Anticipated International Environmental Agreements

Ömer Tuğrul Açıkgöz
Department of Economics,
Yeshiva University
acikgoz@yu.edu.

Hassan Benchekroun
Department of Economics and CIREQ
McGill University
hassan.benchekroun@mcgill.ca

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Abstract:

We examine the impact of cooperation in the future on current emissions in transboundary pollution game. In many instances reaching an international environmental agreement (IEA) proves to be difficult. Even when all parties involved acknowledge that the absence of an agreement is catastrophic and an agreement must be reached, reaching a final agreement tends to take time. It is this delay in reaching and implementing an agreement that we investigate in this paper.

We show that the impact of a future agreement on current emissions is ambiguous. We examine four types of IEAs. The first type is a percentage cut of future emission policy, the second is a constant reduction of emissions, the third type of IEAs fixes emissions in period 2 at a constant level or cap (regardless of the stock of pollution in period 2) and the fourth is a move from the business as usual policy to the first-best emission policy which maximizes the joint welfare of all countries (in period 2).

In the first type of IEAs we show that the impact of an IEA in the future results in an increase (a decrease) of current emissions when the elasticity of marginal utility is larger (smaller) than one. In the case of the linear-quadratic framework where utility and the damage from the stock of pollution are quadratic and the accumulation of pollution is linear, we show that an IEA in the future results in a decrease of current emissions if the damage from pollution is sufficiently large. Otherwise the impact of an IEA in the future is ambiguous and depends on the level of the stock of pollution.

In the case of the second type of IEAs, we show that an IEA in the future unambiguously results in an increase of current emissions. For the third type of IEAs we show that emissions in period 1 are a decreasing function of the cap that will prevail in period 2: i.e., a tighter cap in period 2 results in larger emissions in period 1.

In the case of the fourth type of IEAs, we give a necessary condition for a future IEA to result in a decrease of current emissions with respect their business as usual level. We show the linear-quadratic case and the case where utility is logarithmic that this necessary condition is never satisfied.

Keywords: Climate agreement; future agreements; transboundary pollution; dynamic games.

JEL: Q53; Q54; Q58; Q59.

1 Introduction

We consider an international pollution game. It is well known that in the presence of externalities, a non-cooperative equilibrium where each country ignores the externality it generates, is inefficient (not Pareto-optimal). The formation of a global coalition where each country acts in a cooperative way results in a Pareto superior outcome. The difficulty of implementing a cooperative solution comes from the incentive of each country to unilaterally deviate from the agreement reached. There is a large body of the literature devoted to mechanisms that would overcome such obstacle. These mechanisms typically propose an efficient equilibrium and then specify the rules that would be implemented in case a coalition member does not observe the agreement. In the absence of a supranational authority any agreement needs to be self-enforcing. However self-enforcing international environmental agreements (IEAs) suffer from a strong free-riding incentive that each player has (see, e.g., Barrett (2005)). This difficulty of reaching an agreement can in principle be overcome by an ad-hoc system of transfers and incentives to prevent free riding (see e.g., Carraro and Sinisalco (1993) or Germain, Toint, Tulkens and de Zeeuw (2003) and Petrosyan and Zaccour (2003) in the case of a stock pollutant). Calvo and Rubio (2013) offers a recent survey, in the case of stock pollutants, of IEA models and solutions to the free riding problem. However, the process of finalizing the details of an agreement, is often very tedious and lengthy. In the case where many countries are involved this process can take years to be finalized even if the concerned countries have expressed their commitment to cooperation (e.g. the Kyoto protocol and Uruguay rounds of negotiations on tariffs).

In this paper we consider a transboundary stock pollution game and study the impact of such a delay in the implementation of a cooperative solution on the emissions of each country before cooperation starts. We do not formalize the process by which a cooperative solution is implemented, we rather assume that at some future date countries will adopt an emission policy that is more environmentally friendly than the business as usual policy. We conduct our analysis in the context of a transboundary pollution game where a number of countries produce homogeneous products and where pollution is emitted as a by-product. Emissions of pollution accumulate and constitute a transboundary stock of pollution which creates a damage that affects all countries. It is well known that a Markov Perfect Nash Equilibrium (MPNE) of the game when countries behave in a non-cooperative way results in larger emissions of pollution than the cooperative solution where each country adopts the pollution strategy to maximize the joint welfare of all countries (see e.g., the surveys of dynamic pollutions games in Jorgensen, Martin-Herran and Zaccour (2010) or Long (2011)).

More precisely, we consider a two period transboundary pollution game. We first determine the equilibrium under the business as usual (BAU) scenario, i.e. non-cooperation over the two periods and the first-best cooperative equilibrium, i.e. countries cooperate over the two periods and choose a profile of emissions strategies in each period that maximize the sum of all countries welfare. We then examine the case where countries cooperate in period two only. We examine four types of IEAs that can be considered in period two. In the first type of IEAs, countries are assumed to agree on a percentage decrease with respect the period two's BAU emission rule. In the second type of IEAs, countries agree on a uniform (constant) decrease with respect to the period two's BAU emission rule. In the third type of IEAs countries are assumed to agree on a given level of emissions for period 2. In the fourth type of IEAs we assume that countries adopt in period two the first cooperative equilibrium emission rule. Thus in the case of IEAs of type 1, 2 and 4, countries in period 1 anticipate an agreement however the exact level of emissions in period 2 will depend on the state of the world of period 2 where as in the case of an IEA of type 3, countries in period 1 are assumed to anticipate an exact level of emissions under an agreement regardless of the level of the prevailing stock of pollution in period 2. IEAs of type 1 can be explained by the fact that the larger the decrease of emissions with respect to the BAU scenario the larger the resistance of interests group in the economy whereas IEAs of type 2 can be motivated by the existence of a limit in the abatement capacity of an economy. An IEA of type 4 represents a benchmark 'ideal' scenario in period two since countries are assumed to choose the first-best emission rule in period two.

We show that an IEA in period 2 on current emissions can be ambiguous. Under an IEA of type 2 we show that an IEA in period 2 unambiguously results in an increase of emissions in period 1 compared to the BAU scenario. In the case of the fourth type of IEAs, we derive necessary conditions for an IEA to result in a decrease of emissions in period 1. We show that this necessary condition is never satisfied for two class of models: the linear quadratic case and the case of logarithmic utility. The intuition of this result is that future cooperation results in a decrease of the shadow cost of the stock of pollution. Since the future cost of pollution from current emissions diminishes countries increase their current emissions. However this intuition does not carry over in the case of a type 1 and type 3 IEA. Under an IEA of type 1 a marginal decrease of emissions with respect to the BAU emission strategy can result in a smaller level of emissions in period 1. This happens if the elasticity of marginal utility at the BAU in period 2 is larger than one. This condition is thus trivially satisfied if the utility function has a constant elasticity of marginal utility and if that constant is small than one. This condition can also be satisfied in the linear quadratic framework, if the damage from the stock of pollution is sufficiently small or if the stock is large enough. Thus the mere possibility of a future IEA can have a positive spillover on current emissions and result in countries reducing their current emission.

