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ARTIGOS

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The complexity of international climate cooperation

A complexidade da cooperação climática internacional

ABSTRACT:
Although there are several collective efforts to address the problem of climate change, the main initiatives, such as the Kyoto Protocol and the Paris Agreement, have not shown satisfactory results so far. The difficulty in engaging states into effective coordinated cooperative practices can be explained as a consequence of neoclassical rationality, given that the characterization of states as rationality-endowed entities bound them to situations like the Prisoners' Dilemma (PD) game and its related collective action dilemmas. There are models that provide ways to circumvent PD and foster cooperation among selfish rational agents, such as the application of strategies based on reciprocity (Tit-for-Tat) in iterated games. However, these approaches do not avoid the short-sighted neoclassical rationality that lies at the root of the problem. Thus, in order to develop more productive approaches to the development of global climate change policies, I present a characterization of the international political system as a complex adaptive system (CAS) and argue that this perspective, along with models based on evolutionary games rather than iterated games, provide a more promising approach.

Keywords: International climate cooperation; Game theory; Dilemmas of collective action; Neoclassical rationality; Complex adaptive systems

RESUMO:
Embora existam vários esforços coletivos para enfrentar o problema das mudanças climáticas, as principais iniciativas, como o Protocolo de Quioto e o Acordo de Paris, não têm apresentado resultados satisfatórios até o momento. A dificuldade em envolver os Estados em práticas cooperativas coordenadas efetivas pode ser explicada como consequência da racionalidade neoclássica, uma vez que a caracterização dos Estados como entidades dotadas de racionalidade os vincul a situações como o jogo do Dilema do Prisioneiro (DP), bem como os dilemas da ação coletiva relacionados a esse jogo. Existem modelos que fornecem maneiras de contornar o PD e promover a cooperação entre agentes racionais egoístas, como por exemplo a aplicação de estratégias baseadas na reciprocidade (Tit-for-Tat) em jogos iterados. No entanto, essas abordagens não evitam a racionalidade neoclássica de curto prazo, que está na raiz do problema. Assim, para desenvolver abordagens mais produtivas para o desenvolvimento de políticas globais para lidar com a mudança climática, apresento uma caracterização do sistema político internacional como um sistema adaptativo complexo (CAS) e argumento que essa perspectiva, acompanhada de modelos baseados em jogos evolutivos em vez de jogos iterados, fornece uma abordagem mais promissora.

Palavras-chave: Cooperação climática internacional; Teoria dos jogos; Dilemas da ação coletiva; Racionalidade neoclássica; Sistemas adaptativos complexos

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INTRODUCTION

Over the last decades, several initiatives have been undertaken to deal with the climate change issue. The 1992 Earth Summit marks the beginning of the recognition of climate change as a serious problem by the United Nations and established the UN Framework Convention on Climate Change (UNFCCC), a treaty that aims to prevent "dangerous anthropogenic interference with the climate system" (UNITED NATIONS, 1992). Although it has been recognized at least since 1992 that human activities do indeed contribute to climate change, the Kyoto Protocol, which was established in 1997 and entered into force in 2005, proved to be a flawed agreement with perhaps counterproductive results (ROSEN, 2015), perhaps dubious effectiveness (GRUNEWALD; MARTINEZ-ZARZOSO, 2015), in any way insufficient. Besides, current global mitigation ambition up to 2030 under the framework of Paris Agreement has been regarded by specialists as unable to achieve the 1.5 ^{o}C long-term temperature limit (GEIGES *et al*, 2020). Thus, despite the seriousness of the issue, it has been extremely difficult to achieve a legally binding treaty or at least an efficient global initiative to address global warming in a timely manner.

Given the gravity represented by climate change, it is worth asking why we face so many difficulties in implementing efficient collective action measures on the issue. After all, it is a situation that poses an existential threat not limited to affecting individual states and capable of reaching humanity as a whole. The state-centric logic of IR partially explains this problem, since the characterization of states as rationality-endowed entities bound them to the gloomy realm of Prisoners' Dilemma (PD). Thus, what human societies face with regard to the climate issue is a true collective action dilemma. According to Mancur Olson, when a group of individuals share the same interest, it would be reasonable to expect that collective actions would focus on achieving that interest. However, what happens is that individual agents seek the satisfaction of their own private interests and, therefore, they do not act in favor of the community (OLSON, 1971).

