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An environmentally sustainable global economy.

A coopetitive model

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Abstract

This paper proposes a model representing a global economy which aims to become environmentally sustainable. The model looks both at the production side and the consumption side of the economy. Regarding the production side, the suggested model considers investment and innovation in climate technologies, whereas on the side of the consumption it takes into account economic and policy instruments to change the patterns of consumption of the households. The model follows a game theory approach and applies a theoretical framework à la Cournot. The results of the paper are the following: the model provides win-win solutions, namely strategic situations in which each country takes advantages by cooperating and competing at the same time within the global economy, and where each country gets a positive return. In fact, the model shows the convenience for each country to cooperate and suggests the implementation of policies in order to satisfy the basic requirements of 2030 Agenda for Sustainable Development, in terms of production, consumption and climate change.

Keywords: Climate Change; Environmental Sustainability; Model à la Cournot; Coopetitive Games; Green Economy

Jel classification: Q40, Q48, Q50, C71, C72, C78

1. Introduction

The paper starts from the conclusion of the Paris agreement COP21 of December 2015 aiming at controlling carbon emissions, since "climate change is an urgent and irreversible threat to human societies and to the planet". The agreement, signed by 195 countries, asks for the maximum cooperation of all countries. In addition, the paper takes into account the targets of *2030 Agenda for Sustainable Development* of the United Nations for a better quality of life. This is why we propose a co-petitive model where cooperation is essential, but also competition is necessary, since the countries are competing in the markets. We have already developed a co-petitive model applying to a green economy. Carfi and Schilirò (2012a): 'A co-petitive model for the green economy', but it focused mainly on the production side by developing a strategy regarding low-carbon technologies.

This paper represents a global economy which aims to become environmentally sustainable, but it looks both at the production side and the consumption side. Regarding the production side, the suggested model considers investment and innovation in climate technologies, whereas on the consumption side it takes

into account economic and policy instruments to change the patterns of consumption of the households. The model follows a game theoretic approach and applies a theoretical framework *à la Cournot*.

Although game-theoretical models are not systematically applied in cooperation studies, Game Theory has proved to be extremely useful for cooperation analysis. For example, Brandenburger and Nalebuff (1995, 1996) argued that game theory is useful for understanding co-competitive situations. Clarke-Hill et al. (2003), Rodrigues et al. (2011), Stiles (2001) applied game theory for investigating strategic cooperation. Other authors have faced the problem of cooperation and competition (see Alvarez and Barney, 2001; Hagedoorn et al., 2001; Padula and Dagnino, 2007; Porter, 1985).

Here, the authors use an original recent definition of a co-competitive game, in normal form, given by David Carfi. The model can suggest useful solutions to a specific co-competitive problem. This analytical framework enables us to widen the set of possible solutions from purely competitive solutions to co-competitive ones and, moreover, incorporates a solution designed "to share the pie fairly" in a win-win scenario. At the same time, it permits examination of the range of possible economic outcomes along a co-competitive dynamic path. We also propose a rational way of limiting the space within which the co-competitive solutions apply. The basic original definition we propose and apply for co-competitive games is that introduced by Carfi and Schilirò (2014a, 2012a, 2012b, 2012c, 2012d, 2011) and Carfi (2015, 2012, 2009a, 2009b, 2008). The method we use to study the payoff space of a normal-form game is due to Carfi (2015, 2009b), Carfi and Musolino (2015a, 2015b, 2014a, 2014b, 2013a, 2013b, 2013c, 2012a, 2012b), and Carfi and Schilirò (2014a, 2012a, 2012b, 2012c, 2012d, 2011). Other important applications, of the complete examination methodology, are introduced by D. Carfi and co-authors in Agreste et al. (2012), Arthanari et al. (2015), Baglieri et al. (2016a, 2016b, 2012), Campbell and Carfi (2017, 2015), Carfi and Donato (2016a, 2016b), Carfi et al. (2017a, 2017b), Carfi, et al. (2017), Carfi, et al. (2016), Carfi and Okura (2014), Carfi and Romeo (2015), Carfi and Pintaudi (2012).

A complete treatment of a normal-form game is presented and applied by Carfi (2017, 2015, 2012, 2009a, 2009b, 2008), Carfi and Donato (2016a, 2016b), Carfi and Musolino (2015a, 2015b, 2014a, 2014b, 2013a, 2013b, 2013c, 2012a, 2012b), Carfi and Perrone (2013, 2011), Carfi and Ricciardello (2013, 2012 a, 2012b, 2010, 2009) and Carfi and Schilirò (2014a, 2012a, 2012b, 2012c, 2012d, 2011), Donato (2017). Carfi (2008) proposes a general definition and explains the basic properties of Pareto boundary, which constitutes a fundamental element of the complete analysis of a normal-form game and of a co-competitive interaction.

