DYNAMICAL STABILIZATION OF CURRENCY MARKET WITH FRACTAL-LIKE TRAJECTORIES

David Carfì[1], Francesco Musolino[2]

The goal of this paper is to propose a mathematical model of management that enables real economic operators to take active action in the financial system, by adopting Game Theory and some of its dynamical aspects. Specifically, we study different dynamical interactions - in presence of a financial transaction tax - between a real economic operator hedging the currency risk, called Enterprise, and a bank performing speculative transactions, called Bank. At this purpose, we study the dynamical evolution of the model by pointing out two different fractal-like trajectories, determined by repeating our initial model every year, in which both players obtain increasing gains every year.

Keywords: Currency Markets; Dynamical Models; Game Theory.
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1. Introduction

In recent years we are facing a financial crisis that affects the world of the real economy. Thus, we can see a dual economic operators' orientation:

(1) on one hand, speculators act on financial markets trying to profit;
(2) on the other hand, real economic subjects suffer the crisis and try to protect themselves from the market-risks via hedging operations.

How can we address and adjust these two divergent trends? Is it possible to offer a mathematical model of management that enables real economic operators to take active action in the financial system and to not suffer it? In this paper we try to model an idea of market stabilization and of a consequent boost to the real economy. In particular, we model a possible profitable interaction (from a static and a dynamical point of view) between Enterprise and Bank with respect to Euro-Dollar market, particularly turbulent in the last period (Fig.1).

Scope of the paper. By the introduction of a tax on currency transactions, we propose a method aiming to limit the speculations of medium and big financial operators and, consequently, a way to make more stable the Euro markets. By using Game Theory (for a complete study of a game see [2, 5, 7, 10, 11]), we apply the Carfì and Musolino's model ([3, 6, 18, 9]) to the currency market and we analyze its possible dynamical effects in the long period (for a coopetitive approach see [4, 8]).

University of California, at Riverside Country, United States, Email: `davidcarfi71@yahoo.it`
University of Messina, Italy, Email: `francescomusolino@hotmail.it`

FIGURE 1. From 2001 Euro has had a upward trend versus the USD, but after 04/2008 it has declined by 17% until 03/2012 ([25]).

2. The description of the game

Our **first player** is an Enterprise, i.e. multinational corporation that is often exposed to currency risk. So, taking into account only the 2010, we know the Enterprise has spent the pharaonic sum of 885 million Euros to buy derivative contracts to hedge against currency risk (for that monetary amount, we consider for a moment the big enterprise Ferrari). In our model Enterprise chooses to buy Euro futures in order to hedge against an upwards change of Euro-Dollar exchange rate; in fact, at time 1 Enterprise should convert in Euro a certain quantity M_1 of Dollar credits. Therefore, Enterprise chooses a percentage $x \in [0, 1]$ of the quantity M_1, depending on it wants:

(1) not to hedge, by converting the Dollar credits in Euros, at the current exchange rate, at time 1 (strategy $x = 0$);
(2) to hedge partially, by buying Euro futures for a part of its Dollar credits (strategies $0 < x < 1$);
(3) to hedge totally, by buying Euro futures for all of its Dollar credits (strategy $x = 1$).

Our **second player** is Bank, a bank operating on the Euro spot market. Bank works, in our game, also in the Euro futures market:

(1) taking advantage of possible gain opportunities - given by misalignment between Euro spot and futures prices (both expressed in Dollars);
(2) or accounting for the loss obtained, by closing the short position in the Euro spot market.

These actions determine the payoff of Bank. Bank, therefore, chooses a percentage $y \in [-1, 1]$ of the quantity M_2 of Euros that it may buy (in algebraic sense) with its financial resources, this percentage has the following meaning:

(1) to purchase Euros on the spot market (strategies $y > 0$);
(2) to short sell Euros on the spot market (strategies $y < 0$);
(3) not to intervene on the Euro spot market (strategy $y = 0$).

Graphically the bi-strategy space $E \times F$ of the game is a rectangle with vertices $A = (0, 1)$, $B = (1, 1)$, $C = (1, -1)$, $D = (0, -1)$ (in the following, we shall focus, in particular, also on the points $H = (0, 0)$ and $K = (1, 0)$).