The possibility that an environmental friendly policy may end-up having negative environmental consequences is by now well established: see e.g., Hoel (1991 and 1992) or Eichner and Pethig (2011) in the case where environmentally friendly policies are unilaterally adopted by a sub-group countries or Benchekroun and Ray Chaudhuri (2014) in the case where countries adopt a cleaner technology[1]. A related literature that highlights the role of fossil fuels in the climate change problem examines the role of environmentally friendly policies on the intertemporal extraction of fossil fuels. Within such framework the unintended negative impact on the environment of an environmentally friendly policy

[1] or Benchekroun (2003) in the context of international fisheries.

such as subsidy to cleaner energies was coined 'the green paradox' (see e.g., Sinn (2012), Ploeg and Withagen (2012), Grafton, Kompas and Long (2012) or for surveys, Werf and Di Maria (2012), Ploeg and Withagen (2013) or Long (2013)).

Our paper is closely related to two existing papers, Smulders, Tsur and Yacov (2012) and Beccherle and Tirole (2011), that examine the impact of the announcement of a future environmental agreement. Smulders et al. (2012) show that announcing that a carbon tax will be implemented starting at a future date, results in an increase of the use of fossil fuels (and therefore carbon emissions) in the interim period (that precedes the implementation of the tax), compared to the business as usual scenario. In their model, a final good is produced by capital and energy. The energy sector supplies energy from fossil fuels and/or from a clean energy (e.g., solar energy), the representative household holds shares of capital in the final goods firms and solar energy firms. Their result is driven by the fact that "anticipating the future increase in the price of fossil energy, households respond by reducing consumption and increasing saving in order to smooth consumption at the time of transition to the carbon tax regime. Higher saving rates imply larger capital stocks and enhanced energy demand,in contrast to the original purpose of the announced policy." Their model considers the case of a single country. In contrast in our model we consider the case of several countries facing a transboundary pollution problem and we do not model the consumption-savings decision, we consider rather a closed-form of the relationship between a country's utility and its emissions. In our model it is the countries' strategic behavior that drives the result of a potential negative impact of a future agreement on current emissions.

Beccherle and Tirole (2011) consider a two period game between two countries. The damage from pollution is caused in period two and depends on countries environmental policies in period 2 only. However in period 1 each country can adopt an environmental policy that will impact its own utility in period 2. The paper examines the impact of delaying an agreement to period 2 on the bargaining outcome between the two countries with a focus on the period two's environmental policies. A crucial assumption of the model is that a more lax environmental policy in period 1 results in a more lax environmental policy in period two. While their generic game is quite general it cannot be used to analyze the case where the environmental policy of a country is that country's emissions[2]. In their model the policy chosen in period 1 has an impact on the bargaining outcome in period 2 through the impact on both the cooperative outcome (first-best) and the non-cooperative outcome (the threat point) in period 2. In our paper, we consider the problem of a choice of emissions over two periods in transboundary pollution game. The damage is caused by a stock of pollution that accumulates with the sum of all countries' emissions. Therefore the damage from pollution is caused by emissions of all countries and emissions in period one have an impact on the damage in period two. As is the case in standard transboundary stock pollution games, the equilibrium emission policy, whether in the

[2]Emissions can be used as the environmental policy only if there are adjustment costs of changing emissions between two periods and the adjustment costs are substantial enough for the crucial assumption that more emissions in period one will result in more emissions in period two continues to hold.

non-cooperative or the cooperative scenarios, are non-decreasing in the stock of pollution. Therefore an increase of emissions in a given period increases the stock of pollution in subsequent periods and therefore results in a decrease of emissions in the future[3]. In contrast with Beccherle and Tirole (2011), we do not explicitly model the bargaining taking lace in period two. We assume that in period 2 an agreement in period two will be reached whereby the agreed upon emission policy adopted in period two is more environmentally friendly than the business as usual emission policy. Thus in choosing emissions in period 1, countries do not try to influence the threat point in period 2. However, in our game, the outcome of the agreement in period two still depends on decisions made in period 1 since those decisions impact the stock of pollution in period 2 and therefore impact the outcome of the agreement in the case of IEAs of type 1,2 and 4.

We present the model and the benchmark BAU and first-best equilibrium in section 2. In section 3-6 we examine the impact of an anticipated future agreement of respectively types 1-4 on current emissions. Section 7 offers concluding remarks.

2 Model

There are two periods and n countries. Let P_t denote the initial stock of pollution at time $t = 1, 2$. Let $E_{t,i}$ denote country i's emissions at time t.

The sequence of events in each period is as follows:

Given an initial stock P_t countries choose their emissions $(E_{t,1}, .., E_{t,N})$, emissions add-up to the initial stock of pollution, the sum of the current emissions and the inherited stock cause a damage $D(P_t + \Sigma E_{t,i})$. We have

$$P_2 = (P_1 + \Sigma_k E_{1,k})(1 - \delta)$$

where $\delta \in [0, 1]$ represents the natural rate of decay of the stock of pollution.

Utility of country i from the emission (consumption) in each period

$$u(E)$$

We assume that $u' > 0$ and $u'' < 0$ and $D' > 0$ and $D'' > 0$.

In a non-cooperative setup each country i takes the strategies of emissions of the other countries as given and chooses an extraction strategy. We seek a Markov perfect Nash equilibrium of this game. We solve the game backwards and start solving the equilibrium emissions strategies in period 2.

[3] The crucial assumption of positively related environmental policies across periods does not hold in a transboundary pollution game.

2.1 Period 2:

Given P_2 the problem of country i is

$$Max\left(u\left(E_{2,i}\right)-D\left(P_2+\Sigma_k E_{2,k}\right)\right)$$

The foc gives

$$u'\left(E_{2,i}\right)-D'\left(P_2+\Sigma E_{2,k}\right)=0$$

Since countries are symmetric, we determine a symmetric equilibrium $E_{2,NC}$ a function of the initial stock P_2

$$u'\left(E_{2,NC}\right)-D'\left(P_2+nE_{2,NC}\right)=0 \tag{1}$$

Suppose $u'(0)<\infty$ then for P_2 such that $u'(0)-D'(P_2)>0$ we have $E_{2,NC}=0$ and for $u'(0)\leq D'(P_2)$ there exists a unique positive $E_{2,NC}(P_2)$ solution to 1. If $\lim_{E->0^+}u'(E)=\infty$ and $\lim_{E->\infty}u'(E)=0$ then for each $P_2>0$ there exists a unique positive $E_{2,NC}(P_2)$ solution to 1.