Moreover, to develop our ideas on environmental sustainability, we referred to Baumert et al. (2005), Chu (2016), Drolc (2013), Fiala (2008), Foley et al. (2011), Gauthier et al. (2016), Godland R. (2005), Leitzmann (2003), Lyakhov et al. (2016), Schilirò (2009), United Nations (2011).

2. Methods

In our model we have two players.

- The 1st player A is constituted by the group of countries which are developed and possess the technological and financial capabilities to invest in green technologies. These are countries able to develop, produce innovative technologies and products "green oriented", adopt alternative sources of energy in order to fight the global warming.

According to the Paris agreement COP21 the developed countries have a leading role in mitigation action through absolute targets for reducing domestic emissions.

- The 2nd player B, instead, is the group of countries which are still developing or underdeveloped, which are interested to adopt solutions to fight the global warming. But these countries do not possess the technological and financial capabilities to invest in green technologies. According to the Paris agreement, one of the three main objectives is promoting resilience and adaptation investments in developing countries, in particular to reduce threats to food production.

The sets of possible individual strategies

The 1st player A has the technological and financial capabilities and the will to pursue actions aimed at producing "green" energy-saving innovative technologies and "green oriented products" in order to reduce dependence on oil, coal and gas that, at the same time, have a positive effect on the environment, the climate and the welfare of the citizens.

The 2nd player B has financial and technological constraints. His choice is whether to follow the same strategy of A or to continue producing as before, without worrying about the impact on the environment. The choice also depends on the cooperation of A in providing the transfer of green technologies and financial resources to produce "green oriented good".

This model is able to provide win-win solutions to avoid the disintegration of the environment.

Definition of possible cooperative strategies to be determined through a joint decision-making of the two players

The cooperative "green" strategy at a global level moves on three lines

1. Investment in low-carbon technologies to reduce the CO2 emissions.
2. Investment in eco-sustainable urban infrastructure with low environmental impact.
3. Reduction in the emissions (production and consumption) of oil, coal and gas (highly polluting energies).

Definition of an economic environment in which the interactive action takes places

In the model, there is a competition between the two agents (A and B). This competition takes place at the level of productions, which use high technology, or even medium technologies with "green" purposes.

The competitive strategy is based on productions: x and y . These productions are essentially homogeneous. The product consists in the aggregate of all possible "green oriented products" that the two players A and B can produce using green technologies.

The basic idea of the model is to shift the technology of productions towards a "green" frontier. In this model of competition between agents (the two groups of countries) the driver is the production, in particular the production of biological food. The model is a duopoly model *à la Cournot*. This model allows to find a solution which is profitable for both players (win-win solution). Such solution is profitable but it is also environmental or "green" oriented.

The economic model

The co-petitive model we propose hereunder must be interpreted as a normative model, in the sense that it will show the more appropriate solutions and win-win strategies chosen within a cooperative perspective, under precise conditions imposed by assumption.

Strategies

The strategy sets of the model are:

1. the set E of strategies x of a certain country c - the possible aggregate biological-food production of the country c - which directly influence both payoff functions, in a proper game theoretic approach *à la Cournot*;
2. the set F of strategies y of the rest of the world w - the possible aggregate biological-food production of the rest of the world w - which influence both payoff functions;
3. the set C of 2-dimensional shared strategies z , set which is determined together by the two game players, c and the rest of the world w .

Interpretation of the cooperative strategy

Any vector z in C is the 2-level of aggregate investment for the environment sustainability economic approach, specifically z is a couple (z_1, z_2) , where:

1. the first component z_1 is the aggregate investment and innovation, of the country c and of the rest of the world w , in climate technologies;
2. the second component z_2 is the aggregate algebraic sum, of the country c and of the rest of the world w , of economic and policy instruments (valued in dollars) to change the patterns of consumption of the households.

In the model, we assume that c and w define ex-ante and together the set C of all cooperative strategies and (after a deep study of the co-petitive interaction) the couple z to implement as a possible component solution.

Main strategic assumptions

We assume that:

any real number x , in the canonical unit interval

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

is a possible level of aggregate production of the country c;
any real number y , in the same unit interval

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

is the analogous aggregate production of the rest of the world w;
a real couple (2-vector) z , belonging to the canonical square

$$C := U^2 = [0, 1]^2$$

is the 2-investment of the country c and of the rest of the world w for new low-carbon innovative technologies, in the direction of sustainability of natural resources and for the environmental protection.

