The association between stock market and exchange rates for advanced and emerging markets – A case study of the Swiss and Polish economies

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2012

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Abstract

This paper investigates the differences in structures of causal relationships between stock and currency markets for advanced and emerging economies on the example of Switzerland and Poland. The bootstrap–based linear causality analysis as well as nonlinear causality tests were conducted for both considered countries. Results of linear causality analysis indicated that for Swiss economy the portfolio approach seems to be the right pattern while for Poland the traditional and portfolio approaches were found to be appropriate. On the other hand the results of nonlinear analysis provided solid basis to claim that for Switzerland both approaches are acceptable while for Poland nonlinear causality was not reported in any direction. Results of nonlinear causality test were generally unchanged after GARCH(1,1) filtration. The existence of strong causal links from stock to currency markets of both economies seems to have a practical application for investors helping to hedge their portfolios against currency shocks.

Keywords: stock markets, exchange rates, Granger causality, bootstrap techniques, GARCH models.

JEL Classification: G15, C32.

1. Introduction

The relationship between exchange rate and the performance of stock market is one of the most important issues for economists around the world. This is not surprising if we take into consideration the fact that both these variables are expected to have a significant influence on the performance of country's economy. The complex analysis of dynamic links between these quantities may therefore be useful for describing the rate of development of considered economies. Another important issue is whether this relationship may be significantly distinct for emerging and advanced economies.

The theoretical background for the existence of links between exchange rate and stock market is generally based on one of two main concepts. The first approach (which is usually called as *traditional approach*) is based on the idea that changes of exchange rate cause fluctuations of performance of stock market (usually measured by returns). This causal impact is explained through the fact that fluctuations of exchange rate may have a significant influence on company's competiveness (through the impact on input and output prices[1]). This may in turn cause changes of company's incomes and therefore the value of its stock prices. However, this phenomenon usually has contrary consequences for exporters and importers. For example, the rise of exchange rate will cause loos of profits of exporters and fall of their stock prices. On the other hand, the competiveness of importers in domestic markets will increase and the price of their stocks should rise.[2] This economic mechanism causes inverse effects in case of appreciation of country's currency (i.e. decrease of exchange rate).

The competitive theory, so-called *portfolio approach*, is based on assumption that the performance of stock market is a causal factor for movements of exchange rate. This dynamic relationship is believed to exhibit negative correlations. To throw some light on these interactions let us assume that stock prices fall. This should trigger reduction of domestic wealth and in consequence the lower (domestic) demand for money together with drop of the interest rates. Furthermore, the decline of stock prices may cause that foreign investors will reduce demand for domestic assets and currency. Altogether the reduction of demand for currency, relatively large currency supplies and finally the capital outflow lead to rise of exchange rate. In contrary the increment of stock prices should encourage foreign investors to

[1] For more details see (Joseph, 2002).
[2] Considered regularities are valid not only for multinational companies but also for domestic business entities since they may import some inputs that are crucial for their activity.

participate intensively in country's equity market. This process naturally leads to capital inflow and therefore reduction of exchange rate.[3]

In addition, in the macroeconomic there is a well known theory, so-called *twin deficit*. According to this theory increase of government's budget deficit causes trade deficit and the link between these two macroeconomic indicators is the interest rate which can have effect on exchange rate of domestic currency. Rising interest rate is the result of necessity of financing the budget deficit. The increase of interest rate is one of the main sources of foreign (speculative) capital inflows and rise of foreign demand for domestic currency. The domestic goods and services become worldwide more expensive and the results is fall of exports i.e. trade deficit.

The economists stress that the widely observed link between budget and the trade deficits by the means of interest rates and exchange rates is possible if the latter are also linked empirically. But the size of interest rate, according to economic theory, is negatively related to stock prices. One of the reasons explaining that phenomenon is that a rise in the interest rate reduces the present value of future dividend incomes which could reduce stock prices. On the other hand, lower interest rate supports investments and economic activities which would cause stock prices to rise. Therefore, there may exist a (causal) link between stock prices (returns) and exchange rate.

The simplicity of considered approaches is one of their biggest advantages, but on the other hand it is a serious drawback. In the age of globalization of financial markets and ongoing augmentation of number and types of various connections between domestic and multinational business entities, the complex characteristic of the relationship between currency and stock markets seems to require extensive analysis which takes into consideration the individual properties of each economy.[4] This point of view seems to be (at least in some part) in line with conclusions of previous papers concentrated on examination of links between performance of stock market and movements of exchange rate. This literature is surely far from conclusive, as for some economies more or less significant results were documented but for many countries no significant relationship has been found so far. Let us

[3] For more details see (Granger et al., 2000).

