A model of coopetitive game for the environmental sustainability of a global green economy

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May 2012

A Model of Coopetitive Game for the Environmental Sustainability of a Global Green Economy

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Abstract:

The present paper provides a model of coopetitive game for environmental sustainability of a global green economy, looking for a win-win solution within a complex construct of a type originally devised by Branderburger and Nalebuff. The model here suggested is environmental sustainable since it should lead to maintain natural capital, by using mainly renewable resources. In addition, this model of coopetitive games for environmental sustainability aims at reducing emissions of greenhouse gases, determining the reduction of global pollution, in this way it contributes to the establishment of a sustainable and lasting global green economy. Finally, the model determines a change in the patterns of consumption of households towards goods and human behaviors with a lower environmental impact. So the coopetitive strategy, in our model, consists in implementing a set of policy decisions, whose purpose is to be environmental sustainable and to enforce the global green economy. This is why the coopetitive variable is represented by a set of variables that together guarantee the achievement of the environmental sustainability of a global green economy. Thus, this original model aims to enrich the set of tools for environmental policies.

Keywords: Coopetitive Games; Coopetition; Environmental Sustainability; Global Green Economy

JEL Classification: Q42; Q30; C78; C71; Q56; Q20; Q58; C72

1. Introduction

The total environmental impact of humankind as a whole on the Earth's ecosystems depends both on population (which is increasing) and impact per person, which, in turn, depends in complex ways on what resources are being used, whether or not those resources are renewable, and the scale of the human activity relative to the carrying capacity of the ecosystems involved.

Unfortunately, as stated in the report of the United Nations (2011), there is no international consensus on how to manage global resources, in particular the problem of global food security (i.e. how to nourish a population of 9 billion by 2050), the dramatic problem of freshwater scarcity, which is already a global problem, with half the population of developing regions without sanitation, the drinking water target appears to be out of reach. In addition, the increasing dependence on fossil fuels, the problems of security of supply and the best solutions for mitigating climate change require important and urgent measures that must be adopted at a global level.

1.1 Environmental Sustainability

Therefore, if we all want to live in an environmental sustainable world, we must look for the maintenance of natural capital. This is the basic idea of environmental sustainability (Goodland, 2005). In fact the notion of environmental sustainability (ES) emphasizes the environmental life-support systems without which neither production nor humanity could exist. These life-support systems include atmosphere, water and soil; all of this need to be healthy, meaning that their environmental service capacity must be maintained. So ES can be represented by a set of constraints on the four major activities regulating the scale of the human economic subsystem: the use of renewable and nonrenewable resources on the source side, and the pollution and waste assimilation on the sink side. This is why ES implies that careful resource management be applied at many scales, from economic sectors like agriculture, manufacturing and industry, to work organizations, to the consumption patterns of households and individuals and to the resource demands of individual goods and services.

The notion of environmental sustainability is compatible with the emergence of the green economy, which has become a very attractive option after the global crisis of 2008-2009.

1.2 Global Green Economy

The green economy is identified as environmentally sustainable economy, based on the belief that our biosphere is a closed system with finite resources and a limited capacity for self-regulation and self-renewal. Since we depend on the earth's natural resources, we must create an economic system that respects the integrity of ecosystems and ensures the resilience of life supporting systems. The green economy is also socially just, since it is based on the belief that culture and human dignity are precious resources that, like our natural resources, require responsible stewardship to avoid their depletion. But the green economy is also locally rooted, since it is based on the belief that an authentic connection to territory is the essential pre-condition to sustainability and justice.

Then, the global green economy is an aggregate of individual communities meeting the needs of its citizens through the responsible production and exchange of goods and services. The growth and development of the global green economy is compatible with environmental sustainability over time, since it seeks to maintain and restore natural capital[1].

1.3 What is new here?

This paper applies a model of coopetitive games for environmental sustainability in a macro global context. The idea of coopetitive games looking for a win-win solution derives from the notion of coopetition, which is a complex construct originally devised by Branderburger and Nalebuff (1995, 1996). We have already proposed a first model of coopetitve games applied to global green economy (Carfì, Schilirò, 2011b.). In this former model we have considered strategies of a certain country *C* and of the rest of the world *W* which concern investment in food production, while the coopetitive variable, determined together for *C and W*, is represented by the level of investment for environmental and natural resources.

1.4 The goals

In the present paper the goals are wider. The model here suggested is environmental sustainable since it should lead to maintain natural capital, by using mainly renewable resources. In addition, this model of coopetitive games for environmental sustainability aims at reducing emissions of greenhouse gases, determining the reduction of global pollution, in this way it contributes to the establishment of a sustainable

[1] The Green Economy Report by United Nations (2010) demonstrates that greening can generate increases in natural capital, becoming environmental sustainable and also produce a higher rate of Gross Domestic Product (GDP) growth.

and lasting global green economy. Finally, the model determines a change in the patterns of consumption of households towards goods and human behaviors with a lower environmental impact. So the coopetitive strategy, in our model, consists in implementing a set of policy decisions whose purpose is to be environmental sustainable and to enforce the global green economy. This is why the coopetitive variable is represented by a set of variables that together guarantee the achievement of the enviromental sustainability of a global green economy. Thus, this original model aims to enrich the set of tools for environmental policies.

2. The coopetitive model

As in any other coopetitive model we have developed (Carfì, Schilirò 2011a, Carfì, Schilirò, 2011, b) the present model provides a *win-win solution*, a situation in which each country must cooperate and compete at the same time. In our case this *win-win solution*, which is bargaining Pareto solution, shows the convenience for each country to participate actively to an environmental sustainability program within a coopetitive framework. Finally, the present model takes into account the sunk costs, since for any country that must decide whether to make an investment in green technologies or for maintaining natural renewable resources it must consider the presence of sunk costs.

The coopetitive strategies in our model are:

1. investment in maintenance of natural renewable resources;
2. investment in green technologies against pollution (air, water);
3. incentives and disincentives to change the patterns of consumption of the households.

2.1 Strategies

The strategy sets of the model are:

1) the set E of strategies x of a certain country c - the possible aggregate 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 word w - the possible environmental sustainable aggregate production of the rest of the world w - which influence both pay-off functions;

3) the set C of 3-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 3-level of aggregate investment for the ES economic approach; specifically z is a triple (z_1, z_2, z_3), where:

1) the first component z_1 is the aggregate investment, of the country c and of the rest of the world w, in maintenance of natural renewable resources;

2) the second component z_2 is the aggregate investment, of the country c and of the rest of the world w, in *green technologies against pollution*;

3) the third component z_3 is the aggregate algebraic sum, of the country c and of the rest of the world w, of incentives (negative) and disincentives (positive) 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 their coopetitive interaction) the triple z to implement as a possible component solution.

