Precautionary Effect and Variations of the Value of Information

Laurent Gilotte and Michel de Lara

NOTA DI LAVORO 28.2005

FEBRUARY 2005

CCMP – Climate Change Modelling and Policy

Laurent Gilotte, *CIRED and CERMICS*
Michel de Lara, *CERMICS*

Corso Magenta, 63, 20123 Milano (I), web site: www.feem.it, e-mail: working.papers@feem.it

Precautionary Effect and Variations of the Value of Information

Summary

For a sequential, two-period decision problem with uncertainty and under broad conditions (non-finite sample set, endogenous risk, active learning and stochastic dynamics), a general sufficient condition is provided to compare the optimal initial decisions with or without information arrival in the second period. More generally the condition enables the comparison of optimal decisions related to different information structures. It also ties together and clarifies many conditions for the so-called irreversibility effect that are scattered in the environmental economics literature. A numerical illustration with an integrated assessment model of climate-change economics is provided.

Keywords: Value of Information, Uncertainty, Irreversibility effect, Climate change

JEL Classification: D62, D63, H23, Q29

Research reported in this paper has been supported by a grant from the Institut Français de l'Energie (IFE). Comments and suggestions by Philippe Ambrosi, Patrice Dumas, Minh Ha-Duong, Jean-Christophe Pereau and Neomal Silva are gratefully acknowledged.

Address for correspondence:

Laurent Gilotte
CIRED
Jardin Tropical
F-94736 Nogent-sur-Marne
Cedex
France
E-mail:gilotte@centre-cired.fr

1 Introduction

In relation to information, two issues are recurrent in the applied literature dealing with climate change[1]. Firstly, the degree to which the emissions of greenhouse gases should be reduced today will hinge on our assumption on the extent of our future knowledge about the climate. Secondly, how much should we be ready to pay now through, for example, investment in scientific research, in order to acquire information in the future?

The second of these questions relates to the *value of information*, or more explicitly the *value of an information structure*[2]. It is a familiar concept in the economics of uncertainty, which has been used for example in order to try and set an upper-bound to the value of a substantial research program to reduce climate-related uncertainties (Manne and Richels, 1992).

As for the first question, it is central to the theoretical literature on irreversibility and uncertainty [3] and relates to the ‘irreversibility effect’ (Henry, 1974a). This effect states roughly that, when there is a source of irreversibility in the system we control, then the learning effect[4] is precautionary. Most of the literature on the subject looks for conditions under which the effect holds. In one of the seminal papers, Arrow and Fisher (1974), noted the “increasing concentration of carbon dioxide in the global atmosphere” as an application for the reasoning. However, most of the theoretical findings, including theirs’, can hardly be used to help and interpret the results of integrated-assessment models (IAM) of climate and economics such as DICE (Nordhaus, 1994). In effect, analytical models usually involve simplifications that are extreme in regard to the climate change issue. For instance, environment is always captured by a scalar variable that follows a linear dynamic, whereas in DICE 98 (Nordhaus and Boyer, 2000) the environment is a five-component vector with a non-linear dynamic for the atmospheric temperature.

Moreover, as Ulph and Ulph (1997) noted, it is not possible to conclude in advance and “as a matter of principle” about the direction of the learning effect for the climate change issue. This would require the condition identified by Epstein (1980), which is not met even in the “simplest model of global warming” that they set out. It implies that, in complex numerical models that embed irreversibility sources, the direction of the learning effect may depend on the data. Moreover, it may depend on the prior beliefs of the decision maker. This idea is reinforced by more recent results by Gollier *et al.* (2000). In a two-period setting close to Ulph and Ulph’s, they show that the irreversibility effect is guaranteed for all risks if the utility function belongs to a restrictive class.

Concepts that can be used for interpreting (rather than conjecturing) the behaviour of complex models were sought. We found promising to follow Ha-Duong (1998), who proposed to rely on how, in the second-period problem, the value of information is modified by the initial decision. He argues it should be a better guide than the notion of quasi-option value, which is traditional to the irreversibility literature since introduced by Arrow and Fisher (1974). Moreover, results about quasi-option value do not hold in the general case (Hanemann, 1989). Ha-Duong implements this idea with a particular model: the initial decision is taken in a set of two elements (high or low abatement), uncertainty is described by two states of nature (dangerous or benign). Once the initial decision has been taken, he looks at the value of getting perfect information before the next decision and points that this value of information depends on the initial decision; the irreversibility effect takes place when the value of information, as a function of the initial decision, is greater for

---

[1] See for example Manne and Richels (1992); Nordhaus (1994).

[2] We shall keep the terminology *expected value of information* for the case where the value of the information structure is a random variable, see section 4.

[3] Arrow and Fisher (1974); Henry (1974a,b); Freixas and Laffont (1984); Kolstad (1996); Ulph and Ulph (1997)

[4] By learning effect we refer to how the first-period optimal decision is modified when the decision maker considers that information will arrive in the future.

high initial abatement than for low initial abatement.

Until recently, the irreversibility literature had not really taken advantage of the observation that, once an initial decision is made, the value of information can be defined as a function of that decision. Conrad (1980) emphasized the value of future information from the point of view of the next generation but did not make this dependency explicit. Hanemann (1989) calls it value of information conditional on the initial decision[5], but even in the case where the set of admissible decisions is a real interval, he considers this value only for some particular initial decisions (the optimal decisions with and without information). More recently, however, Rouillon (2001) defined for a particular model of climate-change the value of information as a function of the greenhouse gases (GHG) concentration. He found in one of his cases that, when this value of information (after the initial decision) is a monotone function of the pollution stock, then the optimal emission levels with and without information can be ordered.

We show that this result is in fact very general and ties together different pieces of the literature on uncertainty and irreversibility. It can also be applied properly in integrated assessment models with few modifications and thus connects two themes of the climate change literature, namely, the value of information and the irreversibility effect.

Section 2 presents a standard model of sequential decision under uncertainty. Practically all the specific models studied in the irreversibility literature from Arrow and Fisher to Gollier *et al.* can be seen as particular instance of our model. Formally it is not restricted to environmental problems. We define the ‘ subsequent ’ value of information as the value of the information structure once the initial decision has been taken. In section 3, we show that, when value of information is a (partially) monotone function of the initial decision, then the optimal initial decisions with or without information can be compared. With two different information structures, the same result applies to the value of exchanging one information structure for the other. The result does not require any convexity conditions. It is extended in section 4 to sequential decision problems including endogenous risk, active learning and stochastic dynamic. Section 5 shows how our result unifies and provides an interpretation for the conditions for the irreversibility effect that are given in the literature. Finally, section 6 uses Nordhaus' DICE model to provide a practical application.

2 The standard model of decision with learning

2.1 The decision problem

We consider in this section a rather general model of optimal control under uncertainty, where decisions are taken at two periods of time, namely, at $t = 0$ and at $t = 1$. The decision maker aims at maximizing the expected present benefit

$$\max_{u_0,u_1} \mathbb{E}\left[l_0(u_0) + l_1(u_1, x_1, \gamma)\right] \tag{1}$$
$$\text{s.c.} \qquad x_1 = f(x_0, u_0) \quad \text{and} \quad u_t \in \mathcal{U}_t(x_t),\ t = 0, 1.$$

$x_t \in \mathbb{R}^n$ is the *state of the system* at time t, which depends on the decisions u_t through the dynamics f; its initial value x_0 is known; the decision u_t must be chosen in a admissible set $\mathcal{U}_t \subset \mathbb{R}^{m_t}$ that, in all generality, depends on t and on the state x_t. We make the restriction that the initial decision is a scalar ($\mathcal{U}_0 \subset \mathbb{R}$, i.e. $m_0 = 1$). Finally $l_t(\cdot)$ is the benefit of decision u_t when the system is in the state x_t. The function l_1 depends on γ, a parameter unknown at time $t = 0$ that we represent

---

[5] We shall avoid this terminology, which can be confusing. See footnote 2.

as a random variable over a probability space[6] $(\Omega, \mathcal{F}, \mathbb{P})$, where the $\omega \in \Omega$ are the *states of the nature*. Note that, at this stage, randomness appears only through γ, though the dynamics may be taken as stochastic as we shall see in section 4.

We could actually write this standard model into a more compact form[7] as it is the current practice in the literature on irreversibility and decision under uncertainty. However, the explicit distinction between state and control is convenient for handling the general model with stochastic dynamics presented in section 4.

In what follows, we shall always assume that, for the problems we consider, the *sup* is attained and we shall use the notation *max*.

2.2 Information structure

The decision maker eventually obtains information at time $t = 1$. A rather general way to describe information is to assume the reception at time $t = 1$ of a signal[8] that allows to improve on the law $\mathbb{P}_\gamma$ of the random variable γ by conditioning: in this case, Φ is a random variable (over the same sample space as γ) so that when the decision maker observes Φ, she uses the conditional probability law $\mathbb{P}_\gamma^\Phi$ of γ knowing Φ. More generally, information is a σ-algebra (the one generated by the signal, $\sigma(\Phi)$ in the case hereabove).

'No information' at time $t = 1$ can be represented by a constant signal over Ω or, equivalently, by the trivial σ-algebra $\{\Omega, \emptyset\}$. In the following, we shall denote by $\perp$ a non-informative structure.

At time $t = 1$, the decision maker receives a given realization $\Phi(\omega)$ of the signal Φ before her choice u_1. For any state x_1, the decision u_1 can be seen as a function from Ω to $\mathcal{U}_1(x_1)$ and should be measurable with respect to the σ-algebra induced by the signal function Φ. We denote this requirement by $u_1 \preccurlyeq \Phi$:

$$u_1 \preccurlyeq \Phi \iff \sigma(u_1) \subset \sigma(\Phi)\,. \tag{2}$$

For the problem with information structure Φ, define the 'expected optimal benefit in state $x_1 = x$' as the value function at $t = 1$:

$$V_\Phi(x) \overset{\text{def}}{=} \mathbb{E}\left[\max_{u_1 \in \mathcal{U}_1(x),\, u_1 \preccurlyeq \Phi} \mathbb{E}\left[l_1(u_1, x, \gamma) \mid \Phi\right]\right] \tag{3}$$

which allows to rewrite the decision problem (1) at $t = 0$ as:

$$\max_{u_0 \in \mathcal{U}_0(x_0)} \left[l_0(u_0) + V_\Phi(f(x_0, u_0))\right]. \tag{4}$$

---

[6] In the irreversibility literature Ω is a finite set of the possible values of γ, $\mathcal{F} = \mathcal{P}(\Omega)$, and $\mathbb{P}$ is the prior used by the decision maker at time $t = 0$.

[7] Namely as

$$\begin{aligned} &\max_{u_0 \in \mathcal{U}_0,\, u_1 \in \mathcal{D}(u_0)} \mathbb{E}\left[l_0(u_0) + L(u_1, u_0, \gamma)\right] \\ \text{where} \quad & L(u_1, u_0, \gamma) \overset{\text{def}}{=} l_1(u_1, f(x_0, u_0), \gamma) \\ \text{and} \quad & \mathcal{D}(u_0) \overset{\text{def}}{=} \mathcal{U}_1(f(x_0, u_0)). \end{aligned}$$

[8] The irreversibility literature (for instance Freixas and Laffont, 1984; Kolstad, 1996) relies on a description of information through partitions. However partitions are less general in the non-finite case.

2.3 Subsequent value of the information structure

After any initial decision u_0, the decision maker knows from the deterministic dynamics f what subsequent state of the system, x_1, will enter her new decision problem at time $t = 1$. If she thinks she will not learn about γ (information structure $\perp$) , she may be ready to pay to obtain information from a signal Φ. When buying Φ, she does not know which information she will receive, but she will be able to move from the expected benefit $V_\perp(x_1)$ to the expected benefit $V_\Phi(x_1)$. Let us define therefore[9]

$$\begin{aligned} I_\Phi(x) &\overset{\text{def}}{=} V_\Phi(x) - V_\perp(x) && (5)\\ &= \mathbb{E}\left(\max_{u_1 \in \mathcal{U}_1(x),\, u_1 \preccurlyeq \Phi} \mathbb{E}\left[l_1(u_1, x, \gamma) \mid \Phi\right]\right) - \max_{u_1 \in \mathcal{U}_1(x)} \mathbb{E}\left[l_1(u_1, x, \gamma)\right] \end{aligned}$$

as the *subsequent value of the information* structure Φ when the system will be in state x in $t = 1$. This value is clearly always non-negative.

