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A GAME THEORETIC APPROACH FOR ANALYZING THE CURRENCY EXCHANGES AND THEIR RISKS

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Abstract For the problem of Currency Exchange we can use the Game Theory and to construct a mathematical model for two participants (or more), and in consequence, we need to analyze all parameters which can influence the results of this operations. In order to analyze this problem as a multistage interactive situation, in this paper we use the theory of extensive games and we construct a dynamical model. Every such situation can be represented as a strategic game of two persons (the seller and the buyer). In this case the outcome of the dynamical game can be determined applying the Backtracking method using the best response-sets for every participant. More complicated could be a model for measurement of exchange rate risk for a firm. In this case we could apply some statistical simulation. First of all we need to define the type of the exchange rate risk, (Transaction risk, Translation risk, Economic risk). After defining the types of exchange rate risk that a firm is exposed to, a crucial aspect in a firm's exchange rate risk management decisions is the measurement of these risks.

Keywords: problem of Currency Exchange, mathematical model, multistage interactive situation, extensive games, dynamical model, strategic game, Backtracking method, exchange rate risk.

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1. INTRODUCTION

The currency changes can affect us, whether we are actively trading in the foreign exchange market, planning our next vacation, shopping online for goods from another country, or just buying food or other things imported from abroad. The value of a currency depends on factors that affect the economy such as trade, inflation, employment, interest rates, growth rate and geopolitical conditions.

The Problem of Currency Exchange is a simple situation well known for everybody, however the mathematical model for a sequence of such simple currency exchange operations could be very complicated if we will analyze all parameters which can have important influence for certain participants of this transaction. We can consider some simple national speculations or more complicated transnational speculations.

In this work we analyze the problem when a person has to do some simple operation of currency exchange and choose some exchange point, which is the most adequate for his interests. If we will consider a more complicated situation for some exchange operations of the same participants, during a period of some days or weeks, we can construct a dynamical model with complete (or incomplete) information.

We construct the dynamical model with two active players, one of them is "seller" and the other is "buyer", each of them wants to have some profit (or at least a minimum loss). So, the important decision for the buyer will be "when" and "which operation" is better to do ("to buy" or "to sell"); and the decision for the seller will be: to establish the most adequate price for each type of currency.

The third (passive) player will be considered the "Central Bank", which has the role to establish the daily Exchange Rates ("Benchmark"), as well as monitoring, surveillance of the exchange market and financial speculations, and the analysis / estimation of the risks on the money market (the open market). In the countries with active economy the rules of the game are established by the "Central Bank".

Our objectives for this problem are:

1. To define the dynamical game of the Currency Exchange problem and to give a tree representation. To solve this dynamical game using the backtracking method and the best-response sets for players.
2. To apply the statistical methods to approach the Exchange Risk.

2. PRELIMINARIES

Using the theory of extensive games, we will consider a non-static model, in order to analyze some multistage interactive situations. We will use the definition of the extensive game (González-Díaz, arcía-Jurado, 2010) Γ as a *7-tuple* (A, M, P, U, C, p, h) described below.

Definition of the dynamic game. An extensive (a dynamic) game Γ is a *7-tuple* (A, M, P, U, C, p, h), whose integrants are described below:

The game tree. (A, M) is a finite tree. By a finite tree we mean the following. A is a finite set of nodes and $M \subset A \times A$ is a finite set of arcs, satisfying that: i) there exists a unique distinguished node d: (d is distinguished if $(a, d) \notin M$ for all $a \in A$), and ii) for all $a \in A \setminus \{d\}$ there exists a unique path connecting d and a. We denote by Z the set of terminal nodes (i.e. such nodes $a \in A$ for which there are not arcs starting from it). The finite tree describes the structure of the multistage situation: the nodes which are not terminal represent the decision points of the players; the arcs starting from each node represent the alternatives available for its owner in that particular decision point; the terminal nodes represent the possible endpoints of the game.

The player partition. $P = \{P_0, P_1, ..., P_n\}$ is a partition of $A \setminus Z$, providing an indication of the player who makes a decision in every node which is not terminal.