Game time structure. Our game G requires a construction on 3 times, say time 0, 1 and 2.

0) At time 0, Enterprise knows the quantity of its U. S. Dollar financial credits. It chooses to buy Euro futures contracts in order to hedge the currency risk on its Dollar credits.
1) At time 1, Bank acts with speculative purposes on the currency spot markets (buying or short-selling Euros at time 0) and on the currency futures market (by the opposite action of that performed on the spot market). Bank may so take advantage of the temporary misalignment of the Euro spot and futures prices (expressed in U.S. Dollars), created by the hedging strategy of Enterprise.
2) At time 2, Bank cashes or pays the sum determined by its behavior in the futures market at time 1.

Remark. In this game, we suppose that the no-Euro credits of Enterprise are U.S. Dollar credits, but this game theoretic model is also valid for any currency different from Euro (not only U.S. Dollars, but also Yen for example). For this reason, Enterprise should repeat the behaviors assumed in this model for any type of its no-Euro credits. Hereinafter U. S. Dollars are called simply Dollars.

Assumption 1 (absence of uncertainty). *In the game, we do not introduce the uncertainty (and we do not consider extreme events in our economic world) and so we suppose that attempts of speculative profit (modifying the asset price) are successful.*

In fact, our interest is to show that a tax on speculative profits can limit speculations and not to determine if or how much the speculators gains depend on any possible space of states of the world (see at this purpose [21, 22]). Anyway, even without uncertainty, our model remains likely, plausible and very topical because:

- in a period of crisis, behavioral finance suggests ([23, 12, 17]) the vertical diffusion of a behavior (the so-called herd behavior [20, 14]) conforming to that adopted by the great investors;
- just the decrease (or increase) in demand influences the price of the asset ([16, 13, 1]).

Assumption 2 (Euro spot price). *$S_1(y)$ shall be the Euro spot price (expressed in Dollars) at time 1, after that Bank has implemented its strategy y. It is given by $S_1(y) = (S_0 + ny)u$, where:*

- *the coefficient $n > 0$ represents the effect of the strategy y on the price $S_1(y)$ and depends by the ability of Bank to influence the Euro market and the behavior of other financial agents (assumption 1). We are assuming linear the dependence $n \mapsto ny$ in S_1.*
- *$u = 1+i$ is the capitalization factor with the risk-free interest rate i. The value S_0 and the value ny should be capitalized, because they should be transferred from time 0 to time 1.*

Remark. For sake of calculation the value nu will be indicated by ν.

Assumption 3 (Euro futures price at time 0). *F_0 shall be the Euro futures price (expressed in Dollars) at time 0. It represents the price established at time 0 that Enterprise has to pay at time 1 in order to buy the Euros. By definition (see [15]), the futures price is given by $F_0 = S_0 u$, where S_0 is the Euro spot price at time 0. It is not influenced by strategies x and y.*

Assumption 4 (Euro futures price at time 1). *$F_1(x, y)$ is the oil futures price, established at time 1, after that Enterprise has played its strategy x and Bank has played its strategy y. It is given by $F_1(x, y) = S_1(y)u + mux$, where m measures the influence of x on $F_1(x, y)$ and depends on the ability of Enterprise to influence the Euro market and the behavior of other financial agents (assumption 1).*

The value S_1 should be capitalized because it follows the Hull's relation between futures and spot prices ([15]). The value mx is also capitalized because the strategy x is played at time 0 but has effect on the futures price at time 1.

2.1. The payoff function of Enterprise

The payoff function of Enterprise, referred to time 1, is given by the quantity of the not hedged Dollar credits $(1 - x)M_1$, multiplied by the difference $F_0 - S_1(y)$, between the sale price of the Euro futures and the purchase spot price of the Euro. So, the payoff function of Enterprise is defined by

$$f_1(x, y) = M_1(1 - x)(F_0 - S_1(y)), \tag{1}$$

for every bi-strategy (x, y) in $E \times F$.