The definition makes clear that the value of the information is a function of the state of the system. In applications (Manne and Richels, 1992; Nordhaus, 1994), the value of information is usually defined before decision u_0 has been taken ; therefore it can be considered to depend on x_0.

In order to distinguish between these two notions, *initial* value of information will refer to the usual definition, and *subsequent* value of information to definition by (5). In the following, we shall indifferently use the expressions ‘ value of information ’ or ‘ value of the information structure ’.

More generally, when the state of the system in $t = 1$ is $x_1 = x$, the value of having an information structure Ψ rather than the information structure Φ is:

$$\Delta_{\Psi\Phi}(x) \overset{\text{def}}{=} I_\Psi(x) - I_\Phi(x) \tag{6}$$

If Ψ is finer[10] than Φ, this value is also positive.

3 Learning effect and value of information

3.1 How value of information enters the decision problem

From (4) applied to the non-informative structure $\perp$, the program of the non-informed decision maker writes:

$$\max_{u_0 \in \mathcal{U}_0(x_0)} \left[l_0(u_0) + V_\perp(f(x_0, u_0))\right] \tag{7}$$

From (4) and (7) and the definition of the subsequent value of information in (5), the initial decision problem with information structure Φ writes:

$$\max_{u_0 \in \mathcal{U}_0(x_0)} \left[l_0(u_0) + V_\perp(f(x_0, u_0)) + I_\Phi(f(x_0, u_0))\right] \tag{8}$$

Comparing programs (7) and (8), it appears that the decision maker who expects information optimizes the same objective as the uninformed decision maker *plus* the value of the information, which depends on her initial decision. Her optimal decision can achieve a trade-off: it can be suboptimal from the point of view of the non-informed decision maker but compensate for this by an increase of the value of information.

---

[9] With general utility functions (instead of benefit functions), the value of information is measured in utility units. Equivalent or compensating variations in monetary values can also be defined (Laffont, 1989).

[10] Meaning that the σ-algebra induced by Φ is included in the one induced by Ψ.

Note also that I_Φ, the subsequent value of information, depends on the initial decision even though there is no active learning, i.e. what one expects to learn does not depends on u_0.

More generally, replacing the information structure Φ by the the information structure Ψ leads to a reformulation of the problem (4) as

$$\max_{u_0 \in \mathcal{U}_0(x_0)} \left[l_0(u_0) + V_\Phi(f(x_0, u_0)) + \Delta_{\Psi\Phi}(f(x_0, u_0)) \right].$$

3.2 Comparison of initial and subsequent values of information

Before comparing first period optimal decisions with and without future information, it is easier to compare the subsequent values of information resulting from these decisions. The *initial* value of information enters the comparison laid out in the following proposition (the proof is in Appendix 8).

Proposition 1

Denote by I^0 the initial *value of acquiring the information structure Φ before any decision u_0 is made:*

$$I^0 \overset{\text{def}}{=} \max_{u_0 \in \mathcal{U}_0(x_0)} \left[l_0(u_0) + V_\perp(f(x_0, u_0)) + I_\Phi(f(x_0, u_0)) \right] - \max_{u_0 \in \mathcal{U}_0(x_0)} \left[l_0(u_0) + V_\perp(f(x_0, u_0)) \right]. \quad (9)$$

Let $u_0^\perp$ be an optimal solution of (7), the problem without learning, and u_0^Φ be an optimal solution of (8), the problem with learning. Then,

$$I_\Phi(f(x_0, u_0^\perp)) \le I^0 \le I_\Phi(f(x_0, u_0^\Phi)). \quad (10)$$

This comparison generalizes the relation between the initial value of information and the option value given by Hanemann (1989), who defines option value as $I_\Phi(f(x_0, u_0^\Phi)) - I_\Phi(f(x_0, u_0^\perp))$ for a family of problems where $I_\Phi(f(x_0, u_0^\perp)) = 0$.

The hereabove inequalities show that a decision maker who knows she will receive information in the future *chooses her first decision so as to increase the value of information*, whereas a decision maker who neglects the fact that she will receive information makes a decision that reduces the value she would be ready to pay for information.

We next derive sufficient conditions for the comparison of initial optimal decisions, a problem at the centre of the literature on irreversibility and uncertainty.

3.3 Comparison of optimal solutions; the learning effect

From Proposition 1, we obtain immediately:

$$\forall u > u_0^\perp,\ I_\Phi(f(x_0, u)) < I_\Phi(f(x_0, u_0^\perp)) \Rightarrow u_0^\Phi \le u_0^\perp.$$

Hence, *a practical sufficient condition for comparison of optimal solutions is to know that $u_0 \mapsto I_\Phi(f(x_0, u_0))$ is a strictly decreasing or a strictly increasing function*[11].

Definition 2

The eventual difference between u_0^Φ and $u_0^\perp$ is the learning effect.

More generally we have the following, which is our main result.

---

[11] Note here that we adopt the following terminology: a function f defined on an ordered set is *increasing* if $x \ge y \Rightarrow f(x) \ge f(y)$, and is *strictly increasing* if $x > y \Rightarrow f(x) > f(y)$; the same convention holds for decreasing and strictly decreasing functions.

Proposition 3

Let Φ and Ψ be two information structures (not necessarily comparable in the sense that one is finer than the other).

Let u_0^Φ be any optimal initial decision with information structure Φ, that is

$$u_0^\Phi \in \arg\max_{u_0 \in \mathcal{U}_0(x_0)} \left[l_0(u_0) + V_\Phi(f(x_0, u_0)) \right],$$

and let u_0^Ψ be any optimal initial decision with information structure Ψ:

$$u_0^\Psi \in \arg\max_{u_0 \in \mathcal{U}_0(x_0)} \left[l_0(u_0) + V_\Psi(f(x_0, u_0)) \right].$$

If the value of substituting Ψ for Φ, $u_0 \mapsto \Delta_{\Psi\Phi}(f(x_0, u_0))$, is a strictly decreasing function, then

$$u_0^\Psi \le u_0^\Phi .$$

The result is immediate from (13) in Appendix[12].

The results holds in fact under the weaker assumption that $u_0 \mapsto \Delta_{\Psi\Phi}(f(x_0, u_0))$ is strictly decreasing (respectively strictly increasing) when $u_0 < u_0^\Psi$ (respectively when $u_0 > u_0^\Psi$.)

A more general proposition can be made for non-strictly decreasing (or increasing) functions.

Proposition 4

If the value of substituting Ψ for Φ, $u_0 \mapsto \Delta_{\Psi\Phi}(f(x_0, u_0))$, is a decreasing function, then comparisons are still possible under the form

$$\sup \arg\max_{u_0 \in \mathcal{U}_0(x_0)} \left[l_0(u_0) + V_\Psi(f(x_0, u_0)) \right] \le \sup \arg\max_{u_0 \in \mathcal{U}_0(x_0)} \left[l_0(u_0) + V_\Phi(f(x_0, u_0)) \right] .$$

The proof derives from Proposition 8, see appendix section 9.

As a consequence, if u_0^Φ is unique, it is sufficient that $u_0 \mapsto \Delta_{\Psi\Phi}(f(x_0, u_0))$ be decreasing to conclude that $u_0^\Psi \le u_0^\Phi$.

Before applications in Sections 5 and 6, the following definition relates the comparison of u_0^Φ and $u_0^\perp$ to the 'irreversibility effect' and more generally to the 'precautionary effect of the learning'.

Definition 5

Precautionary effect of learning
In the case where

1. *l_0 is an increasing function (*i.e. *increasing u_0 yields benefits in $t = 0$)*
2. *$u_0 \mapsto l_1(u_1, f(x_0, u_0), \gamma))$ is a decreasing function (*i.e. *u_0 implies some future costs)*

then a decision $u_0^\Phi \le u_0^\perp$ is said to be 'more precautionary' than $u_0^\perp$ and the learning effect from Φ is said to be 'precautionary'. This is also refered to as the 'irreversibility effect'in some specific cases.

---

[12] Freixas and Laffont (1984) give sufficient conditions for the monotonicity of $\Delta_{\Psi\Phi}$ in a setting where the dynamics is reduced to $x_{t+1} = u_t$ and where the state of the system does not enter the benefits l_t but only the admissibility set. However, they do not provide the interpretation of Δ in terms of value of substituting information structures. Kolstad (1996) obtains necessary and sufficient conditions for a problem which is actually a sub-case of Freixas and Laffont though this does not appear at first glance from his notations but has to be derived from his hypotheses.

4 Extension to active learning and stochastic evolution

Possible extensions of the standard case appear in the literature. This section shows that the main result still apply in the general, extended case.

Stochastic dynamic. From period $t = 0$ on, the state of the system $\tilde{x}_t$ is a random variable. Its evolution may depend on an other random variable w_t: $\tilde{x}_{t+1} = f(\tilde{x}_t, u_t, w_t)$. The model in Conrad (1980) is an occurrence of stochastic dynamic in the irreversibility literature.

Endogenous risk An example of endogenous risk can be found in Gjerde et al. (1999) where the law of the date of a climate catastrophe depends on the emission reductions. Endogenous risk arises when the random variable γ depends on the previous decisions, u_0 and u_1. In stochastic control theory, γ is treated as a state variable. Endogenous risk is thus viewed as a particular case of stochastic dynamic.

Active learning Active learning (or dependent learning) takes place when the initial decision can modify the signal the decision maker will receive. It means that in addition to ω, Φ depends on u_0, or more generally on $\tilde{x}_1$ (then the modification is also random). Rouillon (2001) studies a model of active learning in climate change economics and uses the variations of the value of information to conclude about the irreversibility effect.

Comparison in the general model

Consider the problem :

$$\begin{aligned} &\max_{u_0,u_1} \mathbb{E}\left[l_0(u_0,\tilde{x}_0) + l_1(u_1,\tilde{x}_1)\right] \\ &\qquad \text{s.c.} \qquad \tilde{x}_1 = f(\tilde{x}_0,u_0,w_0) \qquad \text{and} \qquad u_t \in \mathcal{U}_t(y_t), t = 0,1 \end{aligned}$$

where w_t is a random variable (r.v.) and y_t a non-stochastic subcomponent of $\tilde{x}_t$, so that the decision maker knows the admissible set $\mathcal{U}(y_1)$ when she makes her choice[13] u_1.

At time $t = 1$, when the state of the system is the r.v. $\tilde{x}$, the information structure Φ delivers a signal that depends on $\tilde{x}$. We denote by $\Phi_{\tilde{x}}$ the corresponding signal function $\Phi_{\tilde{x}} : \omega \mapsto s(\omega, \tilde{x}(\omega))$. The decision-problem can be written as:

$$\begin{aligned} &\max_{u_0 \in \mathcal{U}_0(y_0)} \; \mathbb{E}\left[l_0(u_0,\tilde{x}_0) + V_\Phi(f(\tilde{x}_0,u_0,w_0))\right]. \\ &\qquad \text{with} \quad V_\Phi(\tilde{x}) \overset{\text{def}}{=} \mathbb{E}\left[\max_{u_1 \in \mathcal{U}_1(y),\, u_1 \preccurlyeq \Phi_{\tilde{x}}} l_1(u_1,\tilde{x}) \mid \Phi_{\tilde{x}}\right]. \end{aligned}$$

As in previous section, the decision problem with information can be put under the form:

$$\max_{u_0 \in \mathcal{U}_0(x_0)} \; \mathbb{E}\left[l_0(u_0,\tilde{x}_0) + V_\perp(f(\tilde{x}_0,u_0,w_0)) + I_\Phi(f(\tilde{x}_0,u_0,w_0))\right]$$

and the comparisons of initial decisions now rely on the expectation of I_Φ or $\Delta_{\Psi\Phi}$ as follows.

---

[13] It is sufficient to assume that the decision maker gets full information at time $t = 1$ on a stochastic subcomponent $\tilde{y}_1$; then this information, $\tilde{y}_1$ should be explicitly included for conditioning the problem, even in the case where no additional information arrives.

Proposition 6
If $u_0 \mapsto \mathbb{E}\left[\Delta_{\Psi\Phi}(f(\tilde{x}_0, u_0, w_0))\right]$ *is monotone, comparison of the optimal decisions for the general problems with information structure* Φ *and* Ψ *will be possible. Precise conditions are the same as in Proposition 3.*

It is self-explanatory that $\mathbb{E}\, I_\Phi(f(\tilde{x}_0, u_0, w_0))$ is the expected value of information after decision u_0, and $\mathbb{E}\, \Delta_{\Psi\Phi}(f(\tilde{x}_0, u_0, w_0))$ the expected value of exchanging the information structure Φ for Ψ. It is also possible to define the value of information conditional on a realization of w_0 or of $\tilde{x}_1$.

