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EFFICIENCY OF THE FOREIGN EXCHANGE MARKETS: SDR PERSPECTIVE

Bachelor´s Thesis

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1. INTRODUCTION

There has been a lot of discussion about International Monetary Fund (IMF) and acquittance of debts of the developing countries. Especially last year, when there was a G 8 congress in Edinburgh, the main issue was the acquittance of debts of the developing countries. A substantial number of the debts are debts to the IMF. IMF operates with its own currency, SDR, which has been calculated from four major currencies; Euro, U.S. dollar, Japanese yen and pound sterling. IMF also calculates exchange rates and interest rates to the SDR.

IMF controls the flows of SDR itself and therefore; the efficiency of a foreign exchange market has policy implications of enormous importance. If a foreign exchange market is inefficient, a model that best predicts exchange rate movements can be developed. Therefore, an inefficient foreign exchange market provides opportunities for profitable foreign exchange transactions.

There have been a lot of studies concerning the exchange market efficiency since it was introduced by Fama in 1965. This definition maintains that, the forward rate should be the best predictor of the future spot rate. Fama also asserts that in an efficient market, the prices always fully reflect available information. All the three forms of the market efficiency have been well examined. In this paper, we concentrate on weak form and semi-strong form of efficiency. The weak form of the exchange market efficiency has been investigated among others by Liu and He (1991) and Gupta (1981). The semi-strong form has been examined by Engle and Granger (1987) and Johansen (1988). The semi-strong form has been investigated for example using cointegration. Hakkio and Rush (1989) and Baille and Bollerslev (1989, 1994), found that exchange rates across countries were cointegrated and suggested that foreign exchange markets may not be characterized by the efficient market hypothesis. Other studies, however, have reported different results. Rapp and Sharma (1999), for example, reported that there was no cointegrating vector on a bilateral basis between any of the two exchange rates, providing evidence in support of the efficient market hypothesis. Basically, there is a large literature showing that in an efficient market, prices must fully reflect all relevant and available information.

However, there have not been studies that concentrate on the efficient market hypothesis of SDR foreign exchange market during the existence of the present currency basket. Therefore, we investigate the weak and semi-strong form efficient market hypothesis using exchange rates of the currencies in the basket. The weak form efficiency is examined using unit root tests and semi-strong form is tested using cointegration and vector error correction model. We use daily spot exchange rates for Euro in terms of the U.S. dollar, pound sterling and Japanese yen; hence we act as a European investor.

The first test is the Augmented Dickey-Fuller (1979, 1981) test and the second test is the Phillips-Perron (1988) test. These unit root tests provide evidence on whether the exchange rates follow random walks. Therefore, they are also a test of the weak-form of the efficiency market hypothesis. Basically, our purpose is to prove that past exchange rates cannot be used to predict future exchange rates. Therefore, the participants in the foreign exchange market cannot devise any statistical technique to gain from foreign exchange market transactions consistently.

The cointegration is tested using the Johansen cointegration test. The Johansen test is also a test for semi-strong version of the efficient market hypothesis. We investigate co-movement between the exchange rates of the currencies in the basket. If spot exchange rates are cointegrated, then the series can be expressed with a causal ordering at least in one direction. Thus, it is hypothesized that if the exchange rates are cointegrated, then it is possible to predict one from another, thereby shooting down the efficient market hypothesis. The semi-strong form is also examined using the vector error-correction model, which opens up another channel of causality through the error-correction term which is ignored in standard Granger causality tests.

In this paper we firstly introduce the SDR system and the efficient market hypothesis. Secondly we go through the methodology and data used in the analysis of our study. Then we provide the empirical results and the last section concludes.

2. THEORETICAL BACKGROUND

2.1 Special Drawing Rights

IMF has created the Special Drawing Rights (SDR) to be an international reserve asset and its function is to be a complement to the other reserve assets whose recourses was not enough to finance the expansion of international trade and finance under the Bretton Woods system after the second world war. After the collapse of Bretton Woods, most of the countries adopted floating exchange rate system. Under this system, exchange rates are determined by the private market through supply and demand. In a floating regime, the central bank may also intervene when it is necessary to ensure stability and to avoid inflation; however, it is not often when the central bank of a floating regime will interfere. One major reason for the adoption of a floating exchange rate system was to improve the balance of payments crises that some countries had been facing. (Financial sector of World Bank, 2006)

After the collapse of Bretton Woods system, gold was not in a significant position in the international monetary system. Hence, in 1974 SDR redefined as a basket of currencies. Originally, the currencies of the 16 IMF members with at least one percent of world trade were included in the basket. At the same time the interest rate of SDR raised to 5 %. The interest rate was defined as a weighted average of interest rates on short-term market instruments in France, Germany, Japan, United States and the United Kingdom. The 16-currency SDR basket was not that good, because it was difficult to control and it included some currencies that were not widely traded. So, in 1981 the valuation of the SDR was simplified to the same five-currency basket on which the SDR interest rate was based on. The selection criterion for inclusion in the valuation basket was changed to the currencies of five countries with the largest exports of goods and services over the previous five years. The currencies were U.S. dollar, the Japanese yen, the Deutche mark, the French franc, and the pound sterling. (Financial organization and operations of the IMF, 2006)

Nowadays SDR has only a limited value as a reserve asset and its prime use purpose is to be a currency, which is used in a few international organizations including IMF. In the year 2000, Euro replaced naturally the French franc and the Deutche mark. Hence, the value is calculated every day using a basket of four major currencies: Euro, U.S. dollar, pound sterling and Japanese yen. The composition of the basket is evaluated every fifth year, so IMF could be sure that the basket represents comparative value of the currencies in the international markets.