In 1968, the ecologist Garrett Harding coined the term Tragedy of the Commons (HARDIN, 1968) to sum up the idea that common resources are considered to be overexploitated by individual rational agents. Even if the negative collective result in the long term is fully known by these agents, they do not change their behavior in the short term. For Hardin, no "technical solution" would be feasible and the only way to get around the Tragedy of the Commons would be through some kind of cultural shift.

Formally, the Tragedy of the Commons is a problem of collective action that can be described

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as a PD, which consists of a mathematical model proposed by Melvin Drescher and Merrill Flood within the scope of the RAND corporation in the 1950s to study the delicate relationship between cooperation and competition between rational agents (RAPOPORT; CHAMMAH, 1965). In a PD, even though individual prisoners know that mutual cooperation provides a more beneficial outcome for both than mutual defect, short-term instrumental rationality and fear of receiving a sucker's payoff makes mutual defect inevitable. Besides, within the framework of the Tragedy of the Commons, an extensive and substantial free-riding behavior is also expected (OSTROM, 1999), which has also proved to be an obstacle to global initiatives for cooperation on the climate issue.

Although some solution attempts have been explored, for example in the form of an iterated DP (AXELROD, 2006), the problem of international cooperation between rational agents in an anachic environment remains as a theoretical conundrum in the academic field of IR. With regard to climate change, this theoretical problem has been expressed as an almost insurmountable challenge in terms of effective policymaking. Deep down, both the dilemmas of collective action and the Tragedy of the Commons (as well as the PD game itself) are inevitable expressions of the neoclassical conception of instrumental rationality (ZAFIROVSKY, 2008).

The purpose of this paper is to discuss the problem of international cooperation in the face of the seemingly insurmountable challenge of climate change. I claim that the problem posed by climate change is an example of a collective action dilemma resulting from the neoclassical conception of rationality. Hence, in order to develop more productive approaches to global climate change policies, I argue that it is necessary to consider how the international system relates to the global climate system. The characterization of the international political system as a complex adaptive system (CAS) naturally allows for this. Based on these considerations, I assess that traditional approaches to dealing with collective action dilemmas such as iterated PD (IPD) and reciprocity-based strategies such as Tit-for-Tat are insufficient and, instead, I suggest the use of evolutionary games.

In section 2, I present the relationship between collective action dilemmas and neoclassical rationality. In section 3, I contend that the depiction of the international relations as a complex system is more adequate to face problems such as climate change. Besides, evolutionary games are not binded to instrumental rationality and, thus, are more promising to model international environmental cooperation. In section 4, I present my conclusions.

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THE NEOCLASSICAL CONUNDRUM OF COLLECTIVE ACTION DILEMMAS

According to Stephen Gardiner (2006), the climate change problem presents an agency structure usually understood as a PD model that can manifest itself in the form of a free-rider problem or as a Tragedy of the Commons. In any case, what we have is a social dilemma (in the sense that agents are driven to an unavoidable non-cooperative sub-optimal or Pareto-inferior outcome).

Climate negotiations resemble pretty much a PD in practice. They occur in an anarchical environment because there is no overarching authority to enforce compliance. Hence, sovereign states cannot be forced to join or to adopt climate agreements (GAAST, 2018). Besides, we can consider that states are rational players that aim to maximize their utility (which corresponds, in economic terms, to reducing costs). The PD game can be represented by the pay-off matrix in Figure 1.

Figure 1 - Prisioners' Dilemma

		Player B	
		Cooperate	Defect
Player A	Cooperate	(3,3)	(1,4)
	Defect	(4,1)	(2,2)

Source: Author (2023)

In Figure 1, we can consider that Cooperate (C) refers to "reduce emissions" and Defect (D) corresponds to "do not reduce emissions". Or else C could denote "adopt restrictions" and D could be "do not adopt restrictions". What matters are not the names, but the relationship between the payoffs. It is considered that rational players do not play dominated strategies (NEUMANN; MORGENSTERN, 2007) and, clearly from the matrix in Figure 1, C is a dominated strategy because the payoff for playing C is strictly less than the payoff for playing D, regardless of the opponent's choices. Furthermore, mutual D is a Nash equilibrium (NASH, 1950, 1951) because no player would get a better result if s/he could unilaterally change his(er) strategy.