Moreover, total differentiation of 1 wrt P_2 gives

$$u''\left(E_{2,NC}\right)E'_{2,NC}-\left(1+nE'_{2,NC}\right)D''\left(P_2+nE_{2,NC}\right)=0 \tag{2}$$

which implies

$$E'_{2,NC}=\frac{D''\left(P_2+nE_{2,NC}\right)}{u''\left(E_{2,NC}\right)-nD''\left(P_2+nE_{2,NC}\right)}<0 \tag{3}$$

If countries where to choose a vector of emission strategies that maximize their joint welfare, they would choose the emission strategy $E_{2,Coop}(P_2)$ solution to

$$u'\left(E_{2,Coop}\left(P_2\right)\right)-nD'\left(P_2+nE_{2,Coop}\left(P_2\right)\right)=0 \tag{4}$$

2.2 Period 1:

We now consider the problem in period 1. The problem of country i is

$$Max\left(u\left(E_{1,i}\right)-D\left(P_1+\Sigma_k E_{1,k}\right)+\beta\left(u\left(E_{2,NC}\left(P_2\right)\right)-D\left(P_2+nE_{2,NC}\left(P_2\right)\right)\right)\right)$$

where $\beta\in[0,1]$ is the discount factor.

$$P_2=\left(P_1+\Sigma_k E_{1,k}\right)(1-\delta)$$

The foc

$$\begin{aligned}&u'\left(E_{1,i}\right)-D'\left(P_1+\Sigma_k E_{1,k}\right)\\&+\beta\left(u'\left(E_{2,NC}\left(P_2\right)\right)E'_{2,NC}\left(P_2\right)-\left(\left(1+nE'_{2,NC}\left(P_2\right)\right)\right)D'\left(P_2+nE_{2,NC}\left(P_2\right)\right)\right)\frac{dP_2}{dE_{1,i}}\\=&\ 0\end{aligned}$$

Using the fact that $u'(E_{2,NC}) - D'(P_2 + nE_{2,NC}) = 0$ we have

$$\begin{aligned} & u'(E_{1,i}) - D'(P_1 + \Sigma_k E_{1,k}) \\ & +\beta \left(u'(E_{2,NC}(P_2)) E'_{2,NC}(P_2) - \left(\left(1 + nE'_{2,NC}(P_2)\right) \right) u'(E_{2,NC}(P_2)) \right) \frac{dP_2}{dE_{1,i}} \\ = & \ 0 \end{aligned}$$

or

$$\begin{aligned} & u'(E_{1,i}) - D'(P_1 + \Sigma_k E_{1,k}) \\ & -\beta(1-\delta)\left(1 + (n-1) E'_{2,NC}\right) u'(E_{2,NC}(P_2)) \\ = & \ 0 \end{aligned}$$

For a symmetric equilibrium, the emission strategy in period 1 is $E_{1,NC}(P_1)$ solution to

$$\begin{aligned} & u'(E_{1,NC}(P_1)) - D'(P_1 + nE_{1,NC}(P_1)) \\ & -\beta(1-\delta)\left(1 + (n-1) E'_{2,NC}\right) u'(E_{2,NC}(P_2)) \\ = & \ 0 \end{aligned} \tag{5}$$

We assume that such a solution exists and is unique for each P_1.

We now examine the impact of a foreseen IEA that would implement an emission strategy in period 2 denote $E_{2,C}(P)$ with $E_{2,C}(P) \leq E_{2,NC}(P)$ for all P.

We separately consider four types of IEAs: (i) $E_{2,C}(P) = (1-\varepsilon) E_{2,NC}(P)$, (ii) $E_{2,C}(P) = E_{2,NC}(P) - \eta$, (iii) $E_{2,C}(P) = \bar{E}$ and (iv) $E_{2,C}(P) = E_{2,Coop}(P)$.

3 A first type of IEAs: $E_{2,C}(P) = (1-\varepsilon) E_{2,NC}(P)$

We examine the case where

$$E_{2,C}(P) = (1-\varepsilon) E_{2,NC}(P) \text{ where } \varepsilon \in [0,1]$$

The problem of country i is

$$Max\left(u(E_{1,i}) - D(P_1 + \Sigma_k E_{1,k}) + \beta\left(u((1-\varepsilon) E_{2,NC}(P_2)) - D(P_2 + n(1-\varepsilon) E_{2,NC}(P_2))\right)\right)$$

where $\beta \in [0,1]$ is the discount factor.

$$P_2 = (P_1 + \Sigma_k E_{1,k})(1-\delta)$$

The foc

$$\begin{aligned} & u'(E_{1,i}) - D'(P_1 + \Sigma_k E_{1,k}) \\ & +\beta(1-\delta)\left(u'((1-\varepsilon) E_{2,NC}(P_2))(1-\varepsilon) E'_{2,NC}(P_2) - \left(\left(1 + n(1-\varepsilon) E'_{2,NC}(P_2)\right)\right) D'(P_2 + n(1-\varepsilon) E_{2,NC}(P_2))\right) \\ = & \ 0 \end{aligned}$$

The resulting emission strategy in period 1 denoted $E_{1,C}(P)$ is then solution to

$$\begin{aligned} & u'(E_{1,C}(P_1)) - D'(P_1 + nE_{1,C}(P_1)) \\ & +\beta(1-\delta)\left(u'((1-\varepsilon)E_{2,NC}(P_2))(1-\varepsilon)E'_{2,NC}(P_2) - \left(\left(1+n(1-\varepsilon)E'_{2,NC}(P_2)\right)\right)D'(P_2+n(1-\varepsilon)E_{2,NC}(P_2))\right) \\ = \; & 0 \end{aligned}$$

In order to compare $E_{1,C}(P)$ to $E_{1,NC}(P)$ We need to compare $R(\varepsilon)$ and $R(0)$ where

$$R(\varepsilon) = -\beta(1-\delta)\left(u'((1-\varepsilon)E_{2,NC}(P_2))(1-\varepsilon)E'_{2,NC}(P_2) - \left(\left(1+n(1-\varepsilon)E'_{2,NC}(P_2)\right)\right)D'(P_2+n(1-\varepsilon)E_{2,NC}(P_2))\right)$$

since

$$u'(E_{1,C}(P_1)) - D'(P_1 + nE_{1,C}(P_1)) = R(\varepsilon)$$

and

$$u'(E_{1,NC}(P_1)) - D'(P_1 + nE_{1,NC}(P_1)) = R(0)$$

Since $u'(X) - D'(P_1 + nX)$ is a strictly decreasing function of X we have

$$E_{1,NC}(P_1) > E_{1,C}(P_1)$$

iff

$$R(0) < R(\varepsilon).$$

We examine the impact of a change in ε is given by

$$\begin{aligned} \frac{R'(\varepsilon)}{-\beta(1-\delta)} = \; & -u'((1-\varepsilon)E_{2,NC}(P_2))E'_{2,NC}(P_2) - E_{2,NC}(P_2)u''((1-\varepsilon)E_{2,NC}(P_2))(1-\varepsilon)E'_{2,NC}(P_2) \\ & -\left(-nE'_{2,NC}(P_2)\right)D'(P_2+n(1-\varepsilon)E_{2,NC}(P_2)) \\ & -\left(\left(1+n(1-\varepsilon)E'_{2,NC}(P_2)\right)\right)(-nE_{2,NC}(P_2))D''(P_2+n(1-\varepsilon)E_{2,NC}(P_2)) \end{aligned}$$

The impact of a marginal change in ε in the neighborhood of $\varepsilon = 0$ is given by

$$\begin{aligned} \frac{R'(0)}{\beta(1-\delta)} = \; & (u'(E_{2,NC}(P_2)) - nD'(P_2 + nE_{2,NC}(P_2)))E'_{2,NC}(P_2) \\ & +E_{2,NC}(P_2)u''(E_{2,NC}(P_2))E'_{2,NC}(P_2) \\ & -n\left(1+nE'_{2,NC}(P_2)\right)E_{2,NC}(P_2)D''(P_2+nE_{2,NC}(P_2)) \end{aligned}$$

