COOPERATION AND THE CARBON TRADING GAME: A SYSTEM DYNAMICS APPROACH TO THE PRISONER'S DILEMMA

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ABSTRACT

The danger of people or nations misunderstanding each other's has been of great interest in the study of cooperation (Akerlof, 1997). A very important question on climate negotiations is how errors in perceptions or implementation can affect agreements and create conflict. Noise, in the form of random errors in implementing a choice, is a common problem in real-world climate interactions with consequences on GHGs emissions. The paper shows a system dynamics model that simulates national interactions on climate negotiations with noise from emissions information. It shows the role of information policies in reducing GHGs emissions. It tackles the question of which kinds of data shall be considered a "global public goods" and how to eliminate noise.

KEY WORDS

climate change, system dynamics, game theory, negotiation, cooperation.

1. INTRODUCTION

Game theory has been applied to international politics since the Cold War. In an anarchic world the emergence of cooperation is very relevant. During the Cold War, the most important problem was a security dilemma: nations often seek their own security through means which challenge the security of other (Axelrod, 1984). Even today, the recent agreement between the U.S. and Iran is an example of this security concerns and search for cooperation. Similar problems occur today in climate change negotiations.

A recurrent problem on international multilateral negotiations is when the pursuit of self-interest by each country leads to a poor outcome for all. The Prisoner's Dilemma is a theoretical representation that allows us to model a whole array of situations where poor outcomes can arise due to a lack of cooperation (Axelrod, 1984).

A feature of interactions in the international arena is that choices cannot be implemented without error. Because other countries do not necessarily know whether a given action is an error or a deliberate choice, a single error can lead to significant complications. The effects of errors are known in the literature under the name of "noise" (Axelrod, 1997). These errors could come from information or knowledge sharing. In system dynamics some variables often appear to be somewhat "noisy". In a system part of the behavior is seen as systematic and part as noise.

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Meaningless random variations can significantly affect the behavior of the system (Sterman, 2000).

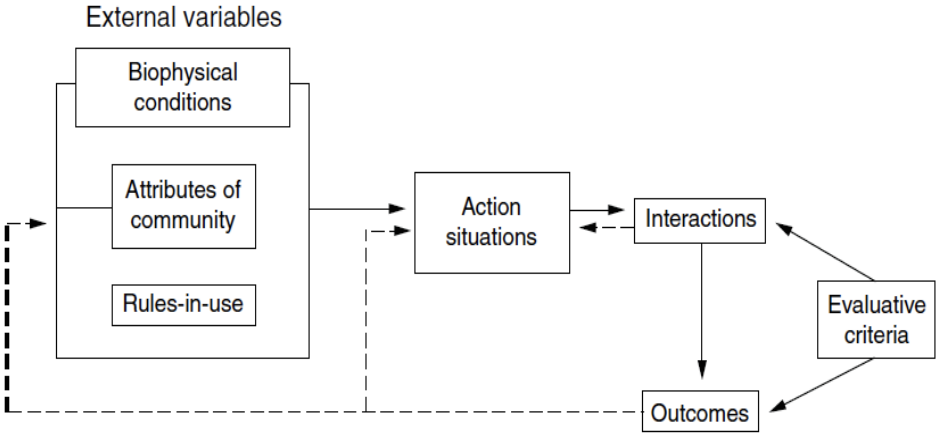
The latest generation of negotiations in the United Nations Framework Convention on Climate Change (UNFCCC) agreed tolaunchan initiative for Reducing Emissions from Deforestation and Forest Degradation, plus conservation, sustainable management of forests and enhancement of forest carbon stocks (REDD+). The plus sign, added in 2009, indicates broad agreement that enhancing carbon stocks is to be included in REDD mechanisms (UNFCC, 2009).

REDD+ requires a reliable method for measuring and monitoring the current state of carbon stocks and their changes over time. A reliable framework for measuring, reporting and verification is needed as a component of forest inventory that facilitates the quantification of possible CO2 reductions over time. This inventory is central to the implementation of REDD+ policies, seen as having the potential to generate enough incentives to end deforestation. REDD+ incentives are also seen as a threat to political decentralization and community management. Discussions concerning the implementation of REDD+ tend to consider either project-based or national-based implementation. Most proposals for REDD+ favor the latter approach, as it permits operations on a larger scale. Furthermore, it requires governments to implement national carbon accounting systems, to control leakage and to distribute the benefits of REDD+ to relevant stakeholders. At first glance, therefore, centralization could be considered a requisite for countries to receive REDD+ funds (Toni, 2011).

Theoretically, Common Pool Resource's research field known as “information commons” explores information and knowledge as public/common goods. Potential problems in the use, governance and sustainability of a common can be used by some characteristic human behavior that lead to social dilemmas such as competition for use, free riding, and overharvesting. Typical threats to knowledge commons are commodification or enclosure, pollution and degradation, and nonsustainability. In this regards, there is a continual challenge to identify the similarities between knowledge commons and traditional commons, such as forest and fisheries, all the while exploring the ways knowledge as a resource is fundamentally different from natural resource commons (Hess and Ostrom, 2007).