5 Value of information as a key to the irreversibility literature

A goal of the literature on irreversibility and uncertainty consists in identifying hypotheses or conditions under which the ‘ irreversibility effect ’ holds. Two kinds of conditions can be examined. A first thread follows Epstein (1980) and concentrates on determining the direction of the learning effect for all possible random vectors γ over a finite sample set and for all comparable information structures. As Ulph and Ulph (1997) noted, this restricts the conclusion to limited classes of problems, for example those later identified by Gollier et al. (2000). An other thread looks for specific problems where the irreversibility effect is verified when Epstein conditions do not apply. This for example the case in Ulph and Ulph (1997).

Though monotonicity of the value of information is only necessary for the irreversibility effect, it turns out that Epstein necessary and sufficient conditions imply a monotone value of information. Besides, many of the specific (necessary) conditions found in the litterature also do. In particular, we have already seen (section 3.2) that Proposition 1 generalizes Hanemann's statement on the quasi-option value (Hanemann, 1989) and that Proposition 3 provides an interpretation for the conditions examined by Freixas and Laffont (1984) for a simple model (section 3.3). We shall see it is also the case for many others, and moreover, this monotonicity is often intuitive without fully-fledged mathematical demonstration.

5.1 Epstein's Theorem and the value of information

Epstein (1980) gave necessary and sufficient conditions that allow to conclude about the direction of the learning effect for all prior beliefs. We show that they also imply a monotone value of information.

For any distribution law ρ on Ω, let us define

$$J(x, \rho) \overset{\text{def}}{=} \max_{u_1 \in \mathcal{U}_1(x)} \mathbb{E}_\rho(l_1(u_1, x, \gamma)) = \max_{u_1 \in \mathcal{U}_1(x)} \int_\Omega l_1(u_1, x, \gamma(\omega))\rho(d\omega) \tag{11}$$

Epstein's Theorem states that initial decisions may be compared for any comparable information structures (one being more informative than the other) when $\frac{\partial J}{\partial x}(x, \rho)$ exists and is convex or concave in ρ varying among discrete probability laws.

We show that Epstein's assumptions, extended to non-discrete probability and without necessarily differentiability in the first decision argument, are sufficient conditions for the value of information to be monotone and therefore to ensure the comparison of initial decisions.

Proposition 7
Assume that

1. *for any* $u_+ \geq u_-$, $J(f(x_0, u_+), \rho) - J(f(x_0, u_-), \rho)$ *is convex (concave) in* ρ,

2. Ψ *is finer than* Φ.

Then the value of substituting Ψ *for* Φ, $u_0 \mapsto \Delta_{\Psi\Phi}(f(x_0, u_0))$, *is an increasing (a decreasing) function.*

Thus, initial decisions may be compared (see the remarks following Proposition 3). The proof is in appendix.

5.2 Linear dynamics and costs; ‘ all or nothing ’ decision set

The seminal literature as well as more recent contributions often considers linear dynamics and costs, which imply all or nothing decisions, or hinges directly on a binary decision set (see for instance Arrow and Fisher, 1974; Henry, 1974a; Ha-Duong, 1998; Fisher, 2000 and Henry, 1974b, part 2). With a binary decision set, the monotonicity of the value of information becomes trivial. Moreover, the direction of variation is easily determined under the hypothesis of total irreversibility, *i.e.* when one of the two possible initial decisions affects the state or the second period cost so that it does not depend any longer on the second period decision. This is for example the case with the model of Arrow and Fisher (1974).

5.3 Value of information in Ulph and Ulph, 1997

The model examined in (Ulph and Ulph, 1997) can be rewritten with our formalism as follows

$$\max_{u_0}\left[l_0(u_0)+\mathbb{E}\max_{u_1\preccurlyeq\Phi}\left[l_1(u_1)-\mathbb{E}[\gamma \mid \Phi]D(\delta x_1+u_1)\right]\right] \tag{12}$$

$$\text{with} \quad x_{t+1}=\delta x_t+u_t \quad \text{and} \quad u_t\in[0,A_t],$$

where u are greenhouse gases (GHG) emissions, x GHG concentrations, l_t utilities, and D a damage function. A_t is the unrestricted level of emissions[14]. Functions l_t are assumed to be strictly increasing and strictly concave, and D strictly increasing and strictly convex. The r.v. γ is assumed to be non-negative.

The authors compare $u_0^{\perp}$, the initial decision without information, and $u_0^{\top}$, the initial decision with perfect information structure (for example $\Phi=\gamma$). With our notations, their theorem 3 states that:

if $(u_0^{\perp}, u_1^{\perp})$ is such that $u_1^{\perp}=0$, then $u_0^{\top}\leq u_0^{\perp}$.

Two features are essential to this result. On the one hand, the assumption that the optimal policy, $u_1^{\perp}=0$, is a corner solution in second period. On the other hand, the shape of the the payoff, which is linear in the random variable.

We show (see Annex 11 for the proof) that, under their hypothesis and their condition $u_1^{\perp}=0$, the conclusion about the irreversibility effect can be generalized to any information structure Φ because the second-period value of this information structure can be shown to be a decreasing function for $u_0 \geq u_0^{\perp}$.

This generalized result can even been obtained intuitively, because, under their conditions, monotonicity of the value of information becomes intuitive. Ulph and Ulph's condition implies that when the GHG concentration in $t=1$, x_1, is above a certain level $\delta x_0+u_0^{\perp}$, then it is optimal

---

[14] Ulph and Ulph do not make this hypothesis which is benign for the problem considered (greenhouse gases emissions cannot be infinite) and simplifies the demonstration.

to cut emissions to zero in $t = 1$ when no information is available. Therefore, if information is obtained when we are in the situation x_1, it might open the opportunity to emit. The value of the information is then equal to the benefit of additional emissions in $t = 1$ minus the expected additional damages. From the envelope theorem, these expected additional damages are strictly increasing at the margin for a small increase of the concentration x_1, whereas benefits do not depend directly of the concentration level. As a consequence, the value of information diminishes and the irreversibility effect applies.

6 Illustration with a modified stochastic version of dice

Here we produce a numerical illustration with a stochastic version of the standard integrated assessment model DICE 98 (Nordhaus et Boyer, 2000). Such a model is already complex compared to the analytical ones present in the literature. But it will appear that, strikingly, the value of information after initial policy choice behaves in a way that can support intuition.

The model is a stochastic optimal-growth model of the world economy. It is designed to maximize the discounted expected value of utility from consumption. The decisions variables are the rate of investment and the rate of emissions reductions in greenhouse gases. The model operates in time steps of 10 years. Perfect information about the uncertain climate parameter arrives in 2040. A simple adaptation of the original model ensures compatibility with the analytical framework of section 4. We make a parameterization of the paths of investment and abatement from now till 2030–2039 with a unique scalar. This scalar, the abatement rate targeted for 2030–2039, summarizes and entirely defines the policy choice in the initial period.

6.1 The climate-economy system

The dynamic evolution of the climate-economy system can be represented with the relation: $z_{i+1} = g(z_i, v_i, \gamma)$ where $i \in \{0, 1, \ldots, T\}$ is the 10-year interval spanning from year $2000 + 10i$ to year $2009 + 10i$; $v_i \in [0, 1] \times [0, 1]$ is the couple of controls, which are the rate of reduction of greenhouse gases and the investment rate in time step i; $z_i \in \mathbb{R}^6$ is the state of the climate-economy system in the beginning of period i comprising the stock of capital; concentrations of carbon in three reservoirs (atmosphere; biosphere and surface ocean; deep ocean); and oceanic and atmospheric global mean temperature rises with respect to pre-industrial times.

The temperature components of z are stochastic. Uncertainty enters their dynamics through the *climate sensitivity* γ. This random variable is equal to the atmospheric temperature rise for a permanent doubling of the carbon concentration in the atmosphere. The r.v. γ is constant through time with values 2.5 °C, 3.5 °C and 4.5 °C and remains unobserved until year 2040. In the first step $i = 0$, the true atmospheric temperature rise with respect to pre-industrial times is also uncertain.

The detailed climate-economy equations are slightly changed from the original version of DICE. The temperature increase equation is an updated calibration that provides a better description of warming over forthcoming decades. A threshold damage function replaces the original quadratic one. Both modifications are taken from Ambrosi et al. (2003). The full description for the original DICE model can be found in Nordhaus (Nordhaus, 1994; Nordhaus and Boyer, 2000).

6.2 The decision problem

At each time step i, a control v_i and a state of the system z_i result in a discounted random utility $L_i(v_i, z_i)$. In fact we have two notions of time. The first notion, the time steps, describes the natural time in the original problem. The second notion describes the decision periods. In accordance with the framework of section 4, there are two decisions period $t \in \{0;1\}$. The initial period, $t = 0$, covers the time steps before learning, $i = 0, \dots, 3$; the next period, $t = 1$, covers the time steps $i = 4, \dots, T$. The decisions u_t define the controls v_i as follows. The initial decision $u_{t=0} \in [0,1]$ is the level of abatement targeted for 2030; it parameterizes the investment and abatement path for time steps $i < 4$ through a function φ from $[0,1]$ into $\mathbb{R}^6$: $(v_i)_{i \in \{0,\dots,3\}}$ is taken equal to $\varphi(u_{t=0})$. The next decision, $u_{t=1} \in [0,1]^{2(T-3)}$, is the vector of investment and abatement rates for $i \geq 4$: $(v_i)_{i \in \{4,\dots,T\}} = u_{t=1}$. Details for the parameterization of the initial policy are in Appendix 12.

The decision problem is

$$\begin{aligned} \max_{u_0} \ \mathbb{E} & \left\{ \sum_{i<4} L_i(v_i, z_i) + \mathbb{E} \left[\max_{u_1 \preccurlyeq \gamma} \sum_{i=4}^{T} L_i(v_i, z_i) \mid \gamma \right] \right\} \\ \text{with} \quad & (v_0, \dots, v_3) = \varphi(u_0) \\ & (v_4, \dots, v_T) = u_1 \in [0,1]^{2(T-3)} \\ & z_{i+1} = g(z_i, v_i, \gamma) \end{aligned}$$

where the path of controls before information is constrained to belong to the family of curves defined by φ. This decision problem clearly pertains[15] to the framework described in section 4 but as far we know it is out of bounds for the rest of the analytical literature about irreversibility, learning and climate change.

6.3 How policy affects the value of information on the climate

The figure 1 page 13 plots the expected value of information as a function of the initial policy. Available initial decisions range from no effort until 2030 (0% emissions reduction) to targeting the maximum effort in 2030 (100% reduction). Three cases are presented corresponding to three different probability distributions for γ: optimistic case, centered case and pessimistic case (see Appendix 12).

In all cases, the expected value of information is strictly decreasing. Consistently, in all cases, the prospect of learning the true value of γ in 2040 is an opportunity to make initially less reduction efforts ($u_0^\top$) than in the never-learn situation ($u_0^\perp$). This is also consistent with the simulations made by Ulph and Ulph (1997). If no certainty can ever[16] be obtained about the future evolution of the climate, the more cautious emission policy $u_0^\perp$ would be preferred. Here, the learning effect is not precautionary.

In an analytical framework with a linear dynamic, Gollier et al. (2000) showed that logarithmic utility implies that the structure of information has no effect on the initial decision. They wondered whether this was the explanation for the little or nonexistent learning effect found in earlier results by Nordhaus (1994), Manne and Richels (1992) and others[17]. Our model departs from Nordhaus' DICE only with some specifications of the dynamics (see section 6.1). But the utility function of the model is logarithmic as it is in DICE. However, the 'learning effect' (the difference between $u_0^\perp$ and $u_0^\top$) ranges from 9 to 21%. In terms of abatement costs this is even larger due to the

---

[15] With $\tilde{x}_0 = (z_0, \gamma)$ and $\tilde{x}_1 = (z_4, \gamma)$ so that $f(\tilde{x}_0, u_0, \gamma) = [g(\dots, (g(\tilde{x}_0, v_0, \gamma), \dots) \dots, v_3, \gamma); \gamma]$. Similarly l_0 and l_1 are defined through L_i and compositions of g.

[16] Kelly and Kolstad (1999) suggest that certainty on the true value of the climate sensitivity with less than 5% rejection might be available only after 2090.

[17] Ulph and Ulph used a quadratic specification for their numerical simulations and found that, for most parameter values, learning made little difference.