Using 2

$$\begin{aligned} \frac{R'(0)}{\beta(1-\delta)} = \; & (u'(E_{2,NC}(P_2)) - nD'(P_2 + nE_{2,NC}(P_2)))E'_{2,NC}(P_2) \\ & +E_{2,NC}(P_2)\left(u''(E_{2,NC}(P_2))E'_{2,NC}(P_2) - nu''(E_{2,NC}(P_2))E'_{2,NC}(P_2)\right) \end{aligned}$$

or

$$\frac{R'(0)}{\beta(1-\delta)} = (u'(E_{2,NC}(P_2)) - nD'(P_2 + nE_{2,NC}(P_2)))E'_{2,NC}(P_2) + E_{2,NC}(P_2)(1-n)u''(E_{2,NC}(P_2))E'_{2,NC}(P_2)$$

$$\frac{R'(0)}{\beta(1-\delta)E'_{2,NC}(P_2)} = \underbrace{u'(E_{2,NC}(P_2)) - nD'(P_2 + nE_{2,NC}(P_2))}_{<0} + \underbrace{E_{2,NC}(P_2)(1-n)u''(E_{2,NC}(P_2))}_{>0}$$

Note that $u'(E_{2,NC}(P_2)) - nD'(P_2 + nE_{2,NC}(P_2)) < 0$ from $E_{2,NC}(P_2)$ larger than first-best emissions which solve $u'(E) - nD'(P_2 + nE) = 0$.

The sign of $R'(0)$ is therefore undetermined.

This condition may be rewritten as

$$\frac{R'(0)}{\beta(1-\delta)} = -(n-1)E'_{2,NC}(P_2)u'(E_{2,NC}(P_2))\left(1 + \frac{E_{2,NC}(P_2)u''(E_{2,NC}(P_2))}{u'(E_{2,NC}(P_2))}\right)$$

The sign of $R'(0)$ depends on the elasticity of marginal utility. It is positive iff

$$-\frac{E_{2,NC}(P_2)u''(E_{2,NC}(P_2))}{u'(E_{2,NC}(P_2))} < 1$$

In the case where utility has a constant elasticity of marginal utility

$$u(E) = \frac{E^{1-\sigma}}{1-\sigma}$$

$$u'(E) = E^{-\sigma} \text{ and } u''(E) = -\sigma E^{-\sigma-1}$$

so

$$-\frac{Eu''(E)}{u'(E)} = \sigma$$

we have $R'(0) > 0$ or $E_{1,NC}(P_1) > E_{1,C}(P_1)$ iff $\sigma < 1$.

Proposition 1:

A marginal proportional reduction of future emissions results in a decrease (an increase) of current emissions iff $\sigma = -\frac{E_{2,NC}(P_2)u''(E_{2,NC}(P_2))}{u'(E_{2,NC}(P_2))} < 1$

$$E_{1,NC}(P_1) > E_{1,C}(P_1) \text{ iif } \sigma < 1.$$

We examine now the linear quadratic case and show that the sign of $R'(0)$ is ambiguous.

The linear quadratic case: $u(E) = E\left(A - \frac{B}{2}\right)E$ and $D(P) = \frac{1}{2}\gamma P^2$. Without loss of generality we set $A = 1$ and $B = 1$.

We have

$$E_{2,NC}(P) = \frac{1-\gamma P}{1+n\gamma}$$

for $1-\gamma P \geq 0$ and $E_{2,NC}(P) = 0$ otherwise. Emissions in period 1 are given by

$$E_{1,C}(P) = \frac{\Gamma + \Phi P}{\Delta}$$

where

$$\begin{aligned}\Delta &= 1+(3+\beta(1-\delta)^2)n\gamma+(3n+\beta(1-\delta)^2(1+\varepsilon^2+2\varepsilon\,(n-1)))n\gamma^2\\ &\quad +(1+\beta(1-\delta)^2\varepsilon^2)n^3\gamma^3\\ &> 0\end{aligned}$$

$$\begin{aligned}\Gamma &= 1+\gamma\left(2n-\beta\left(\delta-1\right)\left(-1+\varepsilon\right)\left(\varepsilon+n\right)\right)\\ &\quad +\gamma^2 n\left(n-\beta\left(\delta-1\right)\left(\varepsilon-1\right)\left(1+n\varepsilon\right)\right)\end{aligned}$$

$$\Phi=-\gamma\left(1+\beta\left(1-\delta\right)^2+\left(1+\beta\left(1-\delta\right)^2\varepsilon^2\right)\gamma^2n^2+\gamma\left(\beta\left(1-\delta\right)^2\left(1+\varepsilon^2+2\varepsilon\left(n-1\right)\right)+2n\right)\right)$$

When $\varepsilon=0$ we have $E_{1,C}(P)=E_{1,NC}(P)$. Examining the sign of $\frac{dE_{1,C}(P)}{d\varepsilon}$ is tedious given the cumbersome expressions of the equilibrium strategy. We argue that the sign of $\frac{dE_{1,C}(P)}{d\varepsilon}$ can be ambiguous.

The case $P=0$

For that we analyze first the case of $P=0$ and study the sign of $\frac{dE_{1,C}(0)}{d\varepsilon}$ in the neighborhood of $\varepsilon=0$ is ambiguous.

We have

$$\left.\frac{dE_{1,C}(0)}{d\varepsilon}\right|_{\varepsilon=0}=\frac{\beta\left(1-\delta\right)\gamma\left(n-1\right)\left(1+n\gamma\right)\Omega}{\Delta^2}$$

where

$$\Omega=1+\left(-1+\beta\left(1-\delta\right)^2+2\delta\right)\gamma n-n^3\gamma^3+\gamma^2n\left(\beta\left(1-\delta\right)^2+n\left(2\delta-3\right)\right).$$

Therefore the sign of $\left.\frac{dE_{1,C}(0)}{d\varepsilon}\right|_{\varepsilon=0}$ is given by Ω.

The term Ω is a cubic function of γ. Its graph in a (γ,Ω) space has an inverted N shape and there exist γ_1 and $\gamma_2>\gamma_1$ where Ω reaches a local minimum and maximum respectively. The function is an increasing function of γ over (γ_1,γ_2) and decreasing elsewhere.

Lemma: *There exists a unique $\bar{\gamma}>0$ such that for $\Omega<0$ for $\gamma>\bar{\gamma}$ and $\Omega>0$ for $0<\gamma<\bar{\gamma}$.*

Proof: We first establish existence of $\bar{\gamma}$ such that $\Omega=0$. This follows from the fact that $\Omega\left(\gamma=0\right)=1>0$, $\lim_{\gamma->\infty}\Omega=-\infty$ and that Ω is continuous.