It is common to require, in PD, that players cannot communicate. After all, knowing the rules of the game and realizing that mutual cooperation provides better results than mutual defection, they could agree beforehand on mutual cooperation. I observe that the presence or absence of communication is irrelevant for the outcome of the PD. Rational players do not choose their strategies according to the collective outcome, but according to the need to maximize their own utility functions. Thus, if the players entered into a prior agreement for mutual cooperation, this would actually be an additional incentive to play D.

The problem (the dilemma) is that if both play D, then each individually receives a pay-off of 2 according to the matrix presented in Figure 1. In

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principle, mutual cooperation would be more advantageous than mutual defections, but rational players do not reason in terms of mutual choices due to restrictions imposed by methodological individualism. Besides, when playing games simultaneously, what is the guarantee that the other player will really cooperate?

In this way, the PD, as it is formulated, condemns the players to mutual defect. In fact, this is due to the definition of a rational player as a utility maximizer (ZAFIROVSKI, 2008). In terms of neoclassical rationality, players are individuals who make their decisions individually. They obviously take into account the expected actions of other players, but they don't consider how their own actions might benefit (or harm) them. It is important to observe that the neoclassical rational agent does not aim to benefit at the expense of others; he only acts guided by his individual preferences, regardless of the results that others will obtain in situations of strategic interaction.

Hardin's Tragedy of the Commons follows the same logic as the PD. Suppose that several rational agents have access to a shared resource, but each individually receives the profits arising from the exploitation of this resource. Let us consider, for example, that the resource is a pastur divided among several cow farmers, each one with *n* cows just to simplify the analysis (without loss of generality). If a given player decides to put one more cow in the pasture, the cost of keeping that additional cow, which corresponds to the portion of the pasture it consumes, is divided among all players. However, the earnings that this cow provides for the player are his alone. The same logic shows that it is rational to add a second cow, a third cow, and so on. Furthermore, all players face the same situation and all have incentives to increase their herds. As a consequence, the pasture is overexploited and depleted, leading to the death of the herds and the ruin of all.

Even knowing in advance that indiscriminate use of the common resource is a direct path to tragedy, no player has an incentive to keep the herd at a reasonable size. In addition to neoclassical rationality being defined in terms of utility maximization, neoclassical rational agents are short-sighted. The shadow of the future (AXELROD, 2006) means that, even if it is possible to predict negative consequences in the long term, decisions are always taken seeking to maximize gains in the shortest possible time.

One way out to avoid free-riding and perhaps to avoid the fatality of the Tragedy of the Commons would be to consider the global environmental policy game as a repeated or iterated PD (IPD). From a series of computational experiments, Robert Axelrod (2006) observed that, although the PD condemns players to mutual defect when played only once, repeating the game an in-

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definite amount of times could lead to the appearance of cooperative behaviors.

Axelrod's aim was to investigate the possibility of cooperation in a world of egoists without central authority and he based his analysis on the Iterated Prisoner's Dilemma (IPD). From computational simulations developed to compare the performance of several behavioural phenotypes, Axelrod found out that a phenotype based on reciprocity (Tit-for-Tat) could lead to the arisal of cooperation and he used these results to propose several ways to foster cooperation in anarchic environments. Thus, in an almost Pavlovian conditioning process, based on rewarding cooperation and punishing defection, individual agents could – without giving up their rationality – learn how to cooperate.

Considering an Iterated Prisoner’s Dilemma, the idea behind Tit-for-Tat strategy is that a given player (player A - the one which adopts Tit-for-Tat) always cooperates in the first encounter with another player (player B). In the next encounter between players A and B, player A will play with the behavior adopted by player B in the previous encounter (reciprocity). In this way, cooperative behavior is reinforced through rewards (bigger pay-offs).

The idea that repeated games could lead to institutionalized international regimes has been explored in the context of international environmental politics. Heitzig *et al* (2011) suggest a repeated public goods game in which players are able to keep each other in check and therefore avoid the free-riding problem. Regarding the possibility to embed climate commitments in international law, Tingley and Tomz (2014) identified significant support for extrinsic reciprocity (to punish climate defectors with economic sanctions), especially when treaties are involved.

