Ozone Depletion and the Depletion of Cooperation: Model-based Management to Keep Collective Action Running Long Term.

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Abstract

This paper presents an evaluation of the capacity of cooperation based on trust to support future collective action for mitigating the Ozone Depletion Crisis. We developed a system dynamics model considering the Ozone Crisis as a social dilemma. We concluded that the dependence of future trust on initial conditions of trust and difficulties for getting feedback about past cooperation effects are problems which require additional complementary mechanisms to keep cooperation running in the long term. Finally, we suggested that to achieve sustainable cooperation in the Ozone Crisis we need to understand the inertia of chlorofluorocarbons (CFC) and their effect on the feedback of cooperation.

Key words: Cooperation based on trust, Ozone Depletion Crisis, Social Dilemmas.

1 Introduction

The Ozone layer (O_3) protects us against the ultraviolet rays allowing life on Earth. Scientists suppose that this layer is fragile and human activities can increase its fragility (Molina, 1997). The literature reports the relationship between chlorofluorocarbons (CFC) made by humans such as CCl_2F_2 and CCl_3F and the reduction of the Ozone concentration in the high atmosphere (Rowland, 1990). The CFC are inert in the low atmosphere and can survive for years without producing any chemical reactions (Molina, 1997). Components based on CFC are used in refrigerants, solvers, and aerosols. The Chlorine (Cl) atom attacks the Ozone (O_3) producing ClO, a free radical. One atom of Cl can destroy 100000 molecules of O_3. Tons of emissions of CFC have produced a significant exhaustion of the Ozone layer (Molina, 1997). Data showed a loss of Ozone of about 3 percent per year from 1970 (Solomon et al., 1986). The depletion of the Ozone layer affects global temperature (Kirk-Davidoff et al., 1999), human life (Longstreth et al., 1995), animal life (Bjorn, 1996), and vegetation (Tevini and Teramura, 1989) because of the increase of ultraviolet rays on Earth. As an answer, the Protocol of Montreal was defined as a frame to eliminate CFC emissions (Montreal Protocol, 1987). Indeed, the Ozone depletion crisis can be studied as a social dilemma (Cameron et al., 1998; Soroos, 1994; Hoffmann, 2005).

People confront social dilemmas every day. A social dilemma is a conflict between individual rationality and the general interest of the group (Ostrom and Walker, 2005, 19). Common resources, which might be depleted unless action is taken or regulations are made, are susceptible to this kind of conflict because of characteristics like subtractability and exclusion (See Table 1). A short term individualistic rationality could produce over-exploitation, pollution and reduce the availability of the common resources. However, groups can confront and avoid this situation. Furthermore, the availability of common resources depends on the way that the appropriators deal with social dilemmas.

There are three possible ways to solve social dilemmas: cooperation, private rights and markets, and the enforcement by an external agent (for example, the state). Private rights and markets have shown problems when they are used in situations of large-scale dilemmas (Ostrom, 1990, 33). Because these alternatives are not always feasible options in large-scale social dilemmas, we are going to focus our work on cooperation.

Classical theories about cooperation are related to three fundamental sources: the Tragedy of the Commons (Hardin, 2009, 1243), the Logic of the Collective Action (Olson, 1971, 1) and the Prisoner's Dilemma (Luce et al., 1958). According to these sources, cooperation is not possible among rational individuals because they want to maximize their expected utility in the short term. These theories suppose that individuals have perfect and complete information about the situation and the consequences of their decisions. The possibility of communication is not considered. As a consequence of these considerations, individuals create a dangerous situation that could lead them to over-use common resources. Classic theories claimed that people are not able to escape from this situation by themselves. As a consequence, their payments are the lowest (Hardin, 2009). For these theories, there are only two ways to avoid this situation: to enforce agreements to reduce the appropriation by an external agent (Hardin, 2009, 1244) and to define private rights of exploitation and markets (Smith, 1981, 439).

Over-exploitation can be solved if the individuals cooperate to reduce their appropriation (Ostrom et al., 2002, 3). However, individuals could decide to free ride and appropriate at the level required to keep a sustainable use of the common resource. If individuals follow their own interest in this situation, they will drive the situation to collective irrationality because all of them will receive the lowest payments as a consequence of the reduction of the common resources' productivity (Schlager, 2002, 801).