2.2 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 and any real number y, in the same unit interval F := **U**, is the analogous aggregate production of the rest of the world w.

Measure units of the individual strategy sets. We assume that the measure units of the two intervals E and F be different: the real unit 1 in the strategy interval E represents the maximum possible aggregate production of country c of a certain product and the real unit 1 in F is the maximum possible aggregate production of the rest of the word 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.

Cooperative strategy. Moreover, a real triple (3-vector) z, belonging to the canonical cube C: = $\mathbf{U}^3$, is the 3-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. Also in this case, the real unit 1 of each factor of C is, respectively:

1) the maximum possible aggregate investment in maintenance of natural renewable resources;

2) the maximum possible aggregate investment in “green technologies” against pollution (air, water);

3) the maximum possible aggregate algebraic sum of incentives and disincentives 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 3-investment $z = (z_1,z_2,z_3)$.

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

2.3 Payoff function of country c

We assume that the payoff function of the country c is the function f_1 of the unit 5-cube $\mathbf{U}^5$ into the real line, defined by

$$f_1(x, y, z) = 4x (1 - x - y) + m_1z_1 + m_2z_2 + m_3z_3 = 4x (1 - x - y) + (m|z),$$

for every triple (x,y,z) in the 5-cube $\mathbf{U}_5$, where m is a characteristic positive real 3-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.

2.4 Payoff function of the rest of the world w

We assume that the payoff function of the rest of the world w, in the examined strategic interaction, is the function f_2 of the 5-cube $\mathbf{U}_5$ into the real line, defined by

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

for every triple (x,y,z) in the 5-cube $\mathbf{U}_5$, where n is a characteristic positive real 3-vector representing the marginal benefits of the investments decided by country c and 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).

2.5 Payoff function of the coopetitive game

We have so build up a coopetitive gain game G = (f, >), with payoff function $f : \mathbf{U}^5 \rightarrow \mathbf{R}^2$, given by

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

$$= 4(x (1 - x - y), y (1 - x - y)) + z\_1(m\_1, n\_1) + z\_2(m\_2, n\_2) + z\_3(m\_3, n\_3) =$$

$$= 4(x (1 - x - y), y (1 - x - y)) + \sum z(m:n),$$

for every triple (x, y, z) in the compact 5-cube $\mathbf{U}^5$, where (m:n) is the 3-family of 2-vectors

$$(m:n) := ((m_1, n_1), (m_2, n_2), (m_3, n_3)),$$

and where $\sum z(m:n)$ is the linear combination of its members weighted by the system of coefficients z, that is the linear superposition (linear combination) of the family (m:n) by the system of coefficients z.

3. Study of the game G = (p, >)

Note that, fixed a cooperative strategy z in the cube $\mathbf{U}^3$, the game $G(z) = (p_z, >)$, with payoff function p_z, defined on the square $\mathbf{U}_2$ by $p_z(x, y) = f(x, y, z)$, is the translation of the game $G(\mathbf{0})$ by the vector $v(z) := \sum z(m:n)$; so that we can study the game $G(\mathbf{0})$ (here $\mathbf{0}$ denotes the origin of the Euclidean 3-space) and then we can translate the various information of the game $G(\mathbf{0})$ by the vector v(z).

So, let us consider the game $G(\mathbf{0})$. This game $G(\mathbf{0})$ has been studied completely in D. Carfì and E. Perrone (see [5]). The conservative part in the payoff space (the part of the payoff space greater than the conservative bi-value (0,0)) is the canonical 2-simplex **T** of the plane, convex envelope of the origin and of the canonical basis e of the Euclidean plane IR^2. This conservative part is represented in the following figure.

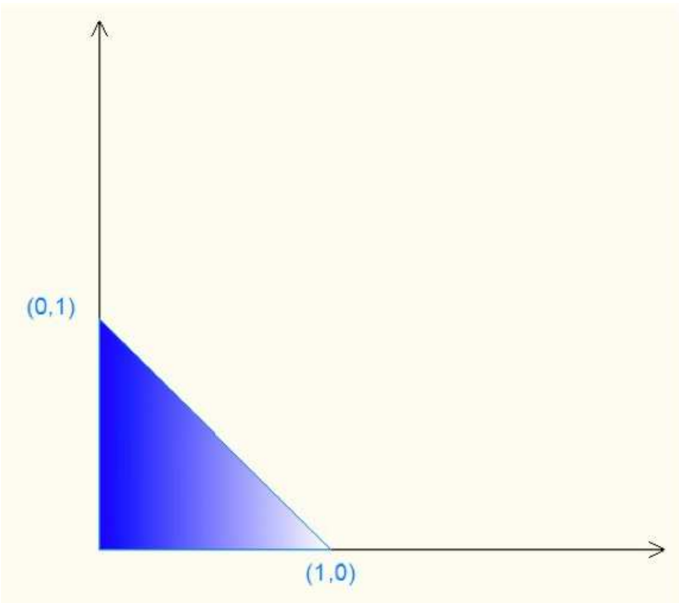

Figure 1. The conservative part of the Cournot payoff space, i.e. the positive part of the image $p_{\mathbf{0}} (\mathbf{U_2})$.

Dynamical interpretation of coopetition. In what follows we are interested in the trajectory of the dynamic path generated by the above conservative part **T** in the coopetitive evolution determined by the function f. The multi-time dynamic path we are interested in is the set-valued function J from the cube $\mathbf{U}_3$ into the space $\mathbf{R}_2$, associating with z the the conservative part J(z) of the game G(z). The trajectory is nothing but the union of all configurations determined by the path J: what we shall call our *coopetitive payoff space*.

3.1 Payoff space and Pareto boundary of the payoff space of G(z)

The Pareto boundary of the payoff space of the z-section normal-form game G(z) is the segment $[e_1, e_2]$, with end points the two canonical vectors of the Cartesian vector plane $\mathbf{R}_2$, translated by the vector $v(z) = \sum z(m : n)$, this is true for every 3-strategy z in the unit cube $\mathbf{U}_3$ (3-dimensional set).