Ostrom (2010) and colleagues at the Workshop in Political Theory and Policy Analysis at Indiana University, have challenged the indiscriminate use of three metaphors commonly applied to CPR situations to predict suboptimal use and/or destruction of resources: (1) Garret Hardin's tragedy of the commons; (2) Olson's logic of collective action; and (3) the Prisoner's Dilemma game. For doing so they develop the IAD framework. This is a general organizing tool that helps to develop a long term research program not only for research on CPRs but also on other problems where individuals find themselves in repetitive situation affected by a combination of factors derived from a physical world, a cultural world, and a set of rules. Self-organized commons require strong collective-action and self-governing mechanisms, as well as high degree of social capital on the part of the stakeholders. Collective action arises when the efforts of two or more individuals are needed to accomplish an outcome in a voluntary manner (Ostrom, 2010). Self-governance requires collective action combined with knowledge and will on the one hand, and supporting and consistent institutional arrangements on the other hand. Social capital refers to the aggregate value of social networks and the inclination that arises from these networks for people to do things for each other (Putnam, 2000).

In the IAD the focal units of analysis are “action arenas”, where participants and an action situation interact as they are affected by exogenous variables and produce outcomes that in turn affect the participants and the action situation. Action arenas exist in the household; neighborhood or community; local, regional, national, and international councils; in firms and markets; and in the interaction among all of these arenas with others. In the simplest and most aggregated way to representing any of these arenas when they are the focal level of analysis exogenous variables affect the structure of an action arena, generating interactions that produce outcomes. Evaluative criteria are used to judge the performance of the system by examining the patterns of interactions and outcomes. Figure 1 shows how outcomes feedback onto exogenous variables and the situation and may transform both over time (Ostrom, 2005).



Source: Ostrom, 2010

Figure 1. Institutional Analysis and Development Framework

1.1 Game Theory And Carbonemissions

The focal unit of analysis is the role of information on carbon trading. The economics of information in carbon markets is analyzed through the game theory model shown in Figure 2. Imagine a game where two players A,B have to decide between having high or low emissions of CO2. If both players decide to have low emissions they are cooperating, if both or one of them decide to have high emissions they are defecting.

	A		
B		low	high
	low	a_1 a_2	a_1 b_2
	high	b_1 a_2	b_1 b_2

Figure 2. Carbon trading game

Scenario 1 (*Cooperation*): Players with low emissions make an investment I_i and receive transfers from the carbon bond market by TR_i , where $i=A,B$. Players having high emissions pay an environmental tax t_i . $a_i=\Pi_i+TR_i-I_i$ and $b_i=\Pi_i-t_i$ where Π_i is the profit derived from firms $i's$ main commercial activity. In this simple model a player would produce at low levels of emissions if $TR_i-I_i<t_i$. In this scenario, in order to achieve an equilibrium where at least one of the players invest in low emissions, transfers would need to be $TR_i>t_i+I_i$. Several fiscal policies involving government transfers TR_i and t_i could be put in place in order to achieve an equilibrium with at least one player has low emissions.

Scenario 2 (*Chicken*): Now assume the production of low or high emissions imply different technologies and therefore different costs. Also assume, players having low emissions can sell carbon assets to those with high emissions. $\Pi_{low}=p\left(q_{low}\right)q_{low}-c_{low}\left(q_{low}\right)+TR\left(q_{high}\right)$ if $q_{high}=0\rightarrow TR=0$ and $\Pi_{high}=p\left(q_{high}\right)q_{high}-c_{high}\left(q_{high}\right)-t\left(q_{low}\right)$ symmetrically if $q_{low}=0\rightarrow t=0$ Regarding carbon market transfers, TR and t are functions of the production decisions of the competition: $TR\left(q_{high}\right)$ and $t\left(q_{low}\right)$. At equilibrium in the carbon bond market $TR=t$ and equal to the market prices for carbon bonds.This redefine the payments in our game as shown in Figure 3.

		A	
B		low	high
	low	$a_1\ \ a_2$	$d_1\ \ c_2$
	high	$c_1\ \ d_2$	$b_1\ \ b_2$

Figure 3. Carbon trading game (chicken equilibria)

where $a_1<c_1$, $b_1<d_1$ and $a_2<c_2$, $b_2<d_2$. This payoff parameters satisfy the inequalities that results in a *Chicken* game. *Chicken* has a payoff structure and set of strategies such that individual players do not have a dominant strategy. *Chicken* has multiple equilibria. In this sense, this problem becomes a signaling problem where each player wants to deviate its competitor from doing the same thing she is doing. Players are on a matching problem where the player with low emissions is searching for the palyer with high emissions and vice versa.

Scenario 3 (*Prisoners Dilemma*): Both players make high emissions at the same time. In this scenario cheating is preferred to cooperation. The reason is that the structure of payments is such that for a player or country there are incentives to cheat even when the other is cooperating. In this scenario no matter what the other player does, defection yields a higher payoff then cooperation. Defection is a dominant strategy.