We can think of the problem of the interdependence between human beings as a social dilemma. When an individual uses a common resource, he can decide how much of the resource he wants to use. If all of the individuals decide to use the same high quantity, the resource's availability is threatened. The social dilemma is configured because the interdependence in this situation can produce a conflict of rationality. If the whole group decides to use more than the capacity of the resource, they can produce over-exploitation, congestion, and pollution. Thus, they can reduce their individual and group payments. Their individual rational decision in this situation of interdependence could drive to a condition against their own interest in the short and long run. However, groups can avoid social dilemmas if they are able to promote cooperation to reduce their individual and collective usage. Today, social scientists accept the possibility of cooperation and they work for a better understanding of the dynamics of cooperation [1] .

		Subtractability(level of rivalry)	
		Low	*High*
Exclusion	*Difficult*	Public Goods	Common Resources
	Easy	Club Goods	Private Goods

Table 1: Economic Goods, Exclusion, and Subtractability (Ostrom and Ostrom, 1977).

Table 1 describes economic goods as functions of subtractability and exclusion. Public goods and Common Resources are susceptible to social dilemmas and we can see how subtractability and exclusion determine if the problem to confront is provision or appropriation.

Availability of the commons is related to the way that groups face social dilemmas through cooperation (Ostrom et al., 2002, 5). The work of scientists have been focused on improving our understanding about how human groups decide to cooperate. For this task, scientists use Game Theory (Von Neumann et al., 1953; Grimes-Casey et al., 2007; Plous, 1987), Econometric methodologies (Clark, 1976; Dasgupta and Heal, 1980; Ophuls, 1977), surveys, Experimental Economics (Smith, 1989), Celullar automata (Akimov and Soutchanski, 1994) and Field Experimentation (Ostrom et al., 2002). Recently, they have used system dynamics (Castillo and Saysel, 2005) and Agent Modeling Methodologies (Fort, 2003; Janssen and Ostrom, 2006; Bousquet et al., 2001; Dalmagro et al., 2006) to design and test the effectiveness of new mechanisms. These works have improved our understanding about cooperation. In one of these, Ostrom (2000) proposed principles for a collective action decision making theory in common resources. Ostrom suggested a dynamic relationship (a feedback loop) among reciprocity, cooperation and trust, and a set of situational variables that influence the dynamics of

[1]Elinor Ostrom received the Nobel Prize in Economics in 2009 for "for her analysis of economic governance, especially the commons"

the cooperation in the appropriation of common resources. Reciprocity includes the possibility to punish others when they do not support the agreements through low fines (Ostrom, 1990, 40). Her theory was developed to explain cooperation in laboratory and field settings (Ostrom, 2000) (Ostrom et al., 1994, 145). The contribution of Ostrom, and her core relationship as the central component of the theory of cooperation, is considered to be the main contribution to this research area. Her theory was designed from specific field and laboratory settings (Ostrom et al., 1994; Ostrom, 2000).

Contemporary theories of collective action consider that cooperation is possible as a consequence of the possibility of communication in several encounters around the appropriation of the resource. Individuals develop a reputation of cooperation from past encounters that enable new cooperation (Ostrom, 2000, 12). In the principles of rational decision making for collective action on common resources, Ostrom offers a frame to explain cooperation based on the possibility of communication face to face. The frame is constituted by core relationships. Reputation, reciprocity and trust drive the change of cooperation according to initial conditions defined by situational variables (Ostrom, 2000, 13) as presented in Figure 1.

The possibility of not enough initial trust to promote and sustain cooperation is a problem because of the nature of the feedback loop that defines the core relationship of the mechanism based on trust. A dynamic version of the mechanism based on trust is presented on Figure 1. Trust promotes reciprocity. Later, reputation is affected by reciprocity. More reciprocity strengthens the reputation and increases cooperation. Finally, a cooperative reputation improves trust. In terms of dynamics, the initial conditions for trust affects the performance of cooperation because the core variables (trust, reputation, and cooperation) are joined in a reinforcing feedback loop that reinforces any initial condition (Sterman, 2000). This is the case when the *mechanism of cooperation based on trust* exhibits dependence to initial conditions (Castillo and Saysel, 2005).

Ostrom suggested the following characteristics for the situation that met the theory (Ostrom, 2000, 11):

- The situation provides deformed and delayed information even in laboratory and field settings.
- The rationality of the individuals is bounded.
- The complexity of the situation is confronted by simple rules that increase the complexity.
- The reciprocity implies to punish the free riders with fines that are gradually established.

