The collapse of Kyoto Protocol: An analysis based on Game Theory

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Abstract. Everyone is a stakeholder in environmental issues. Contemporarily, climate change is incrementally imposing threats to human development, making multilateral cooperation necessary to minimise the impacts of climate-related risks. The Kyoto Protocol was a significant internationally binding agreement that aimed to reduce greenhouse gases emissions, whereas its signatories failed to achieve its target to a large extent. This paper analyzes the reason behind the failure of the Kyoto Protocol through a game-theoretic literature. The main factors that contributed to the collapse of the Kyoto Protocol include the complex nature of the environmental issue and strategic interest in the treaty ratification procedure. The global environment is defined as a public good, therefore, each country has a free-rider incentive to take advantage of others' actions in pollution reduction, which is analyzed through a single prisoners' dilemma game. When such a game is extended to a repeated prisoners' dilemma game with an infinite horizon, there is a possibility that nations adopt a cooperative strategy in the long run. Simultaneously, the ultimatum game provides a representation of the treaty negotiation and ratification process, highlighting the importance of fairness and reciprocity of the treaty for its signatories. Potential solutions include trade sanctions, tax on exports, and the measure of cumulative emission has been evaluated at the end of the paper.

1 Introduction

1.1 Research background and motivation

The compatibility between economic growth and environmental consideration is always a challenge for human development. Under rapid technological advancement, the exposure to unforeseen climate-related risks would interrupt economic activities intermittently. Hence, climate issues have increasingly raised concerns among different countries. They have realised that multilateral collective action is inevitable to address climate change.

In December 1997, the Kyoto Protocol was adopted in order to limit six anthropogenic greenhouse gases emissions. Through a convoluted ratification procedure, the terms of the Kyoto Protocol officially entered into force in February 2005. A binding agreement had been reached among the developed and industrialised countries. However, several non-negligible limitations entail the collapse of the Kyoto Protocol. Foremost, the major carbon emitters were not encompassed in the treaty--the United States, the second-largest emitter of carbon dioxide, rejected the ratification and Canada ultimately withdrew from it. In addition, the Kyoto Protocol exempted developing countries such as China and India, who also contribute to a large proportion of global greenhouse gas emissions. The absence of those vital greenhouse gas emitters, it seems effect-free to obey the terms within the treaty. Therefore, although the Kyoto Protocol was recognised as a significant landmark of multilateral cooperation to combat climate change, most signatories failed to meet their targets and it ultimately became ineffective.

The culprit that entailed the collapse of the Kyoto Protocol was considered as an internal scheme design failure [1], including the scope of its signatories, the standard of setting its target, and the lack of a punitive mechanism. The external factor of nations' incentives to deviate from their commitment is also responsible for its failure. In the language of economics, climate change mitigation is a global public good [2]. The alleviation of global warming would make everyone individually better off, whereas it also underlying the free-rider problem where everyone has the incentive to take advantage from others' actions of reducing carbon emissions, and the advantages brought by the mitigation of irreversible climate-related risks are non-excludable, non-rival, and non-rejectable for everyone, which underlying the complex nature of climate issue. As a significant branch of economics, game theory is ubiquitous in real-life applications. It provides an analysis based on a payoff matrix that examines individual or group decision-making in a strategic setting. With the help of game theoretical methods, it gives us an insight into the international dispute over environmental policies, and helps us to comprehend the deep-rooted reasons, or motivations that countries have to escape from environment-protection treaties. Based on such an analysis, this research can therefore resolve

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the issues and reformulate a more effective international treaty.