The payoff function of Enterprise. Therefore, recalling the assumptions 2 and 3, the payoff function f_1 of the Enterprise is given by:

$$f_1(x, y) = -M_1(1 - x)\nu y = -M_1(1 - x)\nu y. \tag{2}$$

2.2. The payoff function of Bank

The payoff function of Bank at time 1 is given by the multiplication of the quantity yM_2 of Euros bought on the spot market by the difference $F_1(x, y)u^{-1} - S_0 u$ between the Euro futures price $F_1(x, y)$, discounted to time 1 (it is a price established at time 1 but cashed at time 2), and the purchase price of Euros at time 0 capitalized at time 1 (in other words we are accounting for all balances at time 1).

Stabilizing strategy of normative authority. In order to avoid speculations on Euro spot and futures markets by Bank, which is able to modify the Euro prices (assumption 1), we propose that the normative authority imposes to Bank the payment of a tax on the sale of the Euro futures. So Bank can't take advantage of swings of Euro-Dollar exchange rate caused by itself. We assume that this tax is fairly equal to the incidence of the strategy of Bank on the Euro spot price, so the price effectively cashed or paid for the Euro futures by Bank is $F_1(x,y)u^{-1} - \nu y$, where νy is the tax paid by Bank, referred to time 1 (see, for the use of taxes on financial markets, also [19]).

Remark. We note that: if Bank wins, it acts on the Euro futures market (at time 2) in order to cash the win; but, also in case of loss, Bank must necessarily act in the Euro futures market and account for its loss, because (at time 2, in the Euro futures market) it should also close the short position in the Euro spot market.

The payoff function of Bank is defined, for every $(x, y) \in E \times F$, by:

$$f_2(x,y) = yM_2(F_1(x,y)u^{-1} - \nu y - S_0 u). \tag{3}$$

The payoff function of Bank. Recalling the assumption 4, we have

$$f_2(x,y) = yM_2 mx. \tag{4}$$

2.3. The payoff function of the game

The payoff function of the game is so given, for every $(x, y) \in E \times F$, by:

$$f(x,y) = (-\nu y M_1(1-x), yM_2 mx). \tag{5}$$

3. Payoff space

We choose for sake of illustration $M_1 = 1$, $M_2 = 2$ and $\nu = m = 1/2$. This game is already studied in [3, 6], and in the fig. 2(a) we have the payoff space $f(E \times F)$ of our game.

4. Nash equilibria

The Nash equilibria of the payoff function of the game (Eq.5) are already studied in [3, 6].
The set of Nash equilibria is $\{(1,1)\} \cup [H, D]$. The Nash equilibria can be considered quite good, because they are on the weak maximal Pareto boundary.

Analysis of possible Nash strategies. If Enterprise adopts a strategy $x \neq 0$, Bank plays the strategy $y = 1$ winning something, and even if Enterprise plays $x = 0$ Bank can play all its strategy set F, indiscriminately, without obtaining any win or loss. Enterprise, which knows that Bank very likely chooses the strategy 1, hedges by playing $x = 1$. So, despite the Nash equilibria are infinite, it is likely the two players arrive in $B = (1,1)$, which is part of the proper maximal Pareto boundary.

5. Cooperative solutions

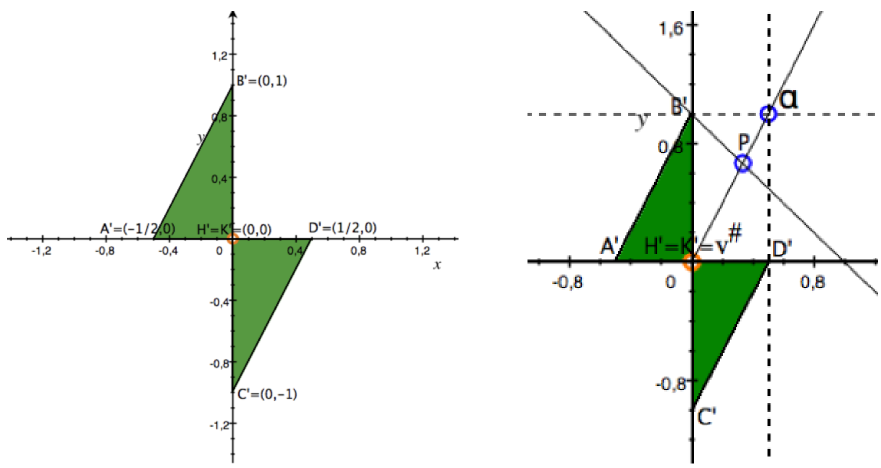
The best (and unique) way for two players to get both a win is to find a cooperative solution. One way would be to divide the maximum collective profit, determined by the maximum of the collective gain functional g, defined by $g(X,Y) = X + Y$ on the payoffs space of the game G, i.e the profit $W = \max_{f(E\times F)} g$.

