International Environmental Agreement as an Equilibrium Choice in a Differential Game

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In the absence of global government, international negotiation and agreement are the core for the solution of global environmental issues. Since the first international United Nations Conference on the Human Environment in 1972, several environmental conventions and protocols have been adopted. Some agree long term targets and some agree to the schedules of pollution control. The latest former example is the Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC) which sets a long term target that holding the increase in the global average temperature to well below 2°C above pre-industrial levels. A prominent and successful latter example is the Montreal Protocol on Substances that Deplete the Ozone Layer, which has set the years to end the production and the consumption of the ozone depleting substances. The other latter examples include the Protocol on the Reduction of Sulphur Emission of the Convention on Long-range Trans-boundary Air Pollution and the Kyoto Protocol of UNFCCC, although in the Kyoto Protocol, the commitment was fragile and some countries seceded.

How can we understand these agreements? Dockner and Long (1993) model an international environmental negotiation as a differential game. Showing the existence of multiple Markov Nash equilibria, they propose a compelling interpretation about an international environmental negotiation: It may be a preplay communication to choose a better Nash equilibrium. This interpretation is supported by the notion of payoff dominance (Harsanyi and Selten, 1988). The negotiation can be seen as a process which reduces the uncertainty about players' behaviors and prevents players from going to a less efficient equilibrium.

By following their idea, this paper investigates what equilibrium is chosen as an international environmental agreement. Formally, this paper studies Dockner and Long's (1993) symmetric two player differential game model about pollution control. We consider symmetric stationary continuous and discontinuous MPNEs. We also consider symmetric open-loop Nash equilibria (OLNEs).[1] We rank their payoffs for each pollution level, with special interest in the payoff dominant equilibrium. Furthermore, we examine the efficiency of the steady state of the payoff dominant equilibrium.

[1] Since we only consider a symmetric equilibrium and a stationary Markov strategy, we omit the terms "symmetric" and "stationary" hereafter.

In the model, there is a continuum of MPNEs and a unique OLNE. As we will show, an MPNE, whether it is continuous or discontinuous, has a unique steady state which is globally asymptotically stable. Therefore there is a one-to-one correspondence between an MPNE and its long-run consequence. This implies that the agreement of a long-term target such as the 2°C target in Paris Agreement can be interpreted as a choice of an MPNE. An OLNE, the strategy of which is a function of time, corresponds to an agreement which commits a schedule of actions like the Montreal Protocol.

Dockner and Long (1993) show that, for a specific Markov equilibrium that they term as the most efficient Markov equilibrium, its steady state, hereafter referred to as the DL steady state, converges to a Pareto efficient steady state as the discount rate approaches zero. Therefore, when the discount rate is very low, we may have an approximately efficient outcome in the long-run even in the noncooperative circumstances. This result has an important implication, because, in the cooperative game theory, many studies find that a coalition by many countries is difficult in an international environmental agreement (Barrett, 2005).

The DL steady state, however, has been argued in two points. First, the equilibrium strategy is not defined over the state space, i.e. it is not subgame perfect.[2] Second, as Rubio and Casino (2002) argue, the steady state is not stable. With a small perturbation, the state variable moves away from the steady state and reaches to the state where the strategy is not defined.

In this paper, we reproduce the DL steady state as the globally asymptotically stable steady state of MPNE, by allowing a discontinuous strategy. Therefore we resolve the criticisms and strengthen the Dockner and Long's efficiency result.

In the application of noncooperative dynamic games to international environmental regulation, it is typical to compare the cooperative solution, an OLNE and a Markov Nash equilibrium (See, for example, Levhari and Mirman, 1980 and Ploeg and de Zeeuw, 1992). The most studies examine a specific Markov Nash equilibrium, the one constituted by linear strategies (linear Markov Nash equilibrium). Tsutsui and Mino (1990) showed a continuum of nonlinear Markov Nash equilibria in a linear quadratic differential game model. Dockner and Long (1993) showed this multiplicity in a pollution control game. Besides the aforementioned result, they showed that the Markov Nash equilibria are more environmentally conservative than the linear Markov Nash equilibrium.[3] Rowat (2000) analyzes a more general linear quadratic models encompassing Tsutsui and Mino (1991) and Dockner and Long (1993) and studies MPNEs of n player asymmetric games in the context of global warming. In the literature, the pay-

[2] The problem was recognized by Tsutsui and Mino (1991) who showed the multiplicity of Markov Nash equilibria in a similar model to Dockner and Long (1993). Dockner and Wagener (2007) use the term "local Markov perfect Nash equilibrium" when a Markov equilibrium is locally subgame perfect.

[3] A property of the linear quadratic model as used by Dockner and Long (1993) is that the elasticity of marginal utility in control variable is increasing. Wirl (2007) shows that, if the elasticity of marginal utility is decreasing, the nonlinear Markov strategies are less environmentally conservative than the linear Markov strategy.

off ranking of Nash equilibria is limited to the comparison of steady states and, except for a few papers such as Dockner and Long (1993), is limited to the comparison among specific equilibria, typically between a linear OLNE and a linear Markov Nash equilibrium.

We rank all continuous and discontinuous MPNEs as well as a unique OLNE over the state space. Our ranking results are summarized as follows. The DL steady state divides the state space into two intervals. In the larger interval, the payoff ranking between two MPNEs is preserved. Therefore, there is an MPNE which is the payoff dominant equilibrium over the interval. The steady state of the MPNE may coincide with the DL steady state and it is globally asymptotically stable. In the smaller interval, the payoff dominant MPNE varies depending on the pollution level. At the pollution level of the DL steady state, keeping the level is the payoff dominant. For the payoff comparison between an MPNE and the OLNE, there may be a unique level of pollution stock such that if pollution is greater than it, the OLNE dominates the MPNE and vice versa. Even the payoff dominant MPNE may be dominated by the OLNE if the pollution stock level is high.

These results indicate that, assuming that an international environmental negotiation is a process to choose the payoff dominant equilibrium, eventually the DL steady state is chosen as the long-run equilibrium. If the pollution level is heavier enough than the DL steady state, a renegotiation may occur once to switch from the OLNE to the MPNE of the DL steady state. If the pollution level is smaller than the DL steady state, every time a renegotiation occurs, and due to the cost of negotiation, although we do not incorporate it in the model, this may imply that no negotiation starts.