3.2 Payoff space of the co-opetitive game G

The payoff space of the coopetitive game G, the image of the payoff function f, is the union of the family of payoff spaces $(p_z(\mathbf{U}_2))_{z \in C}$, that is the convex envelope of the of points 0_2, e_1, e_2, and of their translations by the following three vectors:

- $v(1,0,0) = (m_1, n_1)$;

- $v(1,1,0) = (m_1, n_1) + (m_2, n_2)$;

- $v(1,1,1) = (m_1, n_1) + (m_2, n_2) + (m_3, n_3)$.

3.3 The construction of the Pareto maximal coopetitive path

We show, in the following five figures, the construction of the coopetitive payoff space in three steps, in the particular case in which m = (-1, 1, 1) and n = (2, 1, -1), just to clarify the procedure. Moreover we shall consider here only the coopetitive space S generated by the Pareto maximal boundary $\mathbf{M}_2 = [e_1, e_2]$, since the Pareto Maximal boundary of the coopetitive game G is contained in this part S.

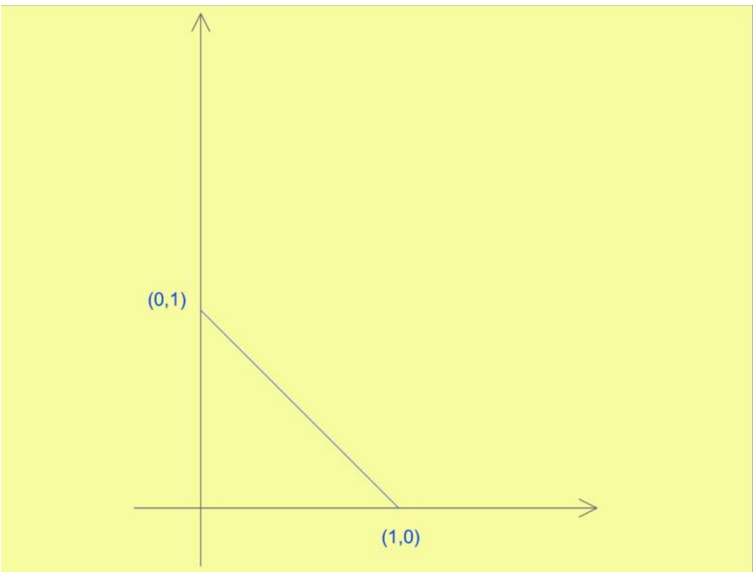

Figure 2. Step 0: $S_0 := \mathbf{M}_2$.

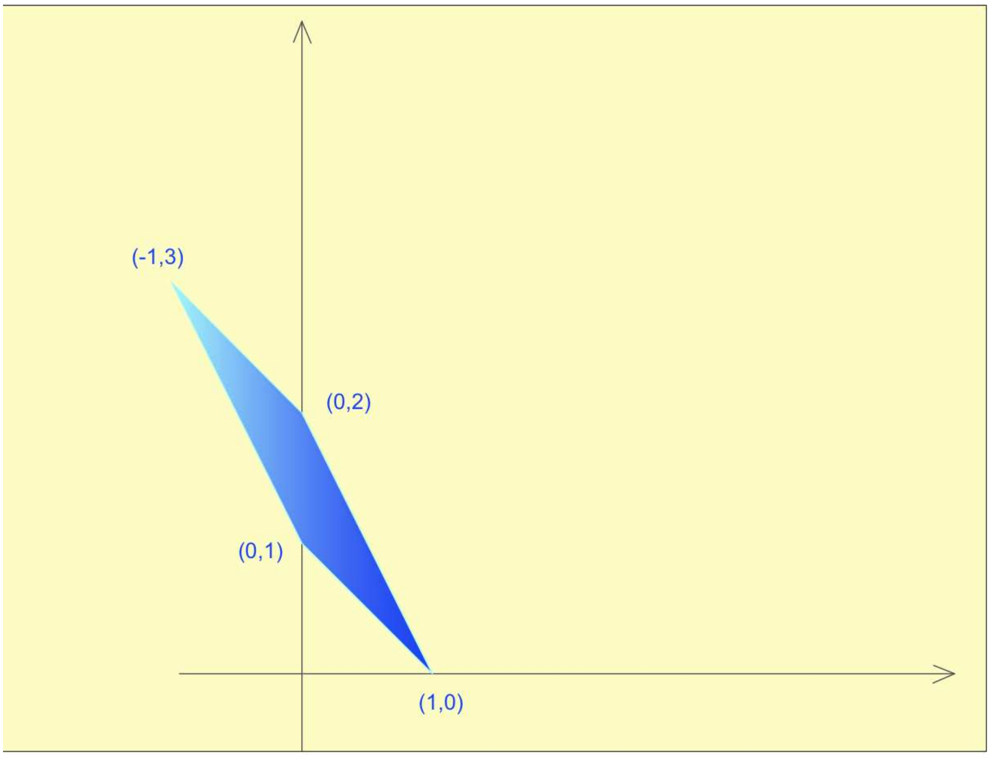

Figure 3. First step: $S_1 := \mathbf{M_2} + \mathbf{U}(-1, 2)$.