The maximum collective profit W is attained (with evidence) at the point B', which

is the only bi-win belonging to the straight line with equation $X+Y=1$ and to the payoff space $f(E\times F)$.
So Enterprise and Bank play $x=1$ and $y=1$, in order to arrive at the payoff B'. Then, they split the obtained bi-win B' by contract.

Financial point of view. Enterprise buys futures to create artificially a misalignment between futures and spot prices, misalignment that is exploited by Bank, which gets the maximum win $W=1$.

A possible division. For a possible **fair division** of this win $W=1$, we employ a transferable utility solution: finding on the transferable utility Pareto boundary of the payoff space a *non-standard Kalai-Smorodinsky solution* (non-standard because we consider only its maximal Pareto boundary). We find the supremum of maximal Pareto boundary, $\sup \partial^* f(E\times F)$, which is the point $\alpha=(1/2,1)$, and we join it with the infimum of maximal Pareto boundary, $\inf \partial^* f(E\times F)$, which is $(0,0)$.



(a) Payoff space of the game G (b) Kalai-Smorodinsky point

The coordinates of the intersection point $P=(1/3,2/3)$ (see fig. 2(b)), between the straight line of maximum collective win (i.e. $X+Y=1$) and the straight line joining the supremum of the maximal Pareto boundary with the infimum (i.e., the line $Y=2X$) give us the desirable division of the maximum collective win $W=1$ between the two players.

6. Dynamical interaction and generated fractal

We suppose that our game is repeated every year. According to Nash equilibria approach, in this case we have an uncontrolled fluctuation of the state of our game in the payoff space (we have infinitely many Nash equilibria, and so it is not possible to know the state evolution of our game, a priori).

But as we have seen in section 5, it is convenient for both players to enter into an agreement and to divide the maximum possible collective gain according to Kalai-Smorodinsky method. For this reason, we can imagine a well-defined evolution

of accounts (in a well-defined payoff space trajectory).
In this context the payoff vector-function, in the first year, is given, for every $(x, y) \in E \times F$, by:

$$f^1(x, y) = (-\nu y M_1(1 - x), y M_2 m x) + (1/3, 2/3), \tag{6}$$

indeed, the Kalai-Smorodinsky bi-gain of the initial game f^0 was the payoff $P := (2/3)(\nu M_1, m M_2)$, and the starting point is so the Kalai-Smorodinsky solution $w := P = (1/3, 2/3)$ itself. Suppose to repeat the above strategic interaction, between the two operators, every year. We obtain the following recursive payoff functions:

$$f^p(x, y) = f^0(x, y) + pw, \tag{7}$$

where f^0 is defined by:

$$f^0(x, y) = (-(1/2)y(1 - x), xy),$$

p is the reference year and $w := (1/3, 2/3)$, for every time p in $\mathbb{N}$.

6.1. Annual repetition of the hedging operation

We suppose that every year Enterprise repeats its hedging operation about its commercial Dollar credits via the same method, and every following year Enterprise increases its economic availability M_1 with the gains obtained in the previous years. At the same time, also Bank repeats its speculative operation, and every following year Bank increases its economic availability M_2 with the gains obtained in the previous years.

Remark. In our game Enterprise can choose if to hedge its commercial Dollar credits. Since Enterprise is an enterprise operating durably on American automobile market, it is very realistic and likely that every year Enterprise has got new commercial Dollar credits to convert to Euro.