However, both the valuation and yield of the SDR are connected to the current markets of their component exchange and interest rates, there is no market for SDR itself where excess supply and demand pressures can be eliminated by adjustments in the price, or value, of the asset. Rather, the IMF itself controls the flows of SDRs to be sure that the liquidity of the system remains. (Financial organization and operations of the IMF, 2006)

2.2 Efficient market hypothesis

The efficient market hypothesis (EMH) was originally represented by Fama in 1965. (Fama, 1965) Fama described an efficient market as a market which contains a large number of competitive profit maximizers interacting in a market taking advantage of all available information in a rational manner. In an efficient market, prices must fully reflect all relevant and available information; it means that, no profit opportunities are left unexploited. If currency markets are efficient, it should not be possible to forecast one spot exchange rate as a function of another. (Fama, 1991; Rapp & Sharma, 1999)

Fama presented a general formula describing how investors create price expectations for securities. That is presented as follows:

$$E(p_{j,t+1} \mid \phi_t) = \left[1 + E(r_{j,t+1} \mid \phi_t)\right] p_{jt} \qquad (1)$$

where, E is expected value operator, $p_{j,t+1}$ is price of security j at time $t+1$, $r_{j,t+1}$ is return on security j during period $t+1$ and ϕ_t is the set of information available to investors at time t.

So, $E(p_{j,t+1} | \phi_t)$ means the expected end-of-period price on security *j*, given the information available at the beginning of the period. Further, the term $1 + E(r_{j,t+1} | \phi_t)$ means the expected return over the forthcoming time period on securities having the same amount of risk as security *j*, given the information available at the beginning of the period. Therefore, the equation (1) states that the expected price of any security at the end of period *(t+1)* is based on the security´s expected normal rate of return during that period. In turn, the expected rate of return is determined by the information set available at the start of the period, ϕ_t. (Sharpe, 1995)

According to the efficient market hypothesis, an efficient market is one in which currencies adjust rapidly to the arrival of new information, and therefore, the current prices of securities reflect all information about the security. Three sets of assumptions imply an efficient market:

I. An efficient market requires that a large number of competing profit-maximizing participants analyze and value securities, each independently of the others.
II. New information concerning securities comes to the market in a random way, and the timing of one announcement is generally independent of others.
III. Competing investors attempt to adjust security prices rapidly to reflect the effect of new information. Although the price adjustment may be imperfect, it is unbiased.

As a conclusion we might say that sometimes the market will over- or under react, but an investor cannot predict which will happen at any given time. The efficient market hypothesis implies that since market prices reflect all available information, including information about the future, the only difference between the prices at time *t* and *t* + 1 are events that cannot possibly be predicted. However, during the last years a growing number of critics have argued against the efficient market hypothesis. (Jagric et al., 2005)

Basically, there are two important features in the EMH. Firstly, an efficient foreign exchange market does not provide opportunities for profitable foreign exchange transactions for speculators and therefore is an important aspect for all currency market participants. If the market is inefficient, participants can use various devices such as trading rules and statistical techniques to predict the movement of exchange rates. Investors and traders in global markets continuously hedge their currency exposures, while speculators take positions in foreign currencies based on their own expectations. For these participants, foreign exchange risk is an important component of their decision making. (Aroskar et al., 2004)

Other very important feature of the EMH is the situation, when the efficient market hypothesis holds; the need for government intervention in the market is minimal. Further, if the market is not efficient, policy-making bodies in the government or institution can determine the best way to influence exchange rates, reduce exchange rate volatility and evaluate the consequences of different economic policies on exchange rates. This is an important feature in this study, because IMF controls the flows of SDR itself. (Fabozzi et al., 2002)

2.2.1 Problems in the efficient market hypothesis

Although the EMH may be a functional economic concept, even a largely desirable condition, it may not be true. Currencies in the markets may not fully reflect all available information and the efficient market hypothesis does not reflect the reality of exchange rates behavior. The early literature on market efficiency was widely interpreted as supportive. But by the late 1970s the different evidence was growing and began to take attention. There are now a large number of empirical researches, which creates doubt upon the degree of market efficiency. Many of these theories are based on the idea that investors do not react rationally to information, but are instead influenced by trends and other psychological phenomena. (Malkiel, 2003)

Many who believe in the idea of the EMH are doubtful whether currency markets are efficient as the (semi-strong) EMH dictates. But even though there may be some weaknesses in the market pricing mechanisms, few academics would reject the concept. There are some reasons for the persistence of commitment to EMH. First, the big number of empirical evidence in support of the EMH can no more be ignored than can the more recent counter evidence.[1] It is arguable that the anomalies are reflections of misspecification of the models used rather than of (exploitable) market inefficiency. Finally, there are some who will cling to the EMH for the sheer weight of its economic logic, at least with respect to developed markets. (Bowman & Buchanan, 1995)

There are a number of institutional or market related characteristics of investment performance that argue against acceptance of the EMH. Perhaps the most obvious force is that in an efficient market there is no strong punishment mechanism operating against investment strategies, which are not that good. In other words, an efficient market is a fair game where the risk adjusted expected return to investor using publicly available information is the same regardless of the investment strategy used. To put it in other terms, we might say that security investments in efficient markets are zero net present value investments. This characteristic of an efficient market is clearly different from most other investing environments.