Contemporary cooperation theories suggest that auto regulation is a way to deal with social dilemmas. Ostrom (2000, 11) developed her theory of cooperation for small-scale social dilemmas in very specific conditions:

- There is face to face communication.
- Agreements are possible and enforceable.
- Groups have few members.
- Members have similar characteristics.

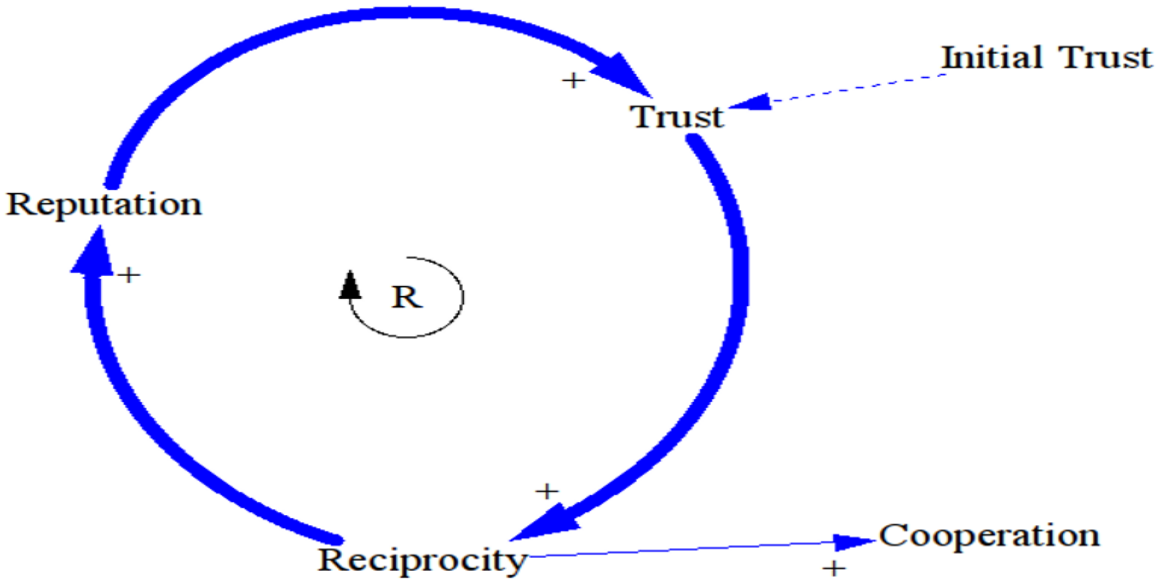

Figure 1: Dynamic version of cooperation based on trust inspired in Ostrom (2000)

- There is perfect information about the state of the resource and the results of others' actions.

These conditions may be satisfied by small-scale social dilemmas. However, these conditions are not satisfied by large-scale social dilemmas.

People face large-scale resource problems that could be assumed as social dilemmas. Payoffs from selfish behavior are higher than payoffs from non-selfish behavior. However, the public gets the worst payoff if most citizens act selfishly. Traffic jams, Electricity crises, Congestion on the Internet, climate change, and many other situations can be explained as a social dilemma (Buck, 1998, 8).

Large-scale resource social dilemmas have special conditions. We can offer some characteristics based on Markóczy (2007, 1931):

- There is not face to face communication, but there is some kind of information about the state of the resource and the others' actions.
- Agreements are possible and enforceable.
- Groups have a lot of members.
- Members do not have similar characteristics.
- Information about the state of the resource and the results of other's actions are imperfect and incomplete.
- There is dynamic complexity.

We described below two types of resource-related social dilemmas according to their scale and their characteristics: small and large-scale. Next, we are going to present our research gap.

1.1 Gap: testing the effectiveness of cooperation's mechanism based on trust in the Ozone Depletion Crisis

The effectiveness of cooperation's mechanisms such as cooperation based on trust has been tested by laboratory experiments, field and model simulation settings. This is not the case in large-scale social dilemmas, because of the differences between the conditions of the situations. We claim that it is possible to test the effectiveness of cooperation's mechanisms based on trust in large-scale social dilemmas such as the Ozone Depletion Crisis. Our simulations can be used to test if initial trust is strong enough to keep cooperation running in the long term in large-scale social dilemmas.