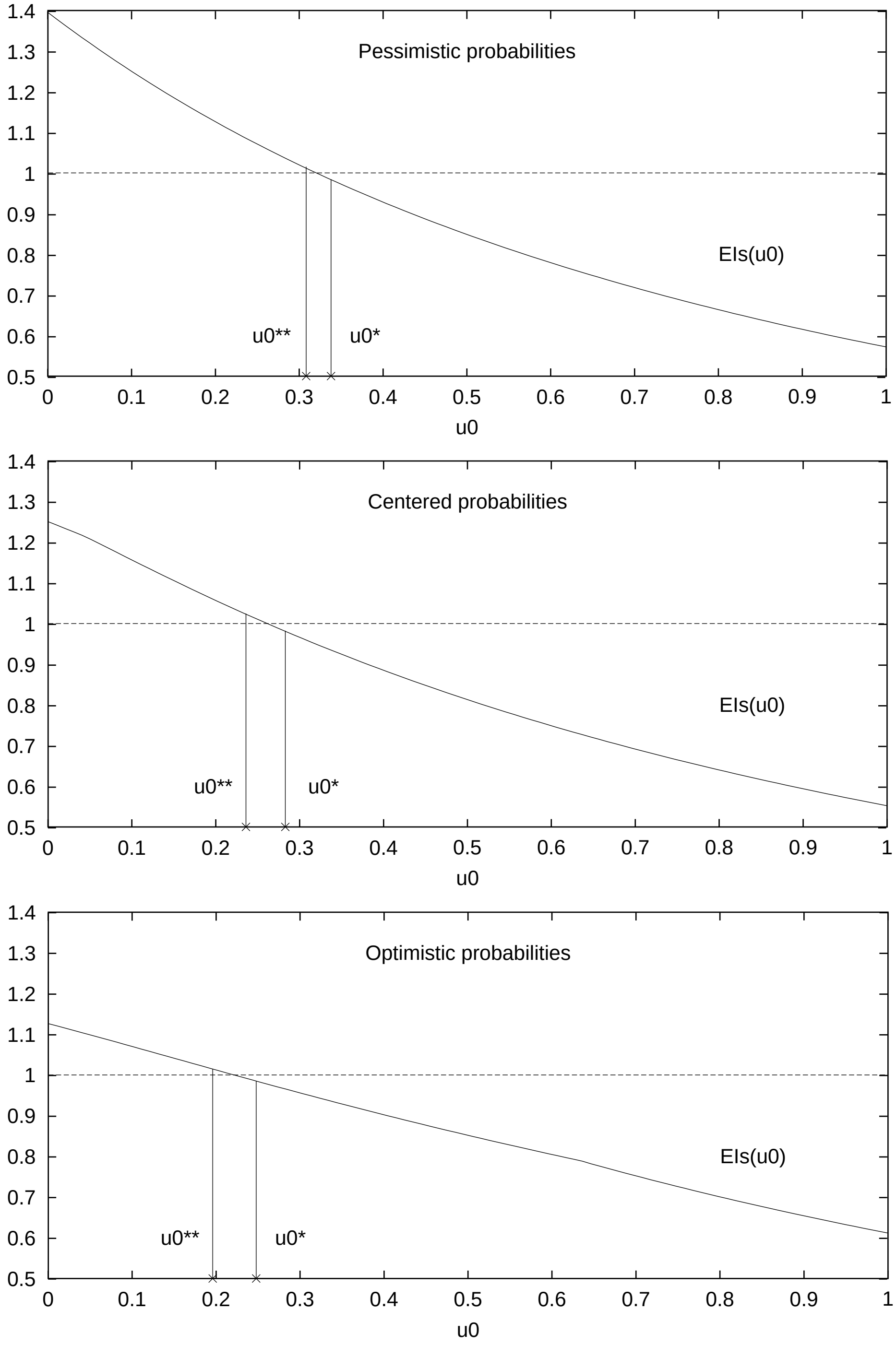

Figure 1: Variations of the expected value of information, EIs(u0), with u_0.
In each case, the expected value of information has been normalized with $\mathbb{E}I^0$, the expected value of information before any decision is made. Note that this normalization is different in each case.

specification of the abatement costs in DICE as a power function (with an exponent greater than 2). Clearly, learning has an effect on decision which is not negligible. Thus, our findings answer the question raised by Gollier *et al.* and show that the weak learning effect found by Nordhaus is also determined by his choice of a particular dynamic and not solely by his logarithmic objective function.

7 Conclusion

This article explored the role of the value of an information structure in analyzing general, sequential decision problems. The difference between value of future information before and after an initial decision is taken was made explicit. The monotonicity of the latter, the *subsequent value of information*, is sufficient for making a conclusion about the direction of the learning effect. Many of the conditions given in the literature as sufficient or as necessary and sufficient for the irreversibility effect can be understood as guarantees for this monotonicity. The present analysis shares a common limitation with the irreversibility literature: the initial decision is assumed to be scalar. But extension is readily available in theory. As long as the set of admissible initial decisions can be ordered even incompletely, Topkis' theorem (Topkis, 1978) leads to a similar conclusion. Extension to multi-scalar decisions would help the interpretation of empirical integrated assessment models. For example in the original DICE model (Nordhaus and Boyer, 2000), assuming that information arrives in 2040, the initial decision vector has eight components (four abatement and investment decisions). However, the difficulty is to find a meaningful order over the decision set.

For communication with policy-makers, there is a practical advantage in analyzing the learning effect in terms of growing or strictly decreasing value of information because value of information is a relatively self-explanatory concept (Ha-Duong, 1998). Finally, the intuitive simplicity of the notion of value of information also suggests application in experimental economics. It should be possible to design experimental tests of rationality under uncertainty that are based on how and whether individuals modify their estimation of the value of improved future knowledge as a consequence of their current decisions.

8 Appendix: Proof of Proposition 1

By definition, the initial value of information is

$$
\begin{aligned}
I^0 \overset{\text{def}}{=} & \overbrace{\max_{u_0 \in \mathcal{U}_0(x_0)} \left[l_0(u_0) + V_\perp(f(x_0,u_0)) + I_\Phi(f(x_0,u_0)) \right]}^{\mathcal{J}_\Phi \overset{\text{def}}{=}} \\
& - \underbrace{\max_{u_0 \in \mathcal{U}_0(x_0)} \left[l_0(u_0) + V_\perp(f(x_0,u_0)) \right]}_{\mathcal{J}_\perp \overset{\text{def}}{=}} .
\end{aligned}
$$

Since $u_0^\perp$ is an optimal solution of the problem without information and since u_0^Φ is an optimal solution of the problem with information, we have, on the one hand,

$$
\mathcal{J}_\perp = l_0(u_0^\perp) + V_\perp(f(x_0,u_0^\perp)) \geq \underbrace{l_0(u_0^\Phi) + V_\perp(f(x_0,u_0^\Phi))}_{\mathcal{I}_\Phi - I_\Phi(f(x_0,u_0^\Phi))}
$$

so that $\mathcal{I}_\Phi - \mathcal{I}_\perp \leq I_\Phi(f(x_0,u_0^\Phi))$.

On the other hand,

$$\mathcal{I}_\Phi = l_0(u_0^\Phi) + V_\perp(f(x_0,u_0^\Phi) + I_\Phi(f(x_0,u_0^\Phi)) \geq \underbrace{l_0(u_0^\perp) + V_\perp(f(x_0,u_0^\perp))}_{\mathcal{J}_\perp} + I_\Phi(f(x_0,u_0^\perp))$$

so that $\mathcal{I}_\Phi - \mathcal{I}_\perp \geq I_\Phi(f(x_0,u_0^\perp))$. Combining both inequalities, we obtain

$$I_\Phi(f(x_0,u_0^\perp)) \leq I^0 = \mathcal{J}_\Phi - \mathcal{J}_\perp \leq I_\Phi(f(x_0,u_0^\Phi))$$

which is Proposition 1.

Similarly we obtain easily:

$$\Delta_{\Psi\Phi}(f(x_0,u_0^\Phi)) \leq \mathcal{J}_\Psi - \mathcal{J}_\Phi \leq \Delta_{\Psi\Phi}(f(x_0,u_0^\Psi)) \tag{13}$$

where u_0^Ψ (respectively u_0^Φ) is any optimal initial decision for the problem with the information structure Ψ (respectively Φ). Note that, without specific hypothesis on the relative informativeness of Φ and Ψ, Δ can assume negative values and $\mathcal{J}_\Psi - \mathcal{J}_\Phi$ can be negative.

9 Appendix: Comparison of arg max

We recall here results on comparison between the arg max of two optimization problems. They may be seen as particular instances of results from a general theory with supermodular functions or functions with increasing differences as developed in Topkis (1998).

Proposition 8

Let $\mathcal{D} \subset \mathbb{R}$, let $g : \mathcal{D} \to \mathbb{R}$ and $h : \mathcal{D} \to \mathbb{R}$. We denote

$$\mathcal{D}_g \overset{\mathrm{def}}{=} \arg\max_{u\in\mathcal{D}} g(u) \subset \mathcal{D} \quad \textit{and} \quad \mathcal{D}_{g+h} \overset{\mathrm{def}}{=} \arg\max_{u\in\mathcal{D}} (g+h)(u) \subset \mathcal{D}\,,$$

and we assume that $\mathcal{D}_g \neq \emptyset$ and $\mathcal{D}_{g+h} \neq \emptyset$.

1. *If h is strictly increasing on $]-\infty, \sup \mathcal{D}_g]$, then*

$$\sup \mathcal{D}_g \leq \inf \mathcal{D}_{g+h}\,.$$

2. *If h is increasing on $]-\infty, \sup \mathcal{D}_g]$, then*

$$\sup \mathcal{D}_g \leq \sup \mathcal{D}_{g+h}\,.$$

3. *If h is strictly decreasing on $[\inf \mathcal{D}_g, +\infty[$, then*

$$\sup \mathcal{D}_{g+h} \leq \inf \mathcal{D}_g\,.$$

4. *If h is decreasing on $[\inf \mathcal{D}_g, +\infty[$, then*

$$\inf \mathcal{D}_{g+h} \leq \inf \mathcal{D}_g\,.$$

Proof. We prove the first statement, the others being minor variations.

Let $u_g^\sharp \in \mathcal{D}_g$. For any $u \in \mathcal{D}$, we have $g(u) \leq g(u_g^\sharp)$. For any $u \in]-\infty, u_g^\sharp[$, we have $h(u) < h(u_g^\sharp)$ if h is strictly increasing. Thus

$$u \in]-\infty, u_g^\sharp[\Rightarrow g(u) + h(u) < g(u_g^\sharp) + h(u_g^\sharp) .$$

We conclude that $\mathcal{D}_{g+h} \subset [u_g^\sharp, +\infty[$, so that

$$\mathcal{D}_{g+h} \subset \bigcap_{u_g^\sharp \in \mathcal{D}_g} [u_g^\sharp, +\infty[= [\sup \mathcal{D}_g, +\infty[.$$

This proves that $\sup \mathcal{D}_g \leq \inf \mathcal{D}_{g+h}$. □

The proof of Proposition 3 is a straightforward consequence with $u_0 \mapsto l_0(u_0) + V_\Phi(f(x_0, u_0)) + \Delta_{\Psi\Phi}(f(x_0, u_0))$ as function g and $u_0 \mapsto -\Delta_{\Psi\Phi}(f(x_0, u_0))$ as function h.

Freixas et Laffont (1984) propose a similar proof for a case with simplified dynamics and criteria (see section 3.3).

10 Appendix: Proof of Proposition 7

Let $\mathcal{P}(\Omega)$ be the set of all distributions on Ω, the states of the world. By classical arguments (Breiman, 1993, p. 77) (as soon as Ω is a complete separable metric space for instance), there exists a regular conditional probability of $\mathbb{P}$ given Φ, denoted by $\mathbb{P}^\Phi : \Omega \times \mathcal{F} \to [0, 1]$ and characterized by:

1. $\forall \omega \in \Omega$, $\mathbb{P}^\Phi(\omega, \cdot) \in \mathcal{P}(\Omega)$;
2. $\forall A \in \mathcal{F}$, $\omega \hookrightarrow \mathbb{P}^\Phi(\omega, \cdot)$ is measurable with respect to Φ;
3. for all bounded random variable Z, $\mathbb{E}(Z \mid \Phi)(\omega) = \int_\Omega Z(\omega')\mathbb{P}^\Phi(\omega, d\omega')$, for $\mathbb{P}$-almost ω.