As a conclusion we might say that markets are not simply either efficient or inefficient. Market efficiency can be viewed as a continuum running from the perfect market to the inefficient market where excess earning opportunities abound. We can then think of any market or currencies in a market as being characterized by some degree of efficiency. (Bowman & Buchanan, 1995; Sharpe, 1995)

2.2.2 Forms of the efficient market hypothesis

Efficient market hypothesis has three forms: weak, semi-strong and strong form. When a market is weak form efficient, its exchange rates reflect all the information available in the past prices or returns. Semi-strong form has the prices of financial assets instantly reflecting publicly available information. In a strong-form efficient market, prices of financial assets reflect even inside information.[2] In this paper our

[1] Keane notes that unexplained exchange rate behavior is not necessarily irrational, and that irrational behavior is not necessarily exploitable, and finally that exploitable behavior is not necessarily worth exploiting. (Keane, 1991)

[2] Inside information is known by the company's board of directors, management, and/or employees but not by the public. It is illegal to use this kind of information in trading.

purpose is to investigate the weak form and semi-strong form. (Wickremasinghe, 2004)

Typically, when people refer to efficient markets, they really mean semi-strong form efficient since that involves some publicly available information that analysts are restricted to using in preparing their recommendations. Basically, if markets are semi-strong form efficient, then they are also weak form efficient. (Sharpe, 1995)

Most of the studies in the literature, which are created to investigate the predictability of exchange rates, test the EMH in its weak or semi-strong form. For example, papers which concentrate on the functionality of the technical trading rules test weak form market efficiency if only past prices and maybe volume information is used as predictor variables. Investigations that include an extended set of predictor variables[3] test semi-strong efficiency. (Timmerman & Granger, 2004)

2.2.2.1 Weak form efficiency

The weak version of the efficiency asserts that the prices of financial assets reflect all the information contained in past prices. Weak form has the most narrowly defined information set, limited to the historical sequence of prices. Therefore, no person can use past data on the exchange rates to predict the future values of rates. In the other words, exchange rates behave randomly, or without any identifiable formula. Many studies show that, a sufficient condition for weak-form efficiency is that exchange rates fluctuate randomly. As a conclusion we can say that, a market is efficient in the weak form if exchange rates follow a random walk process. Investors in weak-form efficient markets cannot expect to find any patterns in the historical sequence of exchange rates that would provide insight into future rates movements and allow them to earn abnormal profits. (Fawson et al., 1996)

The first test to investigate the weak-form efficiency were investigated using such techniques as the autocorrelation test, the Ljung-Box Q-statistics, variance ratio

[3] In stock trading these could be such as default premium, term spreads and other business cycle indicators.

tests, technical trading rules and runs tests. For example, Liu and He used a variance ratio test and Gupta used an autocorrelation test, Box-Pierce statistics, runs test filter rules and cross-correlation tests in studies on weak-form efficiency. (Liu & He, 1991) However, in this study the weak-form efficiency is examined with unit root tests.

Those early tests of weak-form market efficiency failed to find any evidence that abnormal profits could be earned trading on information related to past rates. These tests generally concluded that technical analysis was not effective. In that time the analysis was relied on forecasting exchange rates on the basis of past rates. More recent studies, however, have indicated that investors may overreact to certain types of information, driving exchange rates temporarily away from their investment values. As a result, it may be possible to earn abnormal profits in the short-run by buying currencies that have been oversold and selling currencies whose prices have been bid up excessively. Although, we should remember, that these observations are debatable and have not been universally accepted. (Sharpe, 1995)

Fama has specified three sufficient conditions for weak form efficiency. Firstly, there are no transaction costs. Secondly, information provided in past prices is costlessly available to all market participants. Finally, all agree on the implications of this information for the current price and distribution of future prices of each security. (Brown & Easton, 1988)

2.2.2.2 Semi-strong efficiency

The semi-strong version of the efficient market hypothesis says that the prices of financial assets reflect all publicly available information. The base of this form is that those who predict the movement of currencies based on available public information[4] cannot earn abnormal profits. Since exchange rates are expected to rapidly adjust to releases of such information, no person can use publicly available information to predict the movements of exchange rates. (Fawson et al., 1996)

[4] Such as inflation, money supply and interest rate announcements.

After the latter half of the 1980s, there was a significant change in the methodologies employed to test the semi-strong form of efficiency of foreign exchange markets and this was due to the development of the multivariate cointegration techniques of Johansen and Juselius. (Johansen & Juselius, 1990)

Nowadays the results of tests of semi-strong form market efficiency have been mixed. Most event studies have not succeeded to demonstrate sufficiently large inefficiencies to overcome transaction costs. However, various market anomalies have been discovered whereby securities with certain characteristics or during certain time periods appear to produce abnormally high returns. (Sharpe, 1995)

3 TEST METHODOLOGY AND DATA

3.1 Unit root tests

Stationary series can be defined as one with a constant mean, constant variance and constant autocovariances for each given lags. If time series does not come up with just mentioned conditions, then time series can be called as non-stationary. Actually, most of the economic time series are non-stationary. (Brooks, 2002)

After the defining the stationarity of the time series, next step in investigating unit roots is defining integration degree of the time series. Mathematically it can be expressed as follows,

$$\Delta y_t = (1-L)y_t = y_t - y_{t-1} \tag{2}$$

where, Δy_t is the first difference of series y_t, *L* is the lag operator, which power determines the length of lags. If taking of the first difference from the original series makes the series stationary, the original series is integrated with order one and could be written as $y_t \sim I(1)$. If a non-stationary series y_t must be differenced *d* times before it comes stationary, then it is said to be integrated of order *d*. Therefore, if $y_t \sim I(d)$, then $\Delta^d y_t \sim I(0)$. Then all stationary series can be called zero integrated, also known as $I(0)$-processes. We have to be careful in differing, because overreacting of the integration degree of the series and too strong differing leads to the situation where, the series becomes even more non-stationary. Also, we have to remember that differing changes the information contents and interpretations of the series. (Watsham & Parramore, 1997)