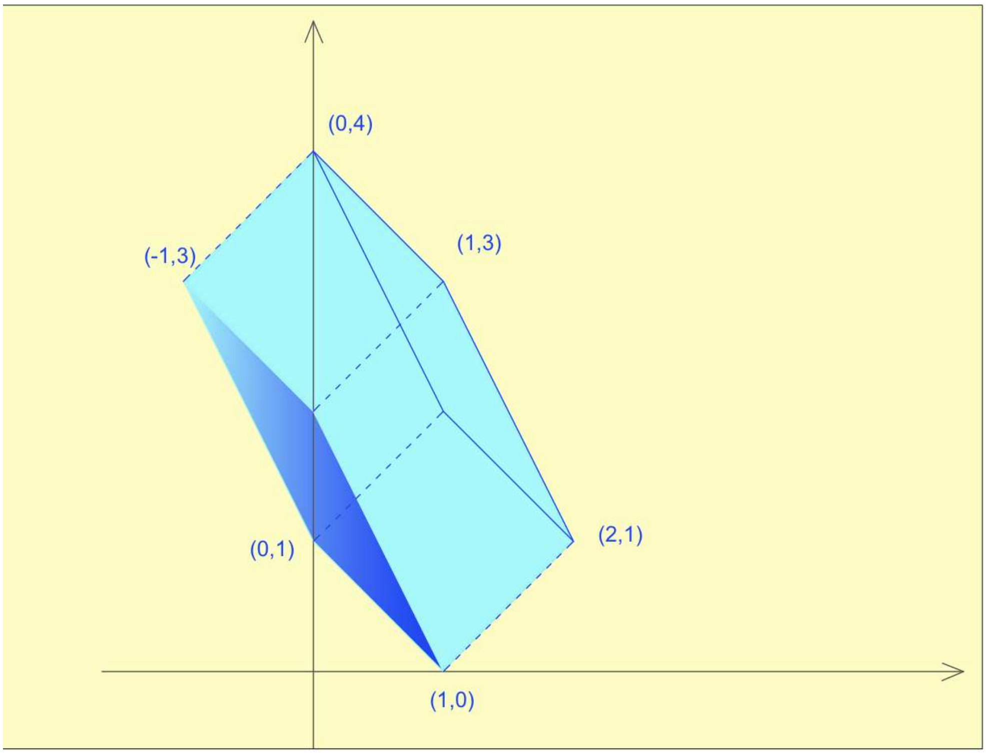

Figure 4. Second step: $\mathbf{S}_2 := \mathbf{M}_2 + \mathbf{U}(-1, 2) + \mathbf{U}(1,1)$.

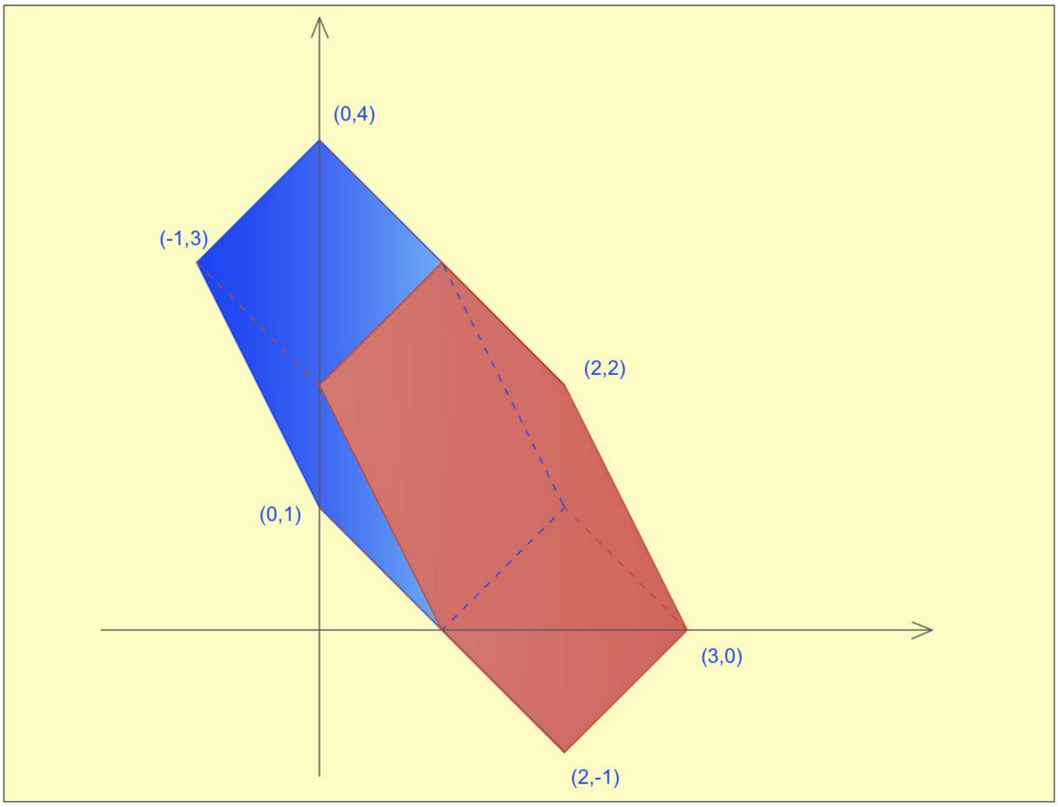

Figure 5. Third and final step: $S_3 := \mathbf{M}_2 + \mathbf{U}(-1,2) + \mathbf{U}(1,1) + \mathbf{U}(1,-1)$.

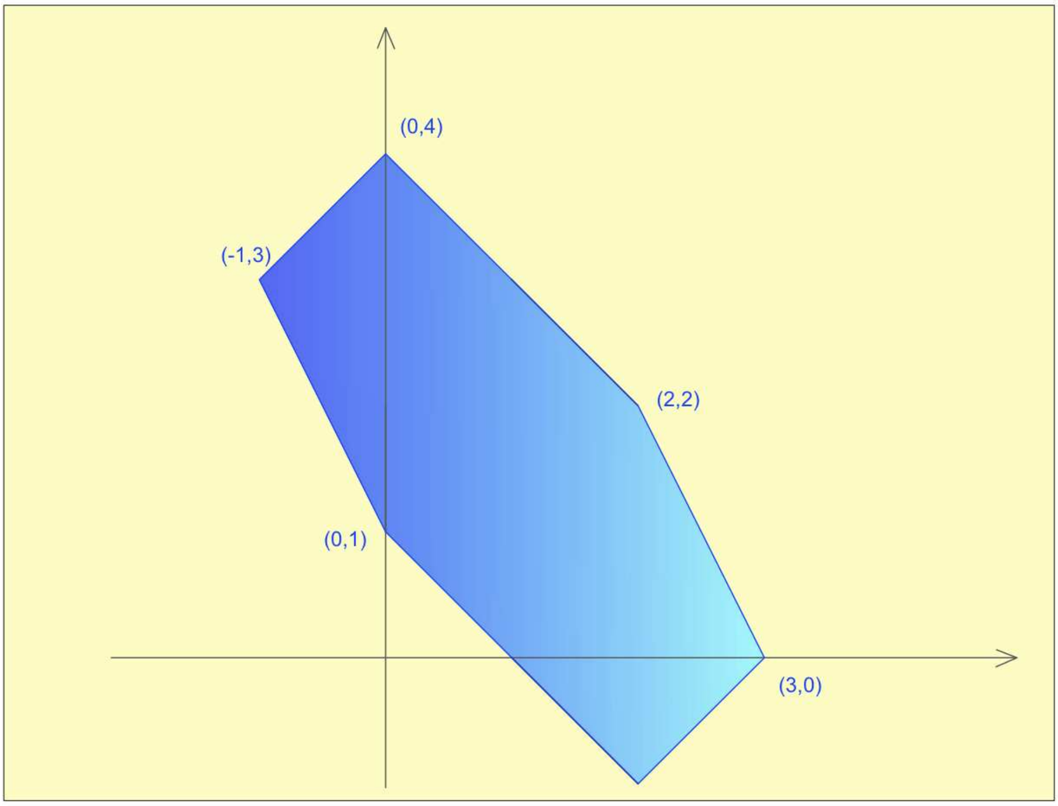

Figure 6. The coopetitive dynamical path of the initial Pareto boundary $\mathbf{M}_2$.

