Game Theory Project

GAME THEORY APPLIED TO CLIMATE CHANGE NEGOTIATIONS

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December 3, 2010

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Introduction

Although the effects of climate change are acknowledged by scientists worldwide, the leading greenhouse gas-emitting countries have failed to adopt emissions standards that might curtail global warming. This begs the following questions, which this paper will aim to answer:

- Why have the main players failed to reach an agreement so far?
- And how can the players find a feasible strategy with a cooperative equilibrium?

1 Framework

Throughout this paper, we model climate negociations as simultaneous games. The models use numerical pay-offs to rank the countries' preferences. These numbers do not refer to monetary values. Rather, they allow us to rank priorities of participating parties and sum up their preferred outcomes.

We will focus on what we consider to be the three biggest "players" in climate negociations, i.e. China, the European Union (EU) and the United States. For simplicity, each country is assumed to have only two possible strategies in each round: "*cooperation*" and "*non-cooperation*". We assume that each player has complete information on pay-offs throughout.

First, we will consider and try to explain the outcomes of the two most recent rounds of climate negociations, the Kyoto and the Copenhagen summits. We assume that these negociations (1) were independent and (2) could not use external commitment devices: each country simply sought to maximise its payoff as described in the game.

We will then set-up a third, theoretical and anticipated game designed to model future negotiations. This game will be repeated every year, we hope therefore that it will allow us to find a strategy that would lead to a cooperative outcome.

By convention, we assign the first pay-off to the United States, the second to China and the third to Europe. We take $I = \{1, 2, 3\}$ to be these three players respectively and S_1, S_2, S_3 to be their strategy sets, each containing *cooperation* and *non-cooperation*, i.e. $S_i = \{C, \bar{C}\}$. We denote the payoff for country i by:

$$U_i : S_1 \times S_2 \times S_3 \to \mathbf{R}$$
$$(s_1, s_2, s_3) \mapsto U_i(s_1, s_2, s_3).$$

2 The Kyoto Summit

2.1 Context

The Kyoto Summit is the first game in our framework of three levels of climate negotiations. For the first time in 1997, countries agreed to negociate global limits on CO_2 emissions to mitigate climate change.

Due primarily to ecological and economic interests, the European Union had the highest motivation to establish a binding system of CO_2 regulations. Within the European Union, member states had agreed on setting different norms of burden-sharing, whereupon Germany and the Northern European states faced the highest reductions. (See appendix A.2)

In contrast to the member countries of the European Union, the United States had only a low interest in a general agreement to limit CO_2 emission. (See appendix A.3)

China, classified as a developing country at the time, benefited from special conditions within the Kyoto framework. Due to small initial per-capita CO_2 emissions, the country was not required to commit to specific emission targets. It was however asked to agree on the principle of the necessity to mitigate climate change and limit emissions. As a result, China had little incentive not to cooperate in the bargaining process. (See appendix A.1)

2.2 Payoffs

Table 1 represents the expected payoffs resulting from the Kyoto negotiations:

Table 1: Kyoto negotiations

(a) EU complies

	China complies	China doesn't comply
US complies	3, 4, 4	2, 3, 3
US doesn't comply	**4, 3, 3**	3, 2, 2

(b) EU doesn't comply

	China complies	China doesn't comply
US complies	2, 3, 4	1, 1, 2
US doesn't comply	3, 1, 2	2, 2, 1

2.3 Consequences

For the US, non-cooperation is clearly a dominant strategy:

$$\forall s_2, s_3 \in S_2 \times S_3, U(\bar{C}, s_2, s_3) > U(C, s_2, s_3).$$

Similarly, China will always choose to cooperate. Lastly, given the American and Chinese strategy, Europe will choose to cooperate.

We thus arrive at a unique Nash equilibrium, in bold: $(\bar{C}, C, C)$, i.e. cooperation for Europe and China, non-cooperation for the US. This is indeed coherent with the outcome of the Kyoto summit. The protocol was ratified by Europe and China but not by the US. Europe in particular commited to reducing CO_2 emissions by 8% by 2012.