[4] In financial literature the concept of so-called *monetary approach* assumes that there is no relationship between stock prices and exchange rate as they may be driven by independent factors. For more details on this issue see (Frenkel, 1976), (Dornbusch, 1976) or (Bilson, 1978).

now briefly present results of previous papers concerned with the links between stock and currency markets.

Some empirical results emphasising the importance of traditional approach may be found in Aggarwal's (1981) paper. Author claims that changes of exchange rate cause fluctuations in balance sheets of international companies. This process simply leads to change of their stock performance. In this case the positive correlation was found based on the monthly data for US stock market indexes and trade-weighted value of the dollar. In contrary, outcomes presented by Soenen and Hennigar (1988) provided evidence of negative correlations between US dollar effective exchange rate and US stock market index. Furthermore, research performed by Solnik (1987) for nine industrialized economies provided solid basis for claiming that fluctuations of exchange rates were insignificant factors in explaining the performance of considered stock markets.

Some important research, once again based on application of monthly data, was performed by Abdalla and Murinde (1997). Authors examined relationship between stock and currency markets on the example of India, South Korea, Pakistan and Philippines. Their findings indicated that traditional approach was the proper model for all countries except Philippines, where portfolio approach was found to be the right pattern.

The links between stock market and exchange rate movements were also examined by Ajayi et al. (1998). These authors concentrated on both emerging and advanced economies using daily as well as weekly data for the period 1985 to 1991. Their findings[5] indicated unidirectional causality from the performance of stock markets to fluctuations of exchange rates for advanced economies. On the other hand, no clear conclusions were reported for emerging markets.

The problem of inconclusive indications occurring in case of examination of emerging markets was also reported by Granger et al. (2000). This time authors have examined relationships between stock prices and exchange rates for nine Asian economies. The traditional approach was found to properly model considered links for Japan, Thailand and Hong Kong, while portfolio approach was found to be the appropriate model for Taiwan. The feedback relationships were found for relatively large number of economies, namely

[5] Results of suitable causality tests were generally unchanged nonetheless whether daily or weekly data was applied.

Indonesia, Malaysia, South Korea and Philippines. On the other hand, for Singapore none of considered approaches was found to be significant.

It should be noted that some researchers have concentrated on examination of the nature of considered relationship only for particular branches of economy. For instance, Chamberlain et al. (1997) focused only on US and Japan banking stock returns and their relationship with exchange rates. Their findings indicated that US returns were caused by exchange rates. On the other hand, this effect was not reported for Japanese bank sector.

The number of papers concerned with the dynamic relationship between stock and currency markets proves that this link is greatly important for academic researchers. However, this issue is also vitally important for domestic as well as international investors since it can potentially provide some essential information which could be used to hedge and diversify portfolios. Furthermore, if exchange rate is found as a causal factor for fluctuations of stock market then the appropriate government policy should be placed on to control exchange rate and therefore help to avoid undesirable events on stock market. On the other hand, if causality runs in the opposite direction then the principles of domestic economy are believed to play key role in modelling the performance of stock market and therefore the fluctuations of exchange rate.

From the above overview it results that for emerging economies, especially in Eastern Europe, the important relationship between the performance of stock market and the exchange value of the domestic currency has received very little direct attention so far.

The objective of this paper is the investigation of the causal relationships between stock market indexes and exchange rates for Switzerland (representing advanced markets) and one of the transition economies i.e. Poland (representing emerging markets). Therefore, this paper fills the gap in literature which, according to the knowledge of the authors, has not focused on examination of stock–currency links for both considered economies so far.[6] These two countries represent different levels of economic development not only in respect to financial markets, but also in terms of technology, infrastructure etc. Thus, it may be interesting to investigate how these obvious differences affect the structure of dynamic links between stock and currency markets. In this paper the traditional linear Granger causality analysis as well as the nonlinear tests are applied to examine dynamic relationships between variables of interest.

[6] As we had already mentioned most of previous studies were concerned with examination of considered links only for advanced economies.

This paper is organized as follows. The next section contains the main research hypotheses to be tested by means of the empirical analysis. Section 3 contains details about considered data set, which are necessary for further reading. Section 4 provides description of the methodology of linear and nonlinear causality tests as well as some preliminary analysis of considered variables. Furthermore, specification of VAR models used for empirical purposes as well as details of considered bootstrap technique are also presented. Section 5 contains results of conducted causality analysis. Section 6 concludes the paper.