The sensor[18] associated to $\mathbb{P}$ and Φ is the random measure $S^\Phi \in \mathcal{P}(\mathcal{P}(\Omega))$ defined by

$$\forall M \in \mathcal{B}(\mathcal{P}(\Omega)) , \quad S^\Phi(M) \overset{\text{def}}{=} \mathbb{P}\{\omega \in \Omega , \quad \mathbb{P}^\Phi(\omega, \cdot) \in M\} . \tag{14}$$

Equivalently, S^Φ is also the image of the measure $\mathbb{P}$ by the mapping

$$\omega \in \Omega \hookrightarrow \mathbb{P}^\Phi(\omega, \cdot) \in \mathcal{P}(\Omega) . \tag{15}$$

It is shown in Artstein and Wets (1993) that

$$\begin{aligned}
\mathbb{E}\left(\max_{u_1 \in \mathcal{U}_1(x),\, u_1 \preccurlyeq \Phi} \mathbb{E}\left[l_1(u_1, x, \gamma) \mid \Phi \right] \right) &= = \int_\Omega \mathbb{P}(d\omega) \left(\max_{u_1 \in \mathcal{U}_1(x),\, u_1 \preccurlyeq \Phi} \int_\Omega l_1(u_1, x, \gamma(\omega'))\mathbb{P}^\Phi(\omega, d\omega') \right) \\
&= \int_{\mathcal{P}(\Omega)} dS^\Phi(\rho) \left(\max_{u_1 \in \mathcal{U}_1(x)} \int_\Omega l_1(u_1, x, \gamma(\omega'))\rho(d\omega') \right) \\
&= \int_{\mathcal{P}(\Omega)} dS^\Phi(\rho) J(x, \rho) .
\end{aligned}$$

---

[18] A sensor is a probability law on the set $\mathcal{P}(\Omega)$ of all distributions on the states of the world, *i.e.* an element of $\mathcal{P}(\mathcal{P}(\Omega))$, the Borel space of probability measures on $\mathcal{P}(\Omega)$. Following Artstein (1999), an information structure can be defined by a sensor since it governs which posterior beliefs will be materialized at the time of decision. Chapter **??** offers more recalls and developments on sensors. See especially section **??** page **??**.

Thus, by (6) and (5), we have

$$\begin{aligned}\Delta_{\Psi\Phi}(x) &= \mathbb{E}\left(\max_{u_1\in\mathcal{U}_1(x),\, u_1\preccurlyeq\Psi}\mathbb{E}\left[l_1(u_1,x,\gamma)\mid\Psi\right]\right)-\mathbb{E}\left(\max_{u_1\in\mathcal{U}_1(x),\, u_1\preccurlyeq\Phi}\mathbb{E}\left[l_1(u_1,x,\gamma)\mid\Phi\right]\right)\\ &= \int_{\mathcal{P}(\Omega)} dS^{\Psi}(\rho)J(x,\rho)-\int_{\mathcal{P}(\Omega)} dS^{\Phi}(\rho)J(x,\rho)\,.\end{aligned}$$

Still following Artstein and Wets (1993) and Artstein (1999), we have that if Ψ is finer than Φ, then S^{Ψ} is more refined than S^{Φ} in the sense that for all $\phi:\mathcal{P}(\Omega)\to\mathbb{R}$ convex,

$$\int_{\mathcal{P}(\Omega)}\phi(\rho)dS^{\Psi}(\rho)\geq\int_{\mathcal{P}(\Omega)}\phi(\rho)dS^{\Phi}(\rho)\,. \tag{16}$$

Thus, under the assumptions, the value of substituting Ψ for Φ, $u_0\mapsto\Delta_{\Psi\Phi}(f(x_0,u_0))$, is an increasing (a decreasing) function.

11 Appendix: Variations of the value of information in Ulph and Ulph, 1997

We express $\frac{dI_{\Phi}}{dx_1}=\frac{dV_{\Phi}}{dx_1}-\frac{dV_{\perp}}{dx_1}$ for the problem (12).

Denote by $\hat{u}_1(x_1)$ the optimal feedback without information:

$$\hat{u}_1(x_1)\overset{\text{def}}{=}\arg\overbrace{\max_{u_1\geq 0}\left[l_1(u_1)-\mathbb{E}\gamma\, D(u_1+\delta x_1)\right]}^{V_{\perp}(x_1)}\,.$$

Unicity of the arg max results from the strict concavity of the mapping $u_1\mapsto l_1(u_1)-\mathbb{E}\gamma\, D(u_1+\delta x_1)$ since, by assumption, l_1 is strictly concave, D is strictly convex, and $\gamma\geq 0$.

Denoting $x_1^{\perp}\overset{\text{def}}{=}\delta x_0+u_0^{\perp}$, we have then $u_1^{\perp}=\hat{u}_1(x_1^{\perp})$ by definition. From Euler's characterization of the maximum of a concave function, the assumption $u_1^{\perp}=0$ implies that $l'(0)-\delta\mathbb{E}\gamma D'(\delta x_1^{\perp})\leq 0$. Now, for any $x_1\geq x_1^{\perp}$, we have

$$l'(0)-\delta\mathbb{E}\gamma D'(\delta x_1)\leq l'(0)-\delta\mathbb{E}\gamma D'(\delta x_1^{\perp})\leq 0$$

since $-D'$ is decreasing (D is convex). Thus, by Euler's condition, $\hat{u}_1(x_1)=0$. Replacing in $V_{\perp}(x_1)$ and differentiating with respect to x_1, we obtain

$$\frac{dV_{\perp}}{dx_1}(x_1)=-\mathbb{E}\left[\gamma\right]\delta D'(\delta x_1).$$

We now turn to $\frac{dV_{\Phi}}{dx_1}(x_1)$. Let

$$u_1^{\Phi}(x_1)\overset{\text{def}}{=}\arg\max_{u_1\preccurlyeq\Phi} l_1(u_1)-\mathbb{E}[\gamma\mid\Phi]D(u_1+\delta x_1)$$

which is a random variable.

By the Danskin theorem (see Clarke, 1990)), we have that

$$\frac{d}{dx_1}\max_{u_1\preccurlyeq\Phi} l_1(u_1)-\mathbb{E}[\gamma\mid\Phi]D(u_1+\delta x_1)=-\mathbb{E}[\gamma\mid\Phi]\delta D'(\delta x_1+u_1^{\Phi}(x_1))\,.$$

By differentiating under the integral sign, we get that

$$\frac{dV_\Phi}{dx_1}(x_1) = \mathbb{E}\big[-\mathbb{E}[\gamma \mid \Phi]\delta D'(\delta x_1 + u_1^\Phi(x_1))\big]$$

Finally,

$$\begin{aligned}\frac{dI_\Phi}{dx_1}(x_1) &= \mathbb{E}\big[-\mathbb{E}[\gamma \mid \Phi]\delta D'(\delta x_1 + u_1^\Phi(x_1))\big] + \mathbb{E}\left[\gamma\right]\delta D'(\delta x_1) \\ &= \mathbb{E}\big[-\mathbb{E}[\gamma \mid \Phi]\delta D'(\delta x_1 + u_1^\Phi(x_1))\big] + \mathbb{E}\big[\mathbb{E}\left[\gamma \mid \Phi\right]\big]\delta D'(\delta x_1) \\ &= \mathbb{E}\big[\mathbb{E}\left[\gamma \mid \Phi\right](D'(\delta x_1) - D'(\delta x_1 + u_1^\Phi(x_1)))\big]\end{aligned}$$

which is non-positive since $u_1^\Phi(x_1, s) \geq 0$ and D is convex. Therefore $u_0 \mapsto I_\Phi(\delta x_0 + u_0)$ is decreasing for all u_0 greater than $u_0^\perp$: the value of information diminishes with initial GHG emissions above their optimal level without information.

12 Appendix: Details for the numerical model

12.1 Summarized description of the modified dice model

The model solve the following problem.

$$\max_{v_0,\dots,v_{d-1}} \mathbb{E}\left\{\sum_{i=0}^{d-1} L_i(v_i, z_i) + \mathbb{E}\left[\max_{(v_d,\dots,v_T)\preccurlyeq\gamma} \sum_{i=d}^{T} L_i(v_i, z_i) \;\Big|\; \gamma\right]\right\} \tag{17}$$

$$\text{with} \quad z_{i+1} = g(z_i, v_i, \gamma) \tag{18}$$

The time horizon is $T = 40$. Time step $i = 0$ corresponds to the period 2000–2009. The date of arrival of information, d, belongs to $\{0, \dots, T+1\}$.

Variables

Controls		
v_i	a_i	GHG reduction rate
	b_i	investment rate
State variables		
z_i	K_i	Capital stock
	$M_i \in \mathbb{R}^3$	Stocks of carbon in 3 reservoirs
	$\theta_i \in \mathbb{R}^2$	Mean temperature rises for atmosphere and ocean
γ	r.v. $\in \{L, C, H\}$	Climate sensitivity
Intermediary, transfer variable		
	Y	Available economic output

Relations

Output	$Y_i = F_i(K_i)(1 - C_i(a_i))(1 - D(\theta_i))$	(19)
Capital accumulation	$K_{i+1} = G(K_i, b_i Y_i)$	(20)
Carbone cycle	$M_{i+1} = H(a_i, K_i, M_i)$	(21)
Reduced-form climate model	$\theta_{i+1} = \Theta(\theta_i, M_i, \gamma)$	(22)
Discounted utility	$L_i(z_i, v_i) = U_i((1 - b_i)Y_i)$	
Admissibility domain for b_i	$b_i \in \ [0, 1 - \varepsilon]$	
Admissibility domain for a_i	$a_i \in \ [0, 1] \quad (C_i(1) < 1 \quad \text{for all} \quad i)$	

The dynamics summarized by function g in Eq. (18) is composed with the four relations (19–22).

Detailed functional forms can be found in Nordhaus (1994) or Nordhaus and Boyer (2000) except for two modifications from Ambrosi et al. (2003) — function Θ in Eq. (22) and damage function D in Eq. (19) — that are reproduced in section 12.5 below.

Random variable Three different distributions are used for the random variable $\gamma \in \{L, C, H\}$

	Climate sensitivity γ		
Probability	L(2.5 °C)	C(3.5 °C)	H(4.5 °C)
optimistic	2/3	1/3	1/3
centered	1/3	2/3	1/3
pessimistic	1/3	1/3	2/3

12.2 Parameterization of the controls in time steps 0 to 3

The goal is to compute the value of information in 2040 ($d = 4$) as a function of a scalar policy decision describing abatement and investment choices from 2000 to 2039. We chose the abatement rate targeted for 2030 as the key policy decision. The problem is to chose a sensible parameterization of investment and abatement before and up to 2030 with this scalar. We propose one that approximates for $i \in \{0, \ldots, 3\}$ the optimal trajectories of the model under the different hypotheses available on the climate sensitivity. Afterwards, the parameterization allows to describe a wider range of trajectories, including non-optimal ones (bad policy choices) in a coherent and continuous manner.

For calibration purposes, we have therefore computed the numerical optimal values for $(v_i)_{i \in \{0 \ldots 3\}}$ in problem (17) under four different hypotheses :

- H1: no uncertainty ($d = 0$) and $\gamma = L$
- H2: no uncertainty ($d = 0$) and $\gamma = C$
- H3: no uncertainty ($d = 0$) and $\gamma = H$
- H4: information in 2040 ($d = 5$). $\gamma \in \{L, C, H\}$, pessimistic probabilities (see above) are used.

	Abatement rate in year				Investment rate in year			
	2000	2010	2020	2030	2000	2010	2020	2030
Hypothesis	a_0	a_1	a_2	a_3	b_0	b_1	b_2	b_3
H1	0.059	0.075	0.093	0.115	0.239	0.232	0.228	0.225
H2	0.092	0.123	0.163	0.215	0.239	0.231	0.227	0.224
H3	0.138	0.194	0.266	0.361	0.238	0.231	0.226	0.223
H4	0.121	0.168	0.230	0.310	0.238	0.231	0.226	0.224

Table 1: Optimal abatement and investment rates under H1–4

The GAMS code for solving numerically problem (17) is 'dice_response_art.gms' provided in attachement. See also section **??**. The numerical model has actually $i = -1$ as first time step corresponding to 1990–1999, but abatement is fixed to $a_{-1} = 0$. Investment is fixed as well with value $b_{-1} = 0.250$. We obtain the following results, displayed below in Table 1

The parameterization chosen, $\varphi : u_0 \mapsto (a_i, b_i)_{i \in \{0 \dots 3\}}$, is defined by

$$\begin{aligned} a_i = \varphi_i^a(u) &= \lambda u + \mu u i + \nu u i^2 \\ &\text{with} \quad \lambda = 0.3006 \quad \mu = 0.0724 \quad \nu = 0.0256 \end{aligned}$$

and

$$\begin{aligned} b_i &= \varphi_i^b \\ &\text{with} \quad \varphi_0^b = 0.239 \quad \varphi_1^b = 0.231 \quad \varphi_2^b = 0.227 \quad \varphi_3^b = 0.224 \end{aligned}$$

Both parameterizations are chosen to approximate the optimal numerical solutions of problem (**??**) under hypotheses H1–H4. Figure 2 displays how φ approximates the optimal decisions in Table 1.

