FONDAZIONE ENI ENRICO MATTEI

NOTA DI LAVORO

73.2009

Self-enforcing Agreements on Water allocation

By **Erik Ansink,** Department of Social Sciences, Wageningen University

SUSTAINABLE DEVELOPMENT Series
Editor: Carlo Carraro

Self-enforcing Agreements on Water Allocation

By Erik Ansink, Department of Social Sciences, Wageningen University

Summary

Many water allocation agreements in transboundary river basins are inherently unstable. Due to stochastic river flow, agreements may be broken in case of drought. The objective of this paper is to analyse whether water allocation agreements can be self-enforcing. An agreement is modelled as the outcome of bargaining game on river water allocation. Given this agreement, the bargaining game is followed by a repeated extensive-form game in which countries decide whether or not to comply with the agreement. I assess under what conditions such agreements are self-enforcing, given stochastic river flow. The results show that, for sufficiently low discounting, every efficient agreement can be sustained in subgame perfect equilibrium. Requiring renegotiation-proofness may shrink the set of possible agreements to a unique self-enforcing agreement. The solution induced by this particular agreement implements the "downstream incremental distribution", an axiomatic solution to water allocation that assigns all gains from cooperation to downstream countries.

Keywords: Self-Enforcing Agreement, Repeated Extensive-Form Game, Water Allocation, Renegotiation-Proofness

JEL Classification: C73, Q25

I thank Arjan Ruijs and Hans-Peter Weikard for detailed comments and I acknowledge financial support by the European Union FP6 Integrated Project AquaTerra (project no. GOCE 505428).

Address for correspondence:

Erik Ansink
Department of Social Sciences
Wageningen University
P.O. Box 8130
6700 EW Wageningen
The Netherlands
E-mail: erikansink@gmail.com

Self-enforcing agreements on water allocation*

Erik Ansink

Abstract

Many water allocation agreements in transboundary river basins are inherently unstable. Due to stochastic river flow, agreements may be broken in case of drought. The objective of this paper is to analyse whether water allocation agreements can be self-enforcing. An agreement is modelled as the outcome of bargaining game on river water allocation. Given this agreement, the bargaining game is followed by a repeated extensive-form game in which countries decide whether or not to comply with the agreement. I assess under what conditions such agreements are self-enforcing, given stochastic river flow. The results show that, for sufficiently low discounting, every efficient agreement can be sustained in subgame perfect equilibrium. Requiring renegotiation-proofness may shrink the set of possible agreements to a unique self-enforcing agreement. The solution induced by this particular agreement implements the "downstream incremental distribution", an axiomatic solution to water allocation that assigns all gains from cooperation to downstream countries.

Keywords: self-enforcing agreement, repeated extensive-form game, water allocation, renegotiation-proofness

JEL classification: C73, Q25

---

*Department of Social Sciences, Wageningen University, P.O. Box 8130, 6700 EW Wageningen, The Netherlands. E-mail: `erikansink@gmail.com`. I thank Arjan Ruijs and Hans-Peter Weikard for detailed comments and I acknowledge financial support by the European Union FP6 Integrated Project AquaTerra (project no. GOCE 505428).

1 Introduction

In this paper I analyse an agreement that is based on the outcome of a bargaining game. This game is followed by a repeated extensive-form game in which countries decide whether or not to comply with the agreement. The motivating example for this particular setup are agreements on river water allocation.

In an international river basin, when water is scarce, countries may exchange water for side payments (Carraro et al., 2007). This type of exchange is generally formalised in a water allocation agreement. The aim of water allocation agreements is to increase the overall efficiency of water use. This increase in efficiency can be obstructed by the stochastic nature of river flow, because countries may find it profitable to break the agreement in case of drought. A recent example is Mexico's failure to meet its required average water deliveries under the 1944 US-Mexico Water Treaty in the years 1992–1997 (Gastélum et al., 2009). Additional case study evidence on agreement breakdowns because of droughts can be found in Barrett (1994a), Beach et al. (2000), Bernauer (2002), and Siegfried and Bernauer (2007). Only a minority of current international agreements take into account the variability of river flow (Giordano and Wolf, 2003; Fischhendler, 2004, 2008). Most agreements do not; they either allocate fixed or proportional shares, or they are ambiguous in their schedule for water allocation. Both the efficiency (Bennett et al., 2000) and stability (Ansink and Ruijs, 2008) of such agreements may be hampered. These effects could be worsened by the impacts of climate change on river flow (McCaffrey, 2003; Drieschova et al., 2008).

In order to accommodate for stochastic river flow, Kilgour and Dinar (2001) developed a flexible water allocation agreement that provides an efficient allocation for every possible level of river flow. This agreement maximises the overall benefits of water use, after which side payments are made such that each country benefits from cooperation. This flexible agreement assures efficiency, but not stability because it ignores the repeated interaction of countries over time. Countries have an incentive to defect from the agreement when the benefits of defecting outweigh the benefits of compliance. Note that there is no supra-national authority that can enforce this type of international agreements. This implies that a stable agreement has to be self-enforcing in the sense that both countries should find it in their interest to comply with the agreement (Barrett, 1994b).[1] In such a setting,

[1]Often, the term self-enforcing agreement refers to agreements that satisfy *internal* and *external stability* (Barrett, 1994b). I follow McEvoy and Stranlund (2009) by using the term to refer to the enforcement of compliance with agreements once they are in place.

renegotiation-proofness of the agreement is a natural requirement (Bergin and MacLeod, 1993; Barrett, 2003).

The objective of this paper is to analyse self-enforcing water allocation agreements. Each year, countries decide whether or not to comply with specified agreement actions. I assess under what conditions such agreements are self-enforcing, given stochastic river flow.[2] To do so, I construct a two-country repeated extensive-form game of river water allocation with stochastic river flow. Before the start of the first stage game, the outcome of a bargaining game determines the agreement specifications: water allocation and side payments. In each stage game, as water flows from one country to the other, the countries act sequentially in using water and making side payments. In doing so, they decide to cooperate or defect; that is to comply with specified agreement actions or not.

Using the theory of repeated extensive-form games (Rubinstein and Wolinsky, 1995; Wen, 2002), I show that this game setting implies that any efficient agreement can be sustained in a subgame perfect equilibrium. When renegotiation-proofness is required, then for sufficiently low discounting, every subgame perfect equilibrium is renegotiation-proof. For sufficiently high discounting, however, there is a unique self-enforcing agreement. This particular agreement implements the "downstream incremental distribution", an axiomatic solution to water allocation constructed by Ambec and Sprumont (2002). The solution induced by this self-enforcing agreement is efficient and assigns all gains from cooperation to the downstream country, as discussed in section 4. This distribution of the gains from cooperation contrasts with the assumption in much of the river sharing literature that being upstream increases a country's power in the basin (cf. LeMarquand, 1977; Wolf, 1998; Barrett, 2003; Zeitoun and Warner, 2006; Carraro et al., 2007).

The results of this paper are driven by the combination of the sequential structure of the game with the requirement of renegotiation-proofness. The sequential structure of the game leads to asymmetry in punishment options to deter defection. The bargaining outcome is sensitive to assumptions on this sequential structure. This clarifies that the distribution of bargaining power over the riparian countries depends heavily on the design of the agreement.