1.2 Research Plan

We will develop a simulation model to test the effectiveness of cooperation based on trust to mitigate the Ozone Depletion Crisis as a large-scale social dilemma. Our study will be developed according to the system dynamics methodological guidelines.

Methodological requirement	Characteristics of the Problem
Feedback	Information feedback
Delays and perception	Dynamic Complexity
Average behavior representation	Group decision making
Explanation capacity	Evaluation of mechanisms to improve cooperation
Representation of dynamic decision making	Iterative and repetitive decision making

Table 2: Methodological requirements to evaluate effectiveness of cooperation based on trust in large-scale social dilemmas

2 Methodology

We used System Dynamics methodology guidelines to develop the model (Forrester, 1961, 17). System Dynamics was applied to guide the design of the dynamic hypothesis, the models, and the design of the computer simulation experiments. We selected System Dynamics because of its capability to satisfy the characteristics of the problem described in Table 2.

The steps we followed to develop the construct and the models of this case were:

- We developed a dynamic hypothesis that explains how trust could promote and sustain cooperation in the Ozone Crisis.
- We designed a model about the Ozone Crisis as a large-scale social dilemma.
- We ran simulation experiments to test the ability of cooperation based on trust to keep cooperation running.

We used System Dynamics (Sterman, 2000; Forrester, 1961) to develop our construct as a dynamic hypothesis, to apply it for modeling the concentration of Ozone in the atmosphere; Then we tested if trust was able to promote cooperation in the long term. We developed the model using Vensim 5.7 for Windows.

3 Results

Initially, we represented the Ozone Depletion Crisis using 2 differential equations. The first equation represents the accumulation process of CFC_{11} in the atmosphere. The average lifetime for CFC_{11} has been established between 75 to 135 years (Harper, 1995). In our simulations, we assumed 75 years as the lifetime for CFC_{11}. The second equation is used to represent Ozone concentration. In our model, Ozone is depleted because the concentration of CFC_{11}. This is presented in Figure 2.

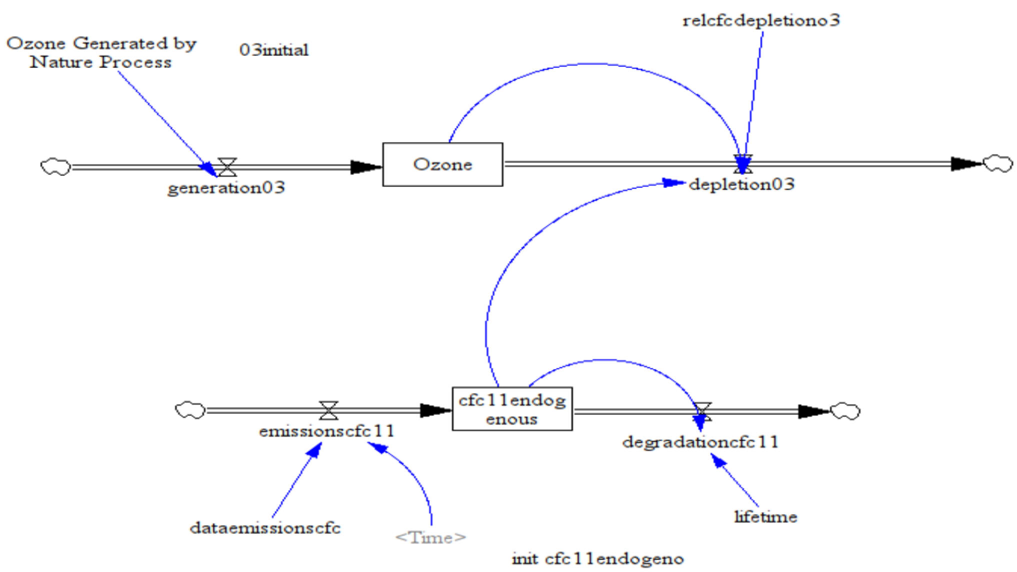

Figure 2: Model for Ozone Depletion Without Mechanism of Cooperation Based on Trust.

Our simulations for this model are able to fit the average behavior for Ozone Data provided by IAC (2010). This is presented in Figure 3.

The behavior of Ozone is explained by the behavior of CFC_{11}. Because of the Montreal Protocol we achieve 0 emissions of CFC_{11}. However, because the lifetime of CFC_{11} in the atmosphere, there is an inertia affecting the consequently expected Ozone recovery. This is presented in Figure 4.