1.2 Literature review

In recent years, environmental issues have drawn more attention to economic researchers and there is a numerous game theoretical literature in this field. Foremost, Osborne & Rubinstein in 1994 discussed the repeated game and compared it with finite and infinite horizon. Further, in 2001, Finus integrated real-world situations into a game theory model, showing that these theoretical results are helpful in the analysis of climate negotiations, specifically, the Kyoto Protocol. In terms of solutions of these complex environmental issues, Barrett in 2003 suggested that trade sanctions may be a useful measure to bind international cooperation. Game theoretically, there will be a preferable equilibrium where all countries are signatories of the treaty, which can be achieved through the introduction of a minimum participation level in the treaty. Admittedly, there is a lack of consideration and evaluation of the willingness of those countries who are responsible for imposing trade restrictions. Overall, these previous works were summarised by Peter John Wood in 2010, who combined mathematical equations and real-life examples. He examined different cases investigated previously, relating to climate change and the negotiation to alleviate it, with non-cooperative game theory. In this paper, it provides an overview of the factors that contributed to the collapse of the Kyoto Protocol, analysing this specific case with game theory, and proposing possible prescriptions to improve international environment agreements in the future. Nevertheless, the assumptions of each model of game theory always have to exclude some factors from analysis--whether the players have full information, whether the players are making their decisions independently, the number of players and their variable payoff, etc. Therefore, the games that analysed in this paper may not perfectly represent all the elements in the real circumstance, but the simplicity of the model would offer a useful insight into the fundamental reasons for the failure of the Kyoto Protocol.

1.3 Research framework

This paper is structured as follows: The first section includes an introduction to the basic terms of the Kyoto Protocol, and the phenomena that indicate its failure; the second part provides detailed case descriptions of the two deep-rooted reasons: the complex nature of environmental issues and countries' profit-related considerations. These analyses are based on the game theoretic analysis, including single prisoners' dilemma, repeated prisoners' dilemma, and the ultimatum game respectively; in the third part, the paper further applies the results of these cases to the difficulties in climate-related negotiations, and discuss how the results are useful for us to make improvements. The potential prescriptions include trade sanctions, taxation on exports, and taking cumulative emissions into account. Towards the end, this paper draws a brief conclusion of the application and usefulness of game theory approaches in international cooperation to combat climate changes, and discusses several limitations of the current solutions.

2. Case description

2.1 Prisoners' dilemma

2.1.1 A Single prisoners' dilemma game

In the simplest way, a circumstance of international negotiation to mitigate greenhouse gas emissions can be represented by a non-cooperative, static situation of prisoners' dilemma [3]. We assume that there are two players—Player 1 and Player 2, who are making their decision independently. Both of them have two possible strategies {Pollute, Abate}. Table 1 portrays a payoff matrix of the possible outcome for two players, with Player 1's payoff listed first. The transverse columns display two strategies for Player 1 and the longitudinal columns represent Player 2's options in the same way (see Table 1).

Table 1. Prisoners' dilemma game

Decision		Player 2	
		Abate	Pollute
Player 1	Abate	100,100	0,101
	Pollute	101, 0	10,10

Intuitionally, the strategy pair (Abate, Abate) seems to be an optimal solution for two players since it maximizes the payoff for each player as (100,100). The economic term Nash equilibrium refers to a situation where each player is best responding, making the optimal choice, and has no intention of unilaterally deviating from its strategy. However, in this case, the Nash Equilibrium of this game gives them a payoff (10, 10). First, concerning the strategy for Player 1, when Player 2 chooses to play Abate, he will be better off by choosing to play Pollute and get a payoff of 101 instead of choosing Abate and get 100. Whereas in this situation, Player 2 will obtain a payoff of 0, thus also giving him a profitable deviation to shift to play Pollute and acquire 10, which is greater than 0. The same argument applied when we considering the strategy for Player 2. Eventually, regardless of what the other player does, none of them will be better off by shifting from Pollute to Abate [4], thus making Pollute the dominant strategy for the two players, and the strategy of (Pollute, Pollute) reaches a static Nash Equilibrium. As long as the game is on a finite horizon, (Pollute, Pollute) is the only Nash Equilibrium consisted.

This is a reflection of the real-world situation where each country is expecting others to take action to mitigate global warming, since a limitation in pollution will inevitably accompanied with a sacrifice of their total output and damnify short-term economic growth. It gives countries an intrinsic incentive to escape from taking their responsibility.