This paper makes three novel contributions. First, I provide a self-enforcing

[2]This paper is therefore a contribution to the challenge raised by Carraro et al. (2007): "Water resources are intrinsically unpredictable, and the wide fluctuations in water availability are likely to become more severe over the years. Formally addressing the stochasticity of the resource, as well as the political, social, and strategic feasibility of any allocation scheme, would significantly contribute to decreasing conflicts over water."

agreement for river water allocation, that is generally applicable to agreements in repeated extensive-form games. Second, I assess how the bargaining outcome on agreement specifications can be affected by the prospect of playing a repeated extensive-form game in which countries decide to comply or defect from the agreement. Third, I analyse renegotiation-proofness in repeated games with an extensive-form stochastic stage game.

The remainder of this paper is organised as follows. In section 2, the setting of the game is presented. In section 3, I show that every efficient agreement can be sustained in a subgame perfect equilibrium, but that requiring renegotiation-proofness may shrink the set of possible agreements to a unique self-enforcing agreement. In section 4, I describe that this unique self-enforcing agreement implements the downstream incremental distribution. In section 5, I conclude.

2 Game setting

In this section I describe the setting of the game, including the bargaining game and the subsequent repeated extensive-form game.

2.1 Model

Consider two countries $i = 1, 2$, that share a river and consider cooperation in water allocation. The countries are ordered along a river with country 1 upstream of country 2. This setting is relevant for situations where two countries share a river or where two adjacent countries share river water, without the participation of other riparians. An example of the latter situation is the Nile basin where the Nile Waters Agreement implements water sharing between Egypt and Sudan, without participation of Ethiopia and the other Nile countries.

Total river flow Q_t in year t is drawn from probability distribution $f(Q_t)$. The share of river flow that is added to the river in country i equals $Q_{i,t} = \gamma_i Q_t$, with $\gamma_i \geq 0$ and $\gamma_1 + \gamma_2 = 1$. Water use $x_{i,t}$ is constrained by both availability and unidirectionality of river flow, and by upstream water use:[3]

$$0 \leq x_{1,t} \leq Q_{1,t}, \tag{1}$$

$$0 \leq x_{2,t} \leq Q_{1,t} + Q_{2,t} - x_{1,t}. \tag{2}$$

[3] Q_t is the river flow that is available for use; it does not include the minimum instream flow that is necessary to sustain the ecological functions of the river. Furthermore, note that $x_{i,t}$ denotes water use, not water diversion (that may re-enter the water system as return flows).

Under a water allocation agreement, countries trade water for side payments, making both countries better off. Side payments $s_{i,t}$ may be monetary or in-kind, with:

$$s_{1,t} = -s_{2,t}. \tag{3}$$

Countries receive payoffs $\pi_{i,t}$, defined as the sum of benefits of water use and side payments:

$$\pi_{i,t}(x_{i,t}, s_{i,t}) = b_i(x_{i,t}) + s_{i,t}. \tag{4}$$

Benefit functions $b_i(x_{i,t})$ are increasing and concave with a maximum at $\bar{x}_i$.

An allocation plan for a given year t is a triple $\omega_t = (Q_t, x_t, s_t)$ with river flow vector $Q_t = (Q_{1,t}, Q_{2,t})$, water allocation vector $x_t = (x_{1,t}, x_{2,t})$, and side payment vector $s_t = (s_{1,t}, s_{2,t})$. An allocation plan ω_t, subject to (1), (2), and (3), is defined by the actions of the countries. Countries' have two possible actions: cooperate (C) or defect (D). When cooperating, countries choose their water use or side payment based on the specified agreement actions. When defecting, countries choose their water use or side payments non-cooperatively. In this case, no side payments are made, $s_t^D = (0, 0)$, and the unidirectionality of river flow implies that country 1, being upstream of country 2, uses any water it needs: $x_{1,t}^D = \min\{Q_{1,t}, \bar{x}_1\}$. Given Q_t, four allocation plans are possible: the cooperative allocation plan $\omega_t = \left(Q_t, x_t^C, s_t^C\right)$, the defection allocation plan $\omega_t = \left(Q_t, x_t^D, s_t^D\right)$, and two allocation plans where one country cooperates and the other defects.

For the game to be interesting, I assume super-additivity:

$$b_1\left(x_{1,t}^C\right) + b_2\left(x_{2,t}^C\right) \geq b_1\left(x_{1,t}^D\right) + b_2\left(x_{2,t}^D\right). \tag{5}$$

Without this assumption, there would be no need for cooperation between the two countries. Note that unidirectionality of river flow implies that country 1 can deliver water to country 2, but not vice versa. Combined, super-additivity and unidirectionality imply that $x_{1,t}^C \leq x_{1,t}^D$ and that water is scarce in the sense that:

$$Q_{1,t} + Q_{2,t} \leq \bar{x}_1 + \bar{x}_2. \tag{6}$$

2.2 Bargaining game

The outcome of the bargaining game determines the cooperative allocation plan for each level of river flow. This allocation plan specifies the actions chosen by countries when they cooperate as discussed in section 2.1.

In order to determine the cooperative allocation plan, I use the Nash bargaining solution. This solution coincides with the limit case of a non-cooperative alternating-offers bargaining game which gives strong foundations to its application (Binmore et al., 1986). Given benefit functions and a disagreement point, the Nash bargaining solution provides the cooperative allocation of water and side payments. Here, the disagreement point equals the payoffs when both countries defect. The allocation of water and side payments in year t is such that it maximises the Nash product given Q_t:

$$\arg\max_{x_t^C, s_t^C} \left[b_1\left(x_{1,t}^C\right) + s_{1,t}^C - b_1\left(x_{1,t}^D\right)\right]^{\alpha} \left[b_2\left(x_{2,t}^C\right) + s_{2,t}^C - b_2\left(x_{2,t}^D\right)\right]^{1-\alpha}, \tag{7}$$

$$\begin{aligned} &\text{s.t.} \\ (1) \quad & 0 \leq x_{1,t} \leq Q_{1,t} \\ (2) \quad & 0 \leq x_{2,t} \leq Q_{1,t} + Q_{2,t} - x_{1,t} \\ & b_i\left(x_{i,t}^C\right) + s_{i,t}^C - b_i\left(x_{i,t}^D\right) \geq 0\ ,\ i = 1, 2, \end{aligned}$$

where α reflects the countries' bargaining power and the constraints are feasibility constraints (1) and (2) and individual rationality constraints.[4] In absence of exogenous differences in bargaining power, α may be endogenously determined by the game structure in section 3. The Nash bargaining solution provides the cooperative allocation plan $\omega_t = \left(Q_t, x_t^C, s_t^C\right)$ for each level of Q_t, used in the water allocation agreement.

The model setup assures that, given Q_t, the Nash bargaining solution maximises the joint benefits of water use. Hence, the cooperative water allocation vector x_t^C, induced by the solution, is efficient. Side payments are used to distribute the gains from cooperation according to the countries' bargaining power. Note that for a given level of Q_t, there is a unique x_t^C that maximises joint benefits of water use. There are many efficient allocation plans, though, distinguished by their level of side payments. The Nash bargaining solution selects one of these efficient allocation plans, depending on the level of α. In section 3, we will see that the prospect of playing the repeated game described in the next subsection may affect the level of α and hence the side payments specified in the agreement.

This completes the description of the bargaining game.

[4]See Houba (2008) for a convex program to implement this type of bargaining solutions for water allocation problems.