	A		
		low	high
B	low	a_1 a_2	d_1 c_2
	high	c_1 d_2	b_1 b_2

Figure 4. Carbon trading game (Prisoner's Dilemma)

1.2 The Prisoner's Dilemma And System Dynamics.

Complex Cooperation

In 1997 Robert Axelrod wrote a book called "The Complexity of Cooperation". One meaning of this title was the addition of complexity to the study of cooperation, basically to the Prisoner's Dilemma. It also introduced the concepts and techniques that are known with the name of complexity theory. This involves the study of many actors and their interactions. A primary research tool for complexity theory is computer simulation and is known by several names, including agent-based modeling, bottom-up modeling and artificial social systems. In this paper we use a different method for the study of complexity: system dynamics.

Figure 5 shows a very simple system dynamics model of the Prisoner's Dilemma. Results are based on the level of payment from cooperation and payment from defection. With a higher payment from defection we obtain the results shown in Figure 6. Since the Cold War, the Prisoner's Dilemma has been an important tool for social scientist to understand international negotiations and conflict. Originally framed in RAND Corporation for its possible application to global nuclear strategy, it is a tool that could and should be applied today to global warming negotiations.

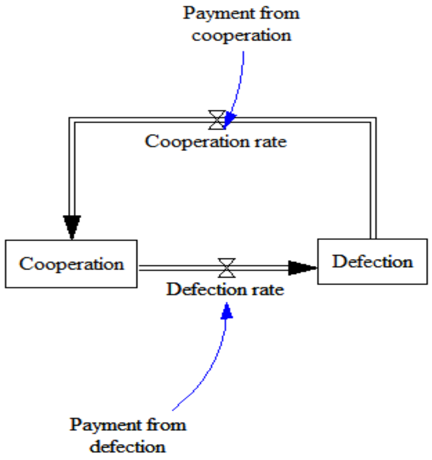


Figure 5. Prisoner's Dilemma

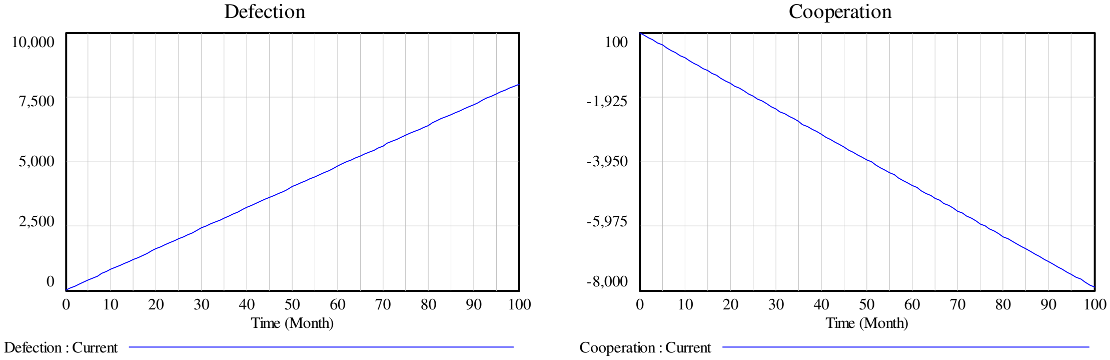


Figure 6

Basic Carbon Cycle

The C-ROADS (Climate Rapid Overview and Decision Support) is a system dynamics model, designed by MIT's Climate Interactive Project (Sterman, et.al, 2013). It features a continuous time compartment model of the greenhouse gas cycles and climate. The basic carbon cycle from C-ROADS is shown in Figure 7.CO2 in the atmosphere depends on the net difference between CO2 released from fossil fuels by anthropogenic forces, CO2 released from soils due to the natural cycle and land use change, and CO2 released from biomass due to the natural cycle and deforestation; and CO2 capture by oceans and forests. This also affects atmosphere's temperature.

C-ROADS is a continuous time model of the greenhouse gas cycles and climate. C ROADS includes an explicit carbon cycle, the budget for and atmospheric stocks ofother GHGs, radiative forcing, global mean surface temperature, sea level rise and surface oceanpH. Here we only use the basic carbon cycle model (Fig. 7). The core carbon of C-ROADS evolved from models developed by Fiddaman (1997, 2002, 2007),Goudriaan and Ketner (1984) and Oeschger*et al.* (1975) and similar to other widely used SCMs (Simple Climate Models) and EMICS (Earth-system Models of Intermediate Complexity) such as those in Nordhaus (1992), Socolow and Lam (2007), and Solomon *et al. (*2009, 2010).