3.1 Dynamic Hypothesis

We claim that cooperation based on trust can keep zero emissions of CFC_{11} and then this can allow the recovery of Ozone concentration. As a consequence of this improvement, people develop trust about the effectiveness of cooperation. Then this allows us to keep the effort to reduce emissions of CFC_{11}. This is represented by a reinforced feedback loop which will offer problems to managers because of the effects of delays regarding the results of cooperation. Our dynamic hypothesis is presented in Figure 5.

We performed simulations to test the effectiveness of cooperation based on trust. We simulate the model both with low and high initial trust requirement. Figure 6 presents how a low requirement of trust can improve the concentration of Ozone.

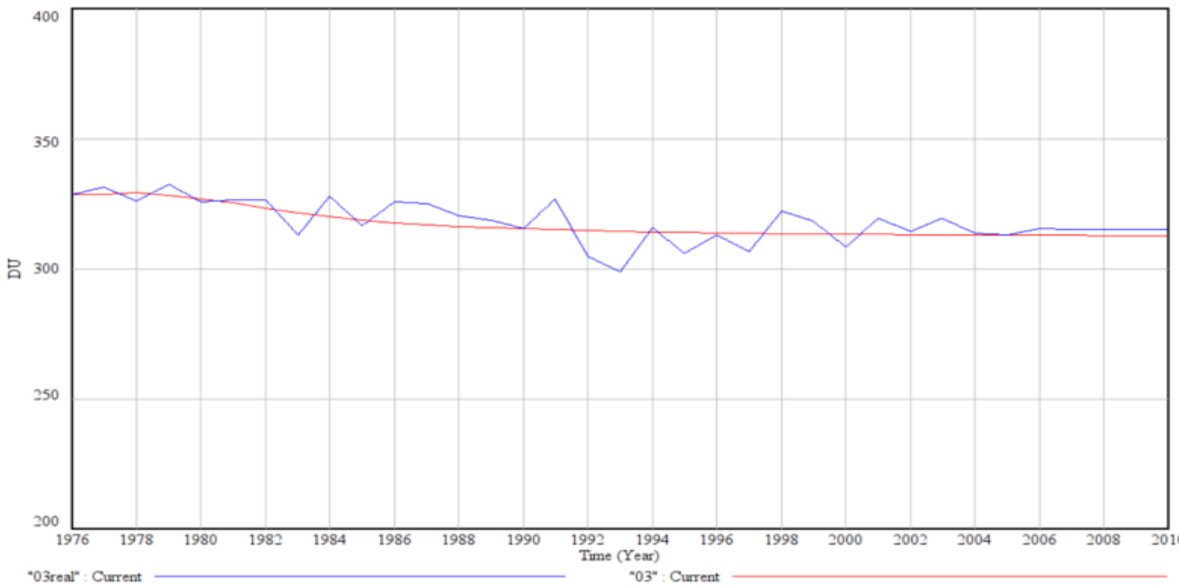

Figure 3: Data vs Simulation for Ozone Depletion Without Mechanism of Cooperation Based on Trust. Data (Blue) by IAC (2010). Simulation in Red.

Figure 7 presents a high requirement of trust and its affects on Ozone concentration. In this case, Ozone depletion persists over time.

3.2 Sensitivity Analysis

We made a sensitivity analysis, which consists of 200 simulations for testing the selected parameter between the defined range using a Uniform Probability Distribution. In the analysis, we tested the sensitivity of the model to the value of lifetime for trust. This is presented on Figure 8. The analysis suggests that the mechanism of cooperation based on trust alone is not effective to keep high cooperation levels in the long term.