3 The Copenhagen Summit

3.1 Context

The second round of our climate change game took place in Copenhagen in 2009: the expiration of the Kyoto protocol scheduled in 2012 necessitated another agreement on the reduction of CO_2 emissions. Although the global situation had evolved since the last negotiations in Kyoto, our three players remained the main actors in the negotiations. The EU's strategy did not undergo any drastic changes: they still pushed for emissions cuts, encouraged by the European Council and Council of Ministers' decision in December 2008 to endorse a climate and energy package. The United States, which remained the world's largest air-polluting country but now had a more climate-friendly administration, displayed a willingness to cooperate only if all other major players also cooperated. China was the actor that underwent the most significant change since the expiration of the Kyoto agreement in 2010: it was no longer considered a developing country. In other words, Chinese cooperation implied tougher emissions standards for the country. As the Chiense cost of cooperation increased, it no longer had an advantage in signing a binding agreement that could affect its economic competitivity. Hence, it had generally higher payoffs for non-cooperation.

3.2 Payoffs

The payoffs are described in table 2.

Table 2: Copenhagen negotiations

(a) EU complies

	China complies	China doesn't comply
US complies	5, 4, 5	3, 5, 4
US doesn't comply	5, 3, 4	**4, 4, 2**

(b) EU doesn't comply

	China complies	China doesn't comply
US complies	3, 3, 3	2, 4, 2
US doesn't comply	4, 2, 2	1, 2, 1

3.3 Consequences

Using a reasoning similar to that in section 2.3, we derive this game's unique Nash Equilibrium (in bold): neither the US nor China agree on cooperation and the EU is the sole player to cooperate. The deciding factor is China's dominant strategy of non-cooperation, which implies a decision by the US not to cooperate either. This matches what we saw unfold during the negotiations: as China and the US refused to cooperate, no agreement between the world's largest air-polluters was signed.

4 Outlook: a Cooperative Equilibrium in a Repeated Game

4.1 Introduction

As seen from the results above, international cooperation in reducing carbon emissions to mitigate climate change is a particularly difficult target. P. Wood, for instance, explains that although public benefit from international cooperation would be tangible, there is a lack of supervising body and strong free-riding incentives [8]: what is missing is a commitment device, a tool to ensure that an agreement, which would be beneficial to all, is adhered to. How can the "rules of the game" be changed to induce a game theoretical equilibrium that favours cooperation with global emissions standards?

In this section, we consider an infinitely repeated game of yearly climate negotiations. We first give an example of a case with a cooperative Subgame Perfect Nash Equilibrium and then go on to derive the general conditions for such an equilibrium to exist.

4.2 Example case

4.2.1 Game setup

Our infinitely repeated game is setup as follows. Each year, countries choose whether to cooperate to reduce climate change or not. For their choice in that year, they earn a total future pay-off: each year of cooperation is assumed to have a lasting impact both on the economy and on climate change. For simplicity, we assume symetric payoffs as described in table 3. We also assume that future cooperation has a weaker effect on the total pay-off: technology should be able to cancel the effects of climate change in the very long term. Hence, we discount payoffs of future decisions by, say, $p = 5\%$ p.a. We set $r = 1 - d = 0.95$.

Table 3: Setup of our game

(a) Yearly payoffs: EU cooperates

	China cooperates	China doesn't cooperate
US cooperates	2, 2, 2	-1, 5, -1
US doesn't cooperate	5, -1, -1	2, 2, -3

(b) Yearly payoffs: EU doesn't cooperate

	China cooperates	China doesn't cooperate
US cooperates	-1, -1, 5	-3, 2, 2
US doesn't cooperate	2, -3, 2	0, 0, 0

4.2.2 The Grim Trigger

Can we use Grimm trigger-like punishment as an effective commitment mechanism? With the Grim trigger, everyone cooperates with the agreement until one person drops out, in which case no-one ever cooperates again. This can for instance be used to find a cooperative equilibrium in the prisoner's dillema. Can this be applied to Climate Agreements?

4.2.3 Application to a Climate Agreement

For full cooperation to be an Subgame Perfect Nash Equilibrium (SPNE), we need to check the following:

1. Total non-cooperation must be a Nash equilibrium in each round of the game. Indeed, once one region has broken away from cooperation, the punishment needs to be sustained and in every country's individual interest. We see from the above that this is indeed the case: for instance, $U_1(C, \bar{C}, \bar{C}) = -3 < 0 = U_1(\bar{C}, \bar{C}, \bar{C})$

2. The punishment should be severe enough to ensure cooperation. But indeed, if a country breaks away, he can expect to gain 3 that year but then be punished by earning $2r^t$ less t years later (discounting to present value) for any $t \geq 1$. The cost of deviating is thence $P = 3 - r\frac{2}{1-r} = 3 - 2 \times 0.95 \times 20 = -35$.

