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Abstract. The paper proposes a coopetitive model for the *Green Economy*. It addresses the issue of the climate change policy and the creation and diffusion of low-carbon technologies. In the present paper the complex construct of coopetiton is applied at macroeconomic level. The model, based on Game Theory, enables us to offer a set of possible solutions in a coopetitive context, allowing to find a Pareto solution in a win-win scenario. The model, which is based on the assumption that each country produces a level of output which is determined in a non-cooperative game of Cournot-type and that considers at the same time a coopetitive strategy regarding the low technologies, will suggest a solution that shows the convenience for each country to participate actively to a *program of low carbon technologies* within a coopetitive framework to address a policy of climate change, thus aiming at balancing the environmental imbalances.

Keywords: coopetition, game theory, green economy, energy-saving technologies, policy of climate change.

JEL Classification: Q42, Q48, Q 50, Q55, C71, C72, C78.

1. Introduction

In this paper we provide a coopetitive model for the *Green Economy*, which is an economy based on sustainable development that results in improved human wellbeing and social equity, while it significantly reduces environmental risks and ecological scarcities. The *Green economy* is becoming an increasingly present reality in developed countries and beyond. The idea that the economic system and the environment involved will take care of themselves, through competition and the narrow self-interest, has become less and less credible nowadays.

Unfortunately, at the global level the balance between renewable resources and consumption is going into red. This means that we will need to begin to use sources that we do not recharge, creating strong environmental imbalances. With a population that has reached the wall of 7 billion and a global per capita consumption, which continues to grow, by mid-century our debt of resources will exceed the 100 per cent of the environmental GDP. If these two factors outweigh in negative (increase in population and increasing per capita consumption), there is the improvement of technology (to do more with less) that plays a positive role. But so far this latter factor has not been able to balance the combined pressure of population growth and consumption. Thus an important issue concerns the climate change policy and the creation and diffusion of low-carbon technologies. In this contribution we discuss feasible solutions that imply the development of low carbon technologies involving a change in the environmental policy of the countries.

In the present paper we apply the notion of coopetition, devised by Branderburger and Nalebuff (1995, 1996) in the field of strategic management, to the *Green Economy*. The notion of coopetition is a complex construct, since, according to this concept, the economic agents (i.e. firms or countries) must interact to find a *win-win solution*, that indicates a situation in which each agent thinks about both

cooperative and competitive ways to change the game. A coopetitive *win-win solution* is therefore a situation in which each agent must cooperate and compete at the same time. Thus, we provide a coopetitive model based on Game Theory which enables us to offer a set of possible solutions in a coopetitive context, allowing us to find a Pareto solution in a win-win scenario. Moreover, the model permits to examine the range of possible economic outcomes along a coopetitive dynamic path.
In the present work we apply a coopetitive model at a country level (Carfì, Magaudda, Schilirò, 2010; Carfì, Schilirò, 2011) instead of microeconomic level of firm (Branderburger, Nalebuff, 1995,1996). Each country has to decide whether it wants to collaborate with the rest of the world in getting an efficient *Green Economy*, even if the country is competing in the global scenario.
Our model will suggest an outcome that aims at balancing the environmental imbalances. The *win-win solution* provided by the model is going to show the convenience for each country to participate actively to a *program of low-carbon technologies* within a coopetitive framework to address a policy of climate change.

The model is based on the assumption that each country produces a level of output, which is determined in a non-cooperative game of Cournot-type. Moreover, it is assumed that there are two types of technologies: one is a high-carbon technology, the other is an innovative low carbon technology. The model also assumes that there is a sunk cost in the investment required to adopt the innovative low carbon technology, this sunk cost constitutes a threshold that any country has to overcome in order to use such a technology. Each country competes in the market with all the other countries, but it may also choose to collaborate with the rest of the world by adopting a low carbon technology, thus contributing to a change in the environmental policy.

The three main variables of our coopetitive model are:
x that represents the strategy of any country c;
y that represents the strategy of the rest of the world w;
z that represents the *coopetitive technology strategy* determined together by the country c and the rest of the world w. z is then the instrumental variable for the climate change policy.