However, the failure of the Kyoto Protocol and the difficulty in coordinating international cooperation to achieve temperature increase targets under the Paris Agreement show that, with regard to cooperation on climate issues, transforming Tit-for-Tat on concrete results has not been that easy. Although computational models based on repeated games draw attention to the possibility of cooperation in an anarchic environment, avoiding both free-riding and the Tragedy of the Commons, such models are algorithms based on operational assumptions and on an instrumental assumption of rationality.

The concept of rationality – generally linked to methodological individualism (UDEHN, 2001) - has never been monolithic in the course of modernity. According to Milan Zafirovski (2008), classical rationality, present in authors such as Adam Smith, in the context of the Scottish Enlightenment, was a more robust concept than neoclassical rationality, much more instrumental and technical, which ultimately came to be identified with

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mere utility-maximizing operations. Neoclassical rationality can be treated in formal terms from the axiomatization of preferences (MAS-COLELL, 1995) and it supports most models based on game theory, repeated or not.

The limitations of the neoclassical conception of rationality have been pointed out by other currents of thought that suggest more fruitful alternatives to deal with problems such as climate change. Ecological Economics, for example, considers agents as Political Economic Persons (PEP), that means, political beings instead of utility maximizers (SÖDERBAUM, 1999). Such characterization considers that individual actors have several roles and are embedded in a network of relationships. Besides, under the Ecological Economics perspective, institutions are not just constraints on behavior, but necessary structures for people to act (VATN, 2005).

Ecological Economics is not the only contemporary economic current that presents an alternative approach to rationality. Post-Keynesian Economics, for example, resort to habits and social factors to explain behaviors. Instead of neoclassical individual rationality, Post-Keynesians argue that rationality has a social dimension and it depends "not just on what I do or choose, but also on how others react to me and to my choices" (PRESSMAN, 2004, p. 490). From such a perspective, the environment is not a mere extension of the economy insofar as individual choices and actions produce social reactions.

According to Colin Wight, politics is the "terrain of competing ontologies" (WIGHT, 2006). Wight deals with the agent-structure problem from an ontological reading of the "methodological individualism versus methodological structuralism" issue. He remarks that the opposition between this views reflects an ontological question regarding the nature of the object of study: "what are its constituent elements and how are they interrelated?" (WIGHT, 2006, p. 63). Following Bhargava (1992) and Udehn (2001), Wight distinguishes between ontological individualism (the claim that only individuals exist) and methodological individualism (the weaker claim that only individuals can explain outcomes).

Anyway, Colin Wight's main point is that methodological choices have normative implications. Hence, when we adopt the methodological individualism of the neoclassical model of rationality to work with things ranging from simple strategic interactions to collective games involving several players in situations such as the Tragedy of the Commons, this choice is accompanied by a modern (neoclassical) characterization for the structure and ontology of the international political system.

To deal satisfactorily with issues such as climate change, however, we need more that a raw distinction between weak and strong method-

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ological individualism. We need an ontological framework which states that individuals must be understood in connection with their environments, that is, a framework which does not allow to consider isolated and atomized individuals and according to which individual actions and choices should be understood from their networks of relationships, both between individuals and between individual agents and the surrounding environment. Such an ontological perspective establishes that subjective relations come first.

Under this perspective, I claim that, in order to deal with problems such as climate change and global warming, a subjective relational ontology is more satisfactory as a characterization of international politics than the traditional modern neoclassical conception that considers individual agents as self-interested and utility maximizers that perform strategic interactions either at the domestic level (interest groups) or at the systemic level (states). In the following section, I present international politics as an example of a complex adaptive system, I defend the need for a relational ontology for international relations and, finally, I argue that evolutionary games – in the full sense of the term – are more adequate than repeated games to promote and coordinate international climate cooperation.

