Coopetitive games for Environmental Sustainability: Climate Change and Decision Global Policies

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Abstract

In this work, we propose and analyze a coopetitive model for the Climate Change environmental sustainability: a global duopoly type game structure, involving a generic type of green technological good. Our model allows to select certain strategy profile solutions within a continuous horizon of possible global scenarios, in the context of the Paris agreement COP21 and after Trump's decision to abandon the agreement itself. More specifically, we construct a parametric coopetitive game with two great actors, US and the group of countries which still agree to COP21. The two actors of our duopoly game compete on the global market by producing and selling green technological goods (for example: electric cars, electric airplanes, hydrogen cars, solar panels, low impact batteries for smart houses, electric cars or self phones, and so on). Our multi-dimensional coopetitive model suggests possible cooperative strategies in order to improve the efficiency and strength of the actions enforced by the countries to mitigate the Climate Change catastrophic risk at the level of its causes and effects.[1]

Keywords: Environmental Sustainability, Climate change, Coopetitive games,

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Green-growth indicator, Green technologies, Paris Agreement COP21.

1. Introduction

In 2018 Romer and Nordhaus received the Nobel Prize for work on Climate change and growth because they 'significantly broadened the scope of economic analysis by constructing quantitative models that explain how the market economy interacts with nature and knowledge'.

Against climate change and environmental issues, the green economy, that is defined as an economy with low carbon emissions, efficient use of resources and social inclusivity (according to the United Nations Environment Program), represents a key tool. A survey of green economy and related questions is offered in Heshmati (2014) and Loiseau et al. (2016), whereas Georgeson et al. review the concept of global green economy Georgeson et al. (2017). In Musango et al. (2014), we find an exam of the effects determined by technology policies. Anbumozhi et al. offer an analysis of the concept of low-carbon green growth and state-of-the-art policies in emerging economies in order to attain regional cooperation for green growth Anbumozhi et al. (2016). Green economy for sustainable development at a global level is emphasized by Carfi and Schilirò Carfí & Schiliró (2012b) and by Vargas et al. Vargas Pineda et al. (2017). Maler adopts a game-theory model based on the theory of cooperative games for analyze international environmental agreements and environmental problems Mäler (1989). Barret, instead, discusses global environmental problems applying concepts of game theory to explore the properties of international environmental agreements Barret (2014).

For what concerns the Paris agreement (see United Nations (2015)), Kompas et al. apply a large-scale and intertemporal computational general equilibrium (CGE) model to account for the various effects of global warming (e.g., loss in agricultural productivity, sea level rise, and health effects) on Gross Domestic Product (GDP) growth and levels for 139 countries over the long-term. These authors estimate the economic gains from complying with the Paris agreement for 139 countries, concluding that such gains are substantial Kompas et al. (2018). We follow this line of analysis and thought for construction of our model and the choice of possible Pareto solutions. However, our paper creates a precise game-theory dynamic path, by applying the notion of 'coopetition', which generates a parametric curve of non-cooperative games with a tuning participation level determined by the carbon emissions of each country. The idea of 'coopetition' was devised by Brandenburger and Nalebuff that argued that game theory can be useful for analyzing coopetitive situations Brandenburger & Nalebuff (1995, 1996). In this regard, Carfì and Okura discussed the use of game-theory models in coopetition studies Carfí & Okura (2014) and Carfì applied coopetition to several economic issues (Carfí & Schiliró (2012a); Carfì & Donato (2018, 2019b); Donato et al. (2018)).

We construct a game theory coopetitive model with two actors, USA and the group of countries which still agree to COP21, following the initial idea proposed in Carfì et al. (2019). The two actors of our duopoly game compete on the global market by producing and selling green technology goods (for example, electric cars, hydrogen cars, solar panels, low impact batteries for smart houses, big electric drones and so on).

With respect to a previous work (Carfì et al. (2019)), now we assume more realistic payoff functions, introducing new cooperative translation terms (see 2.3.3). Moreover, here we propose a way to calculate the green-growth indicator m_c, for every country c. We assume that the composite indicator m_c is influenced and determined by some quantitative statistical variables belonging to the following fields: environmental and resource productivity; environmental dimension of quality of life; economic opportunities and policy responses.

Our coopetitive model underlines possible strategy paths within a competitive global arena in order to:

- improve the actions enforced by all countries to mitigate the climate change catastrophic risk, at the level of its causes and effects;
- develop more efficient green tech;

- mitigate the air pollution issue;
- trigger a global sustainable growth.