2.3 Repeated game

In a repeated game, the stability aspects of a water allocation agreement can be analysed. In the repeated extensive-form game that follows the bargaining game, country 1 is the leader and country 2 the follower, according to the direction of river flow. Given an agreement, the stage game in year t is played as follows:

1. A value for Q_t, which defines the values for $Q_{i,t}$, is drawn from probability distribution $f(Q_t)$ and observed by both countries.

2. Country 1 chooses its water use from the binary strategy set $\left\{x^C_{1,t}, x^D_{1,t}\right\}$. If it complies with the agreement, country 1 plays $x_{1,t} = x^C_{1,t}$. If it defects, country 1 plays $x_{1,t} = x^D_{1,t}$.

3. Country 2 observes the action played by country 1, which determines the maximum value of x_2, according to (2). Subsequently, country 2 chooses its side payment from the binary strategy set $\left\{s^C_{2,t}, s^D_{2,t}\right\}$.

Note that because of super-additivity and the possibility of making side payments, the stage game is a two-country prisoner's dilemma in extensive form, see figure 1. Because $s^C_{2,t} = -s^C_{1,t} < 0$, country 2 has a dominant strategy in the stage game: defect.

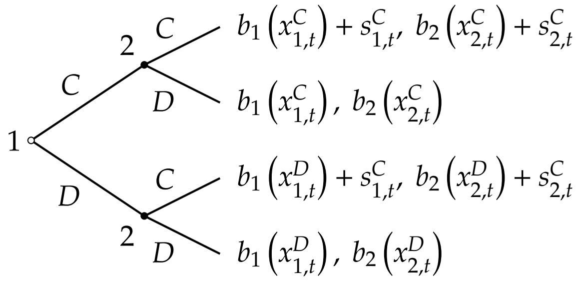

Figure 1: The stage game.

Consequently, in a one-shot game when binding contracts are not feasible, the game has one subgame perfect equilibrium that yields the defection allocation plan. When binding contracts are feasible, the analysis of Kilgour and Dinar (2001) applies: a bargaining game contingent on Q_t yields a Pareto-efficient water allocation vector, with side payments such that the gains from cooperation are equally shared. When the stage game is repeated and binding contracts are feasible, Busch and Wen (1995) have shown that inefficient situations may arise, including delay of the signing of an agreement.

The situation analysed in this paper is different. I analyse a non-binding water allocation agreement that is based on the outcome of a bargaining game, and subsequent interaction of the countries in a repeated game.

This completes the description of the repeated extensive-form game.

3 Self-enforcing agreements

A self-enforcing water allocation agreement for the repeated extensive-form game, described in section 2, is a pair of strategies that provides a subgame perfect and renegotiation-proof equilibrium, as discussed in section 1. In this section, using the two games described in section 2, I first show that every efficient water allocation agreement can be sustained in a subgame perfect equilibrium for sufficiently low discounting. Subsequently, I show how requiring renegotiation-proofness affects this result.

3.1 Subgame perfect equilibria

Given a water allocation agreement that is based on the outcome of a bargaining game, countries decide whether or not to comply with specified agreement actions in each stage game of the repeated extensive-form game. In the repeated game, countries can be punished in case of defection. The decision whether to comply in year t depends on the net present value (NPV) of the expected payoff stream $E(\Pi_{i,t})$, where $\Pi_{i,t} = (\pi_{i,t}, \pi_{i,t+1}, \pi_{i,t+2}, \ldots)$ is the stream of payoffs from time t onward. Using (4), the NPV of the payoff stream in case of compliance is:

$$E\left(\Pi_{i,t}^{C}\right) = b_i\left(x_{i,t}^{C}\right) + s_{i,t}^{C} + \delta E\left(\Pi_{i,t+1}\right), \tag{8}$$

where the last term reflects continuation payoffs, and where $\delta \in [0,1]$ is the discount factor. Due to the sequential structure of the game, the NPVs of the payoff stream in case of defection are not symmetric for country 1 and 2:

$$E\left(\Pi_{1,t}^{D}\right) = b_1\left(x_{1,t}^{D}\right) + \delta E\left(\Pi_{i,t+1}\right), \tag{9}$$

$$E\left(\Pi_{2,t}^{D}\right) = b_2\left(x_{2,t}^{C}\right) + \delta E\left(\Pi_{i,t+1}\right), \tag{10}$$

Note the difference (compliance vs defection) in the first terms of equations (9) and (10). In year t, if country 1 defects by not delivering the agreed upon share of water, then irrespective of the possible start of a punishment phase, country 2 is free to defect too and so will not make the side payment. In year t, if country 2 defects by not making the side payment, it has already received its cooperative share of water, due to the sequential structure of the stage game. Hence, countries face different incentives to defect from agreement actions. Nevertheless, in both cases, defection may be followed by a punishment phase.

Assuming that the countries maximise payoffs, they choose whether to comply based on $E(\Pi_{i,t}) = \max\left(E\left(\Pi_{i,t}^{C}\right), E\left(\Pi_{i,t}^{D}\right)\right)$. Compliance with the agreement is attractive as long as $E\left(\Pi_{i,t}^{C}\right) \geq E\left(\Pi_{i,t}^{D}\right)$.

Repeating the game gives room for punishment. A standard strategy to punish defection is to play a minimax strategy for a number of years. If the threat of punishment is credible and sufficiently severe, no country has an incentive to defect from agreement actions and cooperation can be sustained in equilibrium. This property is generally known as the folk theorem (Fudenberg and Maskin, 1986). The theorem says that, given any feasible and individually rational payoff vector $\pi^{\star}$ of the stage game, there exists $\underline{\delta} < 1$, such that the repeated game has a subgame perfect equilibrium with average payoff vector $\pi^{\star}$ for all $\delta \in \left(\underline{\delta}, 1\right)$ (Theorem 1 in Fudenberg and Maskin, 1986). This theorem holds generally for the case of two players. The game in this paper differs from the standard repeated game in two respects; it features an extensive-form stage game and stochastic river flow. Appropriate modifications of the folk theorem have been constructed for both of these cases, and I briefly discuss these now.

The first modification concerns repeated games with an extensive-form stage game. For this type of games, Sorin (1995) shows that the Fudenberg and Maskin (1986) folk theorem generalises to extensive-form repeated games (see also Rubinstein and Wolinsky, 1995). Wen (2002) explains that the only condition for this generalisation is that the stage game satisfies *full dimensionality*. Full dimensionality requires that the dimension of the set of feasible and individually rational payoff vectors equals the number of players (two in this game). This condition is satisfied through the prisoner's dilemma payoff structure of the game. Hence, the extensive-form stage game does not require modification of the Fudenberg and Maskin (1986) folk theorem.

The second modification concerns stochastic games. A stochastic game has a (finite) collection of states, in each of which a particular stage game is played. Dutta (1995) has shown that the folk theorem generalises to stochastic games when two conditions are satisfied. The first necessary condition is that the individually rational set of payoffs should not vary across histories. This condition is satisfied because the states of the game are determined by Q_t and thereby i.i.d. given the exogenous distribution $f(Q)$. Hence, Q_t is independent from Q_{t-1} and from countries' previous actions. The second necessary condition is full dimensionality, discussed above. Because both conditions are satisfied, this folk theorem can be applied here. The theorem says that given a certain payoff vector $\pi^\star$ that dominates the long-run average minimax payoffs, there exists a $\delta^\star < 1$, such that the stochastic game has a subgame perfect equilibrium that approximates the payoff vector $\pi^\star$ for all $\delta \in (\delta^\star, 1)$ (Theorem 9 in Dutta, 1995). Note that because Q_t is determined exogenously, the set of payoff vectors that dominate the long-run average minimax payoffs equals the set of feasible and individually rational payoff vectors.[5] This equality implies that for the game in this paper, we have $\underline{\delta} = \delta^\star$. Hence, stochastic river flow does not require modification of the Fudenberg and Maskin (1986) folk theorem.