In addition, non-stationary and stationary series have significant differences. Shocks in the stationary series are always temporary. When time goes on, the effect of the shock disappears and time series comes back to the long-run mean level. In the non-stationary series, the shocks are constant, in a way or another. It is normal to think that, for example, new inventions (positive shock) improve the productivity constantly. (Brooks, 2002; Greene, 2003)

3.1.1 Random walk

Time series, which are non-stationary and whose behavior is inflexible[5] are called as random walk. Exchange rates are included in this class. Next we will examine simple random walk. We assume that e_t is random variable, which has time independent mean (μ) and variance (σ^2). Then the following process (3) of y_t

$$y_t = \phi y_{t-1} + e_t \tag{3}$$

where, $\phi = 1$ is called as random walk process. In this case, time series of y_t is possible to conduct with random walk e_t, as follows ($y_o = 0$):

$$y_1 = e_1. \tag{4}$$

Hence, it is possible to express the following form:

$$y_2 = y_1 + e_2 = e_1 + e_2. \tag{5}$$

Therefore the previous is equivalent to the following equation:

$$y_t = \sum_{t=1}^{T} e_t . \tag{6}$$

Hence, mean and variance of the time series y_t, are dependent of time *t* as follows,

$$E(y_t) = t\mu \tag{7}$$

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[5] Wanders up and down, without any clear form.

$$\mathrm{var}(y_t) = t\sigma^2 . \tag{8}$$

Next we take the fist difference of the previous process of the y_t,

$$dy_t = y_t - y_{t-1} = e_t . \tag{9}$$

Now with the given defaults,

$$E(dy_t) = \mu \tag{10}$$

$$\mathrm{var}(dy_t) = \sigma^2 . \tag{11}$$

As a result of the differing of the random walk y_t, process dy_t is stationary. In this case, it is possible to indicate that AR (1)-process root is $\pi_1 = 1$. This root is called as unit root and process as unit root process. In other words, $I(1)$ - process. (Brooks, 2002; Greene, 2003; Watsham & Parramore, 1997)

3.1.2 Testing the non-stationary (unit root)

Dickey and Fuller (1979, 1981) represented the first test, which examines the presence of the unit root. We assume firstly AR(1) model,

$$y_t = \phi y_{t-1} + \varepsilon_t . \tag{12}$$

If we take the first difference of it, we get:

$$\Delta y_t = y_t - y_{t-1} = \phi y_{t-§} + \varepsilon_t - y_{t-1} = (\phi - 1) y_{t-1} + \varepsilon_t = \gamma y_{t-1} + \varepsilon_t . \tag{13}$$

In Dickey and Fuller test, hypothesis can be presented as follows:

H0: $\gamma = 0$ (series contains a unit root)

H1: $\gamma < 0$ (series is stationary)

The test statistics do not follow the usual t-distribution under the null hypothesis, since the null is on of non-stationarity, but rather they follow a non-standard distribution. (Brooks, 2002; Greene, 2003)

As a conclusion, we might say that unit root tests are conducted to examine whether spot exchange rates follow random walks in accordance with the weak-form version of efficiency market hypothesis. In this study unit roots are tested using the Augmented Dickey-Fuller test and the Phillips-Perron test.

3.1.3 Augmented Dickey-Fuller test

An augmented Dickey-Fuller test (ADF) is a test for a unit root in a time series sample. ADF test is a version of the Dickey-Fuller test for a larger and more complicated set of time series models. The augmented Dickey-Fuller statistic, used in the test, is a negative number. The more negative it is, the stronger the rejection of the hypothesis that there is a unit roots at some level of confidence. (Buguk & Brorsen, 2003)

Normal Dickey-Fuller test is valid only if ε_t is white noise. In particular, ε_t is assumed not to be autocorrelated, but would be so if there was autocorrelation in the dependent variable of the regression (Δy_t) which has not been modeled. If this is the case, test would be oversized, meaning that the true size of the test would be higher than the nominal size used. The solution is to augment the test using *p* lags of the dependent variable. The alternative model is now written as in formula (14):

$$\Delta y = \gamma y_{t-1} + \sum_{1=2}^{p} \phi_i \Delta y_{t-i+1} + \varepsilon_t \qquad (14)$$

where Δ represents first differences and y_t is the log of the price index. Since the ADF test results are sensitive to the choice of the lag length, Akaike Information Criterion (AIC)[6] is used to select the optimal lag length of the ADF regression. The test for a unit root using equation (14) consists of testing the null hypothesis that $\gamma = 0$ (or that the series is non-stationary) against the alternative hypothesis that $\gamma < 0$ (or the series is stationary). Dickey and Fuller (1979) proved that the t-statistic of the coefficient γ in equation (14) has a non-standard distribution and, therefore, they tabulated critical values for selected sample sizes. Recently, MacKinnon (1991) estimated the calculation of Dickey-Fuller critical values for any sample size and for any number of variables. Therefore, critical values tabulated by MacKinnon are used in drawing inferences with respect to the time series properties of the variables used in this study. (Brooks, 2002; Greene, 2003; Watsham & Parramore, 1997)

3.1.4 Phillips-Perron test

Phillips and Perron have created a more sophisticated theory of unit root non-stationary. The tests are almost similar to ADF tests, but they contain an automatic correction to the DF procedure to allow for autocorrelated residuals. The tests often give the same conclusions as, and also suffer from most of the same important limitations, the ADF tests. (Brooks, 2002)

Phillips-Perron test is based on the following first order autoregressive (AR(1)) process :

$$\Delta y_t = \alpha + \beta y_{t-1} + \varepsilon_t \quad (15)$$

where y_t is the variable of interest, Δ is the difference operator, α is the constant, β is the slope and *t* is a subscript for time. The non-parametric correction is made to the t-ratio of the β coefficient from equation (15) to account for the autocorrelation