The information partition. U provides a partition of P_i, (denoted by U_i), for every player $i \in N$. Every $u \in U_i$ contains the nodes of player i in which he has the same information about what has happened in the game up to that point.

The choice partition. Although players objectively select alternatives at decision nodes, subjectively they select choices at information sets. So, the choice partition C is a partition of M providing the choices of the players. For every $u \in U_i$, we denote by C_u the set of all choices at u.

The probability assignment. It is a map which assigns a probability distribution p_a over the set $\{(a, b), b \in A, (a, b) \in M\}$ for all $a \in P_0$. So, it provides a description of the random movements in the game.

The utilities. $h = (h_1, ..., h_n)$ provides the utility functions of the players, defined on Z. We assume that every player $i \in N$ has preferences on Z (the set of possible endpoints of the game) and that his preferences are represented by an utility function h_i.

3. EXAMPLES OF EXTENSIVE GAMES

Let us to analyze some practical examples of extensive games. In these examples we analyze some simple exchange transactions with two participants, for which we apply the definition of the extensive game (described above) and we construct the game tree in order to establish the results of the game.

Example 1. The exchange game. Suppose we have an exchange point. We will consider a game with two players. In this case, the first player is considered the seller, and the second player is the buyer. There are some types of currency at this exchange point (dollar, pound sterling, euro, etc. and the national currency of this country). Obviously, all types of exchanges can be made via the national currency.

The problem will be to decide in which condition to keep some type of currency. The seller can decide what strategy to apply if he has a forecast about the demand fluctuations, and how it would be changed in the near future.

The third (passive) player of the game could be considered the "Central Bank", that has the role to establish the daily Exchange Rates ("Benchmark"), as well as monitoring, surveillance of the exchange market and the financial speculations, and the analysis / estimation of the risks on the money market (the open market). In the countries with active economy the rules of the game are established by the "Central Bank".

The seller have to establish everyday the most adequate price for each type of currency. So the parameter Y means the current rate for some currency and should be established by the "Central Bank" under the legal norm, and the parameter μ could be a small positive or negative number, that means a possible increasing or decreasing of the rate for the corresponding currency (according to the legal norms of the "Central Bank").

The parameter X represents the amount of money that the buyer is going to invest for some amount of foreign currency. The parameter ϵ will be also managed by buyer, and it means a possible increasing or decreasing of the amount of money that he is going to invest for the foreign currency. Of course, the parameter ϵ depends on the increasing of the rate for some currency.

Let us to consider that this dynamical game will have two steps:

1. The seller have to decide (in the morning) if to change the rate for some currency or do not change. His decision depends on the demand fluctuations of the last days. Suppose that the rate for euro was Y the last day. The current rate may be changed to $(Y \pm \mu)$. Suppose the rate will be changed with probability $1/2$. We will ignore the case when the rate will not be changed (i.e. the rate is the same Y), and will consider this case as trivial.

2. Suppose that the buyer comes to this exchange point in order to buy $X = 500$ euro. He knew only the rate of the last day for this currency and he did not know the current rate. The buyer, arriving at the exchange point, have to decide if to buy 500 euro, or to buy less euro (in the case which the rate increased), or maybe to buy more euro (in the case which the rate decreased). This decision depends on the exchange fluctuations. So, he can buy $(X \pm \epsilon)$ euro, since he has a limited amount of money. The buyer makes his decision, he buys some amount of euro and the game is over.

In this case the buyer will pay less or more than he could pay for 500 euro the previous day. Thus, for each of these cases, we will have the next differences between current amounts paid for $(X \pm \epsilon)$ euro (in national currency) and the amount which could be paid for X euro the previous day with the rate Y:
(1): $(Y + \mu)(X - \epsilon) - XY = \mu(X - \epsilon) - \epsilon Y = S_1$,
(2): $(Y + \mu)(X) - XY = \mu X$,
(3): $(Y + \mu)(X + \epsilon) - XY = \mu(X + \epsilon) + \epsilon Y = S_2$,
(4): $(Y - \mu)(X - \epsilon) - XY = -\mu(X - \epsilon) - \epsilon Y = S_3$,
(5): $(Y - \mu)(X) - XY = -\mu X$,
(6): $(Y - \mu)(X + \epsilon) - XY = -\mu(X + \epsilon) + \epsilon Y = S_4$.