Thus, a global cooperative strategy does indeed constitute a SPNE. In what general conditions does this stay an equilibrium?

4.3 General case

4.3.1 Setting up the game

We now consider a general discount rate p and symetric payoffs defined in table 4. We set again $r = 1 - p$.

Table 4: Setup of our game

(a) Yearly payoffs: EU cooperates

	China cooperates	China doesn't cooperate
US cooperates	G_0, G_0, G_0	G_1, B_1, G_1
US doesn't cooperate	B_1, G_1, G_1	B_2, B_2, G_2

(b) Yearly payoffs: EU doesn't cooperate

	China cooperates	China doesn't cooperate
US cooperates	G_1, G_1, B_1	G_2, B_2, B_2
US doesn't cooperate	B_2, G_2, B_2	0, 0, 0

4.3.2 Solving for equilibrium

We check again whether our strategy, "Cooperation with Grim Trigger", is a SPNE:

1. Total non-cooperation must be a Nash equilibrium in each phase of the game. This is a safe assumption: under intuitive conditions, no single country has an advantage in being alone to implement tougher emissions standards. We can assume $G_2 < 0$.

2. The punishment should be severe enough to ensure cooperation. We calculate the cost P of breaking away from the "general cooperation" state as follows:

$$\begin{aligned} P &= B_1 - \sum_{t=0}^{\infty} U_i^{(t)}(C,C,C) \\ &= B_1 - \sum_{t=0}^{\infty} r^t G_0 \qquad (\forall i) \\ &= B_1 - \frac{G_0}{1-r} \\ &= B_1 - p^{-1} G_0 \end{aligned}$$

   Hence the condition on B_1 and G_0 for the cooperative equilibrium to be stable, $P < 0$, boils down to the satisfyingly simple equation:

$$G_0 > pB_1. \tag{1}$$

We end up with a condition for our strategy to be acceptable described by (1). In other words, the gain from global cooperation G_0 must be greater than the gain of being alone in not cooperating B_1 times the discount rate p. This is indeed a reasonable hypothesis under yearly negotiations, our strategy seems coherent with climate change negotiations.

5 Conclusion

After having analysed and explained the outcomes of the Kyoto and Copenhagen rounds of climate negotiations, we have developped a strategy that, if agreed on by our three players, could lead to cooperation, tougher climate change legislation and better overall human welfare. We have checked that this strategy was indeed a Subgame Perfect Nash Equilibrium. It relies on the Grimm trigger to break free of a prisoner's dillema situation.

Does this strategy stand a chance in future climate negociations, for instance during the ongoing COP16 meeting in Cancun (29/11–10/12/2010)? The main threat facing our strategy is scalability to the 194 countries participating in the conference: it is unreasonable to allow so many players to trigger a global, indefinite, "Doomsday" punishment. Although this does decrease considerably the possibility of a strong cooperative outcome to the summit, optimists hope that a dose of "forgiveness" and international pressure can still lead to a global agreement.

A Appendices

A.1 Country briefing: China

In brief: China will aim to avoid tough emissions standards but will cooperate to a certain extent if all other players reuce their own emissions.

China stands much to lose from Climate Change

- Agriculture is likely to be most impacted by global warming, with circa 10% of its agricultural production being threatened. [4] Although this amounts to a small share of GDP (c. 1%), the share of the workforce affected would be much higher (c. 4%). [3]
- Floods will become a regular occurrence is most projections, with particularly nefarious consequences for the highly populated, low-lying Shanghai region. [4]
- In worst-case scenarios with a 5°C increase in global temperatures, the disappearance Himalayan glaciers would jeopardise the supply of water to a quarter of the Chinese population. [4]

Equally, much of Chinese growth depends on the availability of cheap energy — such as that provided by coal

- China's economy has been growing at an impressive pace with GDP growth averaging 9 to 14% p.a. in the last decade. [3]
- Much of this growth depends on having inexpensive sources of energy. Coal currently provides c. 80% of Chinese electrical power [5], its coal-based economy doubles every decade [6].
- Although these are hard to quantify, implementing important emissions standards is likely to have an immediate and significant negative effect on Chinese growth.