In this context the payoff functions are given, for every $(x, y) \in E \times F$, by:

$$f^1(x, y) = (-\nu y(4/3)M_1(1 - x), y(4/3)M_2 m x) + (1/3, 2/3), \tag{8}$$

indeed the Kalai-Smorodinsky bi-gain of the initial game f^0 is again the point $P := (2/3)(\nu M_1, m M_2)$ (the coordinate gains are added to the economic availabilities M_1 and M_2 of the initial payoff function f^0), and the starting point is the Kalai-Smorodinsky solution $w := P = (1/3, 2/3)$ itself. Suppose to repeat the above strategic interaction, between the two operators, every year. We obtain the following recursive payoff functions:

$$f^{p+1}(x, y) = (a_{p+1} - a_p) f^0(x, y) + a_p w, \tag{9}$$

where f^0 is defined by:

$$f^0(x, y) = (-(1/2)y(1 - x), xy),$$

and where the sequence $a := (a_p)_{p=-1}^{\infty}$ is recursively defined by $a_{-1} = 0$, $a_0 = 1$ and

$$a_{p+1} = 1 + a_p + (1/3)(a_p - a_{p-1}),$$

for every time p in $\mathbb{N}$ and where $w := (1/3, 2/3)$. We can represent this sequence of interactions by the following payoff evolution (see figure 2).

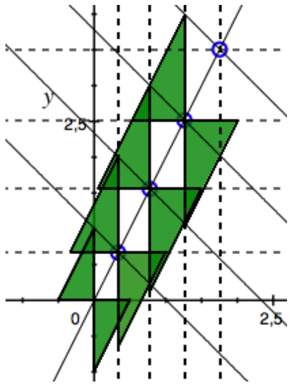


FIGURE 2. Fractal-like payoff.

We note that:

- supposing an annual repetition of our hedging model, both Enterprise and Bank could obtain potentially infinite gains, when the time p tends to infinity;
- we see a fractal-like payoff space trajectory, in fact all triangles in Fig. 2 are similar each others;
- it seems there are two asymptotic straight lines for the payoff trajectory, but it is not, as we shall show in the below proposition. Therefore, our payoff trajectory diverges at infinity.

Proposition. *Let a be the sequence defined by*

$$a_{p+1} = 1 + a_p + (1/3)(a_p - a_{p-1}). \tag{10}$$

Then, a is not convergent.

Proof. We assume, by contradiction, a admits a finite real limit L:

$$\lim_{p \to \infty} a_p =: L.$$

Recalling the Eq.10, when p tends to ∞ we obtain

$$L = 1 + L + (1/3)(L - L),$$

that is $0 = 1$, which is an absurd. This completes the proof. ■

6.2. Investment of obtained gains

We suppose, now, that the two players decide to invest only the obtained gains in the same fashion. In this context, the payoff function after one year is given, for every $(x, y) \in E \times F$, by:

$$f^1(x, y) = (-\nu y(1/3)M_1(1 - x), y(1/3)M_2 mx) + (1/3, 2/3), \tag{11}$$

indeed, again, the Kalai-Smorodinsky bi-gain of the initial game f^0 is the point $P := (2/3)(\nu M_1, mM_2)$ and the starting point is the Kalai-Smorodinsky solution

$w := P = (1/3, 2/3)$ itself. Suppose to repeat the above strategic interaction, between the two operators, every year. We obtain the following recursive payoff functions:

$$f^p(x,y) = (1/3)^p f^0(x,y) + (3/2)w(1 - (1/3)^p),$$

for every time p in $\mathbb{N}$, where, as we already know, f^0 is the function defined by $f^0(x,y) = (-(1/2)y(1-x), xy)$ and $w := (1/3, 2/3)$. We can represent this sequence of interactions by the following payoff evolution (see the figure 3).

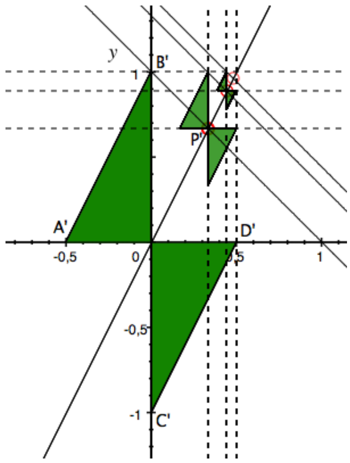


FIGURE 3. Fractal-like payoff.