[6] The Akaike Information Criterion is computed as: $AIC = -2l/T + 2k/T$, where l is the value of the log of the likelihood function with the k parameters estimated using T observations.

of ε_t. This correction is based on an estimate of the spectrum of ε_t at zero frequency that is robust to heteroskedasticity and autocorrelation of unknown form. In this paper, this estimation is based on Bartlett kernel. The optimal bandwidth in the PP equation is selected using the Newey-West (1994) method. Critical values tabulated by MacKinnon are used in making inferences regarding the time series properties of the variables. (Brooks, 2002; Greene, 2003)

3.2 Cointegration

Cointegration is defined as a semi-strong form efficiency test. (Johansen, 1991) If spot exchange rates are cointegrated, then the series can be expressed with a causal ordering in at least one direction. This means that, at least one of the exchange rates is predictable using current available information. Therefore, it is hypothesized that if exchange rates are cointegrated, then it is possible to predict one from another, thereby violating the efficient market hypothesis. (Crowder, 1994; Rapp & Sharma, 1999)

Engle and Granger showed that a linear combination of two or more non-stationary series may be stationary. If such a stationary linear combination exists, the non-stationary time series are said to be cointegrated. Cointegration describes the long-run linear relationship between groups of variables which proofs an equilibrium relationship with each other. Cointegration has a lot of functions, but we are interested in a function, which is made to analyze the efficiency of market. A set of variables is defined as cointegrated if a linear combination of them is stationary. Many time series are non-stationary but move together over time - that is, there exist some influences on the series (for example, market forces), which imply that the two series are bound by some relationship in the long run. (Brooks, 2002; Watsham & Parramore, 1997)

A cointegrating relationship may also be seen as a long-term or equilibrium phenomenon, since it is possible that cointegrating variables may deviate from their relationship in the short run, but their association would return in the long run. In this case, market forces arising from no-arbitrage conditions suggest that there should be an equilibrium relationship between the series concerned. The easiest way to understand this notion is perhaps to consider what would be the effect if the series were not cointegrated. If there were no cointegration, there would be no long-run relationship binding the series together, so that the series could wander apart without borders. Such an effect would arise since all linear combinations of the series would be non-stationary, and hence would not have a constant mean that would be returned to frequently. (Brooks, 2002)

3.2.1 Testing the cointegration

There is one condition when using cointegration tests; the variables entering the cointegration equation should be integrated of the same order. If the variables are integrated of the same order, the second step is to test for cointegration among the variables of interest. In the most cases, if two variables that are $I(1)$ (unit root) are linearly combined, then the combination will also be $I(1)$ (unit root). More generally, if variables with differing orders of integration are combined, the combination will have an order of integration equal to the largest. Typically, this linear combination of unit roots variables will itself have unit roots, but it would obviously be desirable to obtain residuals that are stationary. (Brooks, 2002; Greene, 2003)

The null and alternative hypotheses for any unit root test applied to the residuals of a potentially cointegrated regression are following:

H0: $\gamma = 0$ (series contains a unit root)

H1: $\gamma < 0$ (series is stationary)

Therefore, under the null hypothesis there is a unit root in the potentially cointegrating regression residuals, while under the alternative, the residuals are stationary. Hence, if null hypothesis is not rejected, there is no cointegration. On the other hand, if the null of a unit root in the potentially cointegrating regression´s residuals is rejected, it would be concluded that a stationary linear combination of the non-stationary variables had been found. Therefore, the variables would be classed as cointegrated. If the data is non-stationary[7] and possibly cointegrated, there are at least three methods that could be used: Engle-Granger, Engle-Yoo and Johansen. In this study we investigate cointegration with the Johansen test. (Brooks, 2002; Johansen & Juselius, 1990)

3.2.2 Johansen test

Engle-Granger investigated the first test of the cointegration. Engle-Granger did not allow the testing of hypotheses on the cointegration relationship themselves, but Johansen setup does permit the testing of hypotheses about the equilibrium relationships between the variables. Johansen allows a researcher to test a hypothesis about one or more coefficients in the cointegrating relationship. If there exists *r* cointegrating vectors, only these linear combinations or linear transformations of them, or combinations of the cointegration vectors, will be stationary. (Brooks, 2002)

Eviews 5.0 implements VAR-based[8] cointegration tests using the methodology developed by Johansen. Johansen´s multiple cointegration test is based on the vector autoregression equation as in (16):

$$Y_t = A_1 y_{t-1} + ... + A_p y_{t-p} + Bx_t + \varepsilon_t \qquad (16)$$

where y_t and x_t are, respectively, a *k*-vector of non-stationary $I(1)$ variables and a vector of deterministic variables and ε_t is a vector of innovations. (Johansen, 1991)

The Johansen test is a test to investigate if there are cointegrating relationships among several currencies. The null hypothesis states that there are at most *r* cointegrating relationships. The tests of cointegration are performed sequentially, starting with the hypothesis of zero vectors. Test involves the determination of the

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[7] This has been tested with the unit root tests (ADF and PP).

[8] Vector Auto Regression

optimal number of lags to eliminate autocorrelation. Lag lengths for the cointegration test were selected using Akaike information criterion and Schwarz information criterion.[9] The Johansen test is a sequential test starting from zero to *(n-1)* co-integration vector, where *n* is the number of currencies in the system. Thus, as there are four currencies, there could be, at most, three cointegrating vectors. (Aroskar et al., 2004; Brooks, 2002; Watsham & Parramore, 1997)

In making conclusions about the number of cointegrating relations, two statistics known as the trace statistic and the maximal eigen value statistic are used. The trace statistic is determined using the equation as in follows:

$$\lambda_{trace} = -T \sum_{i=r+1}^{n} \ln(1-\lambda_{\hat{i}}) \qquad r=0,1,2,\ldots n-1 \qquad (17)$$

where *T* is the number of observations, *r* is the number of cointegrating vectors under the null hypothesis and λ_i is the i*th* eigen value.