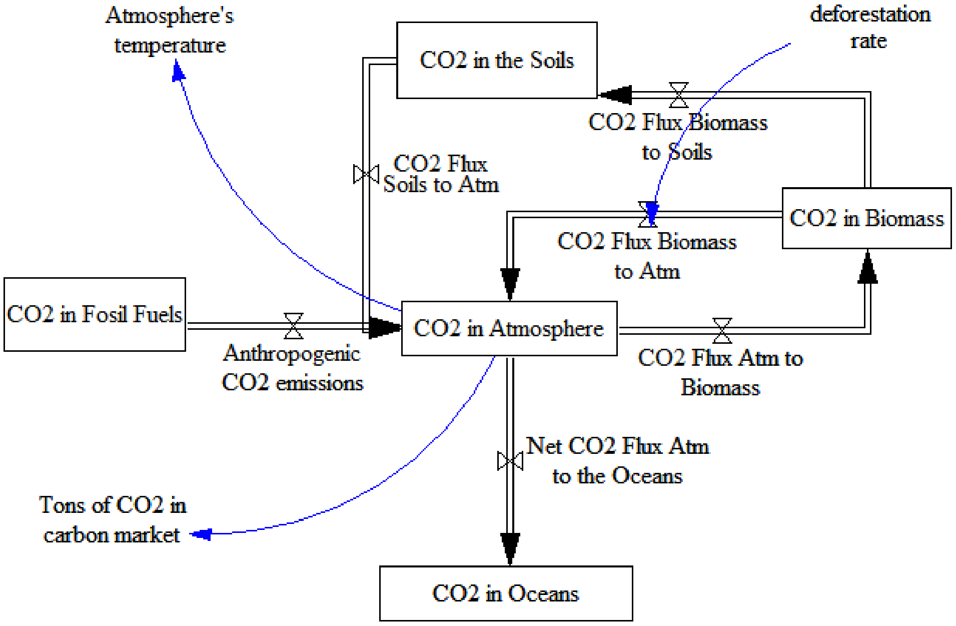


Figure 7. Basic C-ROADS Model

In a pre-Kyoto Protocol's world, without any agreement on emissions reduction and a business as usual scenario the model reports a linear increase in climate change's key variables. With a constant rate of anthropogenic CO2 emissions C-ROADS model reports increases in: CO2 in the atmosphere (Fig. 8.1.) and atmosphere temperature (Fig 8.3). CO2 in biomass (Fig. 8.2.) decreases due to deforestation rate. CO2 increasein the atmosphere is cause by the rate of anthropogenic emissions, the main driver of climate change. As long as anthropogenic emissions remain constant an increase in the atmosphere temperature would be observe.

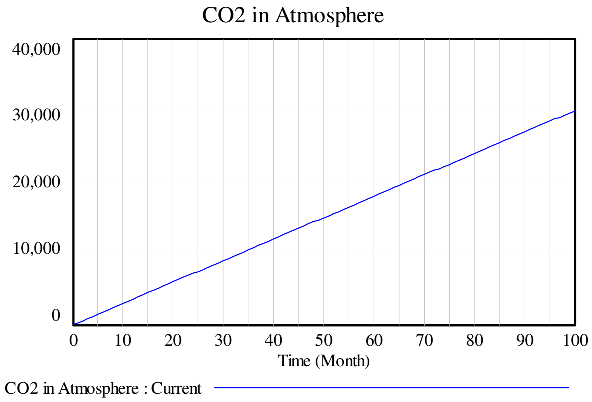


Figure 8.1.

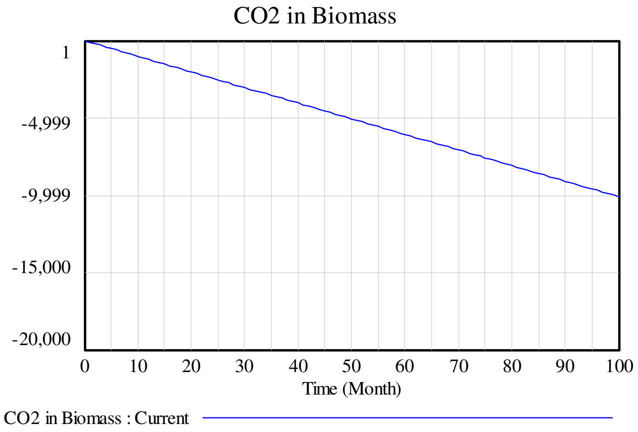


Figure 8.2.

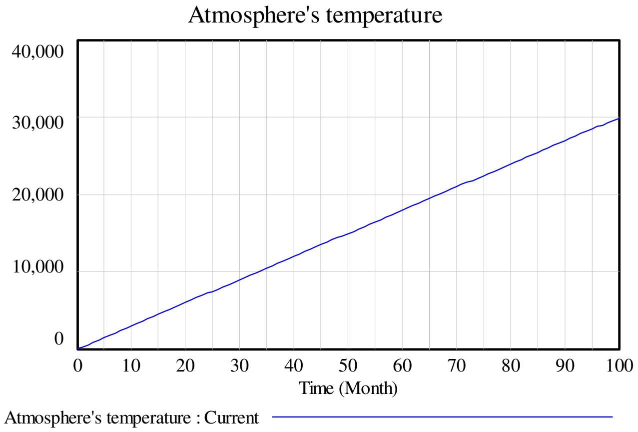


Figure 8.3.

Climate Change Negotiations

Figure 9 shows a model of the impact of international negotiation on climate change on the basic carbon cycle. Using the basic C-ROADS and Prisoner's Dilemma models we obtain different scenarios depending on the payments from cooperation and defection. Figure 10 shows two contrasting scenarios.

