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Formation of Coalitions in Self-Enforcing International Environmental Agreements

Peixin Peter Yu

Dulwich school, London, England, UK
yupeter273@gmail.com

ABSTRACT

Climate change is not a solved issue in the world today: countries are not willing to mitigate for the benefit of everyone. It thus becomes necessary to investigate the reason for the lack of cooperation for a potential solution. This essay plans on modeling the payoffs of players in the international mitigation game, reaching the results that without an incentive provided by the coalition, players are unlikely to mitigate. Moreover, unequal relationships between countries can result in certain countries mitigating themselves while not encouraging their subordinate countries to mitigate.

KEYWORDS

Climate change; Game theory; Coalitions; Cross-country conflicts; Mitigation

1. INTRODUCTION

Climate change has long since been a primary concern for humanity. Greenhouse Gases (GHG) in the atmosphere result in global warming, an effect that causes more frequent extreme weather events, the melting of ice caps, and much more adverse consequences. It is widely acknowledged that once global temperature exceeds 2 degrees Celsius above pre-industrial levels the process would be irreversible and the world would simultaneously suffer multiple effects, and as of May 2024 the world is sitting at a dangerously close 1.2 degrees Celsius above said value [2].

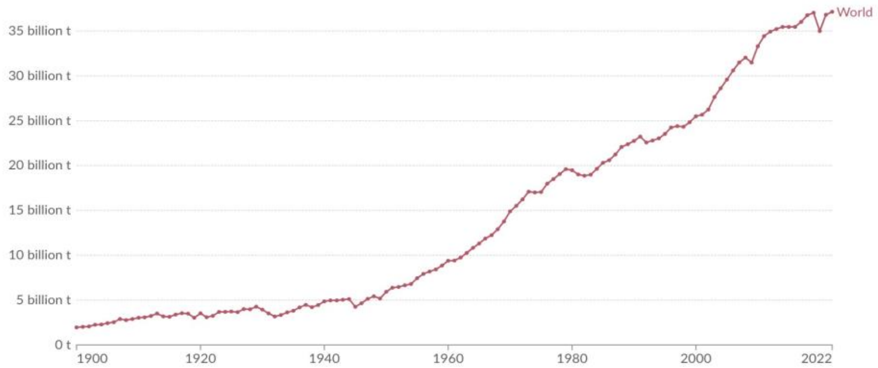

Figure 1. Global CO2 emissions from 1900 to 2022

Attempts have been made at resolving the issue, with a total of 28 UN Climate Change Conferences (COP1 through COP28) being held to discuss international measures and 2 major agreements being made, the Kyoto Protocol which entered into force on 2005 and the Paris Agreement which entered into force on 2016, and yet the results prove to be insufficient as despite the 196 parties' pledges to reduce carbon emissions [3]. It is obvious in Figure 1 that while a dent had been made in the pandemic year due to halting industrial activities, global carbon emissions still continues to increase every year [4].

One reason for this could be the lack of hard enforcement for either agreement. It is very difficult to hold a certain country accountable for its lack of progress and even more difficult to deliver corresponding punishments considering the target could be a global superpower. In fact, the only way the agreements actually influenced the countries' choices is by holding regular meetings in which representatives report their countries' status of mitigation, and even no one could stop the countries even if they later decided to withdraw from the agreement.

As climate change is evidently an urgent matter, this essay hopes to develop a model to explain the current failure of agreements to bring down emission levels and investigate whether the formation of coalitions is possible under the presence of some sort of incentive for mitigation.

The remaining of the paper is organized as follows: in Section 2, we discuss the payoff of players with a naive linear model. In Section 3, the model is revised to be quadratic to better fit the real life scenario. In Section 4, we investigate how relationships between countries impact their decisions. Finally, we conclude the paper in Section 5.

2. NAIVE MODEL

Consider N homogeneous countries, all of which deciding their level of pollution mitigation. We attempt to develop a two-stage model which 1) discovers the optimal strategy for each country (whether or not to join the coalition), and 2) discovers the optimal mitigation each country should take based on their strategy in stage 1. We use backward induction to solve the second and the first stage.