The fact that the game of this paper features an extensive-form stage game and stochasticity simultaneously is not problematic, because extensive-form games may be regarded as a special form of stochastic games (Yoon, 2001). Therefore, the extensive-form stage game and stochastic river flow do not prevent application of the Fudenberg and Maskin (1986) folk theorem. Consequently, any agreement that improves upon minimax payoffs can be sustained in a subgame perfect equilibrium for $\delta \in \left(\underline{\delta}, 1\right)$. The rationality constraints in the Nash product—see (7)—imply that the agreement is individually rational. More precisely, the Nash bargaining solution makes the countries coordinate on efficient equilibria, so we know that the agreement is efficient. The above discussion is summarised in the following proposition.

Proposition 1. *Any efficient water allocation agreement can be sustained in a subgame perfect equilibrium for* $\delta \in \left(\underline{\delta}, 1\right)$.

Consequently, the prospect of playing the repeated game cannot affect the outcome of the bargaining game for this interval of the discount factor. For lower values of the discount factor, the agreement cannot be sustained, so countries may defect in equilibrium. In the next subsection we assess how the requirement of renegotiation-proofness affects these results.

[5]This equality does not hold when the transition rule between states depends on countries' actions or the previous state. This is relevant, for instance, when countries invest in reservoir capacity to create a buffer for drought years.

3.2 Adding renegotiation-proofness

A subgame perfect agreement may only be self-enforcing *ex ante*, because punishments may not be credible *ex post* once a value for Q_t is drawn from probability distribution $f(Q_t)$. Punishments are not credible when the punishment equilibrium is inefficient. Then, it is in both countries' interest to renegotiate out of the Pareto-dominated equilibrium. Hence, a self-enforcing agreement has to satisfy renegotiation-proofness. This requirement rules out equilibria where both countries are hurt by punishment (Bergin and MacLeod, 1993; Barrett, 2003). Formally, I use the concept of a "weakly renegotiation-proof equilibrium", which says that if countries agreed ex ante to play strategy σ, and if the history of the game implies that continuation equilibrium σ^e conditional on σ is to be played, they do not have a joint incentive to switch instead to another continuation equilibrium $\sigma^{e'}$ of σ (Farrell and Maskin, 1989). In other words, payoffs at any subgame must not be dominated by payoffs at any other subgame. This concept of renegotiation-proofness is equal to "internal consistency", used by Bernheim and Ray (1989).

I adapt a punishment strategy suggested by Van Damme (1989) for the (normal-form) repeated prisoner's dilemma. He showed that for this game there exists a punishment strategy, such that any subgame perfect equilibrium of the repeated prisoner's dilemma is renegotiation-proof, for sufficiently low discounting. This particular punishment strategy is the "penance" strategy. Each country starts with C and plays cooperatively as long as the other country does so. If country i plays D in year t, then the punishment phase for i begins. In this punishment phase, country i plays C and country j plays D, until the first time that country i actually plays C, then country j returns to playing C too (Van Damme, 1989). In the subgame perfect and renegotiation-proof equilibrium, if a country defects, it is punished for one period and then the countries revert to the cooperative phase. This punishment phase is renegotiation-proof because of the particular payoff structure of the prisoner's dilemma. Equilibria where one country plays C, while the other plays D are never Pareto-dominated.

This penance strategy can be adapted to the setting of an extensive-form prisoner's dilemma with stochastic river flow. In the extensive-form game of this paper, countries have different means of punishing the other country. Country 1 is in control of water delivery to country 2, while country 2 is in control of the side payment. If country 2 defects, the penance strategy prescribes that (D, C)

is played in the next p stage games.[6] If country 1 defects, however, it can be punished within the same stage game by country 2 (by playing D), in addition to the penance strategy of playing (C, D) in the next p stage games. Therefore, under the penance strategy, country 2 has an additional punishment option compared with country 1. Note that in the extensive-form game, stage game payoffs occur at the end of the stage game. This leads to an additional advantage for country 2: its additional punishment option is not discounted by country 1.

The implication of this asymmetry in punishment options is that for sufficiently low values of δ, when renegotiation-proofness is required, country 1 cannot punish country 2 upon defection, while country 2 can punish country 1. This is formally stated in the following lemma.

Lemma 1. *Given Q_t, there exists $\overline{\delta} > 0$, such that for all $\delta \in \left(0, \overline{\delta}\right)$, there is no renegotiation-proof punishment to deter defection by country 2, while there is a renegotiation-proof punishment to deter defection by country 1.*

Proof. The proof is by construction. Consider the penance strategy described above.

Given Q_t, the immediate gain in payoffs of defection in year t to country 1, using (8) and (9), equals $b_1\left(x^D_{1,t}\right) - b_1\left(x^C_{1,t}\right)$. The total value of the punishment, both in the same stage game and in the next p stage games is $s^C_{1,t} + \sum_{\tau=t+1}^{t+p}\left(\delta^{\tau-t}E\left[s^C_{1,\tau}\right]\right)$. Defection by country 1 is deterred when:

$$b_1\left(x^D_{1,t}\right) - b_1\left(x^C_{1,t}\right) - s^C_{1,t} \leq \sum_{\tau=t+1}^{t+p}\left(\delta^{\tau-t}E\left[s^C_{1,\tau}\right]\right). \tag{11}$$

Given the individual rationality constraint in (7), the LHS of this inequality is non-negative for admissible values of δ while the RHS is non-positive. Hence, defection by country 1 is deterred for any value of δ.

Given Q_t, the immediate gain in payoffs of defection in year t to country 2, using (8) and (10), equals $-s^C_{2,t}$. The total value of the punishment (in the next p stage games) is $\sum_{\tau=t+1}^{t+p}\left(\delta^{\tau-t}E\left[b_2\left(x^C_{2,\tau}\right) - b_2\left(x^D_{2,\tau}\right)\right]\right)$. Defection by country 2 is deterred when:

$$-s^C_{2,t} \leq \sum_{\tau=t+1}^{t+p}\left(\delta^{\tau-t}E\left[b_2\left(x^C_{2,\tau}\right) - b_2\left(x^D_{2,\tau}\right)\right]\right). \tag{12}$$

[6] Van Damme (1989) did not need a multi-period punishment to demonstrate renegotiation-proofness in the normal-form repeated game. Here, it is useful as it increases the severity of punishments.

Given super-additivity and the concavity of the benefit function, both the LHS and the RHS of this inequality are non-negative. It is easy to verify that there exist parameter combinations for which the inequality is violated. For $\delta = \overline{\delta}$, (12) holds with equality. □

Lemma 1 implies that, for $\delta \in \left(0, \overline{\delta}\right)$, country 2 can defect in every single year, without being punished. Obviously, this asymmetry in punishment options may affect the outcome of the bargaining game. When country 1 cannot punish country 2 upon defection, this implies that country 2 can always defect. Hence, country 2 has all bargaining power in the bargaining game that determines the agreement. In terms of the Nash bargaining solution in (7), $\alpha = 0$. The resulting agreement assigns all the gains from cooperation to country 2, leaving country 1 indifferent between C and D. Any other (efficient) agreement would be susceptible to defection by country 2. Consequently, country 1 receives its minimax payoff, exactly compensating country 1 for sustaining the efficient water allocation vector.