Correspondingly, the maximum eigen value is determined using the following formula:

$$\lambda_{\max} = -T \ln(1-\lambda_{r-1}) \qquad r=0,1,2,\ldots,n-2,n-1 \qquad (18)$$

λ_{trace} is a joint test where the null is that the number of cointegrating vectors is less than or equal to *r* against an unspecified or general alternative that there are more than *r*. It starts with *p* eigen values, and then successively the largest is removed.

$\lambda_{\max}$ conducts separate tests on each eigen value, and has as its null hypothesis that the number of cointegration vectors is *r* against an alternative of *r+1*. Critical values for the Johansen cointegration test has been taken form the Osterwald-Lenum (1992) statistical tables. (Brooks, 2002)

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[9] Schwarz information criterion is an alternative to the AIC that imposes a larger penalty for additional coefficients: $SC = -2l/T + k \log T/T$.

3.3 Vector error correction model

The cointegration tests are meant to investigate the long-run co-movements among a set of non-stationary variables. The short-run dynamics among cointegrated variables can be examined using vector error-correction models. A vector error correction model is a restricted VAR constructed for use with nonstationary series that are known to be cointegrated. The VECM has cointegration relations built into the specification so that it restricts the long-run behavior of the endogenous variables to converge to their cointegrating relationships while allowing for short-run adjustment dynamics. The cointegration term is known as the error correction term since the deviation from long-run equilibrium is corrected gradually through a series of partial short-run adjustments. (Engle & Granger, 1987)

If two variables are cointegrated, there exists an error-correction model as in formulas (19) and (20).

$$\Delta x_t = a_1 + b_1 ect_{t-1} + \sum_{i=1}^{m} c_1 \Delta x_{t-1} + \sum_{i=1}^{n} d_1 \Delta y_{t-1} + e_{1t} \tag{19}$$

$$\Delta y_t = a_2 + b_2 ect_{t-1} + \sum_{i=1}^{m} c_2 \Delta y_{t-1} + \sum_{i=1}^{n} d_2 \Delta x_{t-1} + e_{2t} \tag{20}$$

where x_t and y_t are the variables which are cointegrated, Δ is the difference operator, *m* and *n* are the lag lengths of the variables, *ect*s are the residuals from the cointegrating equations and e_{1t} and e_{2t} are white-noise residuals. (Engle & Granger, 1987)

The error-correction model gives another type of causality through the error-correction term which is not present in standard Granger causality tests. Therefore, causality can also be tested by examining the statistical significance of the error-correction term by a separate t-test, the joint significance of the lags of each explanatory variable by a X^2-test; or by a test of error-correction terms and lagged terms of each explanatory variable simultaneously by a joint for X^2-test. (Sims, 1982)

3.4 Data

The data that is used in this study is acquired from Thomson financial Datastream database. We use daily spot exchange rates of Euro in terms of the U.S. dollar, pound sterling and Japanese Yen.[10] Currencies which have been selected are based on the present SDR currency basket. The period has been selected from the beginning of the present currency basket; therefore the period is 1.1.2000-28.2.2006 for a total of 1608 observations. Weekday data were used, as trading does not occur on Saturday and Sunday.

[10] How much we have to pay foreign currency to get one Euro.

4. EMPIRICAL RESULTS

The main interest for us in this paper is to investigate the weak and semi-strong form efficiency of the foreign exchange market in SDR area using Euro as a home currency and U.S. dollar, pound sterling and Japanese yen as foreign currencies. Weak form efficiency is examined using unit root tests while semi-strong efficiency is investigated using cointegration test and the vector error correction model. For our analysis we used Eviews 5.0 program.

4.1 Descriptive statistics

The purpose of this chapter is to analyze the characteristics of the collected data. Table 1 presents the descriptive statistics for daily data consisting the period of 1.1.2000-28.2.2006.

Table 1. Descriptive statistics.
In Table 1 are shown the descriptive statistics for U.S. dollar, Pound sterling and Japanese Yen. In the table are shown mean, standard deviation, skewness, kurtosis and Bera-Jarque. Bera-Jarque measures the normal distribution of data. In Bera-Jarque test, statistically significant values at Chi-square 0.05 level and 2 degrees of freedom are marked with asterisk (*).

	U.S. Dollar	Pound Sterling	Japanese Yen
Mean	1.0680	0.6533	121.9632
Std. Deviation	0.1548	0.0353	14.3930
Skewness	0.0925	-0.0703	-0.4157
Kurtosis	1.4912	1.6245	1.8612
Bera-Jarque	154.8135	128.0806	133.2099
N	1608	1608	1608

Japanese Yen has the highest mean, when correspondingly pound sterling has the lowest mean. Standard deviations are logical comparing to the means. Pound sterling and Japanese Yes has negative skewness values. Negative skewness results in a longer tail on left of distribution, with the mean being below the median and mode. (Watsham & Parramore, 1997) Bera-Jarque test shows that none of the variables are distributed in this period, since the Chi-Square at 0.05 significance level with 2 degrees of freedom is 5.99. When skewness indicates the degree of symmetry in the frequency distribution, kurtosis indicates the peakedness of that distribution. (Watsham & Parramore, 1997) High kurtosis values of all variables indicate high peakedness of the research data.