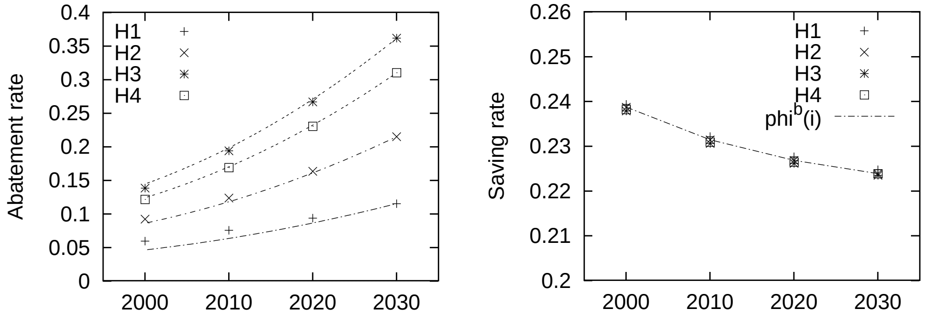

Figure 2: Parameterization of policy before 2040

The left panel of figure 2 shows as dots the optimal abatement rates a_i in time steps $i = 0, \dots, 3$ under hypotheses H1–4. The lines trace the corresponding parameterizations φ^a where u_0 assume in turn the preceding values of a_3 in hypotheses H1–4.

The right panel of Figure 2 displays the optimal investment rates b_i for $i = 0 \dots 3$ under hypotheses H1–H4 and the parametrization φ_i^b as a line. Note that it depends only of the time step and not of u.

12.3 Optimal initial policies with and without learning

After parameterization, the problem is simplified into

$$\max_{0\le u_0\le 1}\ \mathbb{E}\left\{\sum_{i<4} L_i(\varphi_i(u_0), z_i) + \mathbb{E}\left[\max_{(v_4,\dots,v_T)\preccurlyeq\gamma}\sum_{i=4}^{T} L_i(v_i, z_i)\ \Big|\ \gamma\right]\right\} \tag{23}$$

$$\text{with}\quad z_{i+1} = g(z_i, \varphi_i(u_0), \gamma)\quad \text{for}\quad i < d$$
$$\text{and}\quad z_{i+1} = g(z_i, v_i, \gamma)\quad \text{for}\quad i \ge d$$

This problem is solved with MINOS 5 using the GAMS code 'u0opt_dicersp.gms'.For each probability distribution, we obtain the following optimal values for u_0 with information arrival in 2040 or without arrival of information.We have computed the *initial* value of information, I^0 (the difference between the optimal value of the objective with $d = 0$ and with $d = 4$)

Optimal abatement target in 2030 with and without learning

Probability distribution	Information in 2040 u_0^{**}	Never learn u_0^{*}	Initial value of information (in utility units)
Optimistic	0.196	0.248	462
Centered	0.236	0.283	284
Pessimistic	0.308	0.338	193

Table 2:

The values for u_0^{**} and u_0^{*} are reported into Figure 1 of the main paper.

12.4 Computed value of information

By definition,

$$I_s(u_0) = \mathbb{E}\left[\max_{(v_d,\dots,v_T)\preccurlyeq\gamma}\sum_{i=d}^{T} L_i(v_i, z_i)\ \Big|\ \gamma\right] - \max_{(v_d,\dots,v_T)}\mathbb{E}\sum_{i=d}^{T} L_i(v_i, z_i) \tag{24}$$

with $z_{i+1} = g(z_i, v_i, \gamma)$ for $i \ge d$

and the r.v. z_d determined by z_0, γ and u_0 through:

$$z_{i+1} = g(z_i, \varphi_i(u_0), \gamma)\quad \text{for}\quad i < d$$

We screen $[0, 1]$ for values of u_0. For each value of u_0, the problems in Eq. 24 are solved with MINOS 5 using the GAMS code 'vlrinfo_dicersp.gms'.

An extract of the results is given in the next table.

12.5 Detailed modifications to the original dice model

These modifications are taken and reproduced from Ambrosi et al. (2003)

Reduced-form climate model

We detail here the Eq. (22): $\theta_{i+1} = \Theta(\theta_i, M_i, \gamma)$

$$\theta_{i+1} = \Sigma(\gamma)\,\theta_i + \sigma_1 \begin{bmatrix} F_i(M_i) \\ 0 \end{bmatrix}$$

Value of information as a function of initial policy

	Probability distribution		
	pessimistic	centered	optimistic
Initial policy u_0	Value of information *(in utility units)*		
0.000	269	355	520
0.051	255	343	507
0.101	241	328	494
0.152	228	314	481
0.202	217	300	467
0.253	206	286	454
0.303	196	274	441
0.354	187	262	428
0.404	178	250	416
0.455	170	240	404
0.505	163	230	392
0.556	156	220	381
0.606	150	212	370
0.657	143	203	359
0.707	138	195	346
0.758	132	188	333
0.808	127	181	322
0.859	122	174	311
0.909	118	167	300
0.960	114	161	290
1.000	110	157	283

Table 3: Initial policy is the abatement targeted for 2030

where

- $\theta_i = {}^t(\theta_i^{At}, \theta_i^{Oc})$ is the vector of global mean temperature rise (°C) with respect to pre-industrial times for the atmosphere and the ocean.
- $F_i(M_i)$ is the radiative forcing defined by

  $$F_i(M_i) = F_{2X} \log(M_i^{\text{atm}}/280)/\log 2$$

  where M_i^{atm}, subcomponent of M_i, is the CO_2 atmospheric concentration in time step i. M_{PI} is the CO_2 atmospheric concentration at pre-industrial times, set at 280 ppm. F_{2X} is the instantaneous radiative forcing for an atmospheric concentration of $2 \times M_{PI}$, set at 3.71 W.m^{-2}.
- the transfer matrix $\Sigma(\gamma)$ is

  $$\Sigma(\gamma) = \begin{bmatrix} 1 - \sigma_1(F_{2X}/\gamma + \sigma_2) & \sigma_1\sigma_2 \\ \sigma_3 & 1 - \sigma_3 \end{bmatrix}$$

  with coefficient values $\sigma_1 = 0.479$ $\text{C.W}^{-1}.\text{m}^{-2}$, $\sigma_2 = 0.109$ $\text{C}^{-1}.\text{W.m}^{-2}$, $\sigma_3 = 0.131$ and γ is the climate sensitivity.

Damage function

We detail here the function D of Eq. (19) that defines the damages in share of GWP.

$$D(\theta_i) = b(\theta_i^{At} - \theta_0^{At}) + \frac{d}{1 + \exp\left[\frac{K+Z-2(\theta_i^{At}-\theta_0^{At})}{K-Z} \ln\left(\frac{2-e}{e}\right)\right]}$$

where $b = 0.005\,°\mathrm{C}^{-}1$ is the linear trend of the damage; $d = 0.03$ is the magnitude of the jump ; $e = 0.1$ controls the steepness of the jump ; $K = 1.3\,°\mathrm{C}$ and $Z = 2.7\,°\mathrm{C}$ are the temperatures where the non-linear transition begins and ends.

References

Ambrosi, P., J.-C. Hourcade, S. Hallegatte, F. Lecocq, P. Dumas, and M. Ha-Duong: 2003, 'Optimal control models and elicitation of attitudes towards climate change'. *Environmental Modeling and Assessment* **8**(3), 135–147. Special Issue on Modeling the economic response to global climate change.

Arrow, K. J. and A. C. Fisher: 1974, 'Environmental preservation, uncertainty, and irreversibity'. *Quarterly Journal of Economics* **88**, 312–319.

Artstein, Z.: 1999, 'Gains and costs of information in stochastic programming'. *Annals of Operations Research* (85), 128–152.

Artstein, Z. and R. J.-B. Wets: 1993, 'Sensors and information in optimization under stochastic uncertainty'. *Mathematic of Operation Research* **18**(3).

Breiman, L.: 1993, *Probability*, Classics in applied mathematics. Philadelphia: SIAM, second edition.

Clarke, F. H.: 1990, *Optimization and nonsmooth analysis*, Vol. 5 of *Classics in Mathematics*. SIAM.

Conrad, J. M.: 1980, 'Quasi-Option Value and the Expected Value of Information'. *Quarterly Journal of Economics* **94**, 813–820.

Epstein, L. G.: 1980, 'Decision Making and Temporal Resolution of Uncertainty'. *International Economic Review* **21**, 269–283.

Fisher, A. C.: 2000, 'Investment under uncertainty and option value in environmental economics'. *Resource and Energy Economics* **22**, 197–204.

Freixas, X. and J.-J. Laffont: 1984, 'The Irreversibility Effect'. In: M. Boyer and R. Kihlström (eds.): *Bayesian Models in Economic Theory*. Elsevier Science Publishers B.V., Chapt. 7, pp. 105–114.

Gjerde, J., S. Grepperud, and S. Kverndokk: 1999, 'Optimal climate policy under the possibility of a catastrophe'. *Resource and Energy Economics* **21**, 289–317.

Gollier, C., B. Jullien, and N. Treich: 2000, 'Scientific Progress and Irreversibility: an Economic Interpretation of the "Precautionary Principle"'. *Journal of Public Economics* **75**, 229–253.

Ha-Duong, M.: 1998, 'Quasi-Option Value and Climate Policy Choices'. *Energy Economics* **20**, 599–620.

Hanemann, W. M.: 1989, 'Information and the Concept of Option Value'. *Journal of Environmental Economics and Management* **14**, 183–190.

Henry, C.: 1974a, 'Investment Decisions Under Uncertainty: The "Irreversibility Effect"'. *American Economic Review* **64**(6), 1006–1012.

Henry, C.: 1974b, 'Option values in the economics of irreplaceable assets'. *Review of Economic Studies* **41**, 89–104.

Kelly, D. L. and C. D. Kolstad: 1999, 'Bayesian learning, growth, and pollution'. *Journal of Economic Dynamics and Control* **23**, 491–518.

Kolstad, C. D.: 1996, 'Fundamental Irreversibilities in Stock Externalities'. *Journal of Public Economics* **60**, 221–233.

Laffont, J.-J.: 1989, *The economics of uncertainty and information.* Cambridge: MIT Press. Published in France under the title *Cours de théorie microéconomique. II. Économie de l'incertain et de l'information* by Economica, Paris, 1986. Translated by John P. Bonin and Hélène Bonin.

Manne, A. S. and R. Richels: 1992, *Buying Greenhouse Insurance: The Economic Cost of CO_2 Emissions Limits.* MIT Press.

Nordhaus, W. D.: 1994, *Managing the Global Commons.* MIT Press.

Nordhaus, W. D. and J. Boyer: 2000, *Warming the World: Economics Models of Global Warming.* MIT press.

Rouillon, S.: 2001, 'Catastrophe Climatique Irréversible, Incertitude et Progrès de la Connaissance'. *Revue Économique* **52**(1), 61–90.

Topkis, D. M.: 1978, 'Minimizing a submodular function on a lattice'. *Operations Research* **26**, 305–321.

Topkis, D. M.: 1998, *Supermodularity and Complementarity.* Princeton, N.J.: Princeton University Press.

Ulph, A. and D. Ulph: 1997, 'Global Warming, Irreversibility and Learning'. *Economic Journal* **107**(442), 636–650.