Measure units of the strategy sets

We assume that the measure units of the two intervals E and F be different:

- the real unit 1 in E represents the maximum possible aggregate production of country c of a certain biological product
- the real unit 1 in F is the maximum possible aggregate production of the rest of the world w, of the same good (obviously these two units represents totally different quantities, but - from a mathematical point of view - we need only a rescale on E and a rescale on F to translate our results in real unit of productions).
- the real unit 1 of each factor of C is, respectively:
 - a maximum possible aggregate investment and innovation in climate technologies;
 - a maximum possible aggregate algebraic sum of economic and policy instruments to change the patterns of consumption of the households.

Let us assume, so, that the country and the rest of the world decide together, at the end of the analysis of the game, to contribute by a 2-investment $z = (z_1, z_2)$.

We also consider, as payoff functions of the interaction between the country c and the rest of the world w, two *Cournot type* payoff functions, as it is shown in what follows.

Payoff function of country c

We assume that the payoff function of the country c is the function f_1 of the unit 4-cube U^4 into the real line, defined by

$$f_1(x, y, z) = 4x(1 - x - y) + m_1z_1 + m_2z_2 = 4x(1 - x - y) + (m|z)$$

for every triple (x, y, z) in the 4-cube U^4 , where

- m is a characteristic positive real 2-vector representing the marginal benefits of the investments decided by country c and by the rest of the world w upon the economic performances of the country c .

Payoff function of the rest of the world w

We assume that the payoff function of the rest of the world w is the function f_2 of the unit 4-cube U^4 into the real line, defined by

$$f_2(x, y, z) = 4y (1 - y - x) + (n|z)$$

for every triple (x, y, z) in the 4-cube U^4 , where

- n is a characteristic positive real 2-vector representing the marginal benefits of the investments decided by country c and by the rest of the world w upon the economic performances of the rest of the world w itself.

Remark. Note the symmetry in the influence of the pair (m, n) upon the pair of payoff functions (f_1, f_2) .

Payoff function of the co-petitive game

We have so build up a co-petitive gain game $G = (f, \geq)$, with payoff function

$$f : U^4 \rightarrow \mathbf{R}^2,$$

given by

$$\begin{aligned} f(x, y, z) &= (4x (1 - x - y) + (m|z), 4y (1 - y - x) + (n|z)) = \\ &= (4x (1 - x - y), 4y (1 - y - x)) + z_1 (m_1, n_1) + z_2 (m_2, n_2) = \\ &= (4x (1 - x - y), 4y (1 - y - x)) + \sum z (m: n), \end{aligned}$$

for every triple (x, y, z) in the compact 4-cube U^4 , where $(m: n)$ is the 2-family of 2-vectors

$$((m_i, n_i))_{1 \leq i \leq 2} = ((m_1, n_1), (m_2, n_2))$$

and where

$$\sum z (m: n) := \sum_i z_i (m_i, n_i)$$

denotes the linear superposition (linear combination) of the family $(m: n)$ by the system of coefficients z .

3. Results and Discussion

We show, in the following figures (Figures 1-4), the construction of the co-petitive payoff space in three steps, in the particular case in which

$$m = (-1, 1)$$

and

$$n = (2, 3),$$

just to clarify the procedure. Moreover, we shall consider here only the co-
petitive space S generated by the Pareto maximal boundary

$$M_2 = [e_1, e_2],$$

since the Pareto Maximal boundary of the co-competitive game G is contained in
this part S .