4.2 Results of unit root tests

We investigate the unit roots using Augmented Dickey Fuller test and Phillips-Perron test. The tests give statistical values to levels and first differences. We compare these values to the critical values tabulated by MacKinnon (1991). If the value given by the test is larger than the critical value given by MacKinnon, the null hypothesis holds, therefore the series contains a unit root and can be considered as non-stationary.

The critical values for 10%, 5% and 1% significance level in the intercept are -2.57, -2.86 and -3.43. Equivalent values in the intercept and trend are -3.12, -3.41 and -3.96. For the ADF test Eviews 5.0 calculates automatically a lag length parameter using Akaike Information Criterion. For the Phillps-Perron test Eviews 5.0 calculates automatically the lag lengths using Newey-west method and Bartlett kernel method. The maximum lag length used in our analysis is 24. Using these settings to data in our analysis for the period 1.1.2000-28.2.2006 we get results as in follows.

Table 2. ADF test results for unit roots.
In Table 2 are shown the results for ADF test to investigate unit roots. U.S. dollar, pound sterling and Japanese yen are spot exchange rates of the Euro in terms of U.S. dollar, pound sterling and Japanese yen. * implies statistical significance at the one per cent level. ** implies statistical significance at the five per cent level. Lag lengths used in each unit root are given in within brackets with unit root test statistics.

Currency	Level		First Differences	
	Intercept	Intercept & Trend	Intercept	Intercept & Trend
U.S. Dollar	-0.6997 (0)	-2.3277 (0)	-39.9789 (0)*	-39.9744 (0)*
Pound sterling	-1.5764 (2)	-2.9630 (2)	-29.4096 (1)*	-29.4004 (1)*
Japanese Yen	-1.2051 (0)	-3.3365 (1)	-38.8576 (0)*	-38.8451 (0)*

Table 2 reports the results of the ADF unit root test. The unit root tests were performed including an intercept and an intercept and linear time trend in the test equations. All exchange rates under consideration are non-stationary in their levels and become stationary when they are first differenced.

These results are logical with the weak form of the efficient market hypothesis which says that financial time series behave as random walks. In other words, past exchange rates cannot be used to predict future exchange rate. Hence, the participants in the foreign exchange market cannot exploit any statistical technique to gain from foreign exchange market transactions consistently. As the estimation was significant only with one percent significance, it gives strong evidence that the exchange rates of the SDR area follow random walks.

Table 3. PP test results for unit roots.
In Table 3 are shown the results for PP test to investigate unit roots. U.S. dollar, pound sterling and Japanese yen are spot exchange rates of the Euro in terms of U.S. dollar, pound sterling and Japanese yen. * implies statistical significance at the one per cent level. ** implies statistical significance at the five per cent level. Lag lengths used in each unit root are given in within brackets with unit root test statistics.

Currency	Level		First Differences	
	Intercept	Intercept & Trend	Intercept	Intercept & Trend
U.S. Dollar	-0.7003 (4)	-2.3348 (5)	-39.9790 (4)*	-39.9745 (4)*
Pound sterling	-1.6420 (5)	-3.0109 (7)	-39.1539 (3)*	-39.1413 (3)*
Japanese Yen	-1.2194 (8)	-3.1896 (4)	-39.8506 (11)*	-38.8375 (11)*

Table 3 reports the results of the Phillips-Perron unit root test for three currencies against Euro. The unit root tests were performed including an intercept and an intercept and linear time trend in the test equations. The results were similar to the ADF test results and indicate that all exchange rates are non-stationary in their levels and change to stationary in their first differences. All results are significant in one per cent level in the first differences. These results again confirm the earlier results of the ADF test indicating that the foreign exchange rates in the SDR area behave as random walks providing strong support for the weak form of the EMH.

4.3 Results of cointegration test

One requirement of the Johansen technique is that for there to be a cointegrating relationship, variables under consideration should be integrated of the same order. As we mentioned earlier; if a non-stationary series must be differenced *d* times before it becomes stationary, then it is said to be integrated of order *d*. As we just noticed, all series becomes stationary in their first differences, hence it is possible to investigate cointegration with Johansen test.

Eviews 5.0 estimates the cointegration with VAR-based cointegration test. To estimate the cointegration we have to first determine the lag lengths and deterministic components. Lag lengths for the cointegration test were selected using Akaike Information Criterion and Schwarz Information Criterion. The preferred model is that with the lowest AIC and SC value. The criteria AIC and SC indicates that the optimal number of lag included in the VAR is k=1. Results are shown in the Table 4.

Table 4. Test statistics and choice criteria for selecting the order of the VAR.
In Table 4 are shown test statistics and choice criteria for selecting order if the VAR. *indicates the appropriate lag length.

Lag	LogL	AIC	SC
0	148.2740	-0.1807	-0.1706
1	11622.6400	-14.4501*	-14.4099*
2	9923.8640	-12.3435	-12.3033
3	8982.9810	-11.1788	-11.1386

We follow Pantula principle in order to decide whether or not, deterministic components (time trend and constant term) will be included in the short and long-run model. We estimated three alternative models and moving through from the most restrictive to the least restrictive model comparing each time the trace and maximal eigenvalue test statistic to its critical values and stop by choosing the most appropriate model, only when the null hypothesis is not rejected for the first time. Pantula principle selected the cointegration equation with intercept but no trend.

Two test statistics, trace and maximum eigenvalue, are used to investigate the cointegration among the currencies. The values of the trace test statistic are shown in column two of the Table 5 with five and one per cent critical values in columns three and four, respectively. Correspondingly, the maximum eigenvalue test statistics are shown in column five together with their critical values in columns six and seven.