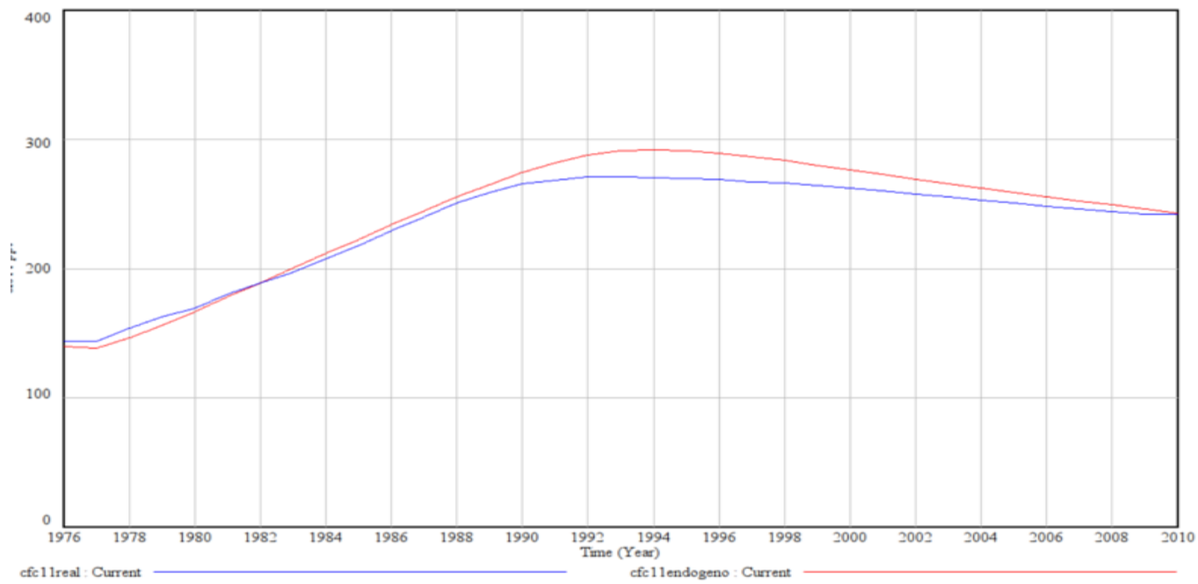

Figure 4: Data vs Simulation for CFC-11 without Mechanism Based on Trust. Data in Blue. Simulation in Red.

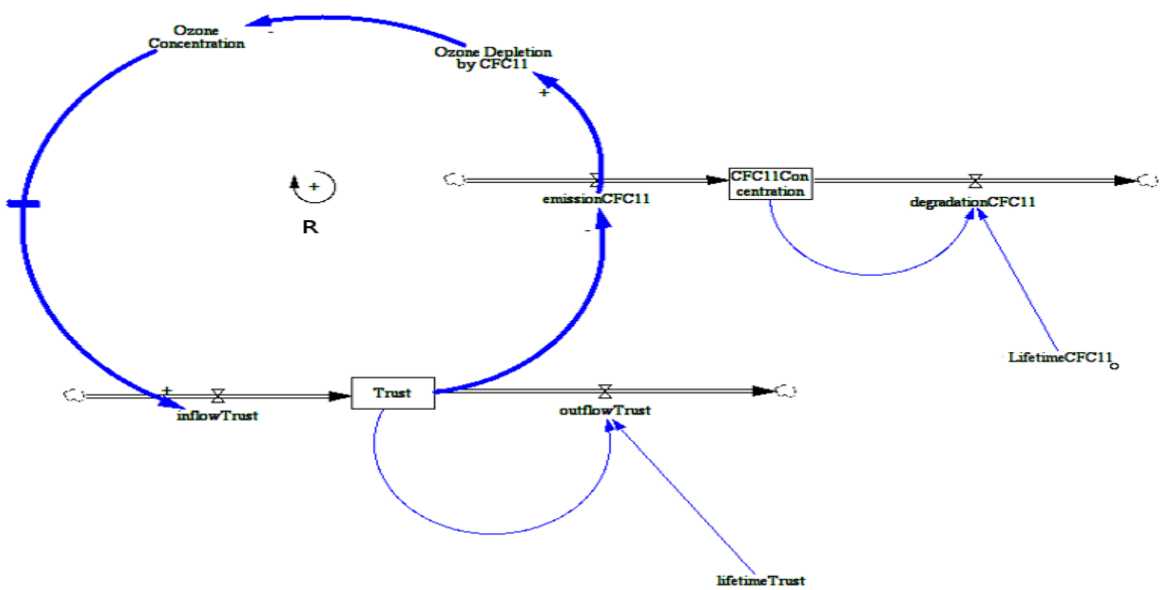

Figure 5: Dynamic Hypothesis about how cooperation based on trust can be applied in the Ozone Depletion Crisis.