Recall that a self-enforcing water allocation agreements is a pair of strategies that provides a subgame perfect and renegotiation-proof equilibrium. From proposition 1 we know that any efficient water allocation agreement can be sustained in a subgame perfect equilibrium for $\delta \in \left(\underline{\delta}, 1\right)$. When, in addition, we have $\delta \in \left(\overline{\delta}, 1\right)$, then any efficient water allocation agreement is also renegotiation-proof and thereby self-enforcing. For $\delta \in \left(0, \overline{\delta}\right)$, only those agreements where all gains from cooperation go to country 2 are self-enforcing, as discussed above.[7]

The above discussion is summarised in the following proposition that forms the main result of this paper.

Proposition 2. *For $\delta \in \left(\overline{\delta}, 1\right)$, any subgame perfect water allocation agreement is self-enforcing. For $\delta \in \left(0, \overline{\delta}\right)$, the unique self-enforcing agreement assigns all the gains from cooperation to the downstream country.*

The payoff distribution for this unique self-enforcing agreement is indicated by S in the stylised payoff space presented in figure 2. In this figure, the solution found by Kilgour and Dinar (2001) is indicated by KD; this solution assumes $\alpha = \frac{1}{2}$ which yields the "midpoint of the contract-curve".

The asymmetry in punishment options is driving the extreme allocation plan induced by the self-enforcing agreement for $\delta \in \left(0, \overline{\delta}\right)$. This asymmetry is a result

[7]Note that $\overline{\delta}$ may be smaller or larger than $\underline{\delta}$. When $\overline{\delta} \leq \delta < \underline{\delta}$, it follows logically that the maximum value of α converges to 0 as δ converges from $\underline{\delta}$ to $\overline{\delta}$.

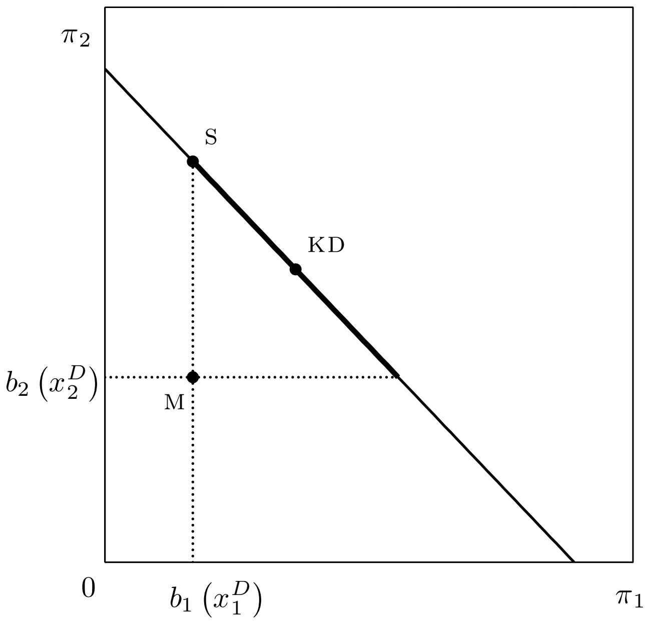

Figure 2: A stylised payoff space; the thick line denotes the set of possible payoffs for efficient agreements that can be sustained in a subgame perfect equilibrium; *M* denotes minimax payoffs (i.e. payoffs under the defection allocation plan); *S* denotes the payoffs for the unique self-enforcing agreement when $\delta \in \left(0, \overline{\delta}\right)$; *KD* denotes the payoffs for the Kilgour and Dinar (2001) solution.

of the specific sequential structure of the stage game in which it is assumed that side payments are made after water is delivered. Given the unidirectional flow of water, this seems the most natural structure of the stage game. This structure can, however, be modified in the following two ways. First, water deliveries and payments could be made in shorter intervals (e.g. monthly instead of yearly), while retaining the same sequential structure of the stage game. This change would increase the values of $\underline{\delta}$ and $\overline{\delta}$, but this does not affect the qualitative outcome of proposition 2. Depending on parameter values it may, however, shrink or expand the interval of values of δ for which renegotiation-proofness holds. Second, the sequential structure could be reversed such that first the side payment is made and only then water is delivered. This change would completely reverse the asymmetry in punishment options, causing all bargaining power to be with country 1 (i.e. $\alpha = 1$).

Clearly, the solution induced by a self-enforcing agreement is very sensitive to both the sequence of water deliveries and side payments (as specified in the water allocation agreement), and the level of discounting. Using the sequence of the stage game described in section 2 yields one of two outcomes. For sufficiently low discounting, any self-enforcing agreement may result out of the bargaining game, depending on the exogenous distribution of bargaining power. For sufficiently high discounting, a unique self-enforcing agreement assigns all bargaining power, and hence all gains from cooperation to the downstream country. This outcome is in contrast with much of the river sharing literature in which it is assumed that being upstream increases a country's power in the basin. Nevertheless, it is in line with recent literature that suggests that factors other than geography play a key role in determining bargaining power and water allocation patterns in a river basin (Dinar, 2006; Zeitoun and Warner, 2006; Zawahri, 2008; Ansink and Weikard, 2009).

4 The downstream incremental distribution

Ambec and Sprumont (2002) developed an axiomatic solution to water sharing, which assures that each country receives a welfare level between a lower and an upper bound. The lower bound is the welfare a country could achieve if all countries make unilateral, non-cooperative, decisions on water use. This bound is based on the principle of "absolute territorial sovereignty" and is similar to the defection allocation plan of this paper. The upper bound is the welfare a country could achieve if upstream countries refrain from using water. This bound is based on the principle of "absolute territorial integrity". A compromise of these two conflicting principles, where each country is guaranteed its lower bound and aspires its upper bound, yields a unique solution. This solution allocates water such that each country's welfare equals its marginal contribution to a coalition composed of its upstream neighbours. Ambec and Sprumont (2002) call this solution the "downstream incremental distribution".

For the case of two countries, the water allocation vector induced by the downstream incremental distribution is such that it assigns all the gains from cooperation to the downstream country (Houba, 2008). Given proposition 2, this distribution is implemented by the self-enforcing agreement for $\delta \in \left(0, \overline{\delta}\right)$. The distribution of payoffs induced by the self-enforcing agreement corresponds to the two-country case of the downstream incremental distribution.

An alternative implementation of the downstream incremental distribution is provided by Ambec and Ehlers (2008). They propose negotiation rules to implement this distribution in a static setting, in which priority is given "lexicographically to the most downstream user". Given a set of players $\{1, 2, \ldots, k\}$, player k proposes an allocation plan to the other players. If all accept, this allocation plan is implemented. If any player declines the proposed allocation plan, player k receives $x^D_{k,t} = Q_{k,t}$ and $s^D_{k,t} = 0$, and player $k - 1$ proposes an allocation plan, etc. Ambec and Ehlers (2008) show that the unique subgame perfect equilibrium of this game implements the downstream incremental distribution.