We note that:

- every year our payoff space becomes smaller and smaller (exactly 1/3 of that one at the previous year)
- there is an elusive point of convergence, which is, by the way, the supremum of the initial payoff space, circumstance very stimulating and of interest from an economic point of view. The following proposition clarify the circumstance.

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Proposition. *Let $\alpha = (1/2, 1)$ be the supremum of the initial payoff space. The point α is an elusive point of convergence of our dynamical bi-strategic space $(f^p(E \times F))_{p\in\mathbb{N}}$, determined by investing only the obtained gains from the preceding step. More precisely, α is the limit of the Kalai-Smorodinky solutions sequence.*

Proof. **Part 1.** We start from the abscissas sequence $x = (x_k)_{k=0}^{\infty}$ of the Kalai solutions. The first year we have $x_0 = 1/3$, the second year $x_1 = 1/3 + (1/3)^2$, the third year $x_2 = (1/3 + (1/3)^2) + (1/3)(1/3)^2$. In general we have

$$x_k = x_{k-1} + (1/3)(1/3)^k, \quad x_{k-1} = \sum_{p=1}^{k} (1/3)^p = (1/3)\sum_{p=0}^{k-1} (1/3)^p.$$

Passing to limit, we have

$$x_\infty = \lim_{k\to\infty} \sum_{p=1}^{k} (1/3)^p = \sum_{k=1}^{\infty} (1/3)^k = \frac{1}{1-(1/3)} - 1 = 1/2.$$

Part 2. We pass to the ordinates sequence y. The first year we have $y_0 = 2/3$, the second year $y_1 = 2/3 + (1/3)(2/3)$, the third year

$$y_2 = (2/3 + (1/3)(2/3)) + (1/3)^2(2/3).$$

In general we have

$$y_k = y_{k-1} + (1/3)^k(2/3), \quad y_k = (2/3)\sum_{p=0}^{k}(1/3)^p.$$

Passing to limit we have

$$y_\infty = (2/3) \lim_{k\to\infty} \sum_{p=0}^{k} (1/3)^p = (2/3)\sum_{k=0}^{\infty}(1/3)^k = \frac{(2/3)}{1-(1/3)} = 1.$$

This completes the proof. ■

7. Conclusions

In this paper, we model a possible profitable interaction between an Enterprise and a Bank in the Euro-Dollar market: Enterprise has to decide whether to hedge against the currency risk by purchasing Euro futures, while Bank performs financial transactions with speculative purposes. The game suggests a possible regulatory model which favors the stabilization of the currency markets via the introduction of *a tax on financial transactions*. We study two different aspects of the same interaction: the static and the dynamical point of view.

Static point of view. By introducing a tax on speculative profits, Bank is induced to an interaction with other economic subjects (e.g. the Enterprise) to obtain a profit and, in this way, we favor the stabilization of the financial market, by limiting uncontrolled and unpredictable speculations. Moreover, we have noted that this possible profit depends on the behavior of Enterprise, which could prevent the gains of Bank. For this reason, we hypothesize an agreement between the two player to divide the maximum collective profit. After, by mean of a contract, Bank gives Enterprise part of this profit (we propose a possible K-S transferable utility solution). Moreover, we can interpret this portion of profit, transferred to the real economic subject, under a dual perspective:

(1) it is the *fair price* to pay in order to eliminate the uncertainty to achieve the most likely Nash equilibrium of the static game;
(2) it is the *fair redistribution* of the wealth generated by the financial transactions.

Dynamical point of view. If we assume a repetition of the model in the long period, we can observe two possible dynamical evolutions of above static interaction.

(1) The two economic operators repeat every years the initial interaction, by adding the K-S gains of the previous year to their economic availabilities (assumed equal every year). Such evolution of the interaction leads to an increasing fractal trajectory, without elusive straight lines or points, and so we obtain a dynamical model that could lead economic crisis to be progressively depleted.

(2) The two operators reinvest only the Kalai-Smorodinsky gains every year, always in the same way. Such dynamical interaction leads to an increasing fractal trajectory with an elusive point of convergence. The elusive point is, by the way, the supremum of the initial payoff space; this circumstance reveals very stimulating and of interest from an economic point of view. In a word, we note that the shadow maximum is not achievable in the short term, but only in the long period.

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