Notice, this game is a two-person extensive game (the first player being the seller, and the second player being the buyer). This game can be represented by the tree presented in Figure 1.

The results for this game can be represented by the next table. As it was mentioned above, the seller's strategy "Not change the rate" is considered trivial, we will not analyze it. So, we ignored it on the tree representation.

Strategy:	$(X-\epsilon)$	(X)	$(X+\epsilon)$
I: $(Y+\mu)$	$(S_1,-S_1)$	$(\mu X,-\mu X)$	$(S_2,-S_2)$
D: $(Y-\mu)$	$(S_3,-S_3)$	$(-\mu X,\mu X)$	$(S_4,-S_4)$
Not change:(Y)	$(\epsilon Y,-\epsilon Y)$	$(0,0)$	$(-\epsilon Y,\epsilon Y)$

Table 1: The outcomes of the game

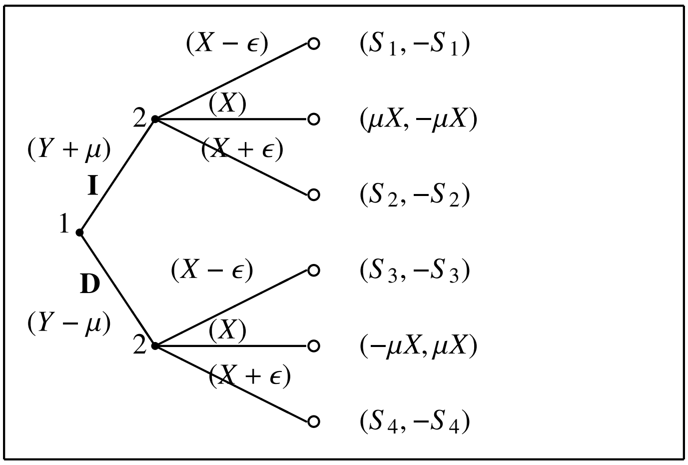

Figure 1. The tree representation of the game.

The results for the cases (1) and (6) could be different for both players, for buyer and for seller too. These results depend on the amount ϵ (i.e. it depends on the amount of currency which the buyer will buy: $X \pm e$).

Thus, for the case (1): if $\epsilon = X\frac{\mu}{Y+\mu}$, then the results for both players will be 0, (i.e. $(0,0)$, because $S_1 = 0$). In this case we will have two possible situations. If $\epsilon > X\frac{\mu}{Y+\mu}$, then the buyer will keep an extra amount of money less, than he would keep if he would buy X euro the previous day, because the rate is greater and he should buy less euro. If $\epsilon < X\frac{\mu}{Y+\mu}$, then the seller will receive a greater benefit than he could receive the previous day, if the buyer would buy only X euro. Thus, if the rate is greater than Y, then the buyer should buy less than X euro. If he will buy more than X euro, the seller will receive a greater benefit.

Analogically, for the case (6): if $\epsilon = X\frac{\mu}{Y-\mu}$, then the results for both players will be 0, (i.e. $(0,0)$, because $S_4 = 0$). In this case we will have two similar situations. If $\epsilon > X\frac{\mu}{Y-\mu}$, then the seller will have a greater benefit than he could receive the previous day for X euro. If $\epsilon < X\frac{\mu}{Y-\mu}$, then the buyer will keep some money and he would spend less than he would pay for the amount of X euro the previous day.

In this case we can give the next interpretation for these results: if the rate is less than Y, then for the buyer is more convenient to buy more than X euro. So, he will have a greater benefit, if in the near future the rate for euro will increase again.

Let us to see some numerical examples for these situations.
Suppose for the case (1), if $X = 500$, $Y = 10$, $\mu = 0.5$, $e = 23.80952$.
Then for $\epsilon = 23$ the result is $S_1 = 5008.5$. If $\epsilon = 24$, then $S_1 = 4998$.
Similarly, suppose for the case (6), if $X = 500$, $Y = 10$, $\mu = 0.5$,
$\epsilon = 26.3157$. If $\epsilon = 26$, the result is $S_4 = 4997$. If $\epsilon = 27$, then $S_4 = 5006.5$.