The Pareto maximal boundary of the payoff space $f(\mathbf{U}_5)$. The Pareto maximal boundary of the payoff space $f(\mathbf{U}_5)$ of the coopetitive game G is the union of segment [P', Q'] with the segment [Q',R'], where the point P' is (0,4), the point Q' is (2,2) and the point R' is (3,0); as our figures are showing.

4. Solutions of the model

4.1 Properly coopetitive solutions

In a purely coopetitive fashion, the solution of the coopetitive game G must be searched for in the coopetitive dynamic evolution path of the Nash payoff N' = (4/9, 4/9).

The Nash payoff coopetitive dynamic evolution path. Let us study this coopetitive dynamical path. We have to start from the Nash payoff N' and then we should generate its coopetitive trajectory, that is the following set

$$\mu := N' + \mathbf{U}(-1,2) + \mathbf{U}(1,1) + \mathbf{U}(1,-1),$$

Where, as usual, the product of a number set X by a vector v is the set of all vectors xv, with x in X.

Purely coopetitive solutions. A *purely coopetitive* solution is obtainable by cooperating on the common set C and (interacting) competing *à la Nash* in a suitable best compromise game G(z*), where the cooperative strategy z* is suitably and cooperatively chosen by the two players, by solving a bargaining problem. To be more precise, we give and use the following definition of properly coopetitive solution.

Definition (of purely coopetitive solution). We say that a strategy triple t = (x,y,z) is a properly coopetitive solution of a coopetitive game G = (f, >) if its image f(t) belongs to the maximal Pareto boundary of the payoff Nash Path of G.

Interpretation. The complex game G just played was developed with reference to the strategic triple (x,y,z), and the functional relation f, which represents a continuous infinite family of games *à la Cournot*. In each member-game of the family, which is a normal-form game with strategy support (E,F), the strategies are just the possible quantities of the common good produced by the two players. In a non-cooperative (Nash-competitive) fashion and for each member-game, the players must employ their own strategies in order to establish the Cournot-Nash equilibrium. On the other hand, in a coopetitive approach, the strategy shared vectors z allow the the players to identify, in the whole coopetitive game G, possible cooperative solutions in a Nash-competitive environment (by environment we mean here, the whole of the game G viewed as a family of normal-form games which should be solved *à la Nash)* In this context, thus we obtain possible *pure coopetitive solutions*.

4.2 Construction of the Nash path

As before, to construct graphically the Nash payoff trajectory

$$\mu := N' + \mathbf{U}(-1,2) + \mathbf{U}(1,1) + \mathbf{U}(1,-1),$$

we can proceed step by step, as the following figures just show.

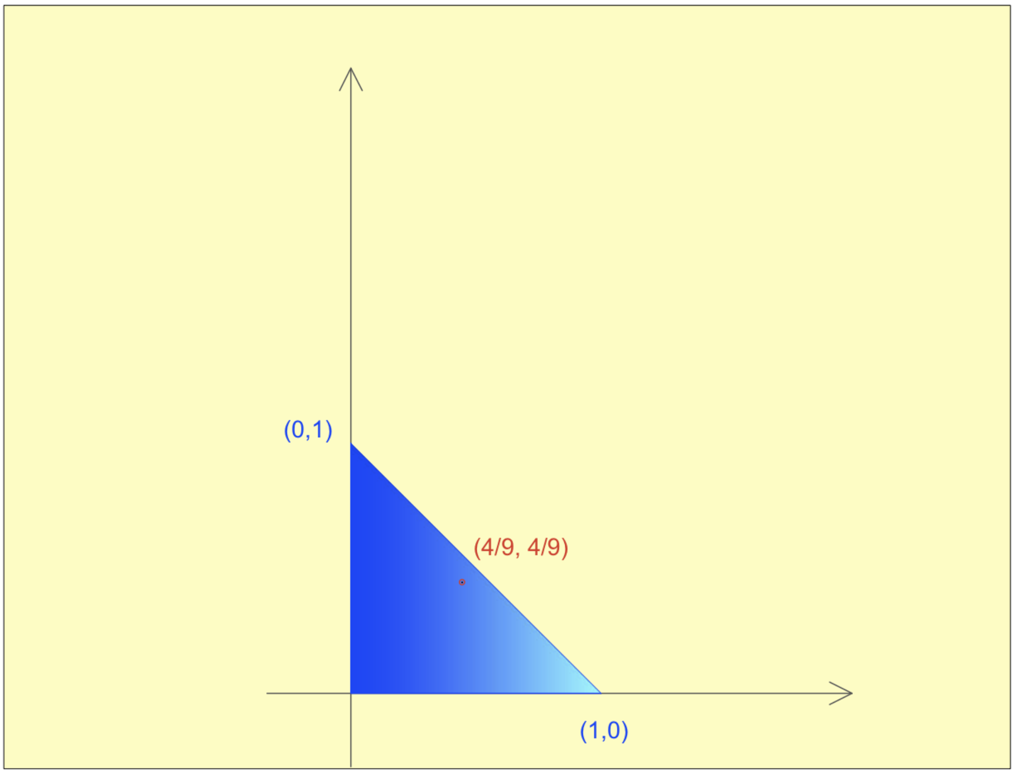

Figure 7. Step 0: N'.

