Cooperation is essential for $2^0$ Target: a new perspective from the Dynamic Game Model

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Abstract. A theoretical country-level dynamic game model involving both the particularity of climate change investment and individual’s subjective initiatives is put forward. Positive, negative, spillover effects of climate change investment and the individual’s dynamic strategies are distinguished and involved into the theoretical model. With numerical simulation and sensitivity analyses, the essentiality of cooperation for $2^0$ target is then proved. The lack of self-driven force for cooperation in climate negotiation is further explained from the perspective of game theory. In addition, the feasibilities to realize generalized Pareto improvement with effective compensation and benefit transfer mechanisms are also confirmed.

Keywords: climate change negotiation, Game model, Cooperation, 2 centigrade degrees.

JEL codes: C70.

1. Introduction

Climate change has been one of the most serious threats influencing the living environments of human beings in the future. As a result of deforestation and massive discharge of GHG (Green House Gas) from fossil fuel combustion, the stock of GHG has been rising, along with higher risks of global warming. Limiting global warming to $2^0$ above pre-industrial global mean temperature has become a widely endorsed goal [1]. AGGG (The WMO/ICSU/UNEP Advisory Group on Greenhouse Gases) claimed that a $2^0$ increment was “an upper limit beyond which the risks of grave damage to ecosystems, and of non-linear responses, are expected to increase rapidly” [2]. However, neither the Kyoto Protocol nor the Copenhagen Accord is sufficient to coordinate each country’s responses to the $2^0$ target. For the Kyoto Protocol, only a group of countries have agreed to legally binding reductions in the first commitment period (2008~2012), which is too tiny to make a difference globally. Moreover, the negotiation about the binding targets in the second commitment period has stalled due to the disagreements about the rights and responsibilities.

Then what would happen to the $2^0$ target given the serious negotiation situation? Up to now, some theoretical analyses have been made to reveal the essence of climate change negotiation with public goods theory [3-5], and externality of public goods leads to the failure of cooperation in climate negotiation. Although it’s intuitively acceptable that there might be a connection between the cooperation failure and the $2^0$ target, few researches can effectively prove the relationship. Taking into account the particularity of global warming and each country’s subjective initiative, the relationship is far more complicated than expected. This article attempts to figure out the relationship with utility and game theory by involving both the particularity and individual initiatives. Firstly, a theoretical model is introduced in Section 2. The particularity of abatement is implemented by distinguishing the three different effects of climate change
investment (CCI) on each country’s utility and the subjective initiatives by dynamic game theory. Secondly, numerical simulation and sensitivity analyses are carried out in Section 3. Finally, this article ends up with discussions and conclusions in Section 4.

2. Theoretical Dynamic Game Model

2.1. Individual utility

For country i at time t, its utility $U_{i,t}$ meets the CRRA (Constant Relative Risk Aversion) form where $\eta_i$ and $C_{i,t}$ donate the index of relative risk aversion and consumption at time t respectively. Each country’s rational target is maximizing its total net utility, i.e., $\int_0^{\infty} e^{\delta t} \times U_{i,t} dt$. where $\delta$ is discounting rate.

$$U_{i,t} = \frac{C_{i,t}^{1-\eta_i}}{1-\eta_i}. \quad (1)$$

Consumption at time t can also be expressed with real GDP growth $g_{i,t}$ by normalizing the initial consumption at 1:

$$C_{i,t} = \exp(\int_0^t g_{i,s} ds). \quad (2)$$

Assuming that in the absence of global warming, real GDP and consumption may grow at a constant rate $g_{i,0}$, and global warming will influence the growth rate with a simple linear relation estimated by Dell et al. $T_t$ means the temperature increment at time t and $\gamma_i$ is the marginal effect of temperature increment on GDP growth for country i.

$$g_{i,t} = g_{i,0} - \gamma_i T_t. \quad (3)$$

Given temperature increment $T_H$ at horizon year H, temperature increment at time t, i.e. $T_t$ follows the trajectory which has been proposed by Weitzman and applied by Pindyck. $T_t = 2T_H \times [1 - (1/2)^{H/t}]$. \quad (4)

For the uncertainty of $T_H$, probability method based on massive IAMs (Integrated Assessment Models) is introduced and applied by Pindyck, which will also be adopted in our theoretical model. Three-parameter Gamma distribution is chosen to fit the uncertainty for its effectiveness with probability density function:

$$f_T(x; r_T, \lambda_T, \theta_T) = \frac{\lambda_T^r}{\Gamma(r_T)} (x - \theta_T)^{r_T - 1} e^{-\lambda_T (x - \theta_T)}, x \geq \theta_T. \quad (5)$$

Owing to the uncertainty of $\gamma_i$, i.e. the marginal effect of temperature increment on GDP growth, probability method with Gamma distribution is suggested by Pindyck based on other researches.

2.2. Effects of CCI

Figure 1 shows the three effects of CCI on utility for each country. For the negative effect, increased CCI leads to less affordable percentage of consumption, which means the adjusted consumption $C_{i,t}^*$ is reduced by CCI where inv_i donates the percentage of CCI to GDP:

$$C_{i,t}^* = C_{i,t} \times (1 - inv_i). \quad (6)$$

1 More information about the theoretical calculation process can be found in Pindyck’s research.
On the contrary, the positive effect refers to the promoting effect of CCI on initial GDP growth as it’s carried out as extra investments in technology, construction and equipments consumption for adaption, all of which will boost the GDP growth with a marginal effect coefficient \( \xi_i \):

\[
g_{i,t}^* = g_{i,0} \times (1 + \xi_i \times \text{inv}_i) - \gamma_i T_i. \tag{7}
\]