Example 2. Suppose another example with the same conditions from the first example and additionally, suppose that the play continues the next day with some seller's actions and some buyer's actions. Thus, suppose that the buyer will come to this exchange point the next day, to see if the rate for euro is the same or is changed. The first two steps are the same as in the first example. The next two steps will be made the second day, as it follows below.

3. The seller will decide if to change again the rates for some currencies or do not. We will consider the same strategies for the seller as in the first example (i.e. the rate could be $(Y + \eta)$ or $(Y - \eta)$).

4. Next, the buyer will decide if to buy an amount of the same currency (i.e. euro) or to sell some euro if his profit in this case would be greater. Thus, he could rationalize in the next manner. If the current rate is decreased (and the rate was decreased the previous day), then he will buy $(X/2 + \epsilon)$ or $(X/2)$ euro (we denote these strategies by B_1 and B_2, respectively). If the current rate is increased (and the rate was increased the previous day too), then he will sell $(X/2+\epsilon)$ or $(X/2)$ euro (we denote these strategies by G_1 and G_2, respectively). We will consider that the buyer will not make some other action in other cases. The buyer will make his decision the second day, and the game is over. This extensive situation is a multistage situation that can be modeled using the extensive game Γ in Figure 2.

Thus, if the second day the rate will be decreased again, or it will be increased again, then the buyer will make some strategy (he will buy or will sell some euro, respectively), in other cases the results will be the same from the first day (i.e. as in the first example) and the game is over after the 3^{rd} step.

We will denote the buyer's strategies for the 4^{th} step as it follow: G_1 := "to sell $(X/2 + \epsilon)$ euro", G_2 := "to sell $(X/2)$ euro", B_1 := "to buy $(X/2 + \epsilon)$ euro", B_2 := "to buy $(X/2)$ euro".

In the figure 2 below, we denoted by:

$p_{11} = (X/2 + \epsilon)(Y + \eta)$,	$p_{12} = (X/2)(Y + \eta)$,
$p_{21} = (X/2 + \epsilon)(Y - \eta)$,	$p_{22} = (X/2)(Y - \eta)$.