2. The model

Our model considers two agents. The first player of the game is represented by United States, a country that has frozen its participation to the agreement COP21. US is now free to produce energy following a non-green production function, not supporting a green-tech production, research and development. However, an inevitable significant portion of green energy and green technology will be produced. The second player W is the set of countries that joined COP21 and still remain in the agreement. These W countries accept to adopt green energy production and green technology production. They need to reduce the greenhouse gases, according to the own goal established, one for each, by the COP21 agreement (see Table 1).

2.1. Indicators of the model

2.1.1. Participation index a

Given the goal established, one for each country c, by the COP21 agreement (see Table 1), appears possible to establish the index of participation of each country c. This index can be estimated as

$$a_c(t) = b_c(t)/b_c^* \tag{1}$$

where

- $b_c(t)$ represents the percentage of domestic reduction of greenhouse gases at time t compared to t_0 levels (the initial time of the agreement for the country c) and is defined as

$$b_c(t) = (e_c(t_0) – e_c(t))/e_c(t_0), \tag{2}$$

where

- $e_c(t_0)$ is the absolute value of emissions of country c in t_0,
- $e_c(t)$ is the absolute value of emissions at time t in $[t_0, t_f]$,

- b_c^* represents the percentage of reduction imposed for each country c by the COP21 agreement and is defined as

$$b_c^* = (e_c(t_0) - e_c(t_f))/e_c(t_0). \tag{3}$$

In our model we assume that the group of countries W totally fulfills the COP21 agreement targets and produces enough energy, adopting a green energy production function, while developing advanced and efficient green technology, in order to reduce the greenhouses emissions exactly according to the percentages indicated by each own goal. On the contrary, we consider the US participation index as an aleatory parameter that could assume, at the final time t_f, every value. In particular:

- $a_U = 0$, i.e. index of participation of 0% to the Paris Agreement;
- $a_U = 1$, i.e. index of participation of 100% to the Paris Agreement;
- $0 < a_U < 1$, i.e. index of participation between 0% and 100%;
- $a_U < 0$, i.e. index of participation less than 0%, in the sense that the domestic greenhouse gases increase in t_f compared to the value at time t_0 (use of highly polluting methodologies);
- $a_U > 1$, i.e. index of participation greater than 100% to the Paris Agreement, that is a domestic reduction in greenhouse gases in t_f greater than the established value.

2.1.2. Green-growth indicator

We construct our original composite indicator for each country c by using the following statistical variables (source OECD):

1. Renewable electricity (% total electricity generation)

Table 1: Some targets of COP21 Paris agreement

Country	Goals of COP21 agreement
EU	at least a 40% domestic reduction in greenhouse gases by 2030 compared to 1990 levels
Russia	25-30% domestic reduction in greenhouse gases by 2030 compared to 1990 levels
Canada	a 30% reduction on 2005 greenhouse gas emissions, by 2030
China	to source 20% of its energy from low-carbon sources by 2030 and to cut emissions per unit of GDP by 60-65% of 2005 levels by 2030
Japan	a 26% reduction in emissions on 2013 levels by 2030
Brazil	a 37% reduction in emissions by 2025, compared to 2005 levels, with a further indicative target of a 43% reduction in emissions by 2030
Indonesia	a 29% reduction in emissions by 2030, compared to business as usual
Australia	a 26 to 28% reduction in emissions by 2030 on 2005 levels
India	a 33-35%reduction in emissions intensity by 2030, compared to 2005 levels
United States	a 26-28% domestic reduction in greenhouse gases by 2025 compared to 2005 levels

2. Mortality from exposure to outdoor PM2.5 and ozone (per 1000 000 inhabitants)
3. Mean population exposure to PM2.5 (micrograms per cubic meter)
4. Development of environment-related technologies (% all technologies)
5. Environmentally related tax revenue (% of GDP)
6. ODA – climate change mitigation (% total ODA)
7. Diesel tax (USD per litre)
8. Municipal waste generated (Kg per capita)

These variables belong to the fields of environmental and resource productivity, environmental dimension of quality of life and economic opportunities and policy responses.

Once we have chosen the variables contributing to our evaluation of the green-growth composite indicator and for which we possess a complete series of data, we can determine m_c for each country, through a simple linear aggregate analysis after renormalization.