Furthermore, the public goods feature of global temperature increment leads to the spillover effect of CCI. Assume that global CCI and upper bound of temperature increment (UBTI) can be captured by Eq. (8) where \( w_i \) is the GDP related weighting factor, then the ultimate temperature increment \( T_{Up} \) determined by gross CCI may further influence each individual’s utility.

\[
T_{Up} = \Phi(\text{inv}_{world}) = \Phi(\sum_i w_i \times \text{inv}_i). \tag{8}
\]

![Fig. 1: Three effects of CCI on utility](image)

### 2.3. Non-cooperative and cooperative dynamic game equilibriums

Taking all the three effects of CCI into consideration, the optimal negotiation strategy for each country under non-cooperative scenario can be resolved with the ‘Backward Induction’ method designed by Aumann [9]. To simplify the model and scenarios, two-country dynamic game equilibrium is designed with the fundamental hypothesis that each country is rational. For non-cooperative scenario, each country attempts to maximize its own net utility whatever others’ dynamic strategies. And for cooperative scenario, the objective is adjusted to maximizing the gross utility of both countries. Table 1 shows the structure of theoretical results where OptInv and Utility represent the CCI percentage and net present utility for different scenarios respectively.

<table>
<thead>
<tr>
<th></th>
<th>Non-cooperative Scenario</th>
<th>Cooperative Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A moves firstly</td>
<td>B moves firstly</td>
</tr>
<tr>
<td>CCI of country A</td>
<td>OptInv(_A)</td>
<td>OptInv(_B)</td>
</tr>
<tr>
<td>CCI of country B</td>
<td>OptInv(_B)</td>
<td>OptInv(_A)</td>
</tr>
<tr>
<td>Country A’s utility</td>
<td>Utility(_A)</td>
<td>Utility(_B)</td>
</tr>
<tr>
<td>Country B’s utility</td>
<td>Utility(_B)</td>
<td>Utility(_A)</td>
</tr>
</tbody>
</table>
3. Simulation and sensitivity analyses

Table 2 gives the initial parameters for simulation which is based on two real countries. With higher initial GDP growth, country A is faced with more severe risks of temperature increment on GDP than country B. According to the simulation results, the CCI of country A and B under non-cooperative dynamic game equilibriums are too tiny to reach the 2°C target globally. In others words, dynamic game results reveals the essentiality of cooperation to deal with climate change effectively.

However, Figure 3 also reveals the lack of initiatives for countries to cooperate. Under cooperative scenario, country A should carry out more CCI for whole utility maximizing purpose. However, because of the three different effects, country A’s utility under cooperative scenario is smaller than that under non-cooperative scenario without compensation. On the contrary, country B can benefit from cooperation owing to the improvement of global warming in spite of more CCI than that in non-cooperative ones. Hence, cooperation can hardly be self-driven without win-win outcome. In addition, the gross utility of country A and B benefit from cooperation, which means it’s possible and feasible for the implementation of cooperation by involving compensation and benefit transfer mechanisms.

In order to make the conclusions more reliable, sensitivity analyses for different parameter assumptions are carried out. Table 3 shows that the main results of what we are concerned about are stable and reliable.

Table 2. Initial Parameters for Simulation

<table>
<thead>
<tr>
<th></th>
<th>Country A</th>
<th>Country B</th>
</tr>
</thead>
<tbody>
<tr>
<td>$g_0$</td>
<td>4.5%</td>
<td>1.5%</td>
</tr>
<tr>
<td>$w$</td>
<td>13.26%</td>
<td>19.02%</td>
</tr>
<tr>
<td>$(r, \lambda, \theta)$</td>
<td>(11.141, 22329, -2.8505e-4)</td>
<td>(103.8, 411600, -1.745e-4)</td>
</tr>
<tr>
<td>$(\eta, \delta, \xi, H)$</td>
<td>(2, 0, 1, 100)</td>
<td></td>
</tr>
<tr>
<td>$(\tau, \lambda, \theta)$</td>
<td>(3.8, 0.92, -1.13)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: The temperature parameters are in accord with Pindyck’s [8] and the individuals’ are based on massive literatures.

![Fig. 2: CCI and temperature increment under different game scenarios](image)

2 In order to avoid potential political issues, we use anonymous names which can be offered under request if necessary.
Table 3. Sensitivity Analyses and Results

<table>
<thead>
<tr>
<th>Base Model</th>
<th>Higher $g_0$</th>
<th>Lower $g_0$</th>
<th>Larger $\eta$</th>
<th>Smaller $\eta$</th>
<th>More risky $\gamma$</th>
<th>Less risky $\gamma$</th>
<th>Larger $\delta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Q2</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Q3</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Notes: Q1: Is cooperation essential for $2^\circ$C target? Q2: Is it self-driven for cooperation? Q3: Is it possible and feasible for the implementation of cooperation?

Fig. 3: Utility of country A and B under different game scenarios

4. Conclusions

By distinguishing the three different effects of CCI on utility, this article puts forward a dynamic game model simulating the strategies of different countries in climate change negotiations. Game equilibrium results together with sensitivity analyses support the three conclusions: firstly, it is essential for cooperation among countries to deal with global warming and to reach the $2^\circ$C target. Secondly, without effective compensations and benefit transfer mechanisms, cooperation can hardly be realized automatically. In other words, global climate negotiation should put enough attention to the institutional design to avoid the collapse of cooperation. Finally, our research also gives a good signal that there’s still room for generalized Pareto improvement to carry out cooperation, which means all countries’ utilities will be better than any situation under non-cooperative scenario if compensation and benefit transfer mechanisms are available and effective.

5. Acknowledgement

This research was funded by the National Natural Science Foundation of China (No.71273153).

6. References