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 2004

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

KTHC	36.2004	*Franca ECKERT COEN and Claudio ROSSI* (lxviii): Foreigners, Immigrants, Host Cities: The Policies of Multi-Ethnicity in Rome. Reading Governance in a Local Context
KTHC	37.2004	*Kristine CRANE* (lxviii): Governing Migration: Immigrant Groups' Strategies in Three Italian Cities – Rome, Naples and Bari
KTHC	38.2004	*Kiflemariam HAMDE* (lxviii): Mind in Africa, Body in Europe: The Struggle for Maintaining and Transforming Cultural Identity - A Note from the Experience of Eritrean Immigrants in Stockholm
ETA	39.2004	*Alberto CAVALIERE:* Price Competition with Information Disparities in a Vertically Differentiated Duopoly
PRA	40.2004	*Andrea BIGANO and Stef PROOST:* The Opening of the European Electricity Market and Environmental Policy: Does the Degree of Competition Matter?
CCMP	41.2004	*Micheal FINUS* (lxix): International Cooperation to Resolve International Pollution Problems
KTHC	42.2004	*Francesco CRESPI:* Notes on the Determinants of Innovation: A Multi-Perspective Analysis
CTN	43.2004	*Sergio CURRARINI and Marco MARINI:* Coalition Formation in Games without Synergies
CTN	44.2004	*Marc ESCRIHUELA-VILLAR:* Cartel Sustainability and Cartel Stability
NRM	45.2004	*Sebastian BERVOETS and Nicolas GRAVEL* (lxvi): Appraising Diversity with an Ordinal Notion of Similarity: An Axiomatic Approach
NRM	46.2004	*Signe ANTHON and Bo JELLESMARK THORSEN* (lxvi): Optimal Afforestation Contracts with Asymmetric Information on Private Environmental Benefits
NRM	47.2004	*John MBURU* (lxvi)*:* Wildlife Conservation and Management in Kenya: Towards a Co-management Approach
NRM	48.2004	*Ekin BIROL, Ágnes GYOVAI and Melinda SMALE* (lxvi)*:* Using a Choice Experiment to Value Agricultural Biodiversity on Hungarian Small Farms: Agri-Environmental Policies in a Transition al Economy
CCMP	49.2004	*Gernot KLEPPER and Sonja PETERSON:* The EU Emissions Trading Scheme. Allowance Prices, Trade Flows, Competitiveness Effects
GG	50.2004	*Scott BARRETT and Michael HOEL:* Optimal Disease Eradication
CTN	51.2004	*Dinko DIMITROV, Peter BORM, Ruud HENDRICKX and Shao CHIN SUNG:* Simple Priorities and Core Stability in Hedonic Games
SIEV	52.2004	*Francesco RICCI*: Channels of Transmission of Environmental Policy to Economic Growth: A Survey of the Theory
SIEV	53.2004	*Anna ALBERINI, Maureen CROPPER, Alan KRUPNICK and Nathalie B. SIMON:* Willingness to Pay for Mortality Risk Reductions: Does Latency Matter?
NRM	54.2004	*Ingo BRÄUER and Rainer MARGGRAF* (lxvi): Valuation of Ecosystem Services Provided by Biodiversity Conservation: An Integrated Hydrological and Economic Model to Value the Enhanced Nitrogen Retention in Renaturated Streams
NRM	55.2004	*Timo GOESCHL and Tun LIN* (lxvi): Biodiversity Conservation on Private Lands: Information Problems and Regulatory Choices
NRM	56.2004	*Tom DEDEURWAERDERE* (lxvi): Bioprospection: From the Economics of Contracts to Reflexive Governance
CCMP	57.2004	*Katrin REHDANZ and David MADDISON:* The Amenity Value of Climate to German Households
CCMP	58.2004	*Koen SMEKENS and Bob VAN DER ZWAAN:* Environmental Externalities of Geological Carbon Sequestration Effects on Energy Scenarios
NRM	59.2004	*Valentina BOSETTI, Mariaester CASSINELLI and Alessandro LANZA* (lxvii): Using Data Envelopment Analysis to Evaluate Environmentally Conscious Tourism Management
NRM	60.2004	*Timo GOESCHL and Danilo CAMARGO IGLIORI* (lxvi):Property Rights Conservation and Development: An Analysis of Extractive Reserves in the Brazilian Amazon
CCMP	61.2004	*Barbara BUCHNER and Carlo CARRARO*: Economic and Environmental Effectiveness of a Technology-based Climate Protocol
NRM	62.2004	*Elissaios PAPYRAKIS and Reyer GERLAGH*: Resource-Abundance and Economic Growth in the U.S.
NRM	63.2004	*Györgyi BELA, György PATAKI, Melinda SMALE and Mariann HAJDÚ* (lxvi): Conserving Crop Genetic Resources on Smallholder Farms in Hungary: Institutional Analysis
NRM	64.2004	*E.C.M. RUIJGROK and E.E.M. NILLESEN* (lxvi): The Socio-Economic Value of Natural Riverbanks in the Netherlands
NRM	65.2004	*E.C.M. RUIJGROK* (lxvi): Reducing Acidification: The Benefits of Increased Nature Quality. Investigating the Possibilities of the Contingent Valuation Method
ETA	66.2004	*Giannis VARDAS and Anastasios XEPAPADEAS*: Uncertainty Aversion, Robust Control and Asset Holdings
GG	67.2004	*Anastasios XEPAPADEAS and Constadina PASSA*: Participation in and Compliance with Public Voluntary Environmental Programs: An Evolutionary Approach
GG	68.2004	*Michael FINUS*: Modesty Pays: Sometimes!
NRM	69.2004	*Trond BJØRNDAL and Ana BRASÃO*: The Northern Atlantic Bluefin Tuna Fisheries: Management and Policy Implications
CTN	70.2004	*Alejandro CAPARRÓS, Abdelhakim HAMMOUDI and Tarik TAZDAÏT*: On Coalition Formation with Heterogeneous Agents
IEM	71.2004	*Massimo GIOVANNINI, Margherita GRASSO, Alessandro LANZA and Matteo MANERA*: Conditional Correlations in the Returns on Oil Companies Stock Prices and Their Determinants
IEM	72.2004	*Alessandro LANZA, Matteo MANERA and Michael MCALEER*: Modelling Dynamic Conditional Correlations in WTI Oil Forward and Futures Returns
SIEV	73.2004	*Margarita GENIUS and Elisabetta STRAZZERA*: The Copula Approach to Sample Selection Modelling: An Application to the Recreational Value of Forests

CCMP	74.2004	*Rob DELLINK and Ekko van IERLAND*: Pollution Abatement in the Netherlands: A Dynamic Applied General Equilibrium Assessment
ETA	75.2004	*Rosella LEVAGGI and Michele MORETTO*: Investment in Hospital Care Technology under Different Purchasing Rules: A Real Option Approach
CTN	76.2004	*Salvador BARBERÀ and Matthew O. JACKSON* (lxx): On the Weights of Nations: Assigning Voting Weights in a Heterogeneous Union
CTN	77.2004	*Àlex ARENAS, Antonio CABRALES, Albert DÍAZ-GUILERA, Roger GUIMERÀ and Fernando VEGA-REDONDO* (lxx): Optimal Information Transmission in Organizations: Search and Congestion
CTN	78.2004	*Francis BLOCH and Armando GOMES* (lxx): Contracting with Externalities and Outside Options
CTN	79.2004	*Rabah AMIR, Effrosyni DIAMANTOUDI and Licun XUE* (lxx): Merger Performance under Uncertain Efficiency Gains
CTN	80.2004	*Francis BLOCH and Matthew O. JACKSON* (lxx): The Formation of Networks with Transfers among Players
CTN	81.2004	*Daniel DIERMEIER, Hülya ERASLAN and Antonio MERLO* (lxx): Bicameralism and Government Formation
CTN	82.2004	*Rod GARRATT, James E. PARCO, Cheng-ZHONG QIN and Amnon RAPOPORT* (lxx): Potential Maximization and Coalition Government Formation
CTN	83.2004	*Kfir ELIAZ, Debraj RAY and Ronny RAZIN* (lxx): Group Decision-Making in the Shadow of Disagreement
CTN	84.2004	*Sanjeev GOYAL, Marco van der LEIJ and José Luis MORAGA-GONZÁLEZ* (lxx): Economics: An Emerging Small World?
CTN	85.2004	*Edward CARTWRIGHT* (lxx): Learning to Play Approximate Nash Equilibria in Games with Many Players
IEM	86.2004	*Finn R. FØRSUND and Michael HOEL*: Properties of a Non-Competitive Electricity Market Dominated by Hydroelectric Power
KTHC	87.2004	*Elissaios PAPYRAKIS and Reyer GERLAGH*: Natural Resources, Investment and Long-Term Income
CCMP	88.2004	*Marzio GALEOTTI and Claudia KEMFERT*: Interactions between Climate and Trade Policies: A Survey
IEM	89.2004	*A. MARKANDYA, S. PEDROSO and D. STREIMIKIENE*: Energy Efficiency in Transition Economies: Is There Convergence Towards the EU Average?
GG	90.2004	*Rolf GOLOMBEK and Michael HOEL* : Climate Agreements and Technology Policy
PRA	91.2004	*Sergei IZMALKOV* (lxv): Multi-Unit Open Ascending Price Efficient Auction
KTHC	92.2004	*Gianmarco I.P. OTTAVIANO and Giovanni PERI*: Cities and Cultures
KTHC	93.2004	*Massimo DEL GATTO*: Agglomeration, Integration, and Territorial Authority Scale in a System of Trading Cities. Centralisation versus devolution
CCMP	94.2004	*Pierre-André JOUVET, Philippe MICHEL and Gilles ROTILLON*: Equilibrium with a Market of Permits
CCMP	95.2004	*Bob van der ZWAAN and Reyer GERLAGH*: Climate Uncertainty and the Necessity to Transform Global Energy Supply
CCMP	96.2004	*Francesco BOSELLO, Marco LAZZARIN, Roberto ROSON and Richard S.J. TOL*: Economy-Wide Estimates of the Implications of Climate Change: Sea Level Rise
CTN	97.2004	*Gustavo BERGANTIÑOS and Juan J. VIDAL-PUGA*: Defining Rules in Cost Spanning Tree Problems Through the Canonical Form
CTN	98.2004	*Siddhartha BANDYOPADHYAY and Mandar OAK*: Party Formation and Coalitional Bargaining in a Model of Proportional Representation
GG	99.2004	*Hans-Peter WEIKARD, Michael FINUS and Juan-Carlos ALTAMIRANO-CABRERA*: The Impact of Surplus Sharing on the Stability of International Climate Agreements
SIEV	100.2004	*Chiara M. TRAVISI and Peter NIJKAMP*: Willingness to Pay for Agricultural Environmental Safety: Evidence from a Survey of Milan, Italy, Residents
SIEV	101.2004	*Chiara M. TRAVISI, Raymond J. G. M. FLORAX and Peter NIJKAMP*: A Meta-Analysis of the Willingness to Pay for Reductions in Pesticide Risk Exposure
NRM	102.2004	*Valentina BOSETTI and David TOMBERLIN:* Real Options Analysis of Fishing Fleet Dynamics: A Test
CCMP	103.2004	*Alessandra GORIA e Gretel GAMBARELLI:* Economic Evaluation of Climate Change Impacts and Adaptability in Italy
PRA	104.2004	*Massimo FLORIO and Mara GRASSENI*: The Missing Shock: The Macroeconomic Impact of British Privatisation
PRA	105.2004	*John BENNETT, Saul ESTRIN, James MAW and Giovanni URGA*: Privatisation Methods and Economic Growth in Transition Economies
PRA	106.2004	*Kira BÖRNER*: The Political Economy of Privatization: Why Do Governments Want Reforms?
PRA	107.2004	*Pehr-Johan NORBÄCK and Lars PERSSON*: Privatization and Restructuring in Concentrated Markets
SIEV	108.2004	*Angela GRANZOTTO, Fabio PRANOVI, Simone LIBRALATO, Patrizia TORRICELLI and Danilo MAINARDI*: Comparison between Artisanal Fishery and Manila Clam Harvesting in the Venice Lagoon by Using Ecosystem Indicators: An Ecological Economics Perspective
CTN	109.2004	*Somdeb LAHIRI*: The Cooperative Theory of Two Sided Matching Problems: A Re-examination of Some Results
NRM	110.2004	*Giuseppe DI VITA*: Natural Resources Dynamics: Another Look
SIEV	111.2004	*Anna ALBERINI, Alistair HUNT and Anil MARKANDYA*: Willingness to Pay to Reduce Mortality Risks: Evidence from a Three-Country Contingent Valuation Study
KTHC	112.2004	*Valeria PAPPONETTI and Dino PINELLI*: Scientific Advice to Public Policy-Making
SIEV	113.2004	*Paulo A.L.D. NUNES and Laura ONOFRI*: The Economics of Warm Glow: A Note on Consumer's Behavior and Public Policy Implications
IEM	114.2004	*Patrick CAYRADE*: Investments in Gas Pipelines and Liquefied Natural Gas Infrastructure What is the Impact on the Security of Supply?
IEM	115.2004	*Valeria COSTANTINI and Francesco GRACCEVA:* Oil Security. Short- and Long-Term Policies