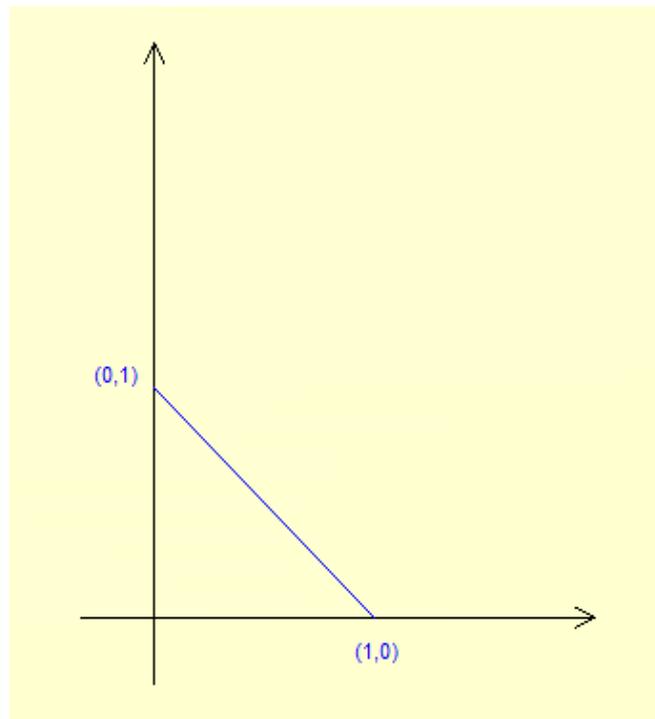


Figure 1. Step 0: $S_0 := M_2$ (the positive part of the Cournot payoff space).

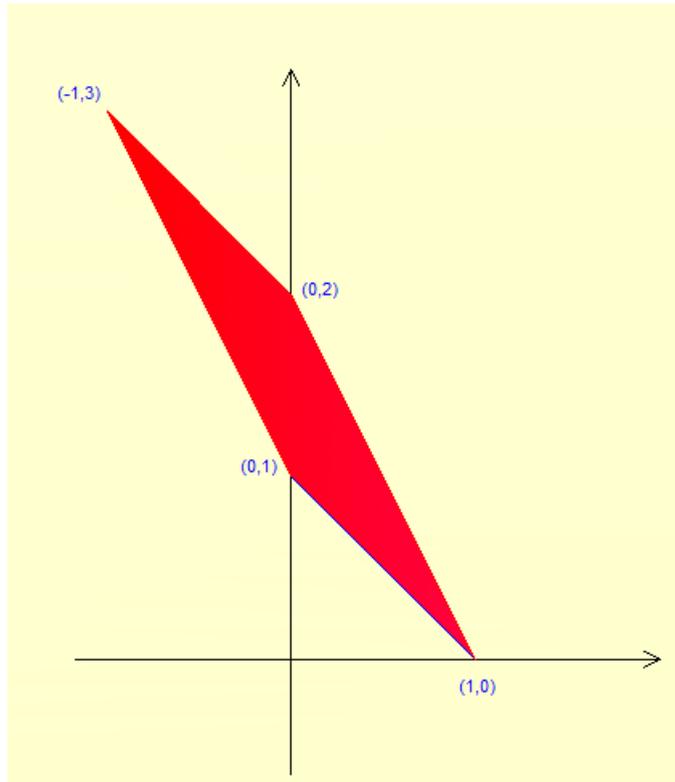


Figure 2. First step: $S1 := M2 + U(-1, 2)$.

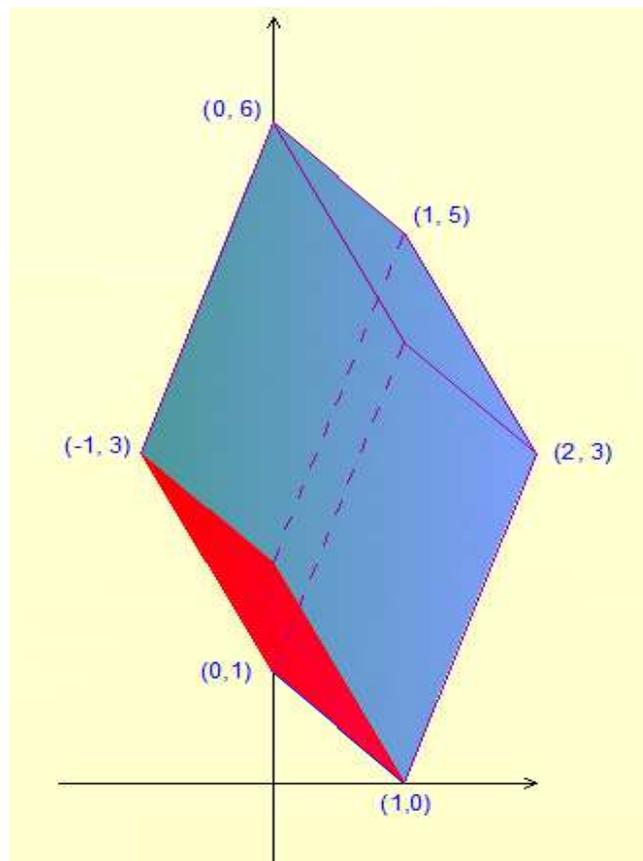


Figure 3. Second step: $S2 := M2 + U(-1, 2) + U(1, 3)$.