2. Coopetitive Games

We define the coopetitive game in the following way.

Let E, F and C be three non-empty sets. We define two players coopetitive gain game carried by the strategic triple (E, F, C) any pair of the form G = (f, >), where f is a function from the Cartesian product E×F×C into the real Euclidean plane $\mathbf{R}^2$ and > is the usual order of the Cartesian plane, defined, for every couple of points p, q, by p > q if and only if the i-th component of the vector p (i.e. the real p(i)) is greater than or equal to the component q(i), of the vector q, for each index i, and the two vectors are different.

Remark. The difference among a two-players normal-form gain game and a two-person coopetitive gain game is simply the presence of the third strategy Cartesian-factor C.

2.1 Terminology and notation

Let G = (f, >) be a two players coopetitive gain game carried by the strategic triple (E, F, C). We will use the following terminologies:
- the function f is called the payoff function of the game G;
- the first component f_1 of the payoff function f is called the payoff function of the first player and analogously the second component f_2 is called the payoff function of the second player;

- the set E is said the strategy set of the first player, the set F the strategy set of the second player;
- the set C the cooperative strategy set of the two players.
- the Cartesian product E×F×C is called the coopetitive strategy space of the game G.

Memento. The first component f_1 of the payoff function f of a coopetitive game G is the function of the strategy space of the game G into the real line defined by

$$f_1(x,y,z) = pr_1(f(x,y,z)),$$

analogously, we proceed for the second component f_2.

We give the following interpretation. We have two players, each of them has a strategy set in which to choose his own strategy; moreover, the two players can/should cooperatively choose a strategy z in a third set C. The two players will choose their cooperative strategy z to maximize (in some sense we shall specify) the gain function f.

2.2 Bargaining solutions of a coopetitive game

The payoff function of a two person coopetitive game is (as in the case of normal-form game) a vector valued function with values belonging to the Cartesian plane $\mathbf{R}^2$; so that we should consider the maximal Pareto boundary of the payoff space im(f) as an appropriate zone for the bargaining solutions.

3. The model: A sustainable coopetitive model of economy

The coopetitive 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.

3.1 Strategies

The main strategic variables of the model are:

1) strategies x of a certain country c - **the aggregate production of the country** c - which directly influence both pay-off functions;

2) strategies y of the rest of the word - **the aggregate production of the rest of the world** w - which influence both pay-off functions;

3) a **bi-dimensional shared strategy** z which is determined together by the two subjects, c and the rest of the world w.

Interpretation of the cooperative strategy.

The vector z is the bi-level of investment for new low-carbon technologies, specifically z is a pair (z(1),z(2)) where z(1) is the investment of the country c and z(2) the total investment of the rest of the world w in low-carbon innovative technologies.

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

3.2 Main Strategic assumptions

We assume that any real number x, in the canonical unit interval

$$E := \mathbf{U} = [0,1]$$

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

$$F := \mathbf{U},$$

is the analogous aggregate production of the rest of the world w.

Measure units of strategy sets E and F. We assume that the measure units of the two intervals E and F be different: the unit 1 in E represents the maximum possible aggregate production of country c and the unit 1 in F is the maximum possible aggregate production of the rest of the word w, obviously these two units are totally different, 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 pair z, belonging to the canonical square

$$C: = U_1 \times U_2 := \mathbf{U}^2,$$

is the bi-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 unit 1 of U_1 is the maximum possible investment for the country c and the unit 1 in U_2 is the possible maximum investment for the rest of the world w in direction of low-carbon technologies.

Let us assume, so, that the country c and the rest of the world w decide together to contribute by the bi-investment $z = (z_1,z_2)$.