Table 2: Notations in Figure 2

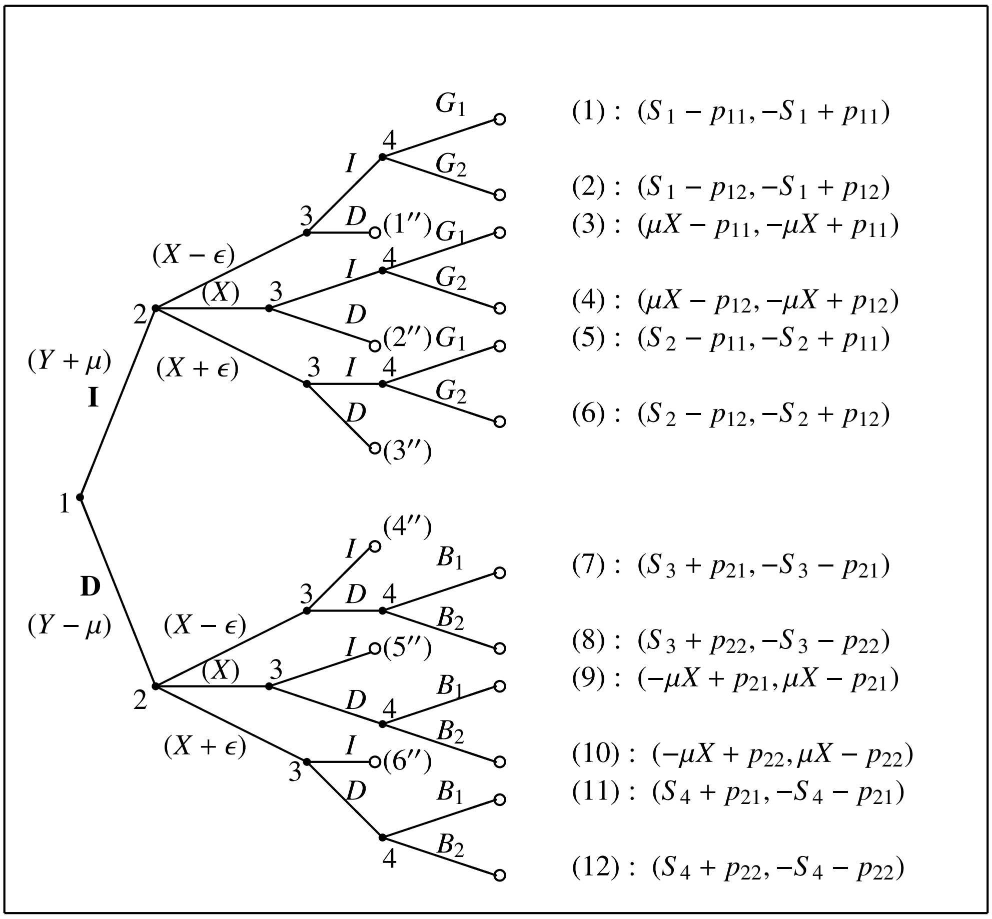

Figure 2. The tree representation of the second game.

After the third step we will have next six cases (as decision points for the second player- "buyer").
Case 1: The first two strategies are $(Y + \mu)$, $(X - \epsilon)$ and the 3^{rd} strategy is I ("increased") or D ("decreased").
Case 2: The first two strategies are $(Y + \mu)$, (X) and the 3^{rd} strategy is I ("increased")

or D ("decreased").
Case 3: The first two strategies are $(Y + \mu)$, $(X + \epsilon)$ and the 3^{rd} strategy is I ("increased") or D ("decreased").
Case 4: The first two strategies are $(Y - \mu)$, $(X - \epsilon)$ and the 3^{rd} strategy is I ("increased") or D ("decreased").
Case 5: The first two strategies are $(Y - \mu)$, (X) and the 3^{rd} strategy is I ("increased") or D ("decreased").
Case 6: The first two strategies are $(Y - \mu)$, $(X + \epsilon)$ and the 3^{rd} strategy is I ("increased") or D ("decreased").

For the first three cases the strategy of the "buyer" will be G_1 or G_2, and for next three cases the strategy of the "buyer" will be B_1 or B_2. There are 6 cases in which the "buyer" will prefer "no action" at the 4^{th} step, these situations are when the "seller" will apply the strategy I ("increased") at the first step, and the strategy D ("decreased") at the 3^{rd} step - (for 3 cases); also when the "seller" will apply the strategy D ("decreased") at the first step, and the strategy I ("increased") at the 3^{rd} step - (for other 3 cases). In these situations the results of the game are the same as in the first example.

These results could be represented by the next matrixes:

In consequence, at the 4^{th} step of this game, for those 6 cases (when the "buyer" will prefer the strategy "no action"), we will have the next results of the game:

$$\begin{array}{rlrl}
(1") := & (S_1, -S_1), & (4") := & (S_3, -S_3), \\
(2") := & (\mu X, -\mu X), & (5") := & (-\mu X, \mu X), \\
(3") := & (S_2, -S_2), & (6") := & (S_4, -S_4).
\end{array}$$

The interpretation for these situations may be made in the similar mode as it was made in the first example. The cases, when the buyer will not make some actions at the second day, will correspond to the same cases from the first example.

Example 3. We can suppose as a special case the similar game (as in the example 2), in which the buyer will make some action in every situation. Thus, suppose the game from the example 2 with four steps, for two days, and additionally, suppose that the buyer will sell or will buy some amount of euro depending on the current rate of euro.

This special case can be represented as a multistage extensive game, and it may have an interesting interpretation, especially for a period longer than two days. If the buyer will have some interest to buy or to sell some currency, he could obtain some profit for a period longer than some weeks. In this case he should analyze each situation every day, and depending on the current rate and the rates from the previous days to make the right decision.

Obviously, for a such game the tree will be very complicated and additionally, we have to analyze also the factors that could influence the Exchange Rates.