2.1.2 Repeated prisoners' dilemma game

In reality, combating climate change is a long-lasting and multigenerational event. When the game becomes infinitely continuous and repeated, the players' strategies may alter to a collectively more favorable outcome for both of them [5]. Therefore, we can consider this situation as a repeated prisoners' dilemma game in extensive form.

Fiugre 1 illustrates a game which is similar to a single-stage game in Table 1, whereas in this circumstance, we assume that players are making their decisions over an infinite period, with unlimited subgames. The payoff for the game will be the sum of the stage-game payoffs. In this case, cooperative behaviour may occur from a long-term perspective. Both players recognize that their payoff would be maximized when they play Abate simultaneously. In each game, Player 1 and Player 2 play a static stage game and independently select their actions. There is a possibility that both of them play a simple "Trigger Strategy", which is, if one player ever defects, another player will deviate from their cooperative outcome forever. This strategy will initiate a large amount of subgame perfect Nash Equilibrium in each stage game since it de-incentivizes players' profitable deviation. Alternatively, a "Tit for Tat" strategy is also available for the players. In this case, players are forgiving, meaning that even if the other player had defected, it is possible to shift back to cooperation if that player stops defective behaviour. The "Tit for Tat" strategy seems more practical in real life, but it is less enforceable than the "Trigger Strategy".

In a nutshell, a deviation from cooperative behaviour will destroy the player's reputation and trigger a punitive profile with less payoffs. For instance, if in one subgame a player defects and leads an outcome of (0,101), their payoff for the next stage of the game will be (10,10). For the one who committed defection, his total payoff would be 121, but ideally, he can obtain a sum payoff of 200 from cooperation. As a result, when they perceive that once they defect in a single game, the cooperation in the rest of the games will be terminated, and the game will continue for additional periods, then a mutually desirable outcome of (Abate, Abate) will stably occur in each period [6]. The reason is that the long-term losses in their payoff caused by the defection outstrip the short-term gains by playing defection.

This game demonstrates that in the long-term multilateral negotiation and the following treaty implementation process, a design of a punishment mechanism that impairs the signatories' payoff when they deviate, could effectively bind the nations' cooperative behaviour.

2.2 Ultimatum game

The absence of the United States and the withdrawal of Canada from the Kyoto Protocol significantly marks its failure. In fact, the United States was unsatisfied with the fact that only Annex B countries (developed countries) had to commit to greenhouse gas emission reduction. Also, there was a tremendous opportunity cost for Canada to meet the carbon reduction target under the terms of the treaty. The reason why those countries rejected the ratification of this environmental-friendly treaty can be analysed by an ultimatum game [7].

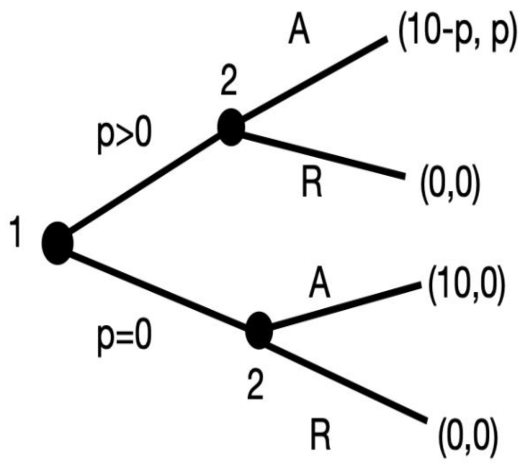

Figure 1. Ultimatum game (Picture credit: Original)

As shown by Figure 1, there is a money offer which valued 10 in total. Player 1 and Player 2 are dividing the offer. Stages 1 and 2 are denoted in this extensive form, where "A" and "R" represent Accept and Reject respectively. In Stage 1, Player 1 makes the choice first, meaning that he could choose to offer Player 2 any amount of money where $p \in [0, 10]$. Player 2 further chooses to "Accept" or "Reject" the offer at Stage 2. If Player 2 chooses "Accept", then he will get the money that Player 1 offers, and Player 1 could retain the rest of the money. Whereas if Player 2 chooses "Reject" that offer, then both players will not get anything.