We now establish uniqueness of $\bar{\gamma}$. The function Ω can have at most three roots. From $\Omega\left(\gamma=0\right)=1>0$ we can infer that Ω cannot have two positive roots only. Suppose Ω has three positive roots then one of the following two statements must hold Ω is strictly decreasing strictly convex in the neighborhood of $\gamma=0$

$$\frac{d\Omega}{d\gamma}=\left(-1+\beta\left(1-\delta\right)^2+2\delta\right)n-3n^3\gamma^2+2n\gamma\left(\beta\left(1-\delta\right)^2+n\left(2\delta-3\right)\right)$$

$$\frac{d^2\Omega}{d\gamma^2}=-6n^3\gamma+2n\left(\beta\left(1-\delta\right)^2+n\left(2\delta-3\right)\right)$$

At $\gamma = 0$ $\left.\frac{d\Omega}{d\gamma}\right|_{\gamma=0} = \left(\beta\left(1-\delta\right)^2 + 2\delta - 1\right) n < 0$

$$\left.\frac{d^2\Omega}{d\gamma^2}\right|_{\gamma=0} = 2n\left(\beta\left(1-\delta\right)^2 + n\left(2\delta - 3\right)\right) > 0$$

$$\left.\frac{d^2\Omega}{d\gamma^2}\right|_{\gamma=0} = 2n\left(\frac{1}{n}\left.\frac{d\Omega}{d\gamma}\right|_{\gamma=0} + \left(n-1\right)2\delta - 3n + 1\right)$$

The term $(n-1)\,2\delta - 3n + 1$ is a strictly increasing function of δ for $n > 1$ therefore, since $\delta \in [0,1]$ is no larger than $(n-1)\,2 - 3n + 1 = -n - 1 < 0$. Therefore if $\left.\frac{d\Omega}{d\gamma}\right|_{\gamma=0} \leq 0$ we must have $\left.\frac{d^2\Omega}{d\gamma^2}\right|_{\gamma=0} < 0$, i.e. Ω is strictly concave in the neighborhood of $\gamma = 0$. This rules out the existence of three positive roots of Ω. This completes the proof.

Proposition 2: *There exists a unique $\bar{\gamma} > 0$ such that for $\gamma < (>)\bar{\gamma}$ the adoption of a marginally more environmental friendly emission policy $E_{2,C}(P) = (1-\varepsilon)\,E_{2,NC}\,(P)$ by all the players results in an increase (decrease) in equilibrium emissions in period 1 in the neighborhood of $P = 0$.*

Proof: This follows from the fact that the sign of $\left.\frac{dE_{1,C}(0)}{d\varepsilon}\right|_{\varepsilon=0}$ is given by the sign of Ω and from the Lemma.

The case $P > 0$.

Recall that

$$E_{1,C}\left(P\right) = \frac{\Gamma + \Phi P}{\Delta}$$

Let $F\left(\varepsilon\right) = \frac{\Phi}{\Delta}$. After substitution and derivation with respect to ε we obtain

$$F\left(\varepsilon\right) = -\frac{\gamma\left(1 + \beta\left(1-\delta\right)^2 + \left(1 + \beta\left(1-\delta\right)^2\varepsilon^2\right)\gamma^2 n^2 + \gamma\left(\beta\left(1-\delta\right)^2\left(1 + \varepsilon^2 + 2\varepsilon\left(n-1\right)\right) + 2n\right)\right)}{1 + (3 + \beta(1-\delta)^2)n\gamma + (3n + \beta(1-\delta)^2(1 + \varepsilon^2 + 2\varepsilon\left(n-1\right)))n\gamma^2 + (1 + \beta(1-\delta)^2\varepsilon^2)n^3\gamma^3}$$

$$F'\left(0\right) = -\frac{2\left(n-1\right)\beta\gamma^2\left(\delta-1\right)^2\left(n\gamma+1\right)^2}{\left(3n^2\gamma^2 + n^3\gamma^3 + 3n\gamma + n\beta\gamma + n\beta\gamma^2 + n\beta\gamma\delta^2 - 2n\beta\gamma^2\delta + n\beta\gamma^2\delta^2 - 2n\beta\gamma\delta + 1\right)^2} < 0$$

An increase in ε results in a decrease of the slope, a steeper emission strategy. From the proposition above we can conclude

Proposition 3: *There exists a unique $\bar{\gamma} > 0$ such that for $\gamma > \bar{\gamma}$ the adoption of a marginally more environmental friendly emission policy $E_{2,C}(P) = (1-\varepsilon)\,E_{2,NC}\,(P)$ by all the players results in an increase (decrease) in equilibrium emissions in period 1 , for all $P \geq 0$.*

for $\gamma > \bar{\gamma}$ the impact of the adoption of a marginally more environmental friendly emission policy $E_{2,C}(P) = (1-\varepsilon)\,E_{2,NC}\,(P)$ by all the players on the equilibrium emissions in period 1 depends on P : There exists $\bar{P} > 0$ such that $E_{1,C}(P) > E_{1,NC}(P)$ iff $P < \bar{P}$.

4 A second type of IEAs: $E_{2,C}(P) = E_{2,NC}(P) - \eta$

We examine the case where

$$E_{2,C}(P) = E_{2,NC}(P) - \eta \text{ where } \eta \in [0, E_{2,NC}(P_{2,NC})]$$

The problem of country i is

$$Max\left(u\left(E_{1,i}\right) - D\left(P_1 + \Sigma_k E_{1,k}\right) + \beta\left(u\left(E_{2,NC}\left(P_2\right) - \eta\right) - D\left(P_2 + nE_{2,NC}\left(P_2\right) - n\eta\right)\right)\right)$$

where $\beta \in [0,1]$ is the discount factor.

$$P_2 = \left(P_1 + \Sigma_k E_{1,k}\right)(1-\delta)$$

The foc

$$\begin{aligned} & u'\left(E_{1,i}\right) - D'\left(P_1 + \Sigma_k E_{1,k}\right) \\ & +\beta(1-\delta)\left(u'\left(E_{2,NC}\left(P_2\right) - \eta\right)E'_{2,NC}\left(P_2\right) - \left(1 + nE'_{2,NC}\left(P_2\right)\right)D'\left(P_2 + nE_{2,NC}\left(P_2\right) - n\eta\right)\right) \\ = & \ 0 \end{aligned}$$

The resulting emission strategy in period 1 denoted $E_{1,C}(P)$ is then solution to

$$\begin{aligned} & u'\left(E_{1,C}\left(P_1\right)\right) - D'\left(P_1 + nE_{1,C}\left(P_1\right)\right) \\ & +\beta(1-\delta)\left(u'\left(E_{2,NC}\left(P_2\right) - \eta\right)E'_{2,NC}\left(P_2\right) - \left(1 + nE'_{2,NC}\left(P_2\right)\right)D'\left(P_2 + nE_{2,NC}\left(P_2\right) - n\eta\right)\right) \\ = & \ 0 \end{aligned}$$

In order to compare $E_{1,C}(P)$ to $E_{1,NC}(P)$ We need to compare $Q(\eta)$ and $Q(0)$ where

$$Q(\eta) = -\beta(1-\delta)\left(u'\left(E_{2,NC}(P) - \eta\right)E'_{2,NC}(P) - \left(1 + nE'_{2,NC}(P)\right)D'\left(P + nE_{2,NC}(P) - n\eta\right)\right)$$

Taking the derivative wrt η gives

$$\frac{Q'(\eta)}{-\beta(1-\delta)} = -u'\left(E_{2,NC}(P) - \eta\right)E'_{2,NC}(P) + n\left(1 + nE'_{2,NC}(P)\right)D''\left(P + nE_{2,NC}(P) - n\eta\right)$$

and

$$\frac{Q'(0)}{-\beta(1-\delta)} = -u''\left(E_{2,NC}(P)\right)E'_{2,NC}(P) + n\left(1 + nE'_{2,NC}(P)\right)D''\left(P + nE_{2,NC}(P)\right)$$