According to Charles D. Kolstad's "Systematic uncertainty in self-enforcing international environmental agreements" [1], to model the mitigation game each country i is playing, there are two things to be considered: the collective benefit gained from mitigated pollution, and the individual cost resulting from the mitigation. The payoff could thus be represented in a linear fashion like so:

$$\Pi_i(q_i, Q) = a_i Q - b_i q_i$$

Where q_i is the country's strategy, Q is the set of strategies of all countries, a_i is the marginal benefit of mitigation, while b_i is the marginal cost of mitigation. We could then let $\gamma = \frac{a_i}{b_i}$, and without loss of generality let $b_i = 1$, resulting in the payoff function being rewritten as:

$$\Pi_i = \gamma Q - q_i = \gamma(Q_{-i} + q_i) - q_i$$

Where Q_{-i} is the set of strategies made by countries other than i. γ here represents the ratio of the marginal benefit to the marginal cost of mitigation.

Now it is important to consider three cases: whether the countries are non-cooperative, fullycooperative, or partially cooperative. This decides the payoff function each country wishes to maximise.

2.1. Non-cooperative Setting

Each country wishes to maximise its own payoff, so taking partial derivative of the payoff function yields:

$$\frac{\partial \Pi_i}{\partial q_i} = \gamma - 1$$

We now wish to find the optimal q_i (to simplify the problem $q_i \in [0,1]$), the total mitigation of all countries, and the optimal payoff under the optimal q_i. The two cases are apparent:

If $\gamma \geq 1$ ($a_i \geq b_i$), then the function is monotonically increasing and $q_i^* = 1$, $E = N$, and $\Pi^* = \gamma n - 1$.

If $\gamma < 1$ ($a_i < b_i$), then the function is monotonically decreasing and $q_i^* = 0$, $E = 0$, and $\Pi^* = 0$.

In a real-world situation, γ is always less than 1 as if else, the dominant strategy for all countries would be to mitigate which is clearly not the case. The results thus show that mitigation is impossible when each country only prioritises its own payoff.

2.2. Fully-cooperative Setting

All countries are now considered to be a member of the coalition, and they thus now wish to maximise the collective benefit. Taking partial derivative of that yields:

$$\frac{\partial \sum_{i \in N} \Pi_i}{\partial q_i} = n\gamma - 1$$

There are two cases based on whether the expression is positive or negative, and the resulting q_i^*, E, and Π^* are identical to the cases listed in the non-cooperative scenario. Here, the results show that γ could be much smaller for countries to still choose to mitigate, however that is only when all countries prioritise the coalition's total payoff more than their own. That is apparently not the case, and thus the third scenario is introduced.

2.3. Partially Cooperative Setting

The partially cooperative scenario is where there are S countries in the coalition among the total N countries. The fringe ($N \backslash S$) refers to countries not in the coalition. This scenario is essentially a combination of the two scenarios above, where the partial derivative is calculated for $i \in N \backslash S$ and $i \in S$. Here we focus on the scenario where $\gamma < 1$. A graph could be drawn for the payoff vs. the number of countries in the coalition under the partially cooperative scenario.

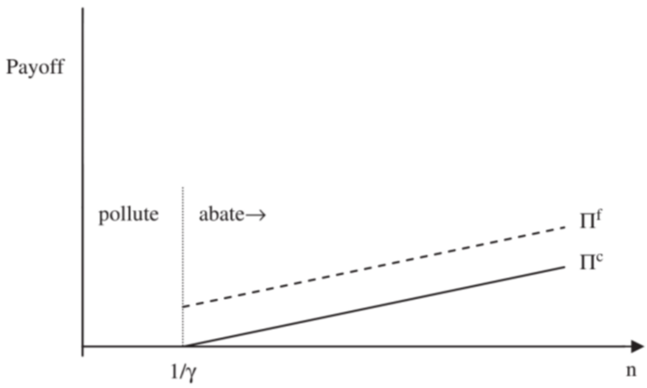

Figure 2. Payoff vs. number of countries in coalition from Kolstad's article

As shown before in the fully-cooperative subsection, the partial derivative of the payoff function for coalition members is $n\gamma - 1$, meaning that when $n < 1/\gamma$, the function is monotonically decreasing and thus coalition members would all have $q_c = 0$. As n overtakes $1/\gamma$, all coalition members now play $q_c = 1$ while fringe members remain with $q_f = 0$, and the two lines become separate. It is apparent that whenever $n > 1/\gamma$, country $i \in S$ can choose to leave the coalition for a better payoff. Here, free riding becomes the dominant strategy as any country could share the benefit of mitigation which other countries pay for. This explains why very few countries choose to join the coalition under today's settings.