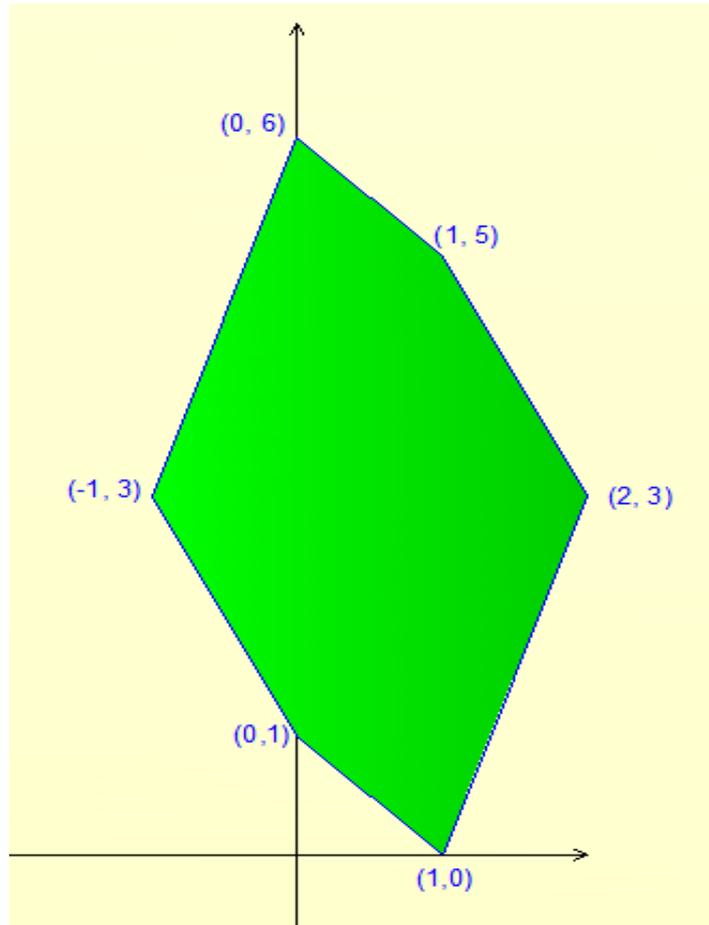


Figure 4. The co-petitive dynamical path of the initial Pareto boundary M_2 .

The Pareto maximal boundary of the payoff space $f(U^4)$ of the co-petitive game G is the union of segments

$$[P', Q'] \cup [Q' R'],$$

where the point P' is $(0, 6)$, the point Q' is $(1, 5)$ and the point R' is $(2, 3)$; as our figures are showing.

Properly co-petitive solutions

In a purely co-petitive fashion, the solution of the co-petitive game G must be searched for in the co-petitive dynamic evolution path of the Nash payoff

$$N' = (4/9, 4/9).$$

Let us study this co-petitive dynamical path. We have to start from the Nash payoff N' and then generate its co-petitive trajectory

$$N := N' + U(-1, 2) + U(1, 3).$$

For the construction of the Nash path, as before, we can proceed step by step (see Figure 5-6-7).

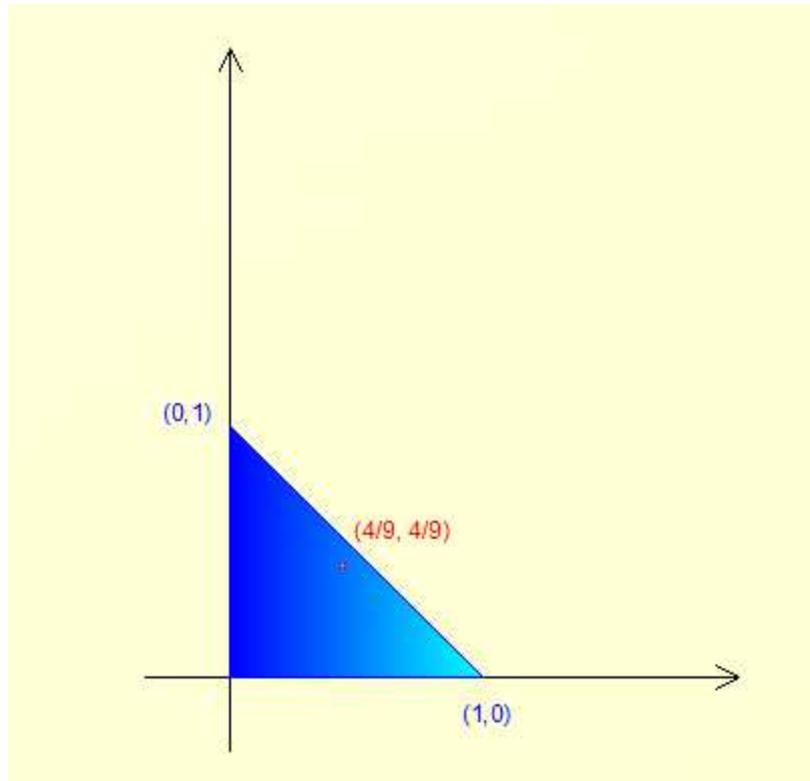


Figure 5. Step 0: N' .