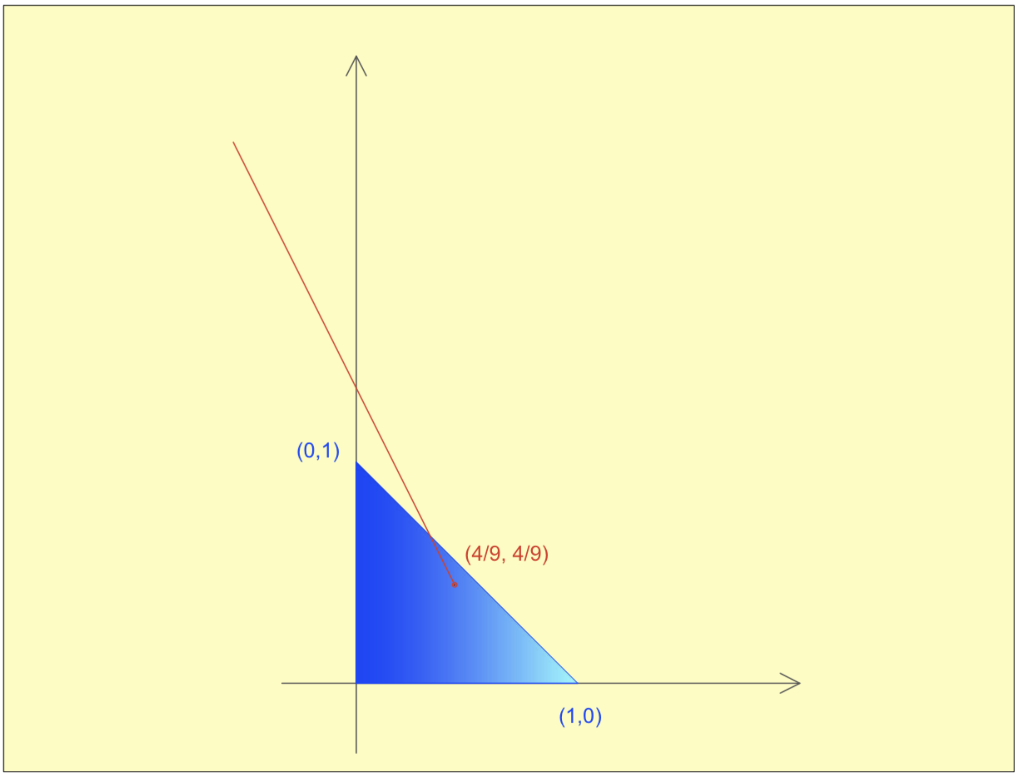

Figure 8. First step: N' + **U**(-1, 2).

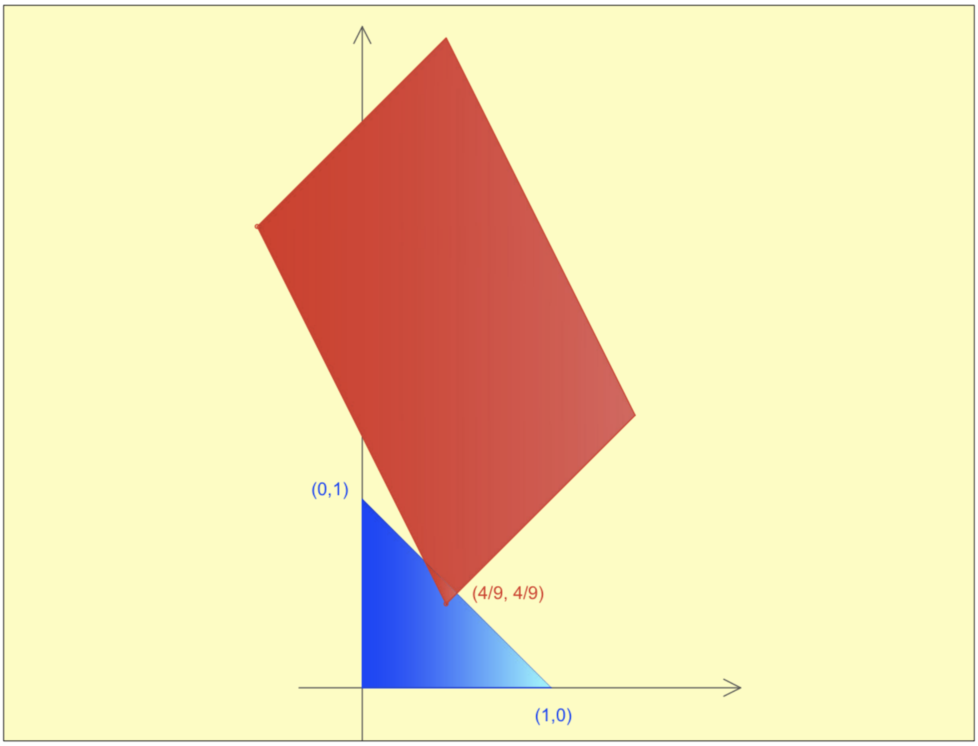

Figure 9. Second step: N' + **U**(-1, 2) + **U**(1,1).