From 2

$$u''\left(E_{2,NC}\right)E'_{2,NC} - \left(1 + nE'_{2,NC}\right)D''\left(P_2 + nE_{2,NC}\right) = 0 \tag{6}$$

so

$$\frac{Q'(0)}{-\beta(1-\delta)} = (n-1)\,u''\left(E_{2,NC}(P)\right)E'_{2,NC}(P) > 0$$

or

$$Q'(0) < 0$$

and therefore in the neighborhood of $\eta = 0$ we have

$$Q(\eta) < Q(0) \text{ for } \eta > 0$$

We have

$$u'(E_{1,NC}(P_1)) - D'(P_1 + nE_{1,NC}(P_1)) = Q(0)$$

and

$$u'(E_{1,C}(P_1)) - D'(P_1 + nE_{1,C}(P_1)) = Q(\eta)$$

Since $u''(E_{1,NC}(P_1)) - D''(P_1 + nE_{1,NC}(P_1)) < 0$ we have

$$E_{1,C}(P_1) > E_{1,NC}(P_1) \text{ for all } P_1$$

Proposition 4:

The adoption of a marginally more environmental friendly emission policy $E_{2,C}(P) = E_{2,NC}(P) - \eta$ by all the players results in an increase of current emissions.

4.1 A third IEA: $E_{2,C}(P) = \bar{E}$

We examine the case where

$$E_{2,C}(P) = \bar{E} \text{ where } 0 < \bar{E} < E_{2,NC}(P_{2,NC})$$

where $P_{2,NC}$ is the stock of pollution at the beginning of period 2 in the non-cooperative scenario. Thus $E_{2,NC}(P_{2,NC})$ represents the equilibrium emissions in period 2 in the absence of an IEA in period 2.

The problem of country i is

$$Max\left(u(E_{1,i}) - D(P_1 + \Sigma_k E_{1,k}) + \beta\left(u(\bar{E}) - D\left(P_2 + n\bar{E}\right)\right)\right)$$

where $\beta \in [0,1]$ is the discount factor.

$$P_2 = (P_1 + \Sigma_k E_{1,k})(1-\delta)$$

The foc

$$\begin{aligned} & u'(E_{1,i}) - D'(P_1 + \Sigma_k E_{1,k}) \\ & -\beta(1-\delta) D'\left(P_2 + n\bar{E}\right) \\ = \; & 0 \end{aligned}$$

The resulting emission strategy in period 1 denoted $E_{1,C}(P)$ is then solution to

$$\begin{aligned} & u'(E_{1,C}) - D'(P_1 + nE_{1,C}) \\ & -\beta(1-\delta) D'\left((P_1 + nE_{1,C})(1-\delta) + n\bar{E}\right) \\ = \; & 0 \end{aligned}$$

Total differentiation wrt $\bar{E}$ gives

$$u''\left(E_{1,C}\right)\frac{dE_{1,C}}{d\bar{E}}-D''\left(P_1+nE_{1,C}\right)n\frac{dE_{1,C}}{d\bar{E}}-\beta\left(1-\delta\right)D''\left(\left(P_1+nE_{1,C}\right)\left(1-\delta\right)+n\bar{E}\right)\left(n\left(1-\delta\right)\frac{dE_{1,C}}{d\bar{E}}+n\right)=0$$

$$\begin{aligned}&\frac{dE_{1,C}}{d\bar{E}}\left(u''\left(E_{1,C}\right)-D''\left(P_1+nE_{1,C}\right)n\frac{dE_{1,C}}{d\bar{E}}-\beta\left(1-\delta\right)D''\left(\left(P_1+nE_{1,C}\right)\left(1-\delta\right)+n\bar{E}\right)n\left(1-\delta\right)\right)\\ =\ &\beta\left(1-\delta\right)D''\left(\left(P_1+nE_{1,C}\right)\left(1-\delta\right)+n\bar{E}\right)n\end{aligned}$$

$$\frac{dE_{1,C}}{d\bar{E}}=\frac{\beta\left(1-\delta\right)D''\left(\left(P_1+nE_{1,C}\right)\left(1-\delta\right)+n\bar{E}\right)n}{\left(u''\left(E_{1,C}\right)-D''\left(P_1+nE_{1,C}\right)n\frac{dE_{1,C}}{d\bar{E}}-\beta\left(1-\delta\right)D''\left(\left(P_1+nE_{1,C}\right)\left(1-\delta\right)+n\bar{E}\right)n\left(1-\delta\right)\right)}<0$$

Therefore a decrease in $\bar{E}$ unambiguously results in an increase of $E_{1,C}$.

Proposition 5: *Suppose that an IEA in period is anticipated to implement a predertermined level of emissions where $\bar{E}<E_{2,NC}\left(P_{2,NC}\right)$, a decrease in the threshold $\bar{E}$ unambiguously results in an increase in current emissions.*

However we should note that setting $\bar{E}=E_{2,NC}\left(P_{2,NC}\right)$ does not yield $E_{1,C}=E_{1,NC}$. Indeed when $\bar{E}=E_{2,NC}\left(P_{2,NC}\right)$

$$u'\left(E_{1,C}\right)-D'\left(P_1+nE_{1,C}\right)-\beta\left(1-\delta\right)D'\left(\left(P_1+nE_{1,C}\right)\left(1-\delta\right)+nE_{2,NC}\left(P_{2,NC}\right)\right)=0$$

$$\left(u'\left(E_{2,NC}\left(P_2\right)\right)-nD'\left(P_2+nE_{2,NC}\left(P_2\right)\right)\right)E'_{2,NC}\left(P_2\right)>0$$

whereas in the non-cooperative scenario

$$\begin{aligned}&u'\left(E_{1,NC}\right)-D'\left(P_1+nE_{1,NC}\right)=\\ &-\beta\left(1-\delta\right)\left(u'\left(E_{2,NC}\left(P_2\right)\right)-nD'\left(P_2+nE_{2,NC}\left(P_2\right)\right)\right)E'_{2,NC}\left(P_2\right)\\ &+\beta\left(1-\delta\right)D'\left(P_2+nE_{2,NC}\left(P_2\right)\right)\\ =\ &0\end{aligned}$$

Let

$$h\left(E\right)=u'\left(E\right)-D'\left(P_1+nE\right)-\beta\left(1-\delta\right)D'\left(\left(P_1+nE\right)\left(1-\delta\right)+n\bar{E}\right)$$

we have $h'<0$ and

$$h\left(E_{1,C}\right)=0$$

and at $\bar{E}=E_{2,NC}\left(P_{2,NC}\right)$ we have

$$h\left(E_{1,NC}\right)=-\beta\left(1-\delta\right)\left(u'\left(E_{2,NC}\left(P_2\right)\right)-nD'\left(P_2+nE_{2,NC}\left(P_2\right)\right)\right)E'_{2,NC}\left(P_2\right)<0$$

and therefore

$$E_{1,C}<E_{1,NC}$$

This is due the feedback effect[4] that is present in the non-cooperative case (i.e., $E'_{2,NC}(P_2)$).