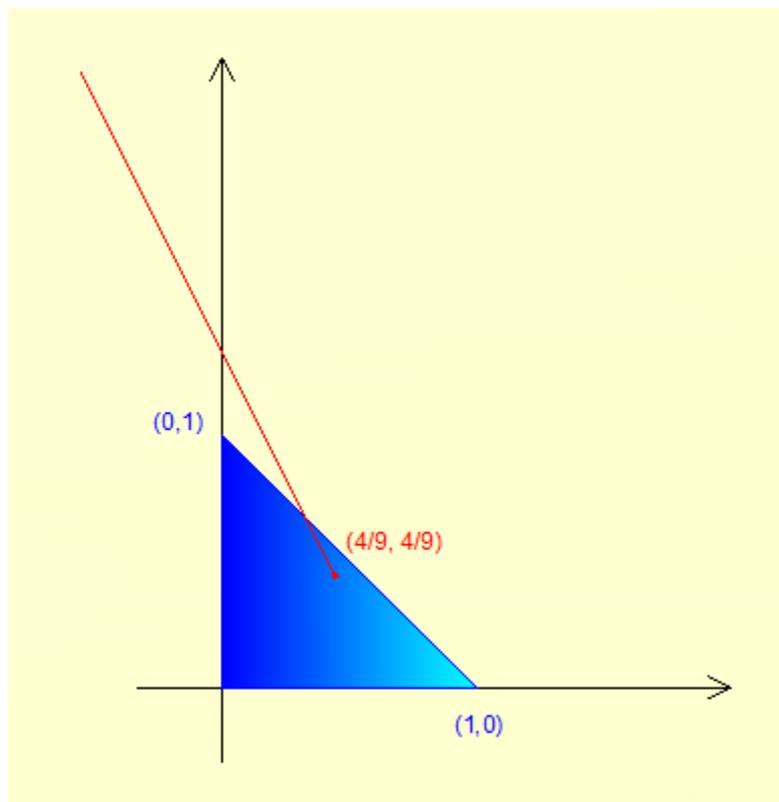


Figure 6. First step: $N' + U(-1, 2)$.

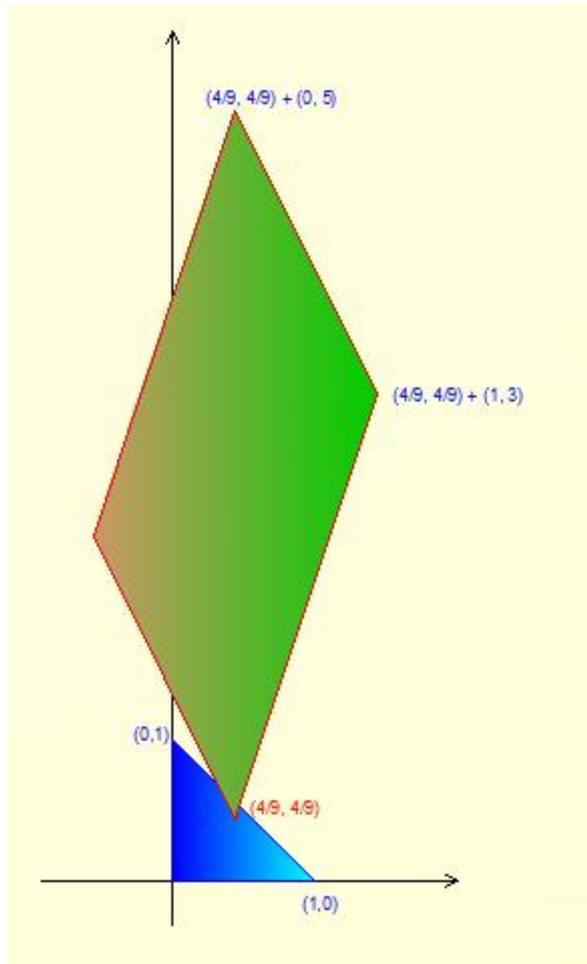


Figure 7. Second step: $N' + U(-1, 2) + U(1, 3)$.