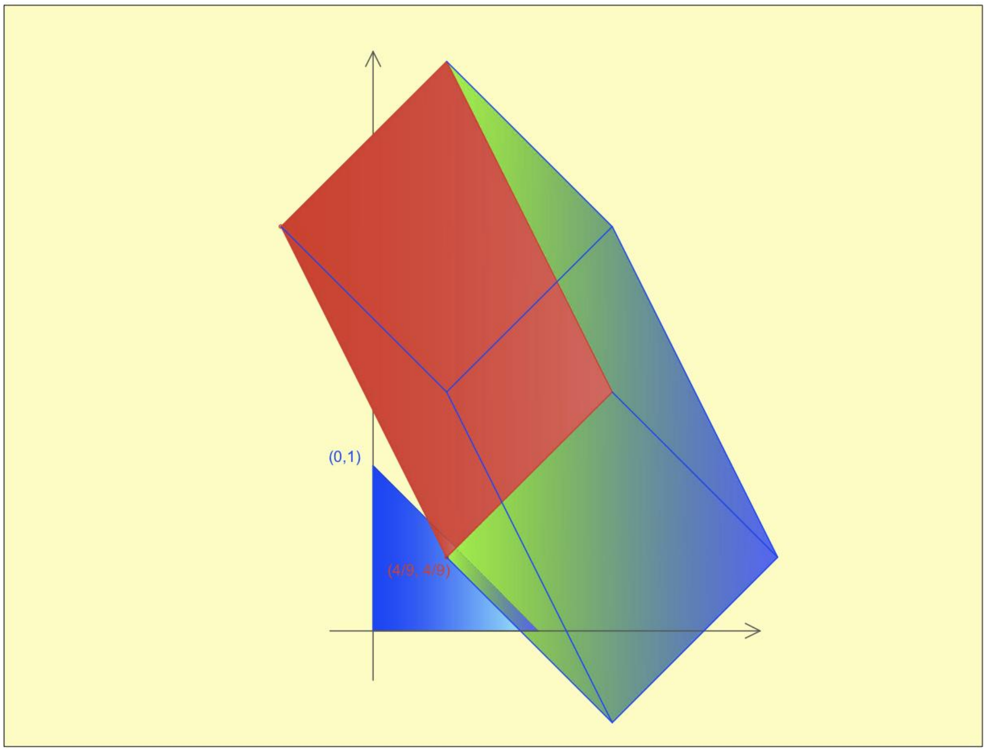

Figure 10. Third and final step: μ = N' + **U**(-1,2) + **U**(1,1) + **U**(1,-1).

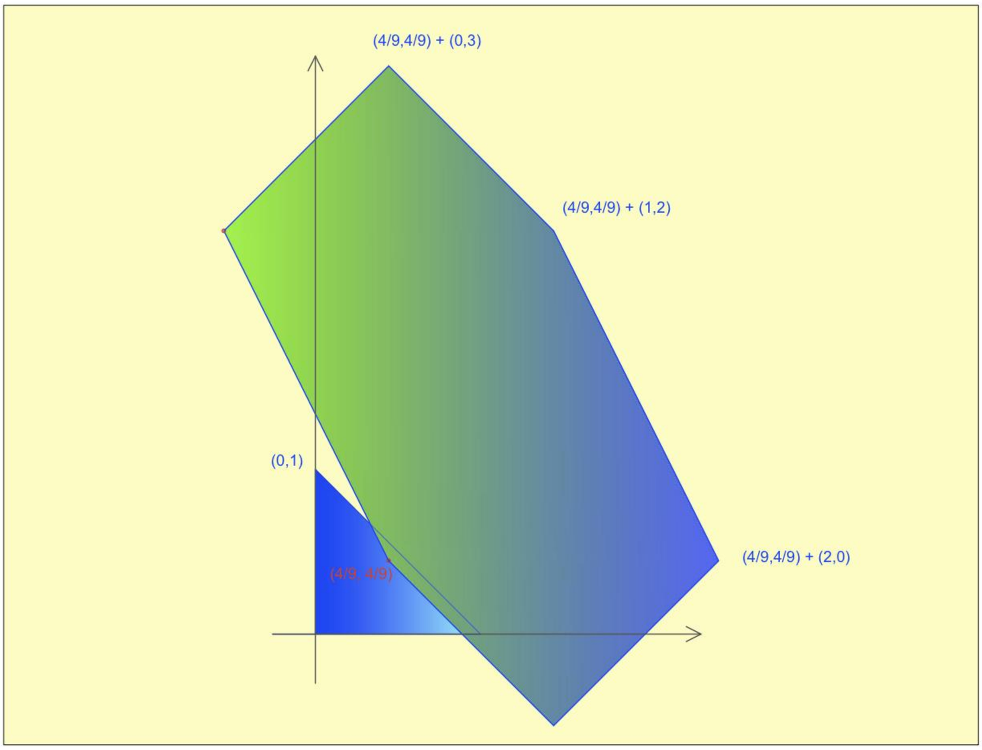

Figure 11. The coopetitive dynamical path of the initial Nash equilibrium N'.

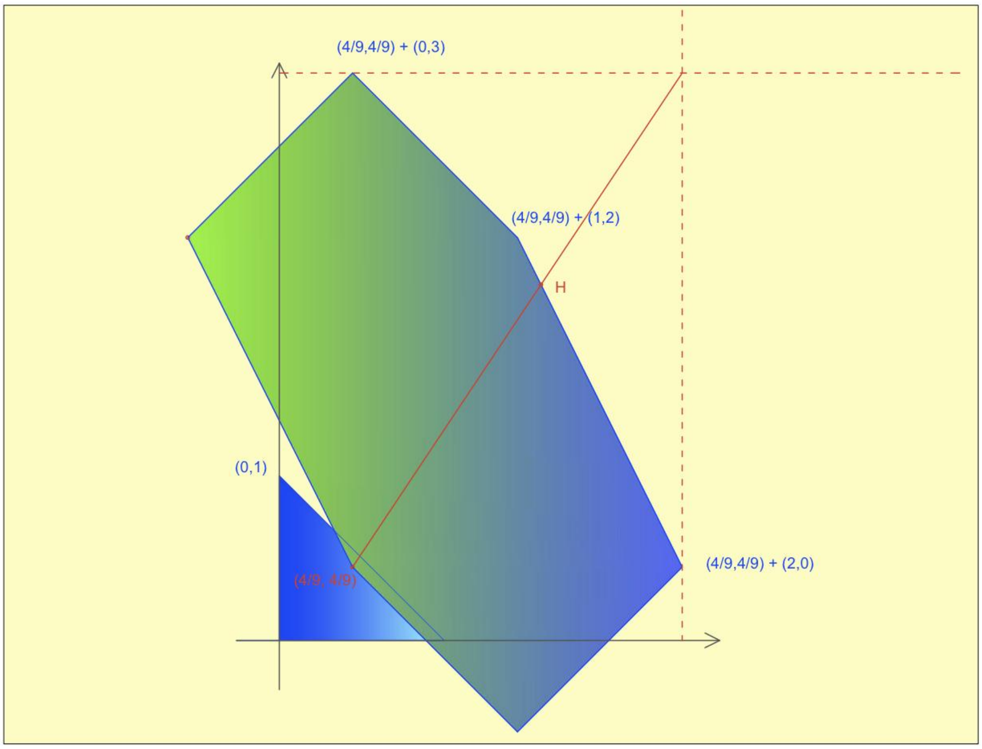

Figure 12. Kalai-Smorodinsky purely coopetitive payoff solution: H.

Kalai-Smorodinsky purely coopetitive payoff solution. We have showed, in the above figure, the Kalai-Smorodinsky purely coopetitive payoff solution with respect to the Nash payoff (the point H). This is the solution of the classic bargaining problem (fr*(μ), N'), where fr*(μ) is the Pareto maximal boundary of the Nash path μ 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.