The Ambec and Ehlers (2008) game, however, assigns all bargaining power exogenously to player k by giving him the advantage of making the first proposal. No explanation is provided as to why this is a correct approach. This weakness has been noticed by Van den Brink et al. (2007) and Houba (2008) who, based on this assumption that downstream countries have all bargaining power, found the downstream incremental distribution unconvincing (see also Khmelnitskaya, 2009). In the game described in sections 2 and 3 of this paper, the distribution of bargaining power follows endogenously from the repeated game setting of the model and the sequential structure of the stage game. This dynamic setting provides a more realistic approach for non-cooperative bargaining on water allocation than those provided by static models. Clearly, implementation of the downstream incremental distribution is more convincing when the dynamic setting is considered in which water allocation agreements are situated. This implementation adds significant credibility to the axiomatic solution developed by Ambec and Sprumont (2002).

5 Conclusion

In the setting of this paper, any efficient agreement can be sustained in a subgame perfect equilibrium for sufficiently low discounting. The requirement of renegotiation-proofness is satisfied for sufficiently low discounting too. For sufficiently high discounting, however, there is a unique self-enforcing agreement. This is the agreement that assigns all bargaining power and all gains from cooperation to the downstream country, and thereby implements the downstream incremental distribution.

I have used a non-cooperative approach to analyse the allocation of water in international river basins. Related approaches have been applied to open-access fisheries (Polasky et al., 2006), transboundary wildlife management (Bhat and

Huffaker, 2007), and international pollution (Germain et al., 2009). Analysis of this topic using cooperative game theory is the subject of Dinar et al. (2006) and Beard and MacDonald (2007). The non-cooperative approach comes closest to actual negotiations on river water allocation. In many current agreements, the allocation of water is—at least to some extent—based on average river flow. This is an important reason for the instability of such agreements (cf. Drieschova et al., 2008).

Kilgour and Dinar (2001) argued for a flexible agreement that adapts to available river flow. I have developed their approach one step further by accounting for countries' incentives to break the agreement. For sufficiently low discounting, this paper shows that any efficient water allocation agreement is self-enforcing. In other words, these agreements are stable. This result supports the approach by Kilgour and Dinar (2001), because given that flexible agreements are efficient, they are stable too. This type of agreement is therefore preferable over conventional agreements such as proportional allocations and fixed flow allocations, which are not efficient and unstable (Ansink and Ruijs, 2008). A related advantage of the self-enforcing agreement is that by offering stability, it can withstand de-stabilising effects of, for instance, climate change. A possible impact of climate change is an increased frequency of years with low river flow. Because the self-enforcing agreement has water allocation and side payments contingent on river flow, the agreement does not need to be reconsidered when these impacts occur.

Based on the results of this paper, a recommendation for countries that meet to negotiate the allocation of river water is to explicitly account for stability issues in their negotiations. Ideally, a water allocation agreement specifies (i) the sequence of water deliveries and side payments, (ii) the water allocation vector and side payments contingent on river flow, and (iii) an appropriate punishment strategy based on the penance strategy outlined in section 3.2. Such an agreement is self-enforcing for sufficiently low discounting, and always more stable than any alternative agreement.

Although most water allocation agreements are bilateral, it seems straightforward to extend the analysis of this paper to cover multilateral agreements. Intuitively, the main results of this paper would not be affected by adding more countries, implying that any efficient multilateral agreement is self-enforcing for sufficiently low discounting. Difficulties may arise, however, when the distribution of river flow (i.e. the parameters γ_i) is such that a certain country cannot be minimaxed. As a result, full dimensionality may not hold, so that the folk theorem does not carry over to the multilateral case. Such an extension is, however, left for future research.

References

Ambec, S. and L. Ehlers (2008). Cooperation and equity in the river sharing problem. In A. Dinar, J. Albiac, and J. Sánchez-Soriano (Eds.), *Game Theory and Policymaking in Natural Resources and the Environment*. London: Routledge.

Ambec, S. and Y. Sprumont (2002). Sharing a river. *Journal of Economic Theory 107*(2), 453–462.

Ansink, E. and A. Ruijs (2008). Climate change and the stability of water allocation agreements. *Environmental and Resource Economics 41*(2), 249–266.

Ansink, E. and H.-P. Weikard (2009). Contested water rights. *European Journal of Political Economy 25*(2), 247–260.

Barrett, S. (1994a). Conflict and cooperation in managing international water resources. World Bank Policy Research Working Paper 1303.

Barrett, S. (1994b). Self-enforcing international environmental agreements. *Oxford Economic Papers 46*(S), 878–894.

Barrett, S. (2003). *Environment and Statecraft*. Oxford: Oxford University Press.

Beach, H. L., J. Hammer, J. J. Hewitt, E. Kaufman, A. Kurki, J. A. Oppenheimer, and A. T. Wolf (2000). *Transboundary Freshwater Dispute Resolution: Theory, Practice, and Annotated References*. Tokyo: United Nations University Press.

Beard, R. and S. MacDonald (2007). Time-consistent fair water sharing agreements. In S. Jørgensen, M. Quincampoix, and T. L. Vincent (Eds.), *Advances in Dynamic Game Theory*. Boston: Birkhäuser.

Bennett, L. L., C. W. Howe, and J. Shope (2000). The interstate river compact as a water allocation mechanism: efficiency aspects. *American Journal of Agricultural Economics 82*(4), 1006–1015.

Bergin, J. and W. B. MacLeod (1993). Efficiency and renegotiation in repeated games. *Journal of Economic Theory 61*(1), 42–73.

Bernauer, T. (2002). Explaining success and failure in international river management. *Aquatic Sciences 64*(1), 1–19.

Bernheim, B. D. and D. Ray (1989). Collective dynamic consistency in repeated games. *Games and Economic Behavior 1*(4), 295–326.

Bhat, M. G. and R. G. Huffaker (2007). Management of a transboundary wildlife population: a self-enforcing cooperative agreement with renegotiation and variable transfer payments. *Journal of Environmental Economics and Management 53*(1), 54–67.

Binmore, K., A. Rubinstein, and A. Wolinsky (1986). The Nash bargaining solution in economic modelling. *RAND Journal of Economics 17*(2), 176–188.

Busch, L.-A. and Q. Wen (1995). Perfect equilibria in a negotiation model. *Econometrica 63*(3), 545–565.

Carraro, C., C. Marchiori, and A. Sgobbi (2007). Negotiating on water: insights from non-cooperative bargaining theory. *Environment and Development Economics 12*(2), 329–349.

Dinar, A., S. Moretti, F. Patrone, and S. Zara (2006). Application of stochastic cooperative games in water resources. In R. U. Goetz and D. Berga (Eds.), *Frontiers in Water Resource Economics*. New York: Springer.

Dinar, S. (2006). Assessing side-payment and cost-sharing patterns in international water agreements: the geographic and economic connection. *Political Geography 25*(4), 412–437.

Drieschova, A., M. Giordano, and I. Fischhendler (2008). Governance mechanisms to address flow variability in water treaties. *Global Environmental Change 18*(2), 285–295.

Dutta, P. K. (1995). A folk theorem for stochastic games. *Journal of Economic Theory 66*(1), 1–32.

Farrell, J. and E. Maskin (1989). Renegotiation in repeated games. *Games and Economic Behavior 1*(4), 327–360.

Fischhendler, I. (2004). Legal and institutional adaptation to climate uncertainty: a study of international rivers. *Water Policy 6*(4), 281–302.

Fischhendler, I. (2008). Ambiguity in transboundary environmental dispute resolution: the Israeli-Jordanian water agreement. *Journal of Peace Research 45*(1), 91–109.

Fudenberg, D. and E. Maskin (1986). The folk theorem in repeated games with discounting or with incomplete information. *Econometrica 54*(3), 533–554.