A COMPLEXITY SCIENCE APPROACH TO INTERNATIONAL RELATIONS

Since the appearance of the science of complex systems, particularly in the context of the Santa Fe Institute in the 1980s, some authors have drawn attention to the possibility of characterizing international politics as a complex system. Erika Cudworth and Stephen Hobden (2013) address the problem of agents and structures in IR and draw attention to its limited focus. Contrary to many structure-agency discussions, under a complexity perspective there is no such thing as an isolated system and the international system itself constantly interacts with several other systems, such as the global food production system and the environmental system. Cudworth and Hobden observe, correctly in my view, that "the human world overlaps with innumerable non-human systems, both animate and inanimate, which can impact and influence, and indeed radically change, the structures of the human world" (CUDWORTH; HOBDEN , 2013, p. 447). In this way, the realization that agencies of different natures interpenetrate in webs of relationships between the complex system of international relations and other complex systems opens up a promising analytical path for dealing

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with contemporary challenges as climate change.

Other authors have been engaged in characterizing IR as a complex system. Neil E. Harrison, for example, argues that complex systems concepts could improve our understanding of world politics and suggest new methods for advising policymakers (HARRISON, 2006). Walter C. Clemens Jr., in turn, contends that the nonlinar and unpredictable relations that occur among societies (and within them) exceed the capacity of the realist and idealist paradigm argues. He argues that a more fruitful approach could start from basic concepts of complexity science (CLEMENS JR., 2013). To cite one more example, Colin Wight states that, at the level of ontology, complexity science's concepts such as "emergence" and "organized complexity" are better to understand the international system (WIGHT, 2015).

In practical terms, social systems (and the system of international political relations can be regarded as a social system) are open systems constantly influenced by external stimuli that come from the surrounding environment as well as from other systems. They also present changing boundary conditions and agents which are continuously adapting their behavior according to environmental changes and learning processes (whether conscious or not).

What is a complex system in general and a complex adaptive system in particular? According to the physicist and Nobel Prize winner Murray Gell-Mann, one of the pioneers of the contemporary science of complexity:

> I favor a comprehensive point of view according to which the operation of CAS [Complex Adaptive System] encompasses such diverse processes as the prebiotic chemical reactions that produced life on Earth, biological evolution itself, the functioning of individual organisms and ecological communities, the operation of biological subsystems such as mammalian immune systems or human brains, aspects of human cultural evolution, and adaptive functioning of computer hardware and software. (GELL-MANN, 1999, p. 18)

Currently, there is no concise definition of a complex system and perhaps it is yet another essentially contested concept (GALLIE, 1956), but this time lying at the triple frontier between the humanities, the social sciences, and the natural sciences. It is possible, however, to identify several characteristics and properties shared by complex systems.

According to H. Moysés Nussenzveig (1999), complex systems are, primarily, non-linear dynamic systems constituted by a large number of units. Each unit establishes interactive relationships with a much smaller number of other units. They are open systems, that is, they interact with the environment (and with other complex systems), hierarchical and present emergent order (that is, they spontaneously self-organize, producing patterns of order).

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Thus, complex systems are composed of a large number of units and the local interactions and relationships that these individual components establish with each other. These local relations, through cooperation and competition effects, produce emergent collective properties capable of affecting the system as a whole.

Nussenzveig notes that so far we do not have a mathematical theory for complex systems. In fact, since the time of his text (1999) until now, we still do not have a mathematically rigorous foundation for complex systems, as we have, for example, for deterministic chaotic dynamical systems, which are based on the concept of sensitivity to initial conditions (that is, very small differences in the initial conditions are persistently magnified by the temporal dynamics of the system), an idea that is expressed through the Lyapunov coefficient (LYAPUNOV, 1992) and in the Poincaré–Bendixson theorem about the long-term behavior of continuous dynamical systems (CODDINGTON; LEVINSON, 1995).

The lack of a rigorous mathematical theory for complex systems raises the question of whether there is such a thing as complexity science in itself, rather than separated branches of several different sciences (LADYMAN *et al*, 2013). Despite the multitude of complexities, some properties are ubiquitous. Nonlinearity, feedback with regard to the interactions that the system establishes with its surroundings (as previously stated, complex systems are open), spontaneous order that arises from uncoordinated interactions between elements, lack of central control, emergence (in the sense that causal capacities of the whole system are not reducible to the intrinsic causal capacities of the component units), and hierarchical organization expressed in many levels of organization (SIMON, 1962).