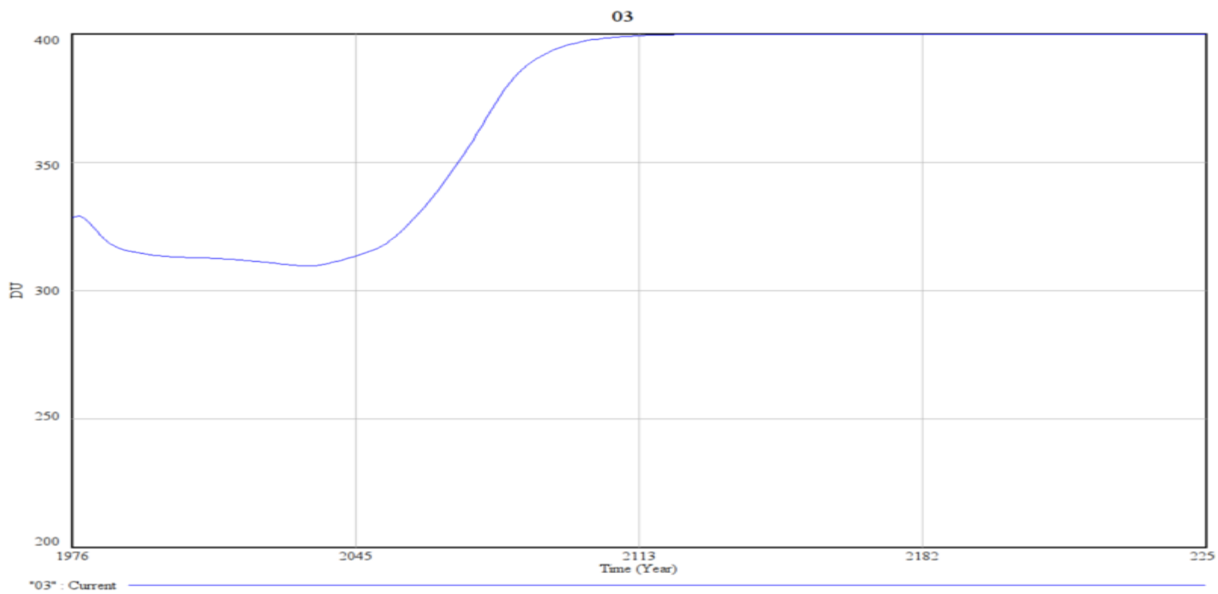

Figure 6: Simulation for a low requirement of trust.

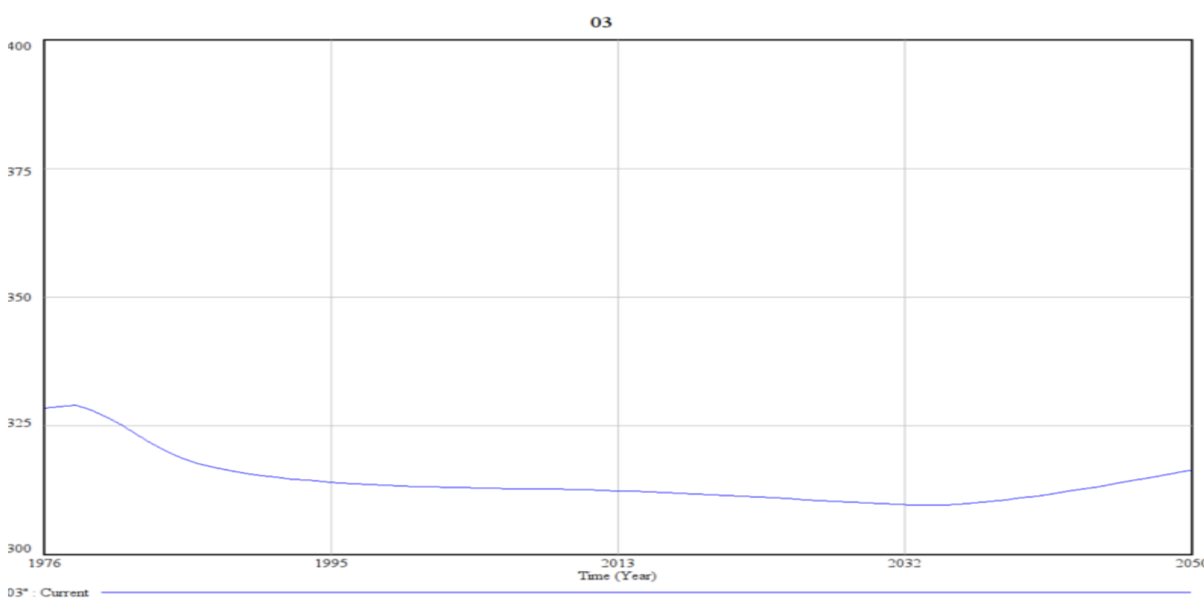

Figure 7: Simulation for a high requirement of trust.