Gastélum, J. R., J. B. Valdés, and S. Stewart (2009). A decision support system to improve water resources management in the Conchos basin. Forthcoming in *Water Resources Management*.

Germain, M., H. Tulkens, and A. Magnus (2009). Dynamic core-theoretic cooperation in a two-dimensional international environmental model. FEEM Working Paper 26.2009.

Giordano, M. A. and A. T. Wolf (2003). Sharing waters: post-Rio international water management. *Natural Resources Forum 27*(2), 163–171.

Houba, H. (2008). Computing alternating offers and water prices in bilateral river basin management. *International Game Theory Review 10*(3), 257–278.

Khmelnitskaya, A. B. (2009). Values for rooted-tree and sink-tree digraph games and sharing a river. Forthcoming in *Theory and Decision*.

Kilgour, D. M. and A. Dinar (2001). Flexible water sharing within an international river basin. *Environmental and Resource Economics 18*(1), 43–60.

LeMarquand, D. (1977). *International Rivers: The Politics of Cooperation*. Vancouver: Westwater Research Centre.

McCaffrey, S. C. (2003). The need for flexibility in freshwater treaty regimes. *Natural Resources Forum 27*(2), 156–162.

McEvoy, D. M. and J. K. Stranlund (2009). Self-enforcing international environmental agreements with costly monitoring for compliance. Forthcoming in *Environmental and Resource Economics*.

Polasky, S., N. Tarui, G. M. Ellis, and C. F. Mason (2006). Cooperation in the commons. *Economic Theory 29*(1), 71–88.

Rubinstein, A. and A. Wolinsky (1995). Remarks on infinitely repeated extensive-form games. *Games and Economic Behavior 9*(1), 110–115.

Siegfried, T. and T. Bernauer (2007). Estimating the performance of international regulatory regimes: methodology and empirical application to international water management in the Naryn/Syr Darya basin. *Water Resources Research 43*(11), W11406.

Sorin, S. (1995). A note on repeated extensive games. *Games and Economic Behavior 9*(1), 116–123.

Van Damme, E. (1989). Renegotiation-proof equilibria in repeated prisoners' dilemma. *Journal of Economic Theory 47*(1), 206–217.

Van den Brink, R., G. Van der Laan, and V. Vasil'ev (2007). Component efficient solutions in line-graph games with applications. *Economic Theory 33*(2), 349–364.

Wen, Q. (2002). A folk theorem for repeated sequential games. *Review of Economic Studies 69*(2), 493–512.

Wolf, A. T. (1998). Conflict and cooperation along international waterways. *Water Policy 1*(2), 251–265.

Yoon, K. (2001). A folk theorem for asynchronously repeated games. *Econometrica 69*(1), 191–200.

Zawahri, N. A. (2008). International rivers and national security: the Euphrates, Ganges-Brahmaputra, Indus, Tigris, and Yarmouk rivers. *Natural Resources Forum 32*(4), 280–289.

Zeitoun, M. and J. Warner (2006). Hydro-hegemony - a framework for analysis of trans-boundary water conflicts. *Water Policy 8*(5), 435–460.

NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI

Fondazione Eni Enrico Mattei Working Paper Series

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

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

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

http://www.repec.org

http://agecon.lib.umn.edu

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

NOTE DI LAVORO PUBLISHED IN 2009

SD	1.2009	Michael Hoel: Bush Meets Hotelling: Effects of Improved Renewable Energy Technology on Greenhouse Gas Emissions
SD	2.2009	Abay Mulatu, Reyer Gerlagh, Dan Rigby and Ada Wossink: Environmental Regulation and Industry Location
SD	3.2009	Anna Alberini, Stefania Tonin and Margherita Turvani: Rates of Time Preferences for Saving Lives in the Hazardous Waste Site Context
SD	4.2009	Elena Ojea, Paulo A.L.D. Nunes and Maria Loureiro: Mapping of Forest Biodiversity Values: A Plural Perspective
SD	5.2009	Xavier Pautrel : Macroeconomic Implications of Demography for the Environment: A Life-Cycle Perspective
IM	6.2009	Andrew Ellul, Marco Pagano and Fausto Panunzi: Inheritance Law and Investment in Family Firms
IM	7.2009	Luigi Zingales: The Future of Securities Regulation
SD	8.2009	Carlo Carraro, Emanuele Massetti and Lea Nicita: How Does Climate Policy Affect Technical Change? An Analysis of the Direction and Pace of Technical Progress in a Climate-Economy Model
SD	9.2009	William K. Jaeger: The Welfare Effects of Environmental Taxation
SD	10.2009	Aude Pommeret and Fabien Prieur: Double Irreversibility and Environmental Policy Design
SD	11.2009	Massimiliano Mazzanti and Anna Montini: Regional and Sector Environmental Efficiency Empirical Evidence from Structural Shift-share Analysis of NAMEA data
SD	12.2009	A. Chiabai, C. M. Travisi, H. Ding, A. Markandya and P.A.L.D Nunes: Economic Valuation of Forest Ecosystem Services: Methodology and Monetary Estimates
SD	13.2009	Andrea Bigano, Mariaester Cassinelli, Fabio Sferra, Lisa Guarrera, Sohbet Karbuz, Manfred Hafner, Anil Markandya and Ståle Navrud: The External Cost of European Crude Oil Imports
SD	14.2009	Valentina Bosetti, Carlo Carraro, Romain Duval, Alessandra Sgobbi and Massimo Tavoni: The Role of R&D and Technology Diffusion in Climate Change Mitigation: New Perspectives Using the Witch Model
IM	15.2009	Andrea Beltratti, Marianna Caccavaio and Bernardo Bortolotti: Stock Prices in a Speculative Market: The Chinese Split-Share Reform
GC	16.2009	Angelo Antoci, Fabio Sabatini and Mauro Sodini: The Fragility of Social Capital
SD	17.2009	Alexander Golub, Sabine Fuss, Jana Szolgayova and Michael Obersteiner: Effects of Low-cost Offsets on Energy Investment – New Perspectives on REDD –
SD	18.2009	Enrica De Cian: Factor-Augmenting Technical Change: An Empirical Assessment
SD	19.2009	Irene Valsecchi: Non-Uniqueness of Equilibria in One-Shot Games of Strategic Communication
SD	20.2009	Dimitra Vouvaki and Anastasios Xeapapadeas: Total Factor Productivity Growth when Factors of Production Generate Environmental Externalities
SD	21.2009	Giulia Macagno, Maria Loureiro, Paulo A.L.D. Nunes and Richard Tol: Assessing the Impact of Biodiversity on Tourism Flows: A model for Tourist Behaviour and its Policy Implications
IM	22.2009	Bernardo Bortolotti, Veljko Fotak, William Megginson and William Miracky: Sovereign Wealth Fund Investment Patterns and Performance
IM	23.2009	Cesare Dosi and Michele Moretto: Auctioning Monopoly Franchises: Award Criteria and Service Launch Requirements
SD	24.2009	Andrea Bastianin: Modelling Asymmetric Dependence Using Copula Functions: An application to Value-at-Risk in the Energy Sector
IM	25.2009	Shai Bernstein, Josh Lerner and Antoinette Schoar: The Investment Strategies of Sovereign Wealth Funds
SD	26.2009	Marc Germain, Henry Tulkens and Alphonse Magnus: Dynamic Core-Theoretic Cooperation in a Two-Dimensional International Environmental Model
IM	27.2009	Frank Partnoy: Overdependence on Credit Ratings Was a Primary Cause of the Crisis
SD	28.2009	Frank H. Page Jr and Myrna H. Wooders (lxxxv): Endogenous Network Dynamics
SD	29.2009	Caterina Calsamiglia, Guillaume Haeringer and Flip Klijnb (lxxxv): Constrained School Choice: An Experimental Study
SD	30.2009	Gilles Grandjean, Ana Mauleon and Vincent Vannetelbosch (lxxxv): Connections Among Farsighted Agents
SD	31.2009	Antonio Nicoló and Carmelo Rodríguez Álvarez (lxxxv): Feasibility Constraints and Protective Behavior in Efficient Kidney Exchange
SD	32.2009	Rahmi İlkiliç (lxxxv): Cournot Competition on a Network of Markets and Firms
SD	33.2009	Luca Dall'Asta, Paolo Pin and Abolfazl Ramezanpour (lxxxv): Optimal Equilibria of the Best Shot Game
SD	34.2009	Edoardo Gallo (lxxxv): Small World Networks with Segregation Patterns and Brokers
SD	35.2009	Benjamin Golub and Matthew O. Jackson (lxxxv): How Homophily Affects Learning and Diffusion in Networks