Nussenzveig also draws attention to an important property of complex systems: learning capacity, that is, adaptability to environmental changes. This brings us to the so-called complex adaptive systems (CAS). In this sense, a CAS resembles biological evolution by means of natural selection. According to Simon A. Levin, the three properties which define a complex adaptive system are:

> (…) diversity and individuality of components, localised interactions among those components and an autonomous process that uses the outcomes of those interactions to select a subset of those components for replication or enhancement. (LEVIN, 2002, p. 4)

The first property depicts the individualities which are present in a complex system. The second property remarks that individual agents tend to interact mostly with their proximate neighbours (long distance interactions are possible, but rare). Finally, the third property describes the connection to the adaptive evolutionary logic: selection

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for replication, according to suited adaptation to environmental changes. Hence, a CAS is a complex system whose parts can also evolve and adapt to a changing environment.

Thus, it is arguable that relation is the most fundamental concept in an adaptive complex system. According to Hayward Alker, relations establish connections and disconnections between objects in a world that unites “phenomenologies and ontologies, with plenty of room for moral imperatives, political and ontological differences, and inter-subjectively shareable historical learning” (ALKER, 2008, p. 320). Hence, the concept of relation allows to study the complex nonlinear connections between purposively-driven agents. Besides, those agents can be rational or not – and this is pertinent because a relational ontology describes models that resemble networks, in which we are more interested in the interrelationships than in isolated individuals, and it is more adequate to describe a CAS than methodological individualism. In this way, the characterization of international relations as a CAS does not oblige to adopt the modern neoclassical perspective for rationality.

Besides, a subjective relational ontology, in contrast to the individualist perspective of neoclassical rationality, finds good ground for dialogue with proposals from contemporary political theory. According to William Connolly:

> (…) an extended “we” may be in the works, a “we” creatively composed of diverse constituencies set in a variety of world regions, faiths, classes, and other subject positions. Each invites others to enter into a loose assemblage as it also retains a distinctive sense of time, place, belonging, suffering, and possibility. (CONNOLLY, 2017, p. 121)

Connolly asserts that the acceleration of climate change and other planetary crises occurs at the same time that we become aware of the "human entanglements with multiple beings and forces with diverse lives and tendencies" (CONNOLLY, 2017, p. 122). His notion of an entangled humanism is heavily inspired by complexity theory and highlights the relationships between our species and other species and forces. From a traditional and neoclassical framework, these relationships are invisible. Connolly’s entanglement refers precisely to the relationships we establish between political agents and also with agents of other natures, thus reflecting the possibility of thinking about global politics as a complex system that constantly interacts with other complex systems.

To adequately address the challenges that contemporary environmental crises pose to us, it is important to consider the complexity of international relations that comprise not only individuals deciding in pursuit of their self-interests, but also links between human societies/communities and

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the natural environment.This is why solutions based on reciprocity strategies such as Tit-for-Tat are insufficient. The iterated PD preserves the neo-classical rationality framework and we need to take into account not only how agents behave in their relationships with each other, but also how they respond and how they adapt to changes that occur in the surrounding environment.

Thus, despite being inspired by adaptive evolution, Axelrod's IPD model operates on a closed system and it does not take into account the role of environmental changes. Regarding adaptive evolution as a complex adaptive system requires an open system that takes into account environmental challenges. I suggest, therefore, that evolutionary games are more adequate than iterated games to face the problem of how to engage and coordinate political agents in global initiatives against climate change and other current challenging situations.

Evolutionary Game Theory (EGT) began with John Maynard Smith and G. R. Price's 1973 paper entitled *The Logic of Animal Conflict*. J. Maynard Smith further developed the subject in two essays published in 1974 and in 1976, and respectively entitled *The theory of games and the evolution of animal conflicts* (MAYNARD SMITH, 1974) and *Evolution and the Theory of Games* (MAYNARD SMITH, 1976). In 1982, Maynard Smith published the book *Evolution and the Theory of Games*, in which he presented the advances achieved in the first decade of the applications of the theory of games to the study of biological evolution (MAYNARD SMITH, 1982).