2.2. Strategies of the model

Strategies x of US (United States), denoting the total production of a certain green technology offered on the global market by US, according to the general principles of a Cournot duopoly model determined by US and the 2^{nd} player W. Any real number x is belonging to the canonical unit interval

$$E := U = [0, 1].$$

Strategies y of the player W (countries that join COP 21 in Paris), denoting the production of the same green technological good, produced, supplied and sold in the Market by player W, in a duopoly economic model with player US. Any real number y is belonging to the same unit interval

$$F := U = [0, 1].$$

Strategies z, representing the coopetitive strategies that must be chosen by 1^{st} and 2^{nd} player together. It represents the common shared investment in developing innovative green technologies, also for the production of green energy. A real number z is belonging to the unit interval

$$C := U = [0, 1],$$

and represents the aggregate investment of US and W for new innovative green technologies.

2.3. *Payoff function of the model*

2.3.1. *Assumption 1.*

We assume the payoff function of US is the function $f_1(.; a)$ of the unit cube U_3 into the real line, defined by

$$f_1(x, y, z; a) = x(1 - (2 - a)x - y) + v_1(z, a) \tag{4}$$

for every triple (x, y, z) in the 3-cube U_3 and for every value of parameter $a = a_U$, which we consider as representing a possible *state of nature*, where

$$\begin{aligned} v_1(z, a) &= (a_U + m_U)z, \text{ if } a_U + m_U > 0 \\ v_1(z, a) &= (a_U + m_U)(1 - z), \text{ if } a_U + m_U < 0 \end{aligned}$$

for a fixed real green-growth indicator m_U.

2.3.2. *Assumption 2.*

We assume the payoff function of the group of countries W is the function $f_2(.; a)$ of the unit cube U_3 into the real line, defined by

$$f_2(x, y, z; a) = y(1 - x - y) + v_2(z, a) \tag{5}$$

for every triple (x, y, z) in the 3-cube U_3 and for every value of the parameter $a = a_U$, where

$$\begin{aligned} v_2(z, a) &= (a_U + m_W)z, \text{ if } a_U + m_W > 0 \\ v_2(z, a) &= (a_U + m_W)(1 - z), \text{ if } a_U + m_W < 0 \end{aligned}$$

for a fixed real green-growth indicator m_W representing all the countries W.

We recall that in our model the participation index of the second player could be assumed ideally constant and equal to 1. Note that the participation index a_U, of the first player, influences also the payoff function of the second player (by the translation vector v), while the green-growth indicator m_U does not.

2.3.3. *Interpretation of the payoff functions.*

In our model, we choose a perturbed asymmetric Cournot duopoly payoff function with a cooperative translation. We decide to model the competitive aspects of the interaction between the two subjects as a normalized duopoly "a la Cournot". We consider that choice as a quite reasonable way to figure out such a global scenario (for a complete study of symmetric and asymmetric Cournot duopoly see Carfí & Perrone (2013)). The perturbation in the Cournot core

$$g_1(x, y, z; a) = x(1 - (2 - a)x - y),$$

is determined by the state of nature a. We assume here that the parameter a determines a positive influence at the level of the characteristic coefficient $(2 - a)$. The perturbation of the classic normalized Cournot duopoly payoff

$$c_1(x, y, z) = x(1 - x - y),$$

reveals indeed simply linear. We prefer dealing with linear perturbations because every possible perturbation can be approximated, in the short run, by linear functions. A more extensive analysis would require non-linear perturbations. On the other hand, the translating term v_1, defined by

$$\begin{aligned} v_1(z, a) &= (a_U + m_U)z, \quad \text{if } a_U + m_U > 0 \\ v_1(z, a) &= (a_U + m_U)(1 - z), \quad \text{if } a_U + m_U < 0, \end{aligned}$$

for a fixed real green-growth indicator m_U, is supposed piecewise-linear, continuous, with a double definition:

- for a positive aggregate determination of the two terms a, m, the cooperative translation is positive, linear and increasing,

Table 2: US Greenhouse gases in Tonnes of CO_2 equivalent, Thousands. Source: OECD (2019a)

Year	US Gas emissions
2005	7 320 276.715
2008	7 145 128.588
2011	6 771 119.194
2014	6 763 141.326
2016	6 511 302.422

- on the opposite case, the cooperative translation reveals negative, linear and increasing as well.

The double definition succeeds in modeling a positive effect of the cooperative variable z, even if the aggregate term $a+m$ reveals negative. Analogous considerations can be repeated for the second payoff function, which is simpler because it presents an unperturbed Cournot duopoly core.

3. Materials and determination of indicators

We propose the study of the game at time $t = 16$ (year 2016). We, so, evaluate the indicators a_U, m_U and m_W in 2016, but the model could be studied at any time in $[t_0, t_f]$. Moreover, we now consider as the second player only the countries of EU15; so, we determine m_W as a simple mean of the m_c of those fifteen countries. We use data of US greenhouse gases (source OECD (2019a)) to determine the parameter a_U, as follows in Table 2.