3. QUADRATIC MODEL

The naive model is convenient yet not comprehensive enough as while the benefit and cost both increase monotonically with q_i, the cost does so marginally increasing. Therefore, the payoff function could be redesigned like so:

$$\Pi_i(q_i, Q) = a_i Q - \frac{b_i q_i^2}{2} = \gamma(Q_{-i} + q_i) - \frac{q_i^2}{2}$$

For the non-cooperative scenario, we again take the partial derivative:

$$\frac{\partial \Pi_i}{\partial q_i} = \gamma - q_i$$

The function thus monotonically increases up till the point where $q_i = \gamma$, when the gradient is 0, then monotonically decreases. Let the number of countries in N be n, then the optimal q_i is γ, the total mitigation $E = \gamma n$, and the optimal payoff is $\Pi^* = \gamma^2 n - \frac{\gamma^2}{2} = (n - \frac{1}{2})\gamma^2$.

For the fully-cooperative scenario, we take the partial derivative of the summation:

$$\frac{\partial \sum_{i \in N} \Pi_i}{\partial q_i} = n\gamma - q_i$$

Therefore, when $n\gamma < 1$ the optimal q_i takes its value, and if otherwise the function is just always monotonically increasing (as $q_i \in [0,1]$) and the optimal $q_i = 1$.

3.1. Stability Analysis

Consider country i in the partially cooperative scenario that can either choose to remain in the coalition or withdraw from it. Let the number of countries in set S be s. If $N\gamma > 1$, then remaining in the coalition yields the payoff below:

$$\gamma \left(\sum_{f \in N \setminus S} q_f + \sum_{d \in S} q_d \right) - \frac{1}{2} = \gamma\left(\gamma(n-s) + s\right) - \frac{1}{2} = \gamma^2(n-s) + \gamma s - \frac{1}{2} \tag{1}$$

If country i withdraws, let the new set S with one less country be S'. Withdrawing from the coalition thus yields the payoff below:

$$\gamma \left(\sum_{f \in N \setminus S'} q_f + \sum_{d \in S'} q_d \right) - \frac{\gamma^2}{2} = \gamma[\gamma(n-s+1) + s - 1] - \frac{\gamma^2}{2} = \gamma^2(n - s + \frac{1}{2}) + \gamma(s-1) \tag{2}$$

The former payoff subtracted by the second gives us:

$$\gamma - \frac{\gamma^2}{2} - 1/2$$

Which is always negative with $\gamma \in [0,1)$. This proves that the coalition will never be stable as withdrawing from the coalition always results in a higher payoff than remaining in the coalition. Again, it is proved that countries that prioritise their own payoffs would never choose to join the climate coalition without any incentive.

3.2. Analysis with Incentive

As proven above, a stable coalition can only exist in the presence of an incentive. Such incentive could exist in the form of direct monetary support from more developed countries, trading tax reduction, etc. We thus add a factor of the incentive into the payoff function for coalition members:

$$\Pi_i(q_i, Q) = \gamma(Q_{-i} + q_i) - \frac{q_i^2}{2} + c_i q_i$$

Where c_i represents the marginal incentive provided for each unit of mitigation. The partial derivative for the non-cooperative scenario remains the same (optimal q_i remains γ), while the partial derivative for the fully-cooperative scenario becomes:

$$\frac{\partial \sum_{i \in N} \Pi_i}{\partial q_i} = n\gamma - q_i + c_i$$

Meaning members of the coalition take $n\gamma + c_i$ of mitigation if it is less than 1 and take 1 otherwise. We again compare the payoff of a country in and out of the coalition, assuming $n\gamma + c_i > 1$:

$$\gamma \left(\sum_{f \in N \setminus S} q_f + \sum_{d \in S} q_d \right) - \frac{1}{2} + c_i = \gamma[\gamma(n-s) + s] - \frac{1}{2} + c_i = \gamma^2(n-s) + \gamma s - \frac{1}{2} + c_i$$

$$\gamma \left(\sum_{f \in N \setminus S'} q_f + \sum_{d \in S'} q_d \right) - \frac{\gamma^2}{2} = \gamma[\gamma(n-s+1) + s - 1] - \frac{\gamma^2}{2} = \gamma^2(n - s + \frac{1}{2}) + \gamma(s-1)$$

Again taking away the second from the first, we have:

$$\gamma - \frac{\gamma^2}{2} - \frac{1}{2} + c_i$$

We want the value of this expression to be non-negative as that would mean a higher/equal payoff inside the coalition than out. We thus have:

$$c_i \geq \frac{\gamma^2}{2} + \frac{1}{2} - \gamma$$

We therefore conclude that for countries to join the coalition, the incentive offered c_i must be greater than or equal to $\frac{\gamma^2}{2} + \frac{1}{2} - \gamma$. The c_i offered to different countries could be different, resulting in the possibility of a stable coalition whose size can be controlled by varying the value of c_i for each country.