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

3.3 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 $\mathbf{U}^4$ into the real line, defined by

$$f_1(x, y, z) = 4x (1 - x - y) + mz_1 + nz_2,$$

for every triple (x, y, z) in the 4-cube $\mathbf{U}^4$, where m is a characteristic positive real number representing the benefits of the low-carbon technologies implemented by country c upon the economic performances of the country c itself; on the other hand n is a characteristic positive real number representing the benefits of the low-carbon technologies implemented by the rest of the world w upon the economic performances of the country c.

3.4 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 interaction is the function f_2 of the 4-cube $\mathbf{U}^4$ into the real line, defined by

$$f_2(x, y, z) = 4y (1 - x - y) + nz_1 + mz_2,$$

for every triple (x, y, z) in the 4-cube $\mathbf{U}^4$, where n is a characteristic positive real number representing the benefits of the low-carbon technologies implemented by country c upon the economic performances of the rest of the world w and mz_2 represents the economical benefit of the low-carbon technologies implemented by w upon the economic performances of w itself.

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

3.5 Payoff function of the coopetitive game

We so have build up a coopetitive gain game G = (f, >) with payoff function f given by

$$\begin{aligned} f(x, y, z) &= (4x (1 - x - y) + mz, 4y (1 - x - y) + nz) = \\ &= 4(x (1 - x - y), y (1 - x - y)) + z(1)(m, n) + z(2)(n, m), \end{aligned}$$

for every triple (x, y, z) in the compact 4-cube $\mathbf{U}^4$.

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

Note that, fixed a cooperative strategy z in the square $\mathbf{U}^2$, 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(0,0) by the vector

$$v(z) = z_1(m, n) + z_2(n, m),$$

so that we can study the game G(0,0) and then we can translate the various information of the game G(0,0) by the vector v(z).

So let us consider the game G(0,0). The last game G(0,0) has been studied completely by Carfì in *Topics in Game Theory* (2011). The conservative part in payoff space (the part of the payoff space greater than the conservative bi-value (0,0)) is the canonical 2-simplex T, convex envelope of the origin and of the canonical basis e of the Euclidean plane $\mathbf{R}^2$.

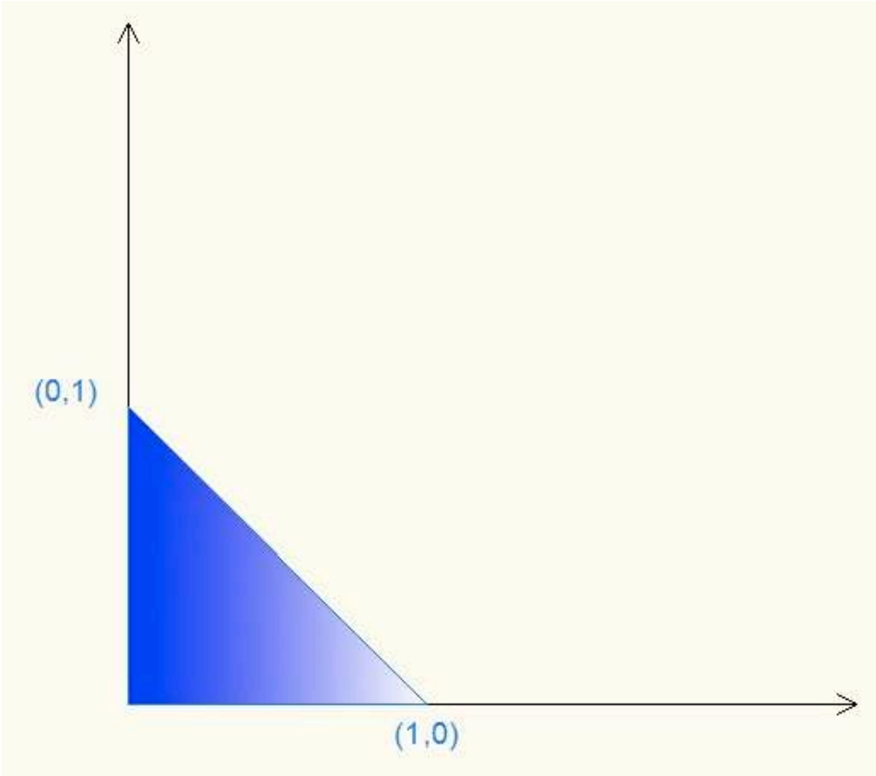

Figure 1. Cournòt payoff space.