SD	36.2009	Markus Kinateder (lxxxv): Team Formation in a Network
SD	37.2009	Constanza Fosco and Friederike Mengel (lxxxv): Cooperation through Imitation and Exclusion in Networks
SD	38.2009	Berno Buechel and Tim Hellmann (lxxxv): Under-connected and Over-connected Networks
SD	39.2009	Alexey Kushnir (lxxxv): Matching Markets with Signals
SD	40.2009	Alessandro Tavoni (lxxxv): Incorporating Fairness Motives into the Impulse Balance Equilibrium and Quantal Response Equilibrium Concepts: An Application to 2x2 Games
SD	41.2009	Steven J. Brams and D. Marc Kilgour (lxxxv): Kingmakers and Leaders in Coalition Formation
SD	42.2009	Dotan Persitz (lxxxv): Power in the Heterogeneous Connections Model: The Emergence of Core-Periphery Networks
SD	43.2009	Fabio Eboli, Ramiro Parrado, Roberto Roson: Climate Change Feedback on Economic Growth: Explorations with a Dynamic General Equilibrium Mode
GC	44.2009	Fabio Sabatini: Does Social Capital Create Trust? Evidence from a Community of Entrepreneurs
SD	45.2009	ZhongXiang Zhang: Is it Fair to Treat China as a Christmas Tree to Hang Everybody's Complaints? Putting its Own Energy Saving into Perspective
SD	46.2009	Eftichios S. Sartzetakis, Anastasios Xepapadeas and Emmanuel Petrakis: The Role of Information Provision as a Policy Instrument to Supplement Environmental Taxes: Empowering Consumers to Choose Optimally
SD	47.2009	Jean-François Caulier, Ana Mauleon and Vincent Vannetelbosch: Contractually Stable Networks
GC	48.2009	Massimiliano Mazzanti, Susanna Mancinelli, Giovanni Ponti and Nora Piva: Education, Reputation or Network? Evidence from Italy on Migrant Workers Employability
SD	49.2009	William Brock and Anastasios Xepapadeas: General Pattern Formation in Recursive Dynamical Systems Models in Economics
SD	50.2009	Giovanni Marin and Massimiliano Mazzanti: Emissions Trends and Labour Productivity Dynamics Sector Analyses of De-coupling/Recoupling on a 1990-2005 Namea
SD	51.2009	Yoshio Kamijo and Ryo Kawasaki (lxxxv): Dynamics, Stability, and Foresight in the Shapley-Scarf Housing Market
IM	52.2009	Laura Poddi and Sergio Vergalli: Does Corporate Social Responsibility Affect the Performance of Firms?
SD	53.2009	Valentina Bosetti, Carlo Carraro and Massimo Tavoni: Climate Change Mitigation Strategies in Fast-Growing Countries: The Benefits of Early Action
GC	54.2009	Alireza Naghavi and Gianmarco I.P. Ottaviano: Firm Heterogeneity, Contract Enforcement, and the Industry Dynamics of Offshoring
IM	55.2009	Giacomo Calzolari and Carlo Scarpa: On Regulation and Competition: Pros and Cons of a Diversified Monopolist
SD	56.2009	Valentina Bosetti, Ruben Lubowski and Alexander Golub and Anil Markandya: Linking Reduced Deforestation and a Global Carbon Market: Impacts on Costs, Financial Flows, and Technological Innovation
IM	57.2009	Emmanuel Farhi and Jean Tirole: Collective Moral Hazard, Maturity Mismatch and Systemic Bailouts
SD	58.2009	Kelly C. de Bruin and Rob B. Dellink: How Harmful are Adaptation Restrictions
SD	59.2009	Rob Dellink, Michel den Elzen, Harry Aiking, Emmy Bergsma, Frans Berkhout, Thijs Dekker, Joyeeta Gupta: Sharing the Burden of Adaptation Financing: An Assessment of the Contributions of Countries
SD	60.2009	Stefania Tonin, Anna Alberini and Margherita Turvani: The Value of Reducing Cancer Risks at Contaminated Sites: Are More Heavily Exposed People Willing to Pay More?
SD	61.2009	Clara Costa Duarte, Maria A. Cunha-e-Sá and Renato Rosa: The Role of Forests as Carbon Sinks: Land-Use and Carbon Accounting
GC	62.2009	Carlo Altomonte and Gabor Békés: Trade Complexity and Productivity
GC	63.2009	Elena Bellini, Gianmarco I.P. Ottaviano, Dino Pinelli and Giovanni Prarolo: Cultural Diversity and Economic Performance: Evidence from European Regions
SD	64.2009	Valentina Bosetti, Carlo Carraro, Enrica De Cian, Romain Duval, Emanuele Massetti and Massimo Tavoni: The Incentives to Participate in, and the Stability of, International Climate Coalitions: A Game-theoretic Analysis Using the Witch Model
IM	65.2009	John Temple Lang: Article 82 EC – The Problems and The Solution
SD	66.2009	P. Dumas and S. Hallegatte: Think Again: Higher Elasticity of Substitution Increases Economic Resilience
SD	67.2009	Ruslana Rachel Palatnik and Roberto Roson: Climate Change Assessment and Agriculture in General Equilibrium Models: Alternative Modeling Strategies
SD	68.2009	Paulo A.L.D. Nunes, Helen Ding and Anil Markandya: The Economic Valuation of Marine Ecosystems
IM	69.2009	Andreas Madestam: Informal Finance: A Theory of Moneylenders
SD	70.2009	Efthymia Kyriakopoulou and Anastasios Xepapadeas: Environmental Policy, Spatial Spillovers and the Emergence of Economic Agglomerations
SD	71.2009	A. Markandya, S. Arnold, M. Cassinelli and T. Taylor: Coastal Zone Management in the Mediterranean: Legal and Economic Perspectives
GC	72.2009	Gianmarco I.P. Ottaviano and Giovanni Prarolo: Cultural Identity and Knowledge Creation in Cosmopolitan Cities
SD	73.2009	Erik Ansink: Self-enforcing Agreements on Water allocation

(lxxxv) This paper has been presented at the 14th Coalition Theory Network Workshop held in Maastricht, The Netherlands, on 23-24 January 2009 and organised by the Maastricht University CTN group (Department of Economics, http://www.feem-web.it/ctn/12d_maa.php).