4. CROSS-COUNTRY ENVIRONMENTAL AND ECONOMIC CONFLICTS

In a real-world scenario, countries are not homogeneous and are sometimes affiliated to each other. For example, developed countries often base their industries in developing countries and thus transferring the origin of pollution. Therefore, the developed country *i* might not suffer a large cost if it mitigates its own pollution, but will suffer much more if the developing country *s* where it bases its industries mitigates. We thus revisit the naive model to factor in that aspect of the problem. We now consider countries *i* and *s* playing the mitigation game. Then *i*'s payoff function becomes:

$$\Pi_i(q_i,q_s) = a_i(q_i + q_s) - b_i q_i - c_i q_s$$

Where c_i is the marginal cost for country *i* per mitigation country *s* takes. The result would be the same if we just take the partial for q_i, so now we attempt to discover the impact of q_s on country *i*'s payoff. We thus take the partial for q_s to get:

$$\frac{\partial \Pi_i}{\partial q_s} = a - c$$

Now, the original $a - b$ could indeed be greater than 0 as mitigating country *i*'s own pollution does not cost too much due to its industries being based in country *s*. Therefore, it is likely that country *i* would choose to mitigate, thus $q_i^*= 1$. However, the same cannot be said for q_s as $a - c$ is clearly less than 0 as otherwise this discussion would be pointless. As a result, country *i* is willing to mitigate while convincing country *s* into not mitigating. Country *s*, on the other hand, does not contain the term $c_s q_s$ in its payoff function and only inherits the basic naive model. Thus the country itself is likely not willing to mitigate (as $a_s - b_s$ is likely greater than 0) and without enforcement from country *i*, such mitigation is extremely unlikely to take place.

Comparing this result with the naive model shows that when countries are equal and unaffiliated with each other not mitigating is often the best strategy, while when countries start to shift the source of pollution into other countries mitigation is possible. The result that the value of a − c dictates the optimal decision of country s to maximise the payoff for country i is consistent for the quadratic model as only the bqi term becomes quadratic, thus not affecting the partial of qs.

Another country p not affiliated with either country in this model would just share the payoff function described in the naive model section and whether it mitigates or pollutes would be based on the value of ap − bp. However, in a real-world scenario this is unlikely, as countries are always competing for resources if not in the industry-based relationship above. Therefore, consider a third country p in the model. Country i does not base its industries in country p, and in fact a trade war is going on and the suffer of either side's economy means good news for the other. In this case, country i's payoff function is now revised to:

$$\Pi_i(q_i,q_s) = a_i(q_i + q_s + q_p) - b_i q_i - c_i q_s + d_i q_p$$

As country p mitigating means burdens on its economy, thus benefits for country i. Taking the partial of qp yields:

$$\frac{\partial \Pi_i}{\partial q_p} = a + d$$

Here, a and d are both positive, meaning it is country i's best interest for country p to mitigate. In context, country p's mitigation both helps preserve worldwide well-being as well as burdens its economy, both effects beneficial for country i. The model thus explains the behaviours of certain countries in the real world: mitigating themselves, trying hard to persuade their competitors to mitigate as well, while not placing any pressure on the developing countries it bases its industries in.

5. CONCLUDING REMARKS

In light of the above, this essay modeled the payoffs of countries in an international mitigation game in a naive linear manner and quadratic manner. it was also took into consideration international relationships' potential impact on such payoffs. Each player tries to maximise its own payoff, and thus the stability of the coalition and minimum incentive are calculated. Three key conclusions can be derived from this essay: 1. In the naive linear model, no country will join the coalition. 2. In the quadratic model, countries will join the coalition if and only if an incentive with value greater than or equal to $\frac{\gamma^2}{2} + \frac{1}{2} - \gamma$ is provided. 3. Cross-country relationships result in the phenomenon that developed countries often mitigate themselves, urge their competitors to also mitigate, while not pressuring developing countries they base their industries in to do so. Regardless of the model used, it is apparent that as things are going on right now, there would not be significant mitigation to stop climate change. Unless a party is willing to put in large amounts of money and effort for the cause, meetings and agreements would not have a large impact on the countries' decisions.

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