4.1 Payoff space and Pareto Boundary of the payoff space of G(z)

The Pareto boundary of the payoff space of the z-section 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

$v(z) = z_1(m, n) + z_2(n, m)$,

this is true for all bi-strategy z in $\mathbf{U}^2$ (bi-dimensional set).

The payoff space of the coopetitive game G, the image of the payoff function f, is the union of the family of payoff spaces

$(\text{im } p(z))_{z \in C}$,

that is the convex envelope of the of points 0, e(1), e(2), and of their translations by the vectors

v(1,0) = (m, n)

and

v(1,1) = (m, n) + (n, m).

Explicative Figures.

We show in the following figures the construction of the coopetitive payoff space in two steps, in the particular case (m,n) = (1,2), just to clarify the procedure.

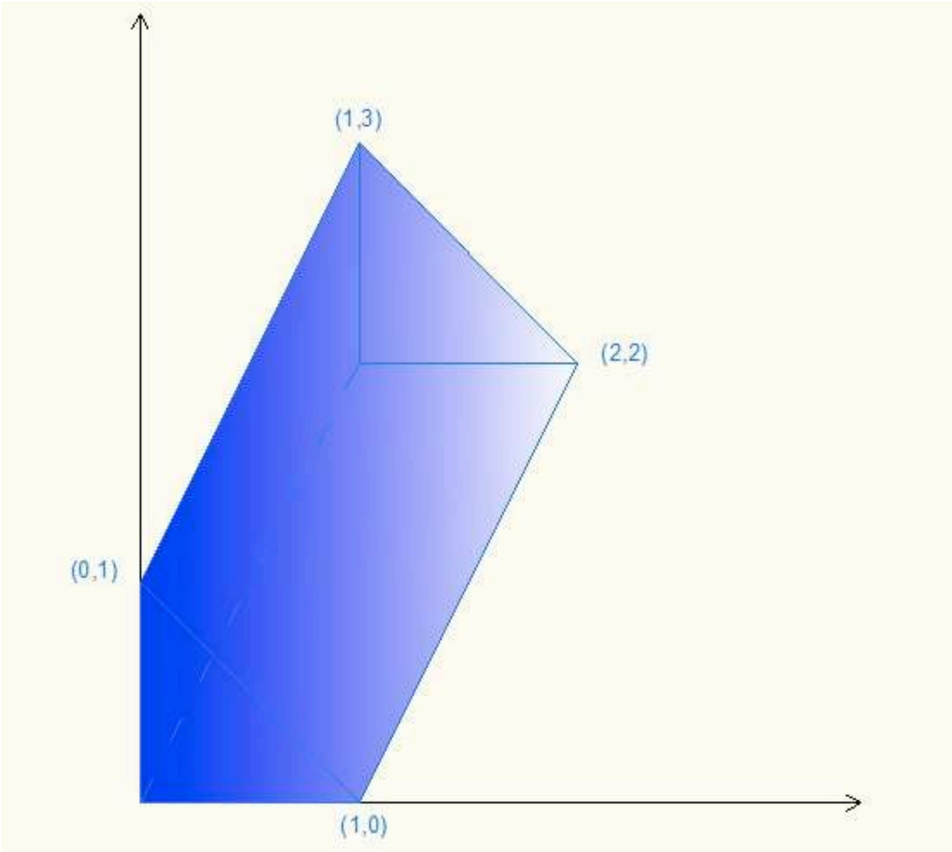

Figure 2. First step. T + [0,1](1,2)