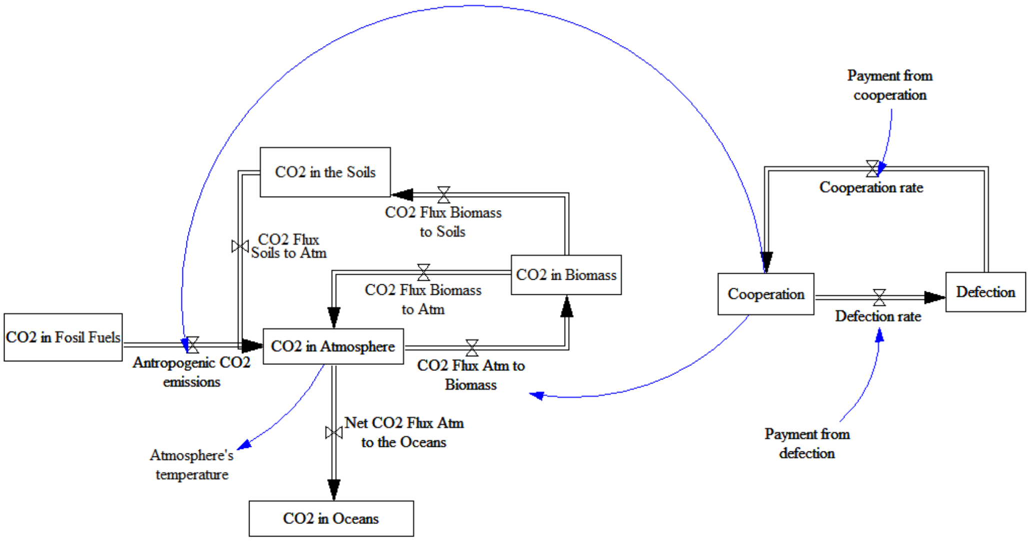
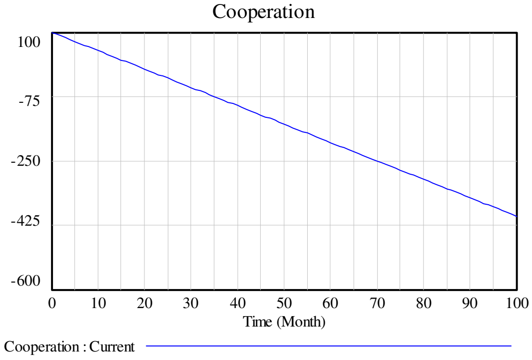


Figure 9. C-ROADS Basic Carbon Cycle and the Prisoner's Dilemma

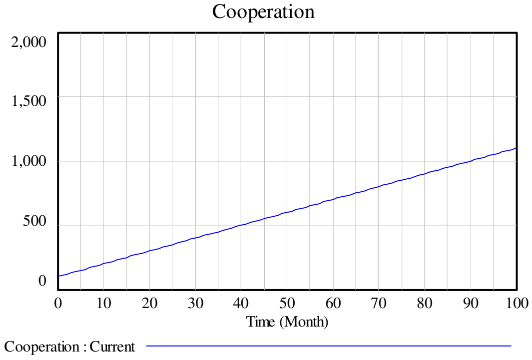
Scenario PC<PD: when payment from cooperation is lower to the payment from defection the model reports a constant fall in cooperation. This causes increases in CO2 in the atmosphere, atmosphere's temperature and a decrease in CO2 in biomass. We could consider this a Prisoner's Dilemma scenario where forests' carbon sequestration is low and carbon saving technologies are not implemented.