In Figure 8, we show the Kalai-Smorodinsky purely co-petitive payoff solution with respect to the Nash payoff (the point H). This is the solution of the classic bargaining problem

$$(\partial^* N, N'),$$

where $\partial^* N$ is the Pareto maximal boundary of the Nash path N and the threat point of the problem is the old initial Nash-Cournot payoff N' .

The payoff solution H is obtained by the intersection of the part of the Nash Pareto boundary which stays over N' (in this specific case, the whole of the Nash Pareto boundary) and the segment connecting the threat point N' with the supremum of the above part of the Nash Pareto boundary.

Then we consider another purely co-petitive solution H' , obtained by using as a threat point the infimum of the maximal boundary of the Nash path.

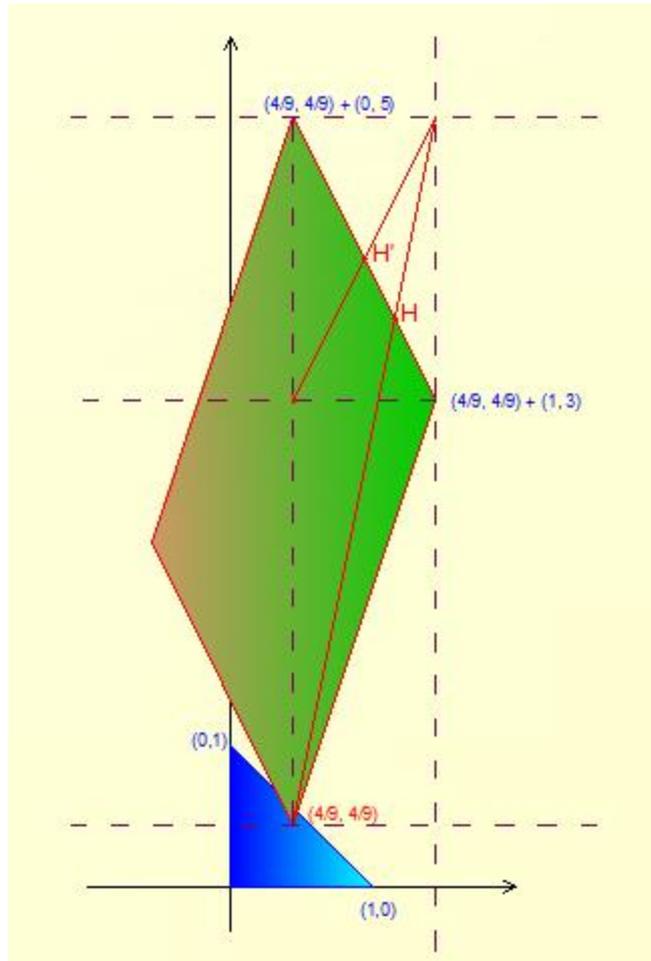


Figure 8. Kalai-Smorodinsky purely cooperative payoff solutions: H and H' .

In this game, the two Kalai-Smorodinsky purely cooperative payoff solutions H and H' are not optimal with respect to the Transferable Utility approach, neither they belong to the maximal Pareto boundary of the game.

Super-Cooperative Kalai-Smorodinsky bargaining solutions

The Kalai-Smorodinsky bargaining solution, with respect to the infimum of the payoff space, equals the intersection of the diagonal segment

$$[\inf G, \sup G]$$

and the Pareto boundary M .

This solution equals the point K of the segment $[Q', R']$. This point K represents a good win-win solution with respect to the initial (shadow maximum) supremum $(1, 1)$ of the pure Cournot game.

The Kalai-Smorodinsky bargaining solution, with respect to the infimum of the Pareto boundary, equals the intersection of the diagonal segment