In The Logic of Animal Conflict, J. Maynard Smith and G. R. Price (1973) used computer simulations of evolutionary games in order to study simple formal models of conflict situations. They found out that Retaliator, a limited-war behavior that always begin with cooperation and that reciprocates in the following rounds, was the only one that showed evolutionary stability (MAYNARD SMITH; PRICE, 1973, p. 16). It is important to notice that evolutionary games – in John Maynard Smith's sense – do not require rational players. Hence, unlike what happens in models based on iterated games such as Axelrod's proposal, evolutionary games do not demand the assumption of neoclassical rationality.

In EGT, the selective forces which act on a population are represented by a fitness function, which is then analysed according to the concept of an evolutionarily stable strategy or ESS, that is, a behavior strategy that cannot be replaced or invaded by a different strategy through a “natural” process of selection (COWDEN, 2012). In traditional game theory, agents make their choices seeking to maximize their utility (which can correspond to profits or to political survival, among other examples). Even though rational agents can change their

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preferences, we assume that they do not do so in the course of a game. In the case of evolutionary games, players' behaviors can respond to environmental changes and selective pressures. Thus, agents adapt their strategies according to the feedback they receive from the environment, in a process of co-constitution between agents and structure that resembles biological evolution by natural selection.

For example, emission reduction strategies have been studied in recent years to tackle the global climate problem. Xue *et al* (2022) use a model based on evolutionary games to investigate the dynamic effects of carbon reduction policies. They came to the conclusion that the benefits for companies are greater with the adoption of carbon emission reduction strategies. Furthermore, even when the costs of adopting carbon emission reduction strategies are higher, enterprises prefer to adopt them when the government adopts a carbon trading policy.

The analysis by Xue et al illustrates how the EGT allows evaluating the coordination of strategies between players of different natures (in this case, companies and governments). The same type of analysis has been employed to study the evolutionary relationships between governments and manufacturers under dynamic carbon trading pricing policies (ZHANG *et al*, 2019). Along a similar line, Rocha and Salomão (2019) present an evolutionary game to study the interplay between polluting firms and auditors and contend that EGT seems to provide an appropriate framework to model long-term environmental culture change in corporations, and Miao *et al* (2014) applied EGT to study the analysis of optimal allocation for water resources. In more general terms, Luqman et al developed an EGT model based on the blame game of Ellingsen and Östling (2011) with a rewards-penalties scenario at the global level to provide a self-enforcing international environmental agreement capable of overcoming both the free rider and renegotiation problems (LUQMAN *et al*, 2022). It is pertinent to mention that Luqman et al explicitly stated that they adopted an evolutionary perspective because it enables to avoid the rationality assumption present in traditional game theory.

In short, EGT has been used in recent times to model specific and general situations with regard to carbon emission reduction policies, water resources allocations, adherence to international environmental agreements, among others. In contrast to game theory in its neoclassical version, EGT requires neither a stance based on methodological individualism nor the adoption of the assumption of the instrumental rationality that guides neoclassical thinking. Furthermore, EGT emerged to model biological adaptive evolution,

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that is, an example of a complex adaptive system. Thus, the characterization of international relations as a CAS influenced by other complex systems (such as the environment itself) presents an adequate conceptual framework to face not only the problem of climate change, but also other problems we face in contemporary times.

CONCLUSIONS

In this work, I addressed the obstacles represented by the dilemmas of collective action for the formulation and implementation of global policies against climate change and global warming. From a modern neoclassical conception of rationality, which considers individual agents as self-interested utility maximizers, the PD is inevitable and, in its collective version, we face the scenario of the Tragedy of the Commons.

Although there are some formal approaches dedicated to overcoming the Tragedy of the Commons and the free-riding problem, such as the iterated version of the PD with the adoption of a strategy based on reciprocity (Tit-for-Tat), in practice main international cooperation initiatives against climate threat have shown insufficient or unsatisfactory results.

I argue that this stems from the neoclassical conception of rationality that does not adequately describe the way in which international relations operate in contemporary times, even more so in light of the problem of climate change. Thus, I defend the need to describe international relations as a CAS and, instead of using approaches such as the IPD to deal with the problems of international cooperation on climate issues, I argue that evolutionary games, which are not necessarily linked to neoclassical rationality, are more promising to deal with the challenges posed by international environmental cooperation.

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