Case 1: $(Y+\mu)\&(X-\epsilon)$		
Strategy:	$G_1 : -(X/2+\epsilon)$	$G_2 : -(X/2)$
$I: \ (Y+\eta)$	(1)	(2)
$D: \ (Y-\eta)$	$(1''): (S_1, -S_1)$	$(1''): (S_1, -S_1)$

Case 2: $(Y+\mu)\&(X)$		
Strategy:	$G_1 : \ -(X/2+\epsilon)$	$G_2 : -(X/2)$
$I: \ (Y+\eta)$	(3)	(4)
$D: \ (Y-\eta)$	$(2''): (\mu X, -\mu X)$	$(2''): (\mu X, -\mu X)$

Case 3: $(Y+\mu)\&(X+\epsilon)$		
Strategy:	$G_1 : \ -(X/2+\epsilon)$	$G_2 : -(X/2)$
$I: \ (Y+\eta)$	(5)	(6)
$D: \ (Y-\eta)$	$(3''): (S_2, -S_2)$	$(3''): (S_2, -S_2)$

Case 4: $(Y-\mu)\&(X-\epsilon)$		
Strategy:	$B_1 : \ (X/2+\epsilon)$	$B_2 : (X/2)$
$I: \ (Y+\eta)$	$(4''): (S_3, -S_3)$	$(4''): (S_3, -S_3)$
$D: \ (Y-\eta)$	(7)	(8)

Case 5: $(Y-\mu)\&(X)$		
Strategy:	$B_1 : \ (X/2+\epsilon)$	$B_2 : \ (X/2)$
$I: \ (Y+\eta)$	$(5''): (-\mu X, \mu X)$	$(5''): (-\mu X, \mu X)$
$D: \ (Y-\eta)$	(9)	(10)

Case 6: $(Y-\mu)\&(X+\epsilon)$		
Strategy:	$B_1 : \ (X/2+\epsilon)$	$B_2 : \ (X/2)$
$I: \ (Y+\eta)$	$(6''): (S_4, -S_4)$	$(6''): (S_4, -S_4)$
$D: \ (Y-\eta)$	(11)	(12)

Table 3: The outcomes of the game (the results of the 4^{th} step).

4. EXCHANGE RATE DYNAMICS & CURRENCY FACTORS

Currency changes affect us, whether we are actively trading in the foreign exchange market, planning our next vacation, shopping online for goods from another country, or just buying food and other goods imported from abroad.

Like any commodity, the value of a currency rises and falls in response to the forces of supply and demand. The supply and demand of a country's money is reflected in its foreign exchange rate.

Consumer spending is influenced by a number of factors: the price of goods and services (inflation), employment, interest rates, government initiatives, and so on. Here are some economic factors we can follow to identify economic trends and their effect on currencies.

Top 5 Factors Affecting Exchange Rates

According to ”Oanda” [6], the most important five factors that affect the exchange rates are the next ones:

1. Interest Rates: "Benchmark" interest rates from central banks influence the retail rates financial institutions charge customers to borrow money. To slow the rate of inflation in an overheated economy, central banks raise the benchmark so borrowing is more expensive.
2. Employment Outlook: Employment levels have an immediate impact on economic growth. An increase in unemployment signals a slowdown in the economy and possible devaluation of a country's currency because of declining confidence and lower demand. If demand continues to decline, the currency supply builds and further exchange rate depreciation is likely.
3. Economic Growth Expectations: To meet the needs of a growing population, an economy must expand. However, if growth occurs too rapidly, price increases will outpace wage advances so that even if workers earn more on average, their actual buying power decreases.
4. Trade Balance: A country's "balance of trade" is the total value of its exports, minus the total value of its imports. If this number is positive, the country is said to have a favorable balance of trade. If the difference is negative, the country has a trade gap, or trade deficit.
5. Central Bank Actions: With interest rates in several major economies already very low, central bank and government officials are now resorting to other, less commonly used measures to directly intervene in the market and influence economic growth. It comes with some risk: increasing the supply of a currency could result in a devaluation of the currency.