IEM	116.2004	*Valeria COSTANTINI and Francesco GRACCEVA:* Social Costs of Energy Disruptions
IEM	117.2004	*Christian EGENHOFER, Kyriakos GIALOGLOU, Giacomo LUCIANI, Maroeska BOOTS, Martin SCHEEPERS, Valeria COSTANTINI, Francesco GRACCEVA, Anil MARKANDYA and Giorgio VICINI*: Market-Based Options for Security of Energy Supply
IEM	118.2004	*David FISK*: Transport Energy Security. The Unseen Risk?
IEM	119.2004	*Giacomo LUCIANI*: Security of Supply for Natural Gas Markets. What is it and What is it not?
IEM	120.2004	*L.J. de VRIES and R.A. HAKVOORT*: The Question of Generation Adequacy in Liberalised Electricity Markets
KTHC	121.2004	*Alberto PETRUCCI*: Asset Accumulation, Fertility Choice and Nondegenerate Dynamics in a Small Open Economy
NRM	122.2004	*Carlo GIUPPONI, Jaroslaw MYSIAK and Anita FASSIO*: An Integrated Assessment Framework for Water Resources Management: A DSS Tool and a Pilot Study Application
NRM	123.2004	*Margaretha BREIL, Anita FASSIO, Carlo GIUPPONI and Paolo ROSATO*: Evaluation of Urban Improvement on the Islands of the Venice Lagoon: A Spatially-Distributed Hedonic-Hierarchical Approach
ETA	124.2004	*Paul MENSINK*: Instant Efficient Pollution Abatement Under Non-Linear Taxation and Asymmetric Information: The Differential Tax Revisited
NRM	125.2004	*Mauro FABIANO, Gabriella CAMARSA, Rosanna DURSI, Roberta IVALDI, Valentina MARIN and Francesca PALMISANI*: Integrated Environmental Study for Beach Management:A Methodological Approach
PRA	126.2004	*Irena GROSFELD and Iraj HASHI*: The Emergence of Large Shareholders in Mass Privatized Firms: Evidence from Poland and the Czech Republic
CCMP	127.2004	*Maria BERRITTELLA, Andrea BIGANO, Roberto ROSON and Richard S.J. TOL*: A General Equilibrium Analysis of Climate Change Impacts on Tourism
CCMP	128.2004	*Reyer GERLAGH*: A Climate-Change Policy Induced Shift from Innovations in Energy Production to Energy Savings
NRM	129.2004	*Elissaios PAPYRAKIS and Reyer GERLAGH*: Natural Resources, Innovation, and Growth
PRA	130.2004	*Bernardo BORTOLOTTI and Mara FACCIO*: Reluctant Privatization
SIEV	131.2004	*Riccardo SCARPA and Mara THIENE*: Destination Choice Models for Rock Climbing in the Northeast Alps: A Latent-Class Approach Based on Intensity of Participation
SIEV	132.2004	*Riccardo SCARPA Kenneth G. WILLIS and Melinda ACUTT*: Comparing Individual-Specific Benefit Estimates for Public Goods: Finite Versus Continuous Mixing in Logit Models
IEM	133.2004	*Santiago J. RUBIO*: On Capturing Oil Rents with a National Excise Tax Revisited
ETA	134.2004	*Ascensión ANDINA DÍAZ*: Political Competition when Media Create Candidates' Charisma
SIEV	135.2004	*Anna ALBERINI*: Robustness of VSL Values from Contingent Valuation Surveys
CCMP	136.2004	*Gernot KLEPPER and Sonja PETERSON*: Marginal Abatement Cost Curves in General Equilibrium: The Influence of World Energy Prices
ETA	137.2004	*Herbert DAWID, Christophe DEISSENBERG and Pavel ŠEVČIK*: Cheap Talk, Gullibility, and Welfare in an Environmental Taxation Game
CCMP	138.2004	*ZhongXiang ZHANG*: The World Bank's Prototype Carbon Fund and China
CCMP	139.2004	*Reyer GERLAGH and Marjan W. HOFKES*: Time Profile of Climate Change Stabilization Policy
NRM	140.2004	*Chiara D'ALPAOS and Michele MORETTO*: The Value of Flexibility in the Italian Water Service Sector: A Real Option Analysis
PRA	141.2004	*Patrick BAJARI, Stephanie HOUGHTON and Steven TADELIS* (lxxi): Bidding for Incompete Contracts
PRA	142.2004	*Susan ATHEY, Jonathan LEVIN and Enrique SEIRA* (lxxi): Comparing Open and Sealed Bid Auctions: Theory and Evidence from Timber Auctions
PRA	143.2004	*David GOLDREICH* (lxxi): Behavioral Biases of Dealers in U.S. Treasury Auctions
PRA	144.2004	*Roberto BURGUET* (lxxi): Optimal Procurement Auction for a Buyer with Downward Sloping Demand: More Simple Economics
PRA	145.2004	*Ali HORTACSU and Samita SAREEN* (lxxi): Order Flow and the Formation of Dealer Bids: An Analysis of Information and Strategic Behavior in the Government of Canada Securities Auctions
PRA	146.2004	*Victor GINSBURGH, Patrick LEGROS and Nicolas SAHUGUET* (lxxi): How to Win Twice at an Auction. On the Incidence of Commissions in Auction Markets
PRA	147.2004	*Claudio MEZZETTI, Aleksandar PEKEČ and Ilia TSETLIN* (lxxi): Sequential vs. Single-Round Uniform-Price Auctions
PRA	148.2004	*John ASKER and Estelle CANTILLON* (lxxi): Equilibrium of Scoring Auctions
PRA	149.2004	*Philip A. HAILE, Han HONG and Matthew SHUM* (lxxi): Nonparametric Tests for Common Values in First-Price Sealed-Bid Auctions
PRA	150.2004	*François DEGEORGE, François DERRIEN and Kent L. WOMACK* (lxxi): Quid Pro Quo in IPOs: Why Bookbuilding is Dominating Auctions
CCMP	151.2004	*Barbara BUCHNER and Silvia DALL'OLIO*: Russia: The Long Road to Ratification. Internal Institution and Pressure Groups in the Kyoto Protocol's Adoption Process
CCMP	152.2004	*Carlo CARRARO and Marzio GALEOTTI*: Does Endogenous Technical Change Make a Difference in Climate Policy Analysis? A Robustness Exercise with the FEEM-RICE Model
PRA	153.2004	*Alejandro M. MANELLI and Daniel R. VINCENT* (lxxi): Multidimensional Mechanism Design: Revenue Maximization and the Multiple-Good Monopoly
ETA	154.2004	*Nicola ACOCELLA, Giovanni Di BARTOLOMEO and Wilfried PAUWELS*: Is there any Scope for Corporatism in Stabilization Policies?
CTN	155.2004	*Johan EYCKMANS and Michael FINUS*: An Almost Ideal Sharing Scheme for Coalition Games with Externalities
CCMP	156.2004	*Cesare DOSI and Michele MORETTO*: Environmental Innovation, War of Attrition and Investment Grants

CCMP	157.2004	*Valentina BOSETTI, Marzio GALEOTTI and Alessandro LANZA*: How Consistent are Alternative Short-Term Climate Policies with Long-Term Goals?
ETA	158.2004	*Y. Hossein FARZIN and Ken-Ichi AKAO*: Non-pecuniary Value of Employment and Individual Labor Supply
ETA	159.2004	*William BROCK and Anastasios XEPAPADEAS*: Spatial Analysis: Development of Descriptive and Normative Methods with Applications to Economic-Ecological Modelling
KTHC	160.2004	*Alberto PETRUCCI*: On the Incidence of a Tax on PureRent with Infinite Horizons
IEM	161.2004	*Xavier LABANDEIRA, José M. LABEAGA and Miguel RODRÍGUEZ*: Microsimulating the Effects of Household Energy Price Changes in Spain

NOTE DI LAVORO PUBLISHED IN 2005

CCMP	1.2005	*Stéphane HALLEGATTE*: Accounting for Extreme Events in the Economic Assessment of Climate Change
CCMP	2.2005	*Qiang WU and Paulo Augusto NUNES*: Application of Technological Control Measures on Vehicle Pollution: A Cost-Benefit Analysis in China
CCMP	3.2005	*Andrea BIGANO, Jacqueline M. HAMILTON, Maren LAU, Richard S.J. TOL and Yuan ZHOU*: A Global Database of Domestic and International Tourist Numbers at National and Subnational Level
CCMP	4.2005	*Andrea BIGANO, Jacqueline M. HAMILTON and Richard S.J. TOL*: The Impact of Climate on Holiday Destination Choice
ETA	5.2005	*Hubert KEMPF*: Is Inequality Harmful for the Environment in a Growing Economy?
CCMP	6.2005	*Valentina BOSETTI, Carlo CARRARO and Marzio GALEOTTI*: The Dynamics of Carbon and Energy Intensity in a Model of Endogenous Technical Change
IEM	7.2005	*David CALEF and Robert GOBLE*: The Allure of Technology: How France and California Promoted Electric Vehicles to Reduce Urban Air Pollution
ETA	8.2005	*Lorenzo PELLEGRINI and Reyer GERLAGH*: An Empirical Contribution to the Debate on Corruption Democracy and Environmental Policy
CCMP	9.2005	*Angelo ANTOCI*: Environmental Resources Depletion and Interplay Between Negative and Positive Externalities in a Growth Model
CTN	10.2005	*Frédéric DEROIAN*: Cost-Reducing Alliances and Local Spillovers
NRM	11.2005	*Francesco SINDICO*: The GMO Dispute before the WTO: Legal Implications for the Trade and Environment Debate
KTHC	12.2005	*Carla MASSIDDA*: Estimating the New Keynesian Phillips Curve for Italian Manufacturing Sectors
KTHC	13.2005	*Michele MORETTO and Gianpaolo ROSSINI*: Start-up Entry Strategies: Employer vs. Nonemployer firms
PRCG	14.2005	*Clara GRAZIANO and Annalisa LUPORINI*: Ownership Concentration, Monitoring and Optimal Board Structure
CSRM	15.2005	*Parashar KULKARNI*: Use of Ecolabels in Promoting Exports from Developing Countries to Developed Countries: Lessons from the Indian LeatherFootwear Industry
KTHC	16.2005	*Adriana DI LIBERTO, Roberto MURA and Francesco PIGLIARU*: How to Measure the Unobservable: A Panel Technique for the Analysis of TFP Convergence
KTHC	17.2005	*Alireza NAGHAVI*: Asymmetric Labor Markets, Southern Wages, and the Location of Firms
KTHC	18.2005	*Alireza NAGHAVI*: Strategic Intellectual Property Rights Policy and North-South Technology Transfer
KTHC	19.2005	*Mombert HOPPE*: Technology Transfer Through Trade
PRCG	20.2005	*Roberto ROSON*: Platform Competition with Endogenous Multihoming
CCMP	21.2005	*Barbara BUCHNER and Carlo CARRARO*: Regional and Sub-Global Climate Blocs. A Game Theoretic Perspective on Bottom-up Climate Regimes
IEM	22.2005	*Fausto CAVALLARO*: An Integrated Multi-Criteria System to Assess Sustainable Energy Options: An Application of the Promethee Method
CTN	23.2005	*Michael FINUS, Pierre v. MOUCHE and Bianca RUNDSHAGEN*: Uniqueness of Coalitional Equilibria
IEM	24.2005	*Wietze LISE*: Decomposition of CO2 Emissions over 1980–2003 in Turkey
CTN	25.2005	*Somdeb LAHIRI*: The Core of Directed Network Problems with Quotas
SIEV	26.2005	*Susanne MENZEL and Riccardo SCARPA*: Protection Motivation Theory and Contingent Valuation: Perceived Realism, Threat and WTP Estimates for Biodiversity Protection
NRM	27.2005	*Massimiliano MAZZANTI and Anna MONTINI*: The Determinants of Residential Water Demand Empirical Evidence for a Panel of Italian Municipalities
CCMP	28.2005	*Laurent GILOTTE and Michel de LARA*: Precautionary Effect and Variations of the Value of Information

(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 9th 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

(lxxi) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications”, organised by Fondazione Eni Enrico Mattei and Consip and sponsored by the EU, Rome, September 23-25, 2004

2004 SERIES

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

2005 SERIES

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