$$[\inf M, \sup M]$$

and the Pareto boundary M itself, and is the point

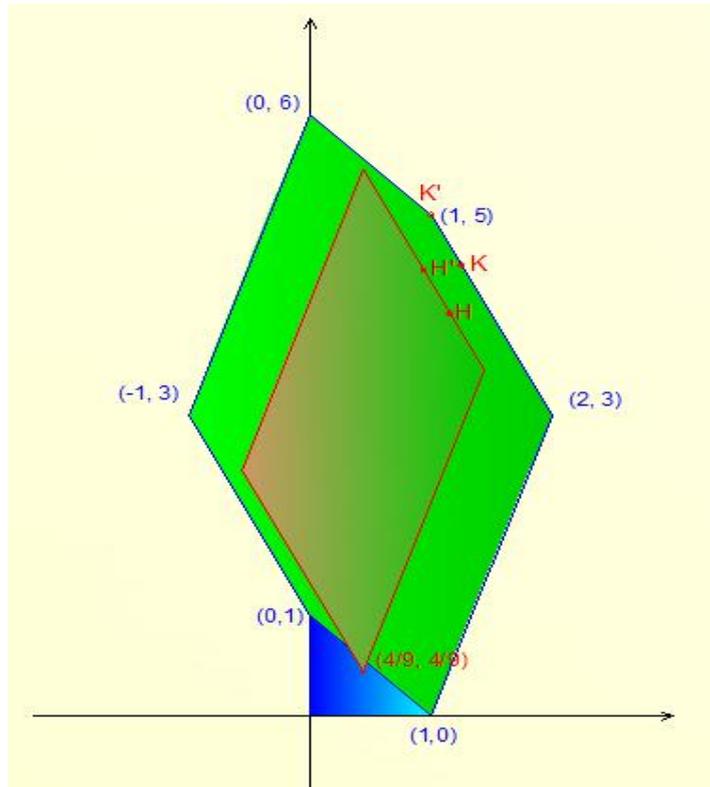


Figure 10. Confrontation between the solutions H , H' , K and K' .

4. Conclusions

This paper proposes an environmentally sustainable global economy. The model which represents this economy looks both at the production side and the consumption side. Regarding the production side, the model considers investment and innovation in climate technologies, whereas on the consumption side it takes into account economic and policy instruments to change the patterns of consumption of the households. The model, based on a theoretical framework *à la Cournot*, follows a game theory approach. Such a model provides win-win solutions, namely strategic situations in which each country takes advantages by cooperating and competing at the same time within the global economy, and where each country gets a positive return, in order to achieve an inclusive and sustainable industrial development. In fact, the model shows the convenience for each country to cooperate and implement policies in order to fully satisfy the basic requirements of *UNIDO 2030 Agenda for Sustainable Development*, in terms of production, consumption and climate change.

In particular, our co-opetitive model shows win-win solutions, upon a Pareto optimal frontier, of a co-opetitive strategic interaction aiming at a policy of environmental sustainability and implementing a green economy. This policy concerns

1. investment and innovation in climate technologies. The application of innovative energy-efficient production processes along with the utilization of renewable energy sources enables countries in the determination of their output

to follow a low-carbon and low-emission growth path with huge benefits for the climate and the environment

2. economic and policy instruments, based on taxation and incentives, to change the patterns of consumption of the households, taking into account the determination of aggregate output of biological food of any country c in a non-cooperative game *à la Cournot* with the rest of the world.

The analytical features of the model are:

1. first, we defined z as the cooperative strategy, which is the instrumental 2-vector (2 dimensions) of the environmental sustainability policy, concerning both production and consumption;

2. second, we adopted a non-cooperative game *à la Cournot* for establishing an equilibrium bi-level (x, y) , that represents the levels of outputs of country c and of the rest of the world w in production of biological food;

3. third, we suggested two types of solutions:

- two pure payoff co-competitive solutions (Fig. 8). Respectively, H , which is the Kalai-Smorodinsky purely co-competitive payoff solution with respect to the Nash payoff, and H' , which is a purely co-competitive solution obtained by using as a threat point the infimum of the maximal boundary of the Nash path.

- two super-cooperative solutions K and K' belonging to the co-competitive maximal Pareto boundary of our game (Fig. 9). K and K' are determined by adopting the Kalai-Smorodinsky method with two different threat points, thus obtaining two best Pareto compromise solutions of which K' is also optimal from the TU (transferable utility) point of view. The main feature of this second solution is that it is an optimal and fair solution.

4. Finally, we provided a confrontation between the solutions H , H' , K and K' , showing the Nash path and the Pareto path (Fig.10). None of the Nash points reveals Pareto efficient. In particular, the fair solution H' is strictly less than the fair solution K' .

To define more specifically the possible practical implications of our model, let us consider the payoff K' . We easily obtain such a payoff compromise solution as the result of infinite possible global politics (profile strategy), one elementary way (perhaps two polarized, but we desire only two propose an elementary example) appearing the following one:

$$K' = f(1/2, 0, 1, 1) .$$

In other terms, a possible agreement could be the profile strategy defined by the following components:

1. player one produces and sells on the global market 1/2 million pieces of production (that is 1/2 of the critical production of the Cournot game, considering it equal to 1 Million);
2. player two produces its vegan healthy food for its internal consumption, but sells 0 in the global market;
3. the players decide together to invest the maximum possible amount of money for their common investment vector strategy z .

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