abdus Salam International Centre for Theoretical Physics - ICTP, the Beijer International Institute of Ecological Economics, and Fondazione Eni Enrico Mattei – FEEM Trieste, February 10-21, 2003
- (lxv) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications” organised by Fondazione Eni Enrico Mattei and sponsored by the EU, Milan, September 25-27, 2003
- (lxvi) This paper has been presented at the 4th BioEcon Workshop on “Economic Analysis of Policies for Biodiversity Conservation” organised on behalf of the BIOECON Network by Fondazione Eni Enrico Mattei, Venice International University (VIU) and University College London (UCL), Venice, August 28-29, 2003
- (lxvii) This paper has been presented at the international conference on “Tourism and Sustainable Economic Development – Macro and Micro Economic Issues” jointly organised by CRENoS (Università di Cagliari e Sassari, Italy) and Fondazione Eni Enrico Mattei, and supported by the World Bank, Sardinia, September 19-20, 2003
- (lxviii) This paper was presented at the ENGIME Workshop on “Governance and Policies in Multicultural Cities”, Rome, June 5-6, 2003
- (lxix) This paper was presented at the Fourth EEP Plenary Workshop and EEP Conference “The Future of Climate Policy”, Cagliari, Italy, 27-28 March 2003
- (lxx) This paper was presented at the 9<sup>th</sup> Coalition Theory Workshop on "Collective Decisions and Institutional Design" organised by the Universitat Autònoma de Barcelona and held in Barcelona, Spain, January 30-31, 2004

**2003 SERIES**

<b>CLIM</b>	<i>Climate Change Modelling and Policy</i> (Editor: Marzio Galeotti )
<b>GG</b>	<i>Global Governance</i> (Editor: Carlo Carraro)
<b>SIEV</b>	<i>Sustainability Indicators and Environmental Valuation</i> (Editor: Anna Alberini)
<b>NRM</b>	<i>Natural Resources Management</i> (Editor: Carlo Giupponi)
<b>KNOW</b>	<i>Knowledge, Technology, Human Capital</i> (Editor: Gianmarco Ottaviano)
<b>IEM</b>	<i>International Energy Markets</i> (Editor: Anil Markandya)
<b>CSRМ</b>	<i>Corporate Social Responsibility and Management</i> (Editor: Sabina Ratti)
<b>PRIV</b>	<i>Privatisation, Regulation, Antitrust</i> (Editor: Bernardo Bortolotti)
<b>ETA</b>	<i>Economic Theory and Applications</i> (Editor: Carlo Carraro)
<b>CTN</b>	<i>Coalition Theory Network</i>

**2004 SERIES**

<b>CCMP</b>	<i>Climate Change Modelling and Policy</i> (Editor: Marzio Galeotti )
<b>GG</b>	<i>Global Governance</i> (Editor: Carlo Carraro)
<b>SIEV</b>	<i>Sustainability Indicators and Environmental Valuation</i> (Editor: Anna Alberini)
<b>NRM</b>	<i>Natural Resources Management</i> (Editor: Carlo Giupponi)
<b>KTHC</b>	<i>Knowledge, Technology, Human Capital</i> (Editor: Gianmarco Ottaviano)
<b>IEM</b>	<i>International Energy Markets</i> (Editor: Anil Markandya)
<b>CSRМ</b>	<i>Corporate Social Responsibility and Management</i> (Editor: Sabina Ratti)
<b>PRA</b>	<i>Privatisation, Regulation, Antitrust</i> (Editor: Bernardo Bortolotti)
<b>ETA</b>	<i>Economic Theory and Applications</i> (Editor: Carlo Carraro)
<b>CTN</b>	<i>Coalition Theory Network</i>