The percentage of emission reduction established by the COP21 agreement for US is 28% in 2025, with respect to the 2005 levels, so, b_U^* equals 0.28 (see Table 1). The value $b_U(16)$ in 2016 is 0.11, with respect to 2005. So, we obtain the value

$$a_U(16) = b_U(16)/b_U^* = 0.39.$$

In Table 3, we show the value of the eight variables used for the determination of the green-growth parameter m_c, for the United States and for the countries of EU15. The minus sign implies that the associated variables negatively contribute to the determination of our composite indicator m_c.

We have normalized all our data with a certain weight system and we have obtained the indicator m_c through a simple linear aggregate analysis. We find values between 0.64 for Sweden and -0.35 for Greece with a mean value for EU15 countries of $m_W = 0.11$. The value of m_U for US, instead, equals -0.79.

4. Results and discussion

We have completely studied the game defined by eq. 4 and 5. In Figure 1, we show (in continuous representation) the payoff space of our game, with $a_U = 0.39$, $m_W = 0.11$ and $m_U = -0.79$, when the coopetitive strategy z varies in [0,1]. Moreover, we see the dashed boundary of the payoff space, in the cases $0 < a_U < 1$, $0 < z < 1$, with $m_U = m_W = 0$. As we see, even with the maximum value of z, the continuous boundary payoff stays on the left of the dashed payoff. This result is due to the low value of a_U in the continuous case. The positive value of m_W shifts the payoff space upward, while the negative value of m_U moves the payoff space to the left.

We propose, as solution of the game, the purely coopetitive solution. We first study the Nash equilibria.

The Nash equilibria trajectory, with respect to the parameter a_U in [0,1], in the strategy space $S = E \times F$, is the image of the parametric curve

$$N : [0,1] \to S : a_U \to N(a_U) = \left(-\frac{1}{4a_U - 7}, \frac{2a_U - 3}{4a_U - 7} \right).$$

In our case the parameter a_U equals 0.39 =39% (see section 3 for the calculation of this percentage). So, the Nash equilibrium is:

$$\begin{aligned} N(0.39) &= \left(-\frac{1}{4 \times 0.39 - 7}, \frac{2 \times 0.39 - 3}{4 \times 0.39 - 7} \right) = \\ &= (0.18, 0.41). \end{aligned}$$

Table 3: Selected data for the determination of green-growth indicator. Source: OECD (2019b)

Country	(1) (%)	(2) (/1 mln hab)	(3) (mg/m^3)	(4) (%)	(5) (%)	(6) (%)	(7) (USD/litre)	(8) (Kg/cap)
AUT	77.65	-396.47	-15.70	10.42	2.88	4.54	0.44	-559.76
BEL	16.46	-460.45	-14.90	9.73	2.03	9.94	0.47	-425.52
DNK	60.64	-339.52	-10.62	19.27	4.11	8.43	0.38	-785.68
FIN	44.51	-205.60	-6.02	12.30	2.88	3.93	0.51	-481.69
FRA	17.34	-268.68	-12.65	11.64	1.97	23.16	0.49	-519.32
DEU	29.28	-474.55	-14.26	11.62	1.94	22.39	0.55	-627.10
GRC	30.47	-572.58	-17.68	8.01	2.77	0.45	0.45	-471.83
IRL	24.35	-235.92	-6.65	5.70	2.17	11.31	0.54	-558.86
ITA	38.07	-459.86	-19.99	9.28	3.85	2.21	0.75	-497.64
LUX	58.23	-321.20	-11.92	12.02	2.00	12.53	0.33	-625.81
NLD	12.94	-395.95	-15.14	7.75	3.35	6.99	0.52	-526.60
PRT	52.84	-370.34	-10.63	4.82	2.20	1.29	0.56	-449.85
ESP	38.58	-305.68	-12.29	11.21	1.89	0.57	0.48	-447.88
SWE	56.65	-149.65	-6.98	12.12	2.21	9.79	0.49	-438.24
GBR	24.66	-388.70	-10.68	11.02	2.32	8.94	0.74	-478.82
US	14.87	-327.81	-10.87	10.22	0.72	0.47	0.12	-737.98