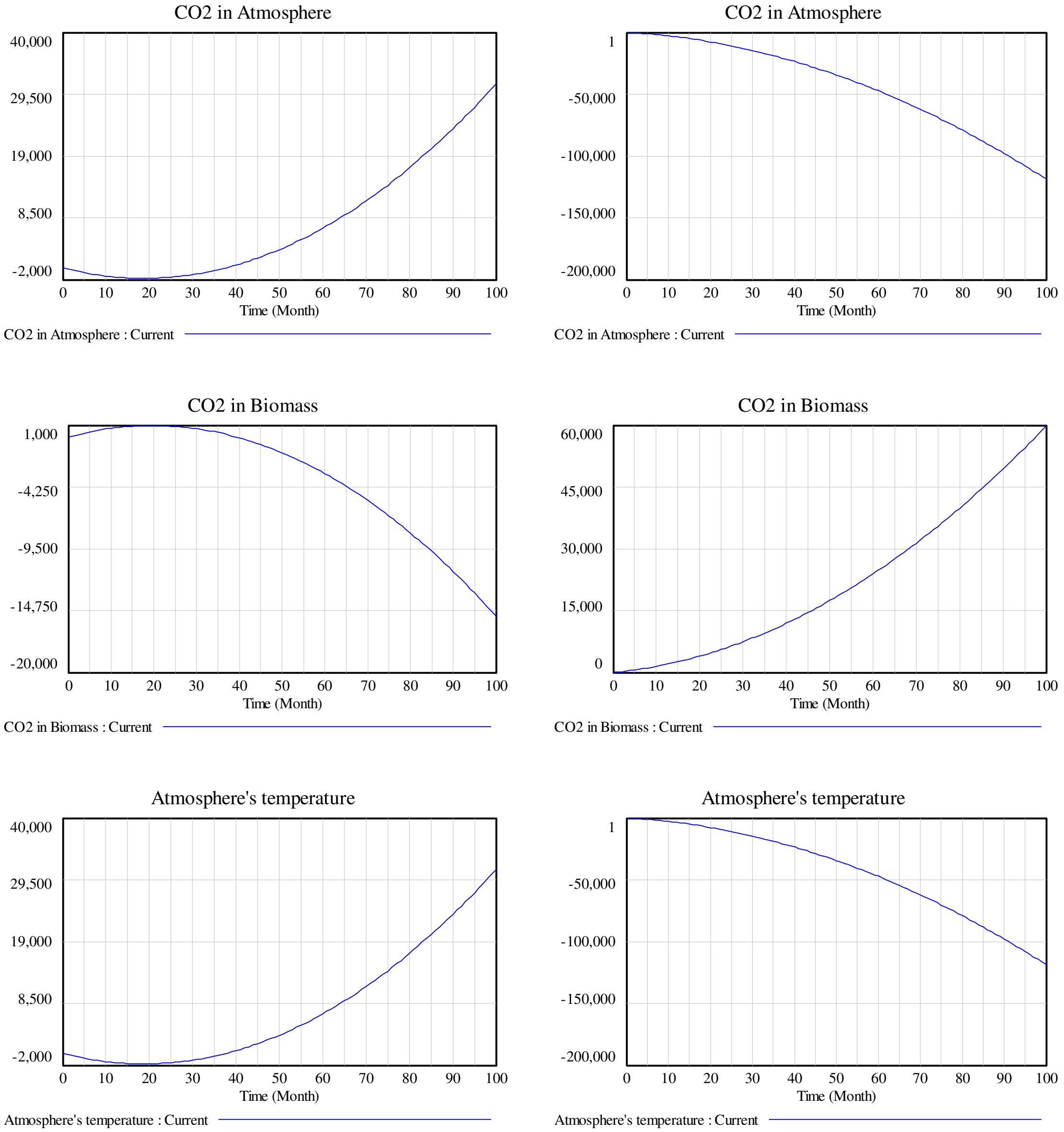
Scenario PC>PD: when payment from cooperation is higher than payment from defection the model reports an increase in cooperation. Higher cooperation causes that CO2 in the atmosphere decrease, CO2 in biomass increases and atmosphere's temperature decreases. This is an scenario where REDD+ mechanisms would be put in place and working and investment in carbon saving technologies would be high.

PC<PD



PC>PD





PC: Payment from cooperation; PD: Payment from defection

Figure 10. Cooperation and Carbon Cycle Scenarios

Noise on Climate Negotiation

The next model (Fig. 11) shows a more realistic (micro) world where climate negotiations and apparent cooperation does not transform immediately in sound policies. In this scenario, errors in perception or implementation could lead to serious conflict. The echo of one mistake can go on indefinitely causing more mistakes so players oscillate among different combinations of choices and are never able to reestablish a sustained pattern of mutual cooperation (Axelrod, 1997).The "noise" from mistakes can be defined as a random error in implementing choice, a common problem in real-world interactions (Jianzhong and Axelrod, 1997).

The result from that noise is the oscillation of main variables s shown in Figure 12. In an oscillatory system, the state of the system constantly overshoots its goal or equilibrium state, reverses, then undershoots and so on. The overshooting arises from the presence of significant time delays in the negative loop, in this case in the form of NOISE. The kind of oscillation observed in Figure 12 is technically known under the name *limit cycles*. In limit cycles, the state of the system remains within certain ranges. In the steady state, after the effects of any initial perturbation have died out, a limit cycle follows a particular orbit in state space. The steady state orbit is known as an attractor, since trajectories near enough to it will move toward it. Limit cycles are quite common in biology and economics: The circadian rhythm, predator-prey population ratio cycle, mass fruiting of plants like bamboo, population explosions of certain insects. In the economy the so called "long waves"are self-perpetuating limit cycles (Sterman, 2000).

Oscillation can be cause by material or information delays. In this case is a delay caused by an information feedback caused by the perception of cooperation. Beliefs, expectations, forecast and projections are based on information available to the decision maker about the past trajectory of variables. A perception or belief is state of the system. In adaptive expectations, a belief changes when it is in error, that is, when actual state of affairs differs from the perceived state of affairs. The larger the error the greater the rate of adjustment in beliefs. This structure is known as first-order information delay or as a first orders exponential smoothing (Sterman, 2000).