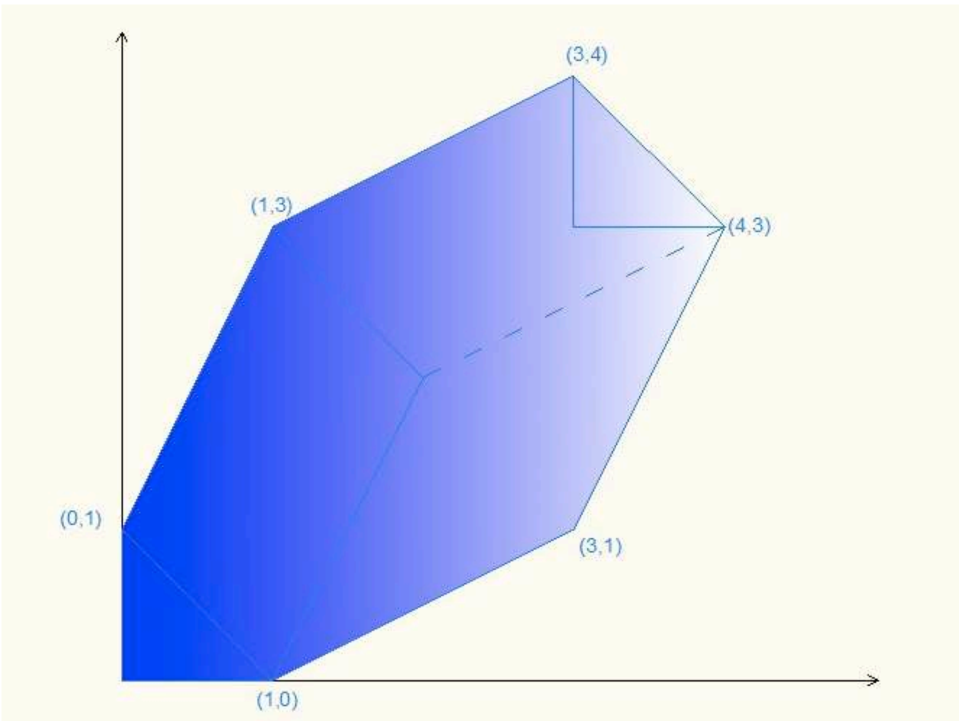

Figure 3. Final step. f(S) = T + [0,1](1,2) + [0,1](2,1).

The Pareto maximal boundary of the payoff space f(S)

The Pareto maximal boundary of the payoff space f(S) of the coopetitive game G is the segment [P',Q'], where the point P' is the translation

$e_1 + v(1,1)$

and the point Q' is the point

$e_2 + v(1,1)$.

In the above figures is the segment [(3,4),(4,3)].

5 Solutions of the model and conclusions

1) **Properly coopetitive solution.** In a purely coopetitive fashion, the solution of the game in the payoff space is the translation of the Nash payoff

   (4/9, 4/9)

   by the vector

   (m + n, m + n);

   that is, in the strategic cube S the solution

   (1/3, 1/3, (1,1)).

   This solution is obtained by cooperating on the set C and (interacting) competing *à la* Nash in the game G(1,1).

Interpretation. The complex game just played was developed with reference to the strategic variables *x*, *y*, z, and the functional relation *f*, which represents a continuous infinite family of games *à la Cournot*, where in each member-game of the family the quantities are the variables which vary in order to establish the Cournot-Nash equilibrium, and where *z* allows the game to identify possible cooperative solutions in a competitive environment, thus we have obtained a "pure coopetitive solution".

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

2) **Super-cooperative solution.** The Nash bargaining solution and the Kalai-Smorodinsky bargaining solution, with respect to the infimum of the Pareto boundary, coincide with the medium point K of the segment [P', Q']. This point K represents a win-win solution with respect to the initial (shadow maximum) supremum (1,1) of the pure Cournot game if and only if the sum m + n is greater than 1.