In this case, when Player 1 chooses p=0, Player 2 will be indifferent between "Accept" or "Reject", as he always gets a payoff of zero. Rationally, player 2 will always choose to "Accept" the offer when p>0, because there is a positive payoff for him. Consequently, the outcome will be (10-p, p) as shown in Figure 2.3, where p is a positive constant. Therefore, considering the strategy for Player 2, he will always "Accept" the offer regardless of Player 1's choice, since it is the best response in every subgame.

The ultimatum game can simulate the ratification process of a climate-related treaty. In Stage 1, the leading countries negotiate the terms of the treaty; In Stage 2, the countries decide whether to ratify the treaty or not. If they refuse to sign it, the entire treaty would be pointless. However, in a realistic setting, there are more factors affecting the choice of Player 2 (i.e. the signatory countries). They also value the fairness and reciprocity of the offer [8,9].

3. Results and discussion

First, to address with the complex nature of environmental problems, the result of a single prisoners' dilemma indicates that countries are intrinsically lack of an incentive to collectively protect the environment, which is reflected in the failure of the Kyoto Protocol. This issue is an obstacle for nations to reach an agreement to mitigate global warming collaboratively. It provides an explanation to the fact that several countries refused to sign the treaty to limit their greenhouse gas emissions, as they are considering their economic output and an escape from the responsibility to protect environment is seemingly uninjurious in the short-term. Nonetheless, such a single-shot game with solely two players, each with only two choices, is overly restrictive in capturing crucial real-world factors comprehensively [10]. Therefore, when the game is extended to an infinite period, forming a repeated prisoners' dilemma, it is likely that players develop a cooperative outcome as they are concerned about the long-term benefits. Also, the "trigger strategies" in the repeated prisoners' dilemma game create a punitive action that deters the countries from deviating from their promise [6]. From the perspective of institutional design, a punishment mechanism, for instance, a trade sanction or taxation levied on the fossil fuels that are exported to those non-cooperative nations, might be an effective solution to restrict the number of non-cooperating countries [11].

Furthermore, for those signatories, the process of negotiating and ratifying the terms of the treaty is also difficult. As shown by the ultimatum game, although it is a rational strategy that always accepts the "offer" since it generates positive payoffs, in reality, the countries also value the fairness and reciprocity of the terms designed in the treaty. Hence, in order to enhance the countries' willingness to ratify environment-related treaties, the terms can be improved to be more equitable for every signatory. From the perspective of treaty designers, they could treat the desired outcome as given, and then further design the terms to reach this outcome [12]. One solution for them could be to take the historical emissions into account, and each country should have an equivalent cumulative emission [13]. The deterioration of the environment is a cumulative process rather than an immediate effect of pollution. Hence, the greenhouse gas emissions could be measured over time, and the countries' cumulative emissions illustrate their responsibility for pollution proportionately, thus this method could redistribute the emission capacity and make every country have an equal emission amount in total. However, this measure is less preferable for those industrialised countries since their historical emission would be much greater than those developing countries, meaning that they would have less permission for carbon emission now. Therefore, how to make such a term acceptable for those developed countries is still debatable.

4. Conclusion

Overall, the failure of the Kyoto Protocol is instructive to design an environment-related treaty in the future. The free riding problem of mitigating climate change is essentially a prisoner's dilemma game with Nash equilibrium, where all countries have a profitable pollution bias. In the long run, an implementation of punishment could be potentially useful to bind the countries in cooperation in an infinitely repeated game, such as trade sanctions and taxation on exports. Further, the ultimatum game demonstrates that during the treaty negotiation process, paying more attention to the fairness and reciprocity of the treaty is necessary to increase countries' willingness of participation. However, this paper does not evaluate the effectiveness of trade sanctions, since it will damnify the economic gain of the countries who imposed sanctions as well. They may consider a retaliatory trade war would be triggered. It leaves us with the question that who should be responsible for imposing the sanction and the extent it would be. Also, there is controversy over how precisely the improvement in the equity of the treaty could be made so that it is generally acceptable. As a result, these areas are still open for more investigation, and more efforts are needed to improve the global environment.

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