Proposition 5: *Suppose that an IEA in period is anticipated to implement a predertermined level of emissions $\bar{E} = E_{2,NC}(P_{2,NC})$. This unambiguously results in a decrease in current emissions.*

5 A fourth type of IEAs: $E_{2,C}(P) = E_{2,Coop}(P)$

We examine the case where we have full cooperation in period 2: Countries choose a vector of emission strategies that maximize their joint welfare.

The resulting emission strategy in period 1 denoted $E_{1,C}(P)$ is then solution to

$$\begin{aligned} & u'(E_{1,C}(P_1)) - D'(P_1 + nE_{1,C}(P_1)) \\ & +\beta(1-\delta)\left(u'(E_{2,Coop}(P_2))E'_{2,Coop}(P_2) - \left(\left(1 + nE'_{2,Coop}(P_2)\right)\right)D'(P_2 + nE_{2,Coop}(P_2))\right) \\ = \; & 0 \end{aligned}$$

Under cooperation we have

$$u'(E_{2,Coop}(P_2)) - nD'(P_2 + nE_{2,Coop}(P_2)) = 0$$

and therefore

$$u'(E_{1,C}(P_1)) - D'(P_1 + nE_{1,C}(P_1)) - \beta(1-\delta)D'(P_2 + nE_{2,Coop}(P_2)) = 0$$

Using 4 we have

$$u'(E_{1,C}(P_1)) - D'(P_1 + nE_{1,C}(P_1)) - \beta(1-\delta)\frac{u'(E_{2,Coop}(P_2))}{n} = 0$$

Recall that for the non-cooperative equilibrium we have

$$u'(E_{1,NC}(P_1)) - D'(P_1 + nE_{1,NC}(P_1)) - \beta(1-\delta)\left(1 + (n-1)E'_{2,NC}\right)u'(E_{2,NC}(P_2)) = 0$$

If $E_{1,NC}(P_1) > E_{1,C}(P_1)$ then, since $u'' - D'' < 0$,

$$u'(E_{1,NC}(P_1)) - D'(P_1 + nE_{1,NC}(P_1)) < u'(E_{1,C}(P_1)) - D'(P_1 + nE_{1,C}(P_1))$$

that is

$$\beta(1-\delta)\left(1 + (n-1)E'_{2,NC}\right)u'(E_{2,NC}(P_2)) < \beta(1-\delta)\frac{u'(E_{2,Coop}(P_2))}{n}$$

or

$$\frac{u'(E_{2,Coop}(P_{2,Coop}))}{u'(E_{2,NC}(P_{2,NC}))} - n\left(1 + (n-1)E'_{2,NC}(P_{2,NC})\right) > 0. \tag{7}$$

[4] The feedback effect of production constraints has been highlighted in Dockner and Haug (1990, 1991) in the context of dynamic import quotas.

where

$$P_{2,NC} = P_1 + nE_{1,NC}(P_1)$$

and

$$P_{2,Coop} = P_1 + nE_{1,C}(P_1)$$

The above condition 7 is a necessary condition for $E_{1,NC}(P_1) > E_{1,C}(P_1)$.

Proposition 6:

If an IEA in period 2 that implements the first-best emissions strategies results in a decrease of current emissions then we must have

$$\frac{u'(E_{2,Coop}(P_{2,Coop}))}{u'(E_{2,NC}(P_{2,NC}))} - n\left(1 + (n-1)E'_{2,NC}(P_{2,NC})\right) > 0. \tag{8}$$

We argue that this condition is never satisfied in the linear-quadratic (LQ) framework and the case where utility is logarithmic (Log).

Indeed, if $E_{1,NC}(P_1) > E_{1,C}(P_1)$ then we have $P_{2,NC} > P_{2,Coop}$ and therefore

$$E_{2,Coop}(P_{2,NC}) < E_{2,Coop}(P_{2,Coop})$$

or

$$u'(E_{2,Coop}(P_{2,NC})) > u'(E_{2,Coop}(P_{2,Coop}))$$

$$\frac{u'(E_{2,Coop}(P_{2,Coop}))}{u'(E_{2,NC}(P_{2,NC}))} - n\left(1 + (n-1)E'_{2,NC}(P_{2,NC})\right) < \frac{u'(E_{2,Coop}(P_{2,NC}))}{u'(E_{2,NC}(P_{2,NC}))} - n\left(1 + (n-1)E'_{2,NC}(P_{2,NC})\right)$$

However we show below in the LQ and Log cases that

$$\frac{u'(E_{2,Coop}(P))}{u'(E_{2,NC}(P))} - n\left(1 + (n-1)E'_{2,NC}(P)\right) < 0 \text{ for all } P$$

in particular

$$\frac{u'(E_{2,Coop}(P_{2,NC}))}{u'(E_{2,NC}(P_{2,NC}))} - n\left(1 + (n-1)E'_{2,NC}(P_{2,NC})\right) < 0$$

Therefore from 7 a necessary condition for $E_{1,NC}(P_1) > E_{1,C}(P_1)$ which implies that $E_{1,NC}(P_1) < E_{1,C}(P_1)$.

The LQ case

Consider the case $u(x) = x\left(A - \frac{1}{2}x\right)$ and $D(P) = \frac{1}{2}\gamma P^2$

After substitution we have

$$\frac{u'(E_{2,Coop}(P_2))}{u'(E_{2,NC}(P_2))} - n\left(1 + (n-1)E'_{2,NC}\right) = -\frac{\gamma n (n-1)^2}{(1 + \gamma^2 n^3 + \gamma n(1+n))} < 0$$

The Logarithmic Case

Consider now the case $u(x) = \ln(x)$ and $D(P) = \frac{1}{2}\gamma P^2$

Then it can be shown that

$$E_{2,NC}(P) = \frac{\frac{\sqrt{4n+\gamma P^2}}{\sqrt{\gamma}} - P}{2n}$$

and

$$E_{2,Coop}\left(P\right)=\frac{\frac{\sqrt{4+\gamma P^2}}{\sqrt{\gamma}}-P}{2n}$$

Condition **??** becomes

$$\frac{-\sqrt{\gamma}P+\sqrt{4n+\gamma P^2}}{-\sqrt{\gamma}P+\sqrt{4+\gamma P^2}}-n\left(1-\frac{(n-1)\left(1-\frac{\sqrt{\gamma}P}{\sqrt{4n+\gamma P^2}}\right)}{2n}\right)<0$$

without loss of generality we set $\gamma=1$

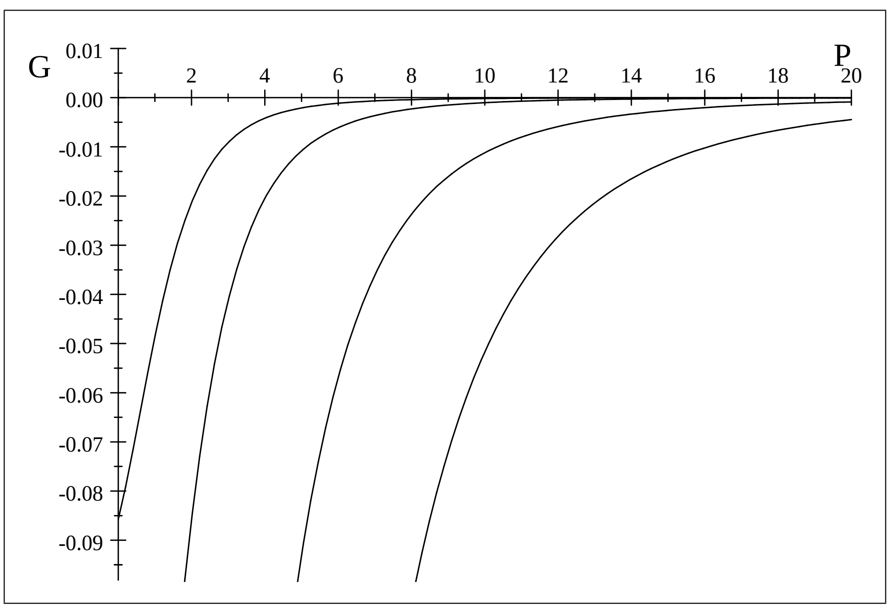
$$\frac{-P+\sqrt{4n+P^2}}{-P+\sqrt{4+P^2}}-n\left(1-\frac{(n-1)\left(1-\frac{P}{\sqrt{4n+P^2}}\right)}{2n}\right)<0 \tag{9}$$