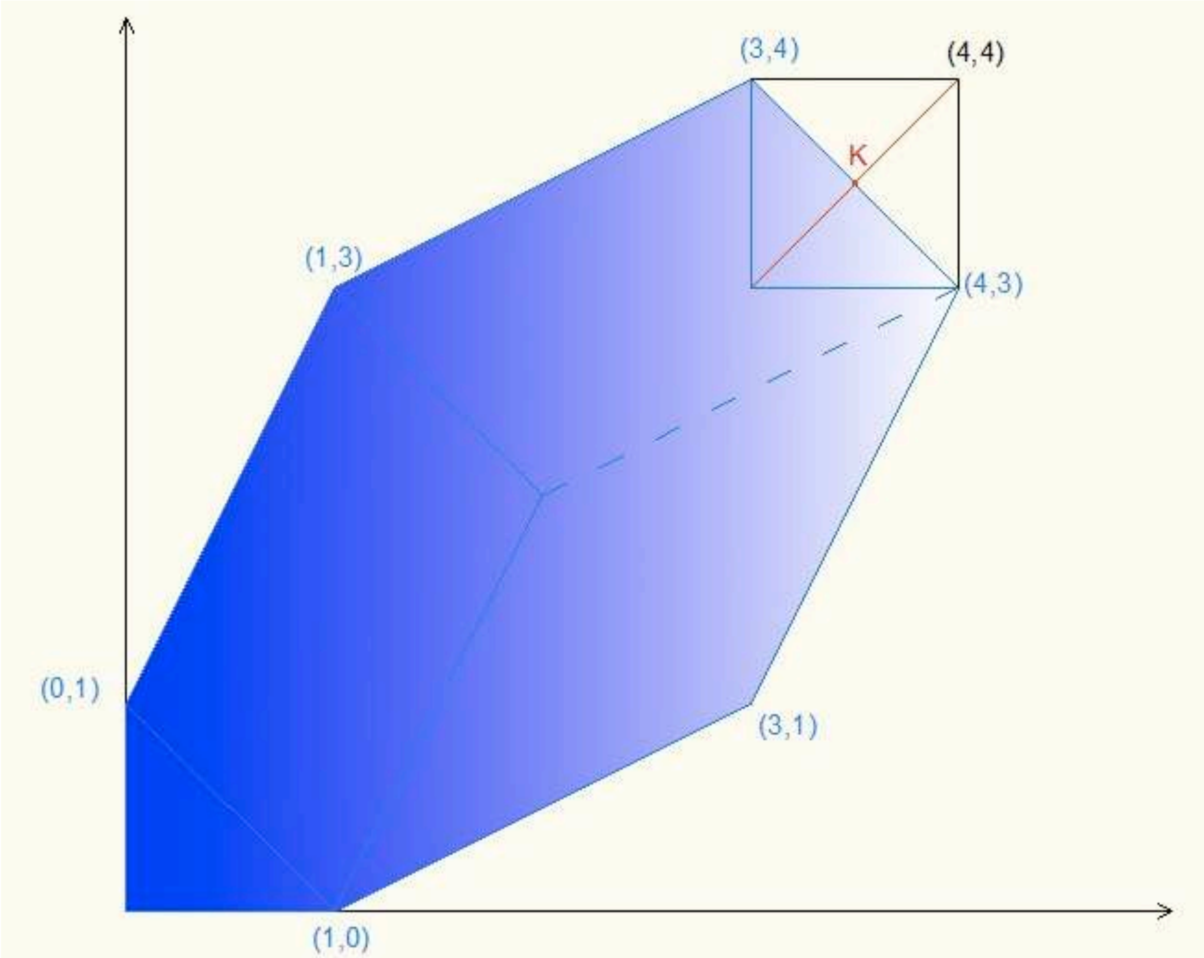

Figure 4. Double cooperative solution in the payoff space: K.

6. Sunk costs

For what concerns the sunk costs, we consider an initial bi-cost (1/3, 1/3) necessary to begin the low-carbon approach to the production, so that in a non-coopetitive environment we have a translation by the vector (-1/3, -1/3) of the Nash equilibrium payoff

(4/9, 4/9).

Although we have a bi-loss, in a coopetitive environment the gain is strictly greater than the absolute value of the bi-loss, thus the new Kalai-Smorodinsky solution

K – (1/3,1/3)

is greater than the old Nash equilibrium payoff. As we show in the below figure by the upper cone of (4/9, 4/9).