2. Main hypotheses

The main objective of this paper is the investigation of causal links between stock and currency markets for Switzerland and Poland. One important issue that distinguishes our paper from the other contributions concerned with exchange rates is the fact that we do not estimate a model of exchange rate determination. Despite general inconclusiveness of previous research conducted for advanced economies, outcomes resulting from some papers[7] strongly point at unidirectional causality from stock market to currency market. Therefore, it may be interesting to test the following:

> Hypothesis 1: There exists a unidirectional linear causal link from changes of the performance of stock market to fluctuations of exchange rate for Switzerland. There is no linear Granger causality in the opposite direction.

Unfortunately, the problem of inconclusive results of causality analysis is related to emerging markets too. However, some reliable results of previous research provided evidences of existence of causality in both directions for particular emerging Asian markets. [8] It may be interesting to compare these findings with the results obtained for Poland as the new EU-member country considered in this paper. This way we have formulated:

> Hypothesis 2: The linear causality between changes of performance of stock market and fluctuations of exchange rate for Poland runs in both directions.

One important issue related to conducting linear Granger causality tests is the sensitivity of testing procedures to failure of standard OLS assumptions. It may be surprising that most of previous papers do not examine this issue at all. Furthermore, standard asymptotic theory of

[7] For example see (Ajayi et al., 1998).
[8] For instance, Granger et al. (2000) reported existence of feedback relationship for four of nine examined Asian economies.

Wald test may in this case lead to spurious results.[9] The application of bootstrap methodology is one of possible solutions however it is reasonable to formulate the question whether results calculated by this method strongly depend on its technical adjustments. Therefore, we shall test the following:

> Hypothesis 3: The results of bootstrap-based causality analysis are not reliable as they strongly depend on testing procedure (especially the number of replications used).

In this paper besides the traditional linear causality test we have also applied nonlinear techniques.[10] This decision seems to be well justified as nonlinear tests provide some additional possibilities in comparison to linear approach. However, most of previously mentioned papers were based on results of linear methods only. Therefore, one may be interested in testing:

> Hypothesis 4: For both considered countries all significant causal links have strict linear nature.

Application of nonlinear methods also requires some specific assumptions. One significant problem related with this issue is the fact that nonlinear tests tend to provide evidence of existence of causality too often when examined time series exhibit heteroscedastic structure. This problem may be examined by testing the following hypothesis:

> Hypothesis 5: Considered nonlinear test tends to over-reject (pointing at the existence of causal links significantly too often) in case of presence of heteroscedastic structures in examined variables.

In order to test above research hypotheses the comprehensive causal analysis must be performed. At very beginning we present the applied dataset.

3. Dataset overview

This paragraph contains short description of dataset used in further computations. As we have already mentioned in introductory paragraph the main goal of this paper is the examination of the existence and kind of causal links between exchange rate and stock market performance for two countries, namely Switzerland (which stands for advanced markets) and Poland,

[9] For instance see (Hacker and Hatemi, 2006). This paper is generally concerned with examination of size properties of considered linear approach also in cases where standard OLS assumptions do not hold.
[10] Nonlinear relationships between variables of interest were considered by other authors, i.e. Krugman (1991).

representing emerging markets in transition). Hence, the considered dataset includes exchange rate of Swiss franc (CHF) to US dollar, exchange rate of Polish złoty (PLN) to US dollar and stock returns[11] of Dow Jones Industrial Average (DJIA),[12] Swiss Market Index (SMI) and main index (WIG) of Warsaw Stock Exchange (WSE). In order to capture considered short-run causal dependences the daily data from the period 2001.03.01 to 2008.08.29 was applied. The application of lower frequency data (weekly data, monthly data etc.) may not be adequate for testing for Granger causality for considered variables.[13] After taking into consideration differences in structure of days, when stock markets were closed in all examined countries, the sample size reduced to 2171 observations. The data describing considered exchange rates was collected from the database of the National Bank of Poland while time series of main index of Warsaw Stock Exchange was gained from PARKIET database. Furthermore, time series of DJIA and SMI were gained from Thompson database. In this paper we use abbreviations for all examined variables. Table 1 contains suitable information:

INSERT TABLE 1 AROUND HERE

A key decision in investigation of the nature of causal links between exchange rate and stock market performance is the choice of suitable variables. In this paper, instead of direct application of some variables described in table 1, we have decided to use their special transformations. Namely, we applied percentage changes of considered exchange rates (these variables will be denoted as *CCU* (percentage change of CHF/USD exchange rate) and *CPU* (percentage change of PLN/USD exchange rate)) [14] and stock return differentials which are expressed as the differences between stock returns of SMI and DJIA as well as between returns of WIG and DJIA.[15] There are some important facts which seem to justify this method of establishing variables. Firstly, since the US stock market occupies major share of the world's equity market then the measurement of performance of country's stock market with respect to performance of the New York Stock Exchange may lead to reliable conclusions.

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[11] In this paper we applied continuous (logarithmic) returns.
[12] The role of US stock market will be explained in further part of this paragraph.
[13] For more details see (Granger et al., 2000).
[14] $CCU_t = \frac{CU_t}{CU_{t-1}} \cdot 100\%$ (analogous formula was used for *CPU*).
[15] Stock return differentials were used in some previous papers, e.g. (Ajayi et al., 1998).

Secondly, this specification is in line with considered definition of exchange rate. Table 2 contains descriptive statistics of variables used in causality analysis:

INSERT TABLE 2 AROUND HERE

Directly from this table we can notice some interesting information. For all considered variables the distance between mean and median is relatively small and oscillates around zero. If we additionally take into consideration values of skewness parameters we will be able to state that our dataset contains variables characterized by relatively symmetrical distributions. Furthermore, for all considered variables the standard deviation usually reaches relatively small values. If we analyze this fact together with positive values of excess kurtosis then we may state that our variables are also characterized by relatively peaked distributions. On the other hand, for all considered variables the distance between extreme values and mean is greater than five times the standard deviation. In some respects this may be interpreted as the evidence of existence of shocks in considered time series of percentage change of exchange rates and stock return differentials.

4. Methodology and preliminary analysis

In this article we use both the linear and nonlinear Granger causality tests to explore the short-run dynamic relationships between exchange rates and stock returns for Switzerland and Poland. As already mentioned we aimed to investigate whether there exist a significant difference in structure of causal links between these variables for advanced and emerging markets.

The definition of causality used in this paper is due to Granger.[16] To throw some light on considered idea we shall make use of the following table:

INSERT TABLE 3 AROUND HERE

[16] For more details see (Granger, 1969).

After choosing numbers of lags L_X and L_Y, we say that the time series $\{Y_t\}$ does not strictly Granger cause the time series $\{X_t\}$, if:

$$F(X_t \mid I_{t-1}) = F(X_t \mid I^*_{t-1}),\ t = 1, 2... \tag{1}$$

where I^*_{t-1} stands for an information set including lagged values of X_t only. If equality (1) does not hold then the knowledge of past values of time series $\{Y_t\}$ improves short-run prediction of current and future values of $\{X_t\}$. In this case $\{Y_t\}$ is said to strictly Granger cause $\{X_t\}$.

The important part of every causality analysis is testing considered time series for stationarity and identifying their order of integration. Thus, as the first step we checked our data for the presence of time trends (stationarity in mean). We run suitable OLS regressions (involving polynomials of order three) finding that for all considered time series deterministic time trend is not present.[17] Taking this result into account we conducted augmented Dickey-Fuller (ADF) unit root test based on following regression:

$$\Delta z_t = a + bz_{t-1} + \sum_{i=1}^{m} c_i \Delta z_{t-i} + \varepsilon_t \tag{2}$$

where $\{z_t\}$ denotes time series being analyzed, m is the lag number, Δ is the differencing operator and ε_t is assumed to be the white noise. The null hypothesis (referring to nonstationarity) is simply described by the condition $b = 0$, and the one-sided alternative is $b < 0$. For the critical values we referred to the (Charemza and Deadman, 1997). Table 4 contains the results of all conducted tests of stationarity. In order to choose the optimal lag length (m) we set up the maximal lag length equal to 15 and then we used AIC and BIC information criteria to choose m from the set {0, 1, …, 15}:

INSERT TABLE 4 AROUND HERE

[17] Complete estimation results of all conducted regressions are available from authors upon request.