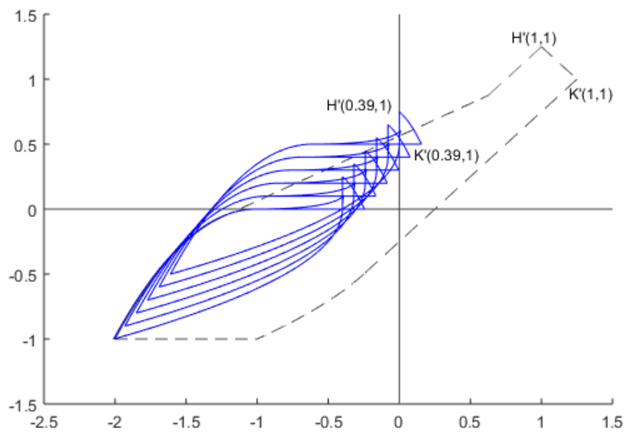

Figure 1: Comparison of two payoff spaces

The purely coopetitve solution, in the payoff space, is represented by the point

$$N'(0.39, 1) = \max_{z \in C} f(N(0.39), z)$$

and the corresponding solution in the strategy space $E \times F \times C$ is given by

$$P(0.39) = (0.18, 0.41, 1).$$

The profile strategy $P(0.39)$ indicates that

- US should produce, supply and sell in the Market a quantity of green technological good of 0.18 in the strategy interval E=[0,1];
- W countries should produce, supply and sell in the Market a quantity of the same green technological good of 0.41 in the strategy interval F=[0,1];
- US and W should invest a maximum quantity of the strategy interval C=[0,1] for developing new innovative green technologies.

In Figure 2, we propose the comparison of the Nash payoff $N'(0.39, 1)$ with the Nash payoff $N'(1, 1)$ of a better situation in which $a_U = 1$. It appears clear that the purely coopetitive solution in the latter case is by far significantly better. From this observation, the conclusions and economic implications easily follow.

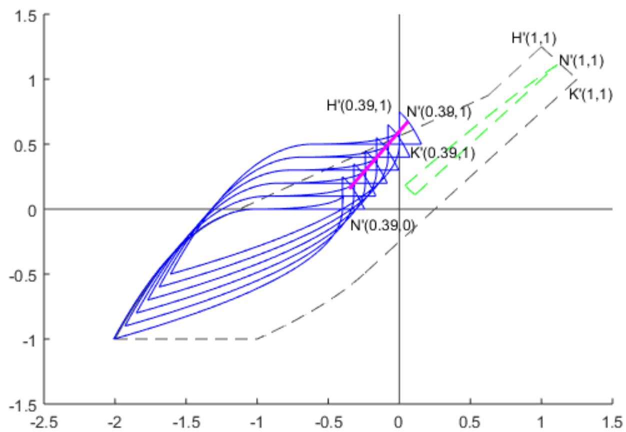

Figure 2: Nash equilibria trajectory

5. Conclusions

We have here proposed a coopetitive model aimed to mitigate the risk of Climate Change and its catastrophic effects: a complex duopoly-type interaction setting at a global level, based on the production of a green technological good. We have constructed a model of interaction between countries involved in the Paris agreement COP21. We have suggested how the cooperation in the development of new green technologies determine gains for all the countries and for the environment. We have used econometric tools for obtaining a green growth composite indicator m_c for every country c and we determined a parameter a_U representing an index of US participation to Paris agreement. We have suggested a coopetitive strategy solution of our game (for a continuum of future possible global scenarios) that could trigger economic growth and effectively contrast Climate Change, in the context of the Paris agreement COP21, after Trump's decision to abandon the agreement itself.

5.1. Limitations, drawbacks and further research

A first limitation of our paper consists in the specific two conditions in which we have studied the game and calculated its solutions:

- the unique time of analysis $t = 16$ (year 2016);
- second player W is constituted only by countries of EU15.

At this purpose, we observe that the game could be studied at any time in $[t_0, t_f]$ and for every other country in the agreement.

A second limitation consists in assuming the respect of the goals imposed by the agreement for the countries constituting the second player. However, it is possible to model the partial success in respecting the agreement of the participating countries, introducing a term a_W in the payoff functions of the players. That additional parameter a_W would determine a perturbation also in the Cournot duopoly function f_2.

A third limitation consists in preferring to deal with linear perturbations in the cooperative translations, although every possible perturbation can be approximated, in the short run, by linear functions. Of course, we may assume non-linear relations between investments z in green-technologies and the gains of the players.

A final limitation of our analysis concerns the chosen *deterministic nature* of the parameter a. A probabilistic approach would be more suitable and that could constitute a development of plans for future researches (for instance a Bayesian approach, following the lines of Carfì & Donato (2019a).

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