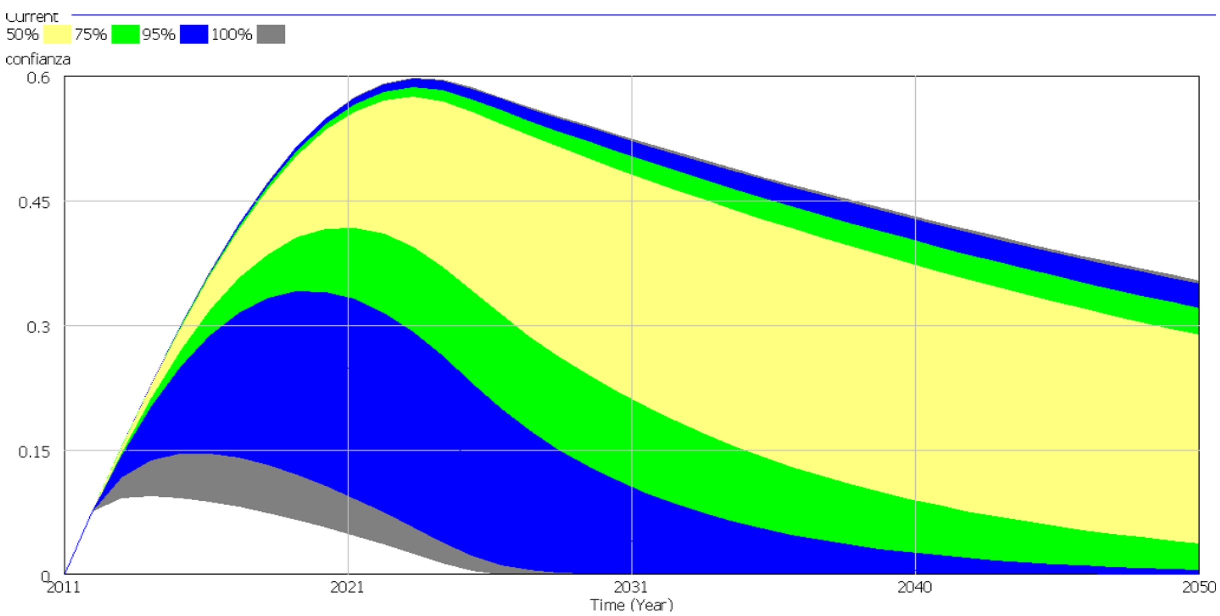

Figure 8: Sensitivity Analysis for Lifetime of Trust for Trust.

4 Discussion

We developed a system dynamics simulation model to test if cooperation based on trust in itself is able to keep high levels of cooperation in the Ozone depletion crisis. We did not find a study about the problem of keeping cooperation sustainable in large scale social dilemmas in the reviewed literature. Our model suggests that cooperation based on trust in itself is not able to keep cooperation in large-scale social dilemmas involving large information delays.

We found that cooperation based on trust is not a panacea. We understand that if we use cooperation based on trust, we need to ensure enough initial conditions for trust and good information feedback about the consequences of cooperation. If cooperation can not be related with an improvement of the shared resource, it is difficult for trust to maintain high levels of cooperation. In this case, delays of the information regarding the results of cooperation can reduce the effectiveness of cooperation based on trust.

We recognize the limitations of our model. It is simple, but we suggested that an even more complex model will produce the same general behavior because our model captures the main structural elements of the situation.

This learning is useful to design new institutions to solve large-scale social dilemmas. System dynamics can be used to test mechanisms to improve cooperation as an alternative to solve crises such as Ozone depletion.

5 Conclusion

We concluded that the initial conditions of trust and the difficulties for getting enough information feedback regarding past cooperation are problems which require other complementary mechanisms in the future. Finally, we suggested that to achieve sustainable cooperation in the Ozone Crisis we need to understand the inertia of chlorofluorocarbons (CFC) and their effect on cooperation.

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