6 Factors That Influence Exchange Rates

According to Jason Van Bergen [7], there are six factors - the most important, that influence the exchange rates:

1. Differentials in Inflation, 2. Differentials in Interest Rates, 3. Current-Account Deficits, 4. Public Debt, 5. Terms of Trade, 6. Political Stability and Economic Performance.

Foreign-Exchange Risk Definitions

There are many definitions of the Foreign-Exchange Risk according to different authors. The most simple definitions according to "Investopedia" [8] are the next two definitions:

1. The risk of an investment's value changing due to changes in currency exchange rates.

2. The risk that an investor will have to close out a long or short position in a foreign currency at a loss due to an adverse movement in exchange rates. Also known as "currency risk" or "exchange-rate risk".

This risk usually affects businesses that export and/or import, but it can also affect investors making international investments. For example, if money must be converted to another currency to make a certain investment, then any changes in the currency exchange rate will cause that investment's value to either decrease or increase when the investment is sold and converted back into the original currency.

On the other hand, the foreign exchange risk can be defined in different forms, specifying the terms for occurrence of the risk.

Foreign exchange risk (also known as FX risk, exchange rate risk or currency risk) is a financial risk that exists when a financial transaction is denominated in a currency other than that of the base currency of the company.

Foreign exchange risk also exists when the foreign subsidiary of a firm maintains financial statements in a currency other than the reporting currency of the consolidated entity. The risk is that there may be an adverse movement in the exchange rate of the denomination currency in relation to the base currency before the date when the transaction is completed.

Investors and businesses exporting or importing goods and services or making foreign investments have an exchange rate risk which can have severe financial consequences; but steps can be taken to manage (reduce) the risk.

Types of exchange rate risk

The three main types of exchange rate risk considered by (Shapiro, 1996; Madura, 1989) are:

1. Transaction risk, which is basically cash flow risk and deals with the effect of exchange rate moves on transactional account exposure related to receivables (export contracts), payables (import contracts) or repatriation of dividends.

2. Translation risk, which is basically balance sheet exchange rate risk and relates exchange rate moves to the valuation of a foreign subsidiary, and, in turn, to the consolidation of a foreign subsidiary to the parent company's balance sheet.

3. Economic risk, which reflects basically the risk to the firm's present value of future operating cash flows from exchange rate movements.

After defining the types of exchange rate risk that a firm is exposed to, a crucial aspect in a firm's exchange rate risk management decisions is the measurement of these risks.

Measurement of Exchange Rate Risk

At present, a widely-used method for measurement of the exchange rate risk is the value-at-risk (VaR) model (Papaioannou, 2006).

Broadly, value at risk is defined as the maximum loss for a given exposure over a given time horizon with $z\%$ confidence. The VaR measure of exchange rate risk is used by firms to estimate the riskiness of a foreign exchange position resulting from a firm's activities, including the foreign exchange position of its treasury, over a certain time period under normal conditions (Holton, 2003).

To calculate the VaR, there exists a variety of models. Among them, the more widely-used (Papaioannou, 2006) are:

(1) the historical simulation, which assumes that currency returns on a firm's foreign exchange position will have the same distribution as they had in the past;

(2) the variance-covariance model, which assumes that currency returns on a firm's total foreign exchange position are always (jointly) normally distributed and that the change in the value of the foreign exchange position is linearly dependent on all currency returns; and

(3) Monte Carlo simulation, which assumes that future currency returns will be randomly distributed.

5. CONCLUSION AND FUTURE WORK

Conclusion. The problem of the Currency Exchange became important and global in all social domains simultaneously with the economic and infrastructure development, leading to multiple international transactions. The mathematical modeling of this decision problem could help us to find the best solution in such situation and to minimize the loss for the participants of such business or financial transactions.

The exchange currency problem is not a simple problem. It is not easy to choose the right moment for a certain transaction and for the lower rate. This involves the using of high-risk strategies for participants.

Future work. As a future work, our purpose is to solve this problem:
- as a dynamic model with complete or incomplete information, applying the Backtracking method using the best response-sets for every participant;
- to apply various models of the VaR calculation for measurement of Exchange Rate Risk and to compare the results.

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