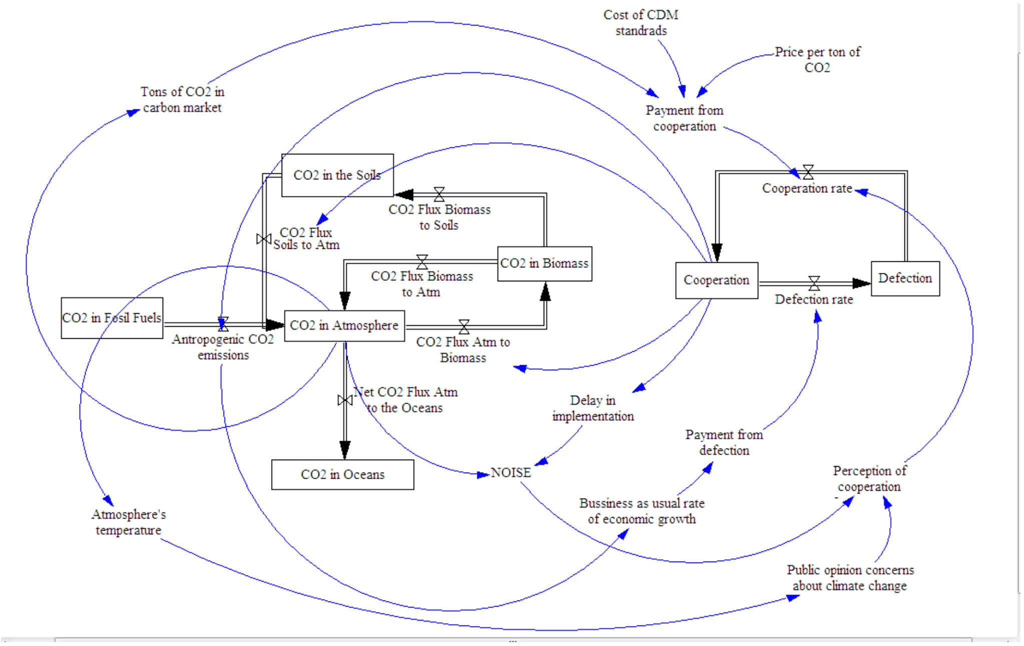


Figure 11. C-ROADS Basic Carbon Cycle and the Prisoner's Dilemma with NOISE

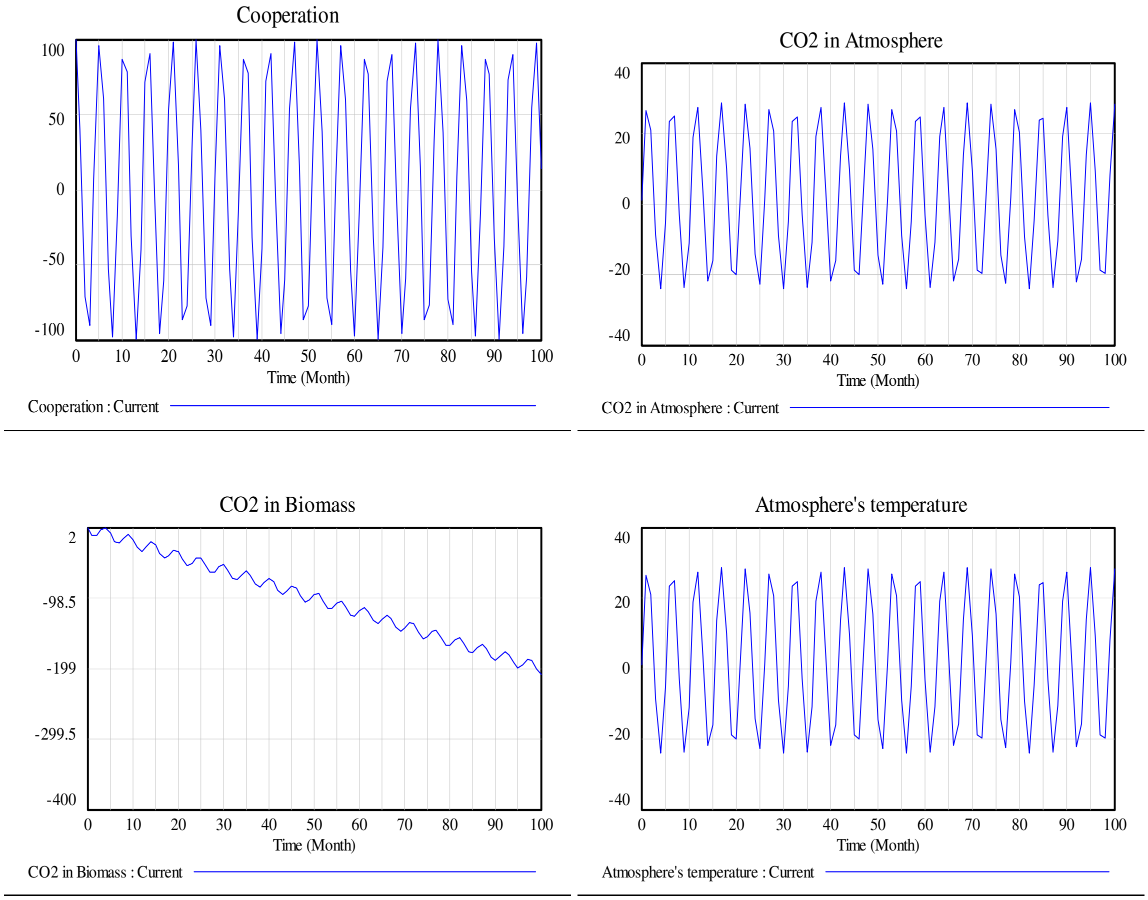


Figure 12

2. DISCUSSION

The ways to cope with noise has been an important research topic in game theory, especially related with the Prisoner's Dilemma. The literature proposes three different approaches to coping with noise (Axelrod, 1997):