We argue that the condition above is satisfied for all $P>0$ and $n>1$.

We are not able to show that condition (9) holds for all $P\geq 0$ and $n>1$. We resort to numerical simulations all of which confirm that condition (9) holds for all $P\geq 0$ and $n>1$. Let

$$G\left(P,n\right)=\frac{-P+\sqrt{4n+P^2}}{-P+\sqrt{4+P^2}}-n\left(1-\frac{(n-1)\left(1-\frac{P}{\sqrt{4n+P^2}}\right)}{2n}\right)$$

The figure below gives the plots of $G\left(.,n\right)$ for $n=2,3,6,10$: the function is negative everywhere



6 Concluding remarks:

The contribution of this paper is twofolds (i) we have shown how strategic behavior can make a delay of an agreement result in the exacerbation of the tragedy of the commons in the pre-agreement phase and (ii) we have identified a form of a future agreement that can result in an attenuation of the tragedy of the commons in the pre-agreement phase. The form of the emission policy that an agreement will yield plays a crucial role. A key element of the IEA of type 1 is that the emission policy under an IEA is flatter than the BAU emission policy. This diminishes the benefits of a player from her emissions in period one. Indeed under an emission policy in period 2 that is downward sloping each player has an extra benefit from emissions since an increase in own emissions results in an increase in the future stock of pollution and in turn in a decrease of the other players' emissions. This feedback is stronger the steeper is the emission policy. An IEA of type 1 in fact affects not only the level of emissions, but it also reduces the slope of the emission policy. In contrast in the case of an IEA that implements period 2's cooperative emission policy, in fact implies anticipating, in the LQ and the LOG case, a steeper emission policy. In this case the feedback is axacerbated and each country responds by increasing its own current emissions. A similar conclusion can be reached for IEAs that aim at reducing period 2's stock of pollution by a given percentage compared to the level of the stock of pollution under BAU. The necessary change in emission policy would result in overall steeper environmental policies, a stronger feedback effect and ultimately larger emissions in period 1.

Our results suggest that strategic behavior can have important effects on the short run effect of anticipated agreements in public games in general. The slope of the contribution policy as a function of the stock of public good would play a crucial role in the effect of a future agreement on contributions in the pre-agreement phase. A careful examination of the slopes of the contribution policy under cooperation and under BAU is required. The optimistic message of this paper is that it is possible to have agreement over contribution policies for the future than can diminish the extent of the tragedy of the commons in the short run.

References

Barrett, S., (2005). The Theory of International Environmental Agreements. In K.-G. Mäler and J. Vincent (eds.), Handbook of Environmental Economics, Vol. 3, Amsterdam: Elsevier, pp. 1457-1516.

Beccherle, J. and J. Tirole (2011), "Regional initiatives and the cost of delaying binding climate change agreements.", *Journal of Public Economics*, vol. 95, pp: 1339–1348.

Benchekroun, H. and A. Ray Chaudhuri, (2014) "Trans-boundary pollution and clean technologies." forthcoming, *Resource and Energy Economics*. http://dx.doi.org/10.1016/j.reseneeco.2013.09.004.

Benchekroun, H., (2003), "Unilateral production restrictions in a dynamic duopoly", *Journal of Economic Theory*, Vol. 111 (2), p. 214-239.

Calvo, E. and S. J. Rubio (2012) "Dynamic Models of International Environmental Agreements: A Differential Game Approach" *International Review of Environmental and Resource Economics*, **6**, 289–339.

Carraro, C. and D. Siniscalco (1993) "Strategies for the international protection of the environment" *Journal of Public Economics*, **52**, 309-28.

Dockner, E. and A. A. Haug, (1990) "Tariffs and Quotas under Dynamic Duopolistic Competition", *Journal of International Economics* 29, 147-59.

Dockner, E. and A. A. Haug, (1991) "Closed-Loop Motive for Voluntary Export Restraints", *Canadian Journal of Economics* 24, 679-85.

Eichner, T. and R., Pethig (2011), "Carbon Leakage, The Green Paradox, And Perfect Future Markets," *International Economic Review*, vol. 52(3), pages 767-805, 08.

Germain, M., P. Toint, H. Tulkens and A. de Zeeuw (2003) "Transfers to sustain dynamic core-theoretic cooperation in international stock pollutant control" *Journal of Economic Dynamics and Control*, **28**, 79-99.

Grafton, Q., Kompas, T., and N. V. Long (2012), "Substitution between biofuels and fossil fuels: is there a Green Paradox?" Journal of Environmental Economics and Management, Vol. 64(3), pp. 328-341.

Hoel, M. (1991),"Global Environmental Problems: The Effects of Unilateral Actions taken by one country,"*Journal of Environmental Economics and Management,* 20:55-70.

Hoel, M. (1992), "International environmental conventions: the case of uniform reductions of emissions," *Environmental*

and Resource Economics, 2,141-59.

Jørgensen, S., G. Martin-Herran and G. Zaccour (2010) "Dynamic Games in the Economics and Management of Pollution" *Environmental Modeling and Assessment*, 15, 433-467.

Long, N. V., (2011). Dynamic games in the economics of natural resources: A survey, *Dynamic Games and Applications,* vol. 1(1): 115-148.

Long (2013), N. V., "The Green Paradox in Open Economies", paper presented at Societe Canadienne des Sciences Economiques meeting in Quebec, May 2013.

Petrosyan, L., and G. Zaccour, 2003. Time-consistent Shapley value allocation of pollution cost reduction, *Journal of Economic Dynamics and Control,* vol. 27: 381-398.

Ploeg and Withagen (2012), "Is there really a green paradox?" *Journal of Environmental Economics and Management*, 64, pp: 342-363.

Ploeg and Withagen (2013), "Global warming and the green paradox", OxCarre, Discussion Paper 116.

Sinn, H. W. (2012), *The Green Paradox*, MIT Press.

Smulders, S., Y. Tsur and A. Zemel (2012), "Announcing climate policy: Can a green paradox arise without scarcity?" *Journal of Environmental Economics and Management*, 64, pp: 364–376.

Werf, E. and C., Di Maria (2012), "Imperfect environmental policy and polluting emissions: the Green Paradox and beyond," *International Review of Environmental and Resource Economics*, 6 (2), pp: 153–194.