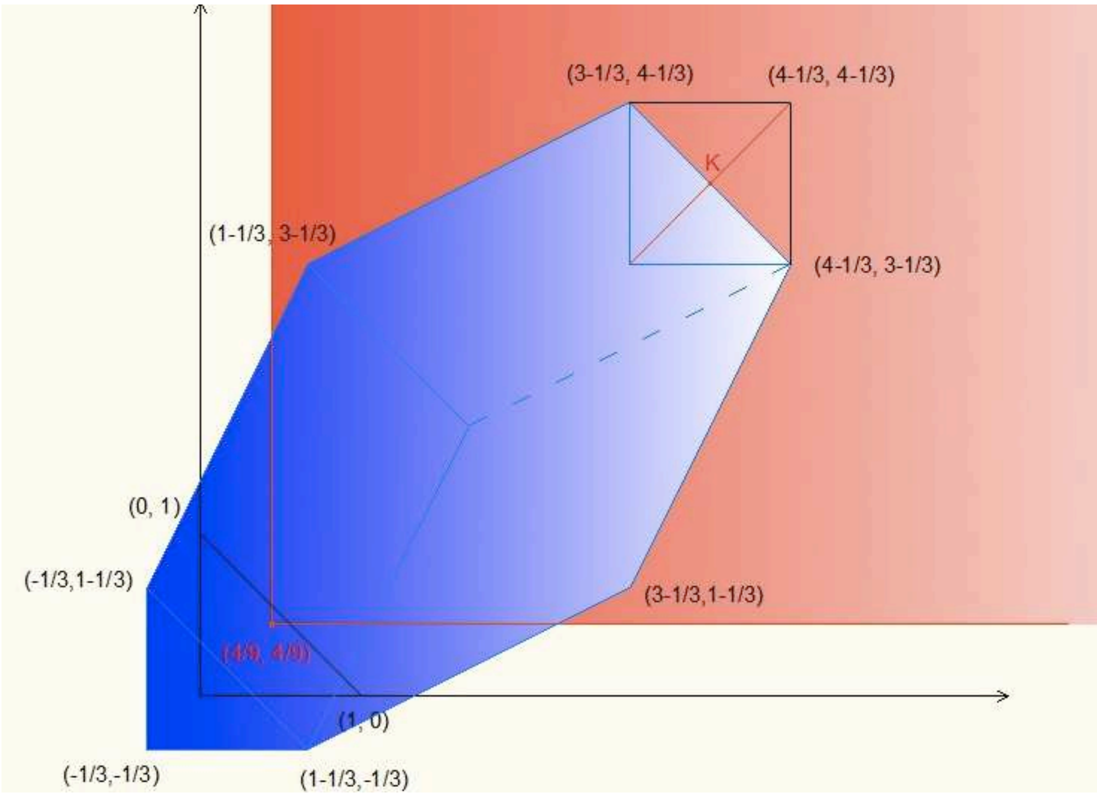

Figure 5. Translation by the sunk costs.

7. Conclusions.

Our coopetitive model has tried to demonstrate which are the win-win solutions of a coopetitive strategy that aims at a policy of climate change to implement a Green Economy. This policy concerns the adoption of innovative low carbon technologies, taking into account its sunk costs, and the determination of aggregate output of any country c in a non-cooperative game *à la* Cournot.

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

- firstly, we defined z as the coopetitive variable, which is the instrumental variable of the climate change policy, but also we considered z as a bi-dimensional variable z_1 and z_2;

- secondly, we adopted a non-cooperative game *à la Cournot* for establishing an equilibrium level of the bi-strategy (x,y), that represents the level of output of country c;

- thirdly, we introduced the sunk costs in the function of low carbon technologies;

- finally, we suggested not only a "pure coopetitive solution", but also a "super-cooperative solution" on the Pareto boundary, adopting the Kalai-Smorodinsky method, thus obtaining a "best compromise solution".

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