1. *Generosity*: Allowing some percentage of the other player's defection to go unpunished has been widely advocated as a good way to cope with noise. This prevents a single error from echoing indefinitely.
2. *Contrition:* A reciprocating strategy such as *tit-for-tat* can be modified to avoid responding to the other player's defection after its own unintended defection. This allows a quick way to recover from error. It is based on the idea that one should not be provoked by other player's response to one one's own unintended defection.
3. *Win-Stay, Loose-Shift:* A strategy based on the principle that if the most recent payoff was high, the same choice would be repeated, but otherwise the choice would be changed.

We should ask how generosity, contrition and/or*win-stay, loose-shift* strategies are related with noise and information management. Digital open big data can be effective in eliminating noise. Ostrom and Hess (2009) identify seven major types of property rights that are most relevant to use in regard of obtaining cooperation in building information commons. These are: *(i)* access, refers to the right to enter a defined physical area and enjoy non-substractive benefits; *(ii)*contribution, the right to contribute to the content; *(iii)* extraction, the right to obtain resource units or products of a resource system; *(iv)* removal,the right to remove one's artifact from the resource; *(v)* management/participation, the right to regulate internal use patterns and transform the resource by making improvements; *(vi)* exclusion, the right to determine who will have access, contribution, extraction and removal rights and how those rights may be transferred; *(vii)* alienation, the right to sell or lease extraction, management/participation, and exclusion rights.

During the 17th session of the Conference of the Parties to the UNFCC (COP17) and 7th session of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol (CMP7) held in Durban, South Africa, in 2011 some agreements were reach in terms of defining guidance on systems for providing information on how safeguards are addressed and respected and modalities relating to forest reference emission levels and forest reference levels. Information systems should (UNFCCC, 2010, 2011):

a) Be consistent with REDD+ Guidelines.
b) Provide transparent and consistent information that is accessible by all relevant stakeholders and updated on a regular basis.
c) Be transparent and flexible to allow for improvement over time.
d) Provide information on how all of the safeguards referred to REDD+ are being addressed and respected.
e) Be country-driven and implemented at the national level.
f) Build upon existing systems, as appropriate.

REDD+ development initiatives should shift their approaches from top-down interventions to a grassroots participatory perspective where indigenous knowledge plays an important role. Initiatives to reduce the risks associated with the emission of greenhouse gases should encourage polycentric approaches likely to achieve benefits at multiple scales and for disparate actors. Others are concerned with REDD+ impacts on indigenous peoples and communities, the ability of governments to adequately report emissions reductions or to control possible corruption. After all, REDD+ is more than just funding for developing countries and is likely to evolve into a market-based carbon trading system, an option that involves higher stakes and is far more controversial. Policy makers have also begun to realize just how much REDD+ success will depend on changes in forest governance at multiple levels (Ostrom, 2009).

Toni (2011) consideredthat REDD+ will change the structure of incentives for subnational policymakers, encouraging them to pursue further decentralization, control deforestation and restore degraded forests in order to keep receiving REDD+ funds. Decentralization referring to the transfer of powers and resources from central to democratically elected subnational governments; this has been commonly called either democratic decentralization or devolution. Reasons given in favor of decentralization include that it: (1) Increases local participation and local democracy; (2) improves efficiency and equity of service delivery; and (3) strengthens local government.

How this type of decentralization will affect municipal governments, however, remains an open question but an open information system seems to be a necessary condition for stopping deforestation and degradation. Community forest management (CFM) is one proven strategy for forest communities to move beyond deforestation or degradation and achieve sustainable management, under certain conditions. Where successful, CFM is often associated with both secure rights to forest resources and the development of multi-scaled governance institutions (Cronkleton, Bray and Medina, 2011).

Community based monitoring and certifications present an opportunity for the decentralization of information management and sharing. Nevertheless, important problems of bias and moral hazard should be address. One of the problems that more commonly hinder the efforts to find methods to reduce emissions is inadequate certification. For policies that provide diverse rewards for projects that reduce greenhouse gas emissions, there is a need for skilled personnel to certify that a project does indeed reduce ambient CO2 by some specified amount over a defined time period. An industry of consultants has emerged for filling this task. While many consultants are trained as scientist, the greatly increased need for certification has generated opportunities for at least some contractors lacking appropriate skills to make a living in the new "certification game" (Ostrom, 2009). Community based monitoring faces a similar problem. Few scientific expertise, low technical skills and digital divide are important obstacles for the implementation of carbon markets and fight deforestation and climate change. Is of utmost importance to invest in community capacity building in order to achieve REDD+ goals.

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