Without specific incentives, China's dominant strategy is to undercut Western emissions standards

- For public health and sustainability reasons, China does have an advantage in imposing National emissions restrictions.
- However, to remain competitive and support growth, China's optimal strategy will be for its standards to be inferior to their Western counterparts. This will support the development of Chinese industry through competitive mechanisms.
- Two other factors favour a policy that delays tougher emissions standards:

  Time discounting — for political reasons, it might be in the Chinese government's interest to delay decisions with negative economic consequences.

Aggregate growth — long-term GDP is less affected by growth rates 20 years from now than by today's growth rates.

- The threat of being judged by popular opinion is less credible in closed-door negotiations such as those that took place at the Copenhagen summit. China can easily stall any agreement while avoiding public responsibility for the Summit's failure to reach a satisfactory outcome. [6]

How can incentives be put in action to change the payoffs and reach a dominant strategy of cooperation?

- China has a strong renewable energy industry, second behind Germany. [5]
- Given adequate incentives and a favourable global renewable energy marketplace, its dominant strategy might shift to investing in this industry and locking in the returns of green investments.
- These incentives could be implemented by a global "carbon emissions right" market with significantly higher prices per ton compared to those seen in today's markets.

A.2 Country briefing: European Union

In brief: The European Union will generally aim for cooperation.

European Union's risks in incurring in a significant climate change

Some European regions are particularly vulnerable to climate change. We refer in particular to:

- southern Europe and the Mediterranean basin: heat and droughts are important risk factors;
- the Alps: snow and ice are melting more and more rapidly;
- coastal zones, deltas and floodplains: the sea level is rising, intense rainfall, floods and storms are becoming more frequent;
- the Arctic and Outermost regions: in these regions increasing global warming is particularly harmful. [2]

Moreover, social damage is expected with threats both to real estate and human security. Damages to property and infrastructure are already responsible for heavy costs on society and the economy. Sectors relying on certain weather conditions, temperatures and precipitation levels (e.g. agriculture, forestry, energy and tourism) will be particularly affected. We can finally suppose that Europe has an reputational incentive in pushing for emissions standards: its ability to to direct the attention to environmental issues will help the Union in proving its pre-eminence as a civil power.

Costs of cooperating

The European Union has adopted emissions reduction policies in its own legislation. After the UN Framework Convention on Climate Change (UNFCCC) and the Kyoto Summit (in which Europe brought about a clear intent to agree on a global action against climate change), the engagement continued on the internal front. [2] In March 2007 the *EU climate and energy package* was decided. It implied the following strong commitments:

1. A reduction in EU greenhouse gas emissions of at least 20% below 1990 levels, by 2020.
2. 20% of EU energy consumption to come from renewable resources.
3. A 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency.

Thus, we can infer that cooperation in an international framework do not add significant costs to the European agreements already in force.

Conclusion

In brief: The European Union has considerable internal environmental standards and would benefit from international cooperation on fighting climate change. Even in the case of non-global cooperation, the Union will generally favour emissions standards.

A.3 Country briefing: USA

In brief: The United States will cooperate if all actors cooperate, but it will not to cooperate if China does not cooperate.

Political Context

There are two competing competing views of US interests regarding environmental standards.

Proponents of tougher environmental standards argue that the economy evolves through technological innovation, the creation of new products, and behavioral adaptation to new technological opportunities and resource constraints. This evolutionary view of the economy suggests that the transition to low-carbon fuels could set off a surge of economic innovation and growth comparable to energy transitions of our past economic history. However, even proponents of this view agree that this involves considerable risk for the US economy.

Opponents on the other hand argue that emissions standards have considerable direct effect on productivity and growth. They focus on the competitive disadvantage that tougher climate legislation would impose on US companies, as well as widespread increases in energy prices this would imply.

Quantifying Costs

If greenhouse gas emissions fall by 80% by 2050, economic impacts are mild, and economic growth continues to be robust despite higher delivered energy prices. [7]

However, if climate change isn't mitigated, under worst-case assumptions, higher energy prices could lead to a 1–3% decrease in GDP and household consumption comparedto the baseline scenario. This implies a marginally slower rate of economic growth over two decades, from about 2.71 percent per year to 2.68 percent per year. Predicted impacts on household welfare are smaller still, as households will adjust their consumption behaviour to mitigate the impact of price increases. [7]

Conclusion

Overall, the US has considerable technology to mitigate the short-term effects of Climate Change. The country is likely to support climate legislation only if it can be certain that other main economies will do the same to avoid putting their economy at a competitive disadvantage.

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