Table 5. Johansen test results for cointegration among the three exchange rates.
In Table 5 are shown the results for Johansen test to investigate cointegration among three currencies. Letters a and b imply statistical significance at the one and five percent level, respectively. Critical values were obtained from Osterwald-Lenum (1992). Lag lengths in vector autoregressions were selected using AIC and SC criterion. The deterministic components are selected using the Pantula principle suggested by Johansen.

Null Hypothesis	Trace Statistics	5% Critical Value	1% Critical Value	Maximal Eigen Value Statistics	5% Critical Value	1% Critical Value
r=0	36.559 (b)	34.910	41.070	26.144 (b)	22.000	26.810
r≤1	10.414	19.960	24.600	8.290	15.670	20.200
R≤ 2	2.123	9.240	12.970	2.123	9.240	12.970

The trace statistic reveals that there is one cointegrating relationship among the three currencies. In other words, the trace statistic results are significant at the five per cent level for the first null hypotheses. For the maximum eigen value statistic the results gives also one cointegration relationship among the currencies. Therefore, the maximum eigen value statistic results are significant at the five per cent level for the first null hypotheses.

This result indicates that there is a long-run co-movement among these three exchange rates. Therefore, the movement of a particular exchange rate is related to the movement in the other exchange rates. This is also a violation of the efficiency of the foreign exchange market in SDR area in its semi-strong form.

4.4 Results of vector error correction model

As the VECM specification only applies to cointegrated series, the Johansen cointegration test must be run first. The Johansen cointegration test investigates long-run co-movement and showed that there is one cointegration relationship among the exchange rates. The short-run dynamics among cointerated variables are examined using vector error correction model. The model was estimated for three currencies and estimation results are reported in the Table 6.

Table 6. Temporal causality results based on the Vector Error-Correction Model.
In Table 6 are shown the results for temporal causality results based on the Vector Error-Correction Model. a, b and c imply significance at the 1%, 5% and 10 % level, respectively. Δ indicates the first difference. One error-correction term was included in the error-correction model as there was one cointegration relationships among the three exchange rates. ECTs are the estimated t-statistics testing the null hypothesis that each ECT is statistically significant. Number of lags in the VECM was selected using AIC and SC tests.

Dependent variable	Short-run causality, X^2-statistics			Error-correction term, t-statistics
	Δ USD	ΔPSTE	Δ YE	ECT
Δ USD	-	0.01464	3.99836 (b)	-2.94493
ΔPSTE	0.06901	-	8.28111 (a)	1.83246
Δ YE	0.00025	0.00011	-	-1.21660

The significance of the X^2-test statistics for the hypothesis that all the lags of a particular exchange rates series are zero in the vector error-correction model for a currency indicates a causal relationship. A causal relationship is also indicated by a significant t-statistic for the error-correction term. The critical values with 1%, 5% and 10% for the X^2-test are 6.635, 3.841 and 2.706. Correspondingly, the critical values with 1%, 5% and 10% for the t-test are 6.965, 6.314 and 3.078.

The results show that there are two causal relationships from Japanese yen to U.S. dollar and pound sterling. The causal relationship from Japanese yen to pound sterling is significant at one per cent level and relationship from Japanese yen to U.S. dollar at five per cent level. The error-correction terms are not statistically significant in any of the error-correction models. Therefore, the identical causal relationships are of a short-run nature. Existence of causal relationships indicates the predictability of one exchange rate from one or more of the other exchange rates. Hence, these results provide evidence against the semi-strong form of the efficient market hypothesis in SDR area.

5. CONCLUSIONS

In this study we examined the weak and semi-strong form efficiency of the foreign exchange market in SDR area using daily exchange rates of Euro in terms of the U.S. dollar, pound sterling and Japanese yen for the period 1.1.2000- 28.2.2006. Unit root tests (ADF and PP) were used to test the weak form of the efficient market hypothesis, while semi-strong form of the efficient market hypothesis was examined using Johansen cointegration test and vector error correction model.

Unit root test results provide strong evidence that the exchange rates of SDR area follow random walks. These results support the efficient market hypothesis in its weak form. Consequences of these results are that the participants in the foreign exchange market in SDR area cannot device any rule or technique that can be used to predict future movements of an exchange rate from its past values.

However, the results of Johansen cointegration test and vector error correction model gives evidence against the validity of the semi-strong form of the efficient market hypothesis which asserts that prices of financial assets cannot be predicted using publicly available information. As the hypothesis of efficiency in the semi-strong form does not hold, the movement of one or more exchange rates can be predicted from the movements of the other exchange rates. Therefore, the participants in the foreign exchange market in SDR area can make profitable transactions both in short and long-run.

The exchange rate between domestic and foreign currency is a major economic policy variable. Hence, the efficiency or inefficiency of a foreign exchange market is very important for policy-makers of any country or institution, especially to IMF who controls the flows of the SDRs itself, to be sure that the liquidity of the system remains. When the efficient market hypothesis holds, the need for government or policy-makers intervention in the market is minimal.

The results of this study have also policy implications as they indicate that the foreign exchange market of SDR area is not efficient in its semi-strong form. The management of IMF can make informed decisions on exchange rates, take actions to reduce exchange rate volatility and evaluate the consequences of various economic policies for exchange rates. Policy-making bodies in IMF can determine the best way to influence the exchange rates and limit exchange rate volatility. As the efficiency in the semi-strong form does not hold, participants in the SDR market can devise various trading rules or techniques to make abnormal profits from transactions in the foreign exchange market. However, they should of course consider the costs involved in such activities to determine their profitability.

For further research the strong form of the foreign exchange market efficiency can be examined. Also other econometric techniques can be employed, such as asymmetric and nonlinear models and high-frequency data.

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