Kalai-Smorodinsky purely coopetitive TU payoff solution. In this game the Kalai-Smorodinsky purely coopetitive payoff solution is not optimal with respect to the Transferable Utility approach; indeed the TU Pareto boundary of our Nash path is the straight line N' + (0,3) + span(1,-1), and the payoff H does not belong to this line. The unique point of intersection among this TU boundary and the segment connecting the threat point N' with the supremum of the Nash Pareto boundary is what we define the *Kalai-Smorodinsky purely coopetitive TU payoff solution*.

4.3 Super-cooperative solutions

We can go further, finding a Pareto solution obtainable by double cooperation, in the following sense: we assume that in the game the two players will cooperate both on the cooperative 3-strategy z and on the bi-strategy pair (x,y).

Super cooperative Nash bargaining solution. The super cooperative Nash bargaining payoff solution, with respect to the infimum of the Pareto boundary, is by definition the point of the Pareto maximal boundary M obtained by maximizing the real functional $h : \mathbf{R}^2 \rightarrow \mathbf{R}$ defined by $(X,Y) \rightarrow (X - a_1)(Y - a_2)$, where a is the infimum of the Pareto maximal boundary. In our case a is the origin of the plane, so this solution coincide with the medium point Q' = (2,2) of the segment [P', (4,0)]. This point Q' represents a win-win solution with respect to the initial (shadow maximum) supremum (1,1) of the pure Cournot game, since it is strongly greater (both components are stricltly greater) than (1,1).

Super cooperative Kalai-Smorodinsky bargaining solution. The Kalai-Smorodinsky bargaining solution, with respect to the infimum of the Pareto boundary, coincide with the intersection of the diagonal segment [inf M, sup M] and the Pareto boundary M itself: the point K = (12/7,16/7), of the segment [P', Q']. This point K also represents a good win-win solution with respect to the initial (shadow maximum) supremum (1,1) of the pure Cournot game.

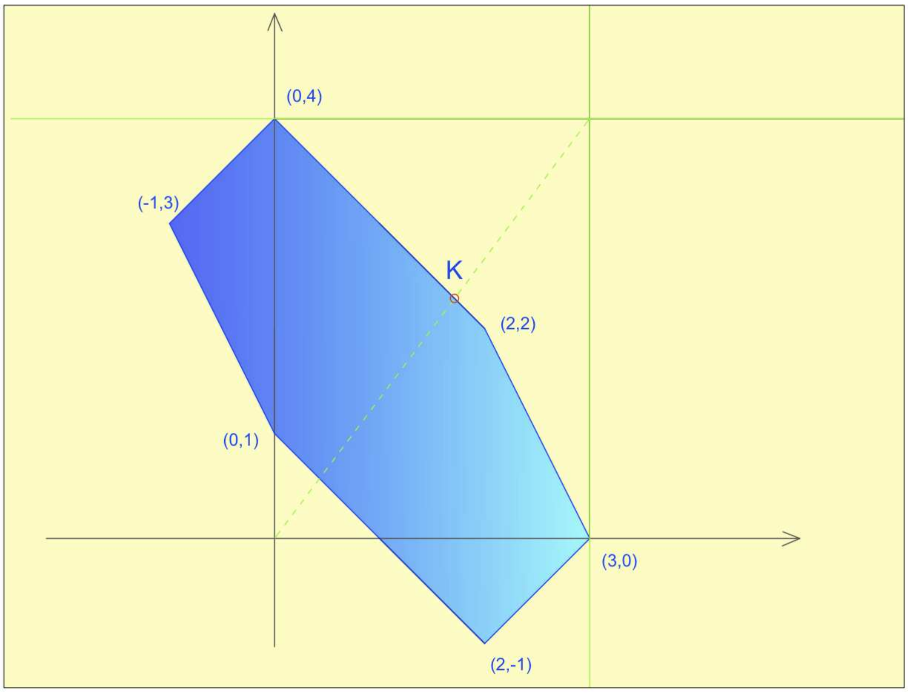

Figure 13. Super-cooperative Kalai-Smorodinsky solution in the payoff space: K.

Super cooperative Kalai-Smorodinsky transferable utility solution. The transferable utility solutions of our game in the payoff space are all the payoff pairs staying on the straight line

aff(P',Q') = (0,4) + span (1,-1),

the feasible TU solutions are those belonging to the segment s = [(0,4),(3,1)]. Note, anyway, that the Kalai-Smorodinsky solution of the bargaining problem $(s,\mathbf{0}_2)$ is again the point K: the super cooperative Kalai-Smorodinsky transferable utility solution coincides with the super cooperative Kalai-Smorodinsky bargaining solution.

4. Sunk costs

For what concerns the sunk costs, we consider an initial bi-cost (1, 1) necessary to begin the ES approach to the production, so that, in a non-coopetitive environment, we have a translation by the vector (-1, -1) of the Nash equilibrium payoff (4/9, 4/9).

Although we have an initial bi-loss, in a co-opetitive environment the gain is strictly greater than the absolute value of the bi-loss, thus the new super-cooperative Kalai-Smorodinsky solution K **-** (1,1) is greater than the old Nash equilibrium payoff.

6. Conclusions

Our coopetitive model has tried to demonstrate which are the win-win solutions of a coopetitive strategic interaction that aims at a policy of Environment Sustainability and for implementing a Green Economy. This policy concerns

1) investment in maintenance of natural renewable resources;

2) investment in green technologies against pollution (air, water);

3) incentives and disincentives to change the patterns of consumption of the households;

taking into account the sunk costs, and the determination of aggregate output of any country c in a non-cooperative game *à la Cournot* with the rest of the world.

The *original analytical elements* that characterized our coopetitive model are the following:

- firstly, we defined z as the cooperative strategy, which is the instrumental 3-vector (with 3 dimensions) of the ES policy;

- secondly, 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;

- thirdly, we introduced the sunk costs of the ES approach;

- finally, we suggested not only a pure coopetitive solution, but also two super-cooperative solutions on the coopetitive maximal Pareto boundary of our interaction, adopting the Nash bargaining and the Kalai-Smorodinsky methods, thus obtaining two best compromise solution.

In conclusion, this model could constitute a valuable framework for the implementation of appropriate environmental policies.

Acknowledgements. *The authors wish to thank **Dr. Eng. Alessia Donato** for her valuable help in the preparation of the figures.*

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