Directly from table 4 one can easily see that all considered time series were found to be stationary. In order to confirm these findings Kwiatkowski, Phillips, Schmidt and Shin (KPSS) test was additionally conducted. This test is based on following regression:

$$z_t = r_t + D_t + \varepsilon_t \tag{3}$$

where $\{z_t\}$ denotes time series being analyzed, r_t is a random walk process, D_t contains all deterministic variables and ε_t is assumed to be the stationary error term. We should underline that this time the null hypothesis refers to stationarity of $\{z_t\}$ series. The form of D_t component[18] determines shape of test statistics and critical values. In order to calculate the test statistics we assumed D_t to include intercept only (level stationarity) and then we applied Newey-West method of estimating so-called long-run variance.[19] Results of KPSS test are presented in table 5:

INSERT TABLE 5 AROUND HERE

The analysis of results presented in table 5 provided solid evidence to claim that all considered time series are stationary. Although we did not find evidence of presence of statistically significant time trends in our data, we re-run both ADF and KPSS tests including time variables in suitable regressions. The results of all conducted tests were in line with outcomes presented in tables 4-5 (no evidence of nonstationarity at 1% significance level).

In order to test for linear Granger causality we used vector autoregression model (VAR) of the form:

[18] If D_t includes only constant (constant and linear trend) the null hypothesis refers to level stationarity (trend stationarity).

[19] According to Newey-West approach, the bandwidth m and sample size T satisfy the relationship $m = \left\lfloor 4\left(\frac{T}{100}\right)^{\frac{2}{9}} \right\rfloor$, where $\lfloor \cdot \rfloor$ denotes the floor function. More details on this issue may be found in (Newey and West, 1987).

$$\begin{cases} y_t = \mu_y + \sum_{j=1}^{k} \alpha_{0,j} y_{t-j} + \sum_{j=1}^{k} \beta_{0,j} x_{t-j} + \varepsilon_{y,t} \\ x_t = \mu_x + \sum_{j=1}^{k} \alpha_{1,j} x_{t-j} + \sum_{j=1}^{k} \beta_{1,j} y_{t-j} + \varepsilon_{x,t} \end{cases} \quad (4)$$

where time series $\{y_t\}$ and $\{x_t\}$ denote the pair of analyzed variables.[20] In order to choose the proper lag length (*k*) we set up the maximal lag length equal to 10 and then we used AIC and BIC information criteria to choose *k* from the set {0, 1, …, 10}. For both considered VAR models this value was found to be equal to three. The idea of testing for linear Granger causality in terms of VAR approach is based on checking the statistical significance of suitable model parameters. Namely, if the null hypothesis $\beta_{0,j} = 0$ ($\beta_{1,j} = 0$) for $j = 1,...,k$ is rejected at sensible significance level, then we may say that $\{x_t\}$ Granger causes $\{y_t\}$ ($\{y_t\}$ Granger causes $\{x_t\}$). The latter may be tested based on simple Wald test. Depending on variant of test the applied critical values are taken from suitable *F* or chi-square distribution. At this place we must underline some important facts since the simplicity of mentioned testing method has got some serious drawbacks. Firstly, if considered time series ($\{x_t\},\{y_t\}$) are indeed nonstationary then the results of linear causality analysis (conducted in previously described way) may lead to spurious results.[21] A possible solution for this problem is the construction of Vector Error Correction Model (VECM) or application of Toda–Yamamoto (1995) approach.[22] However, the outcomes presented in tables 4-5 ensure that we do not have to consider this problem in our research. Secondly, parametric tests (like Wald test) require some specific modelling assumptions (for example in asymptotic variant the error term should be white noise[23]). If these assumptions do not hold then the test results may be spurious. Thus, before conducting linear causality analysis we run some diagnostic tests of residual series resulting from VAR models.[24] For VAR model constructed for *CCU* and *RSMI-RDIJA* variables the Doornik-Hansen test for multivariate normality (with null hypothesis referring to

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[20] In this paper we investigated two VAR models constructed for $\{x_t\}=\{CCU_t\}, \{y_t\}=\{RSMI_t - RDJIA_t\}$ and $\{x_t\}=\{CPU_t\}, \{y_t\}=\{RWSE_t - RDJIA_t\}$ time series.

[21] This phenomenon was investigated by Granger and Newbold (1974, empirical findings) and Phillips (1986, theoretical explanation).

[22] Since estimation of VECM requires complicated initial analysis the Toda-Yamamoto method has gained a considerable attention in recent years, e.g. (Hacker and Hatemi, 2006), (Mantalos, 2000). Furthermore, Toda-Yamamoto approach may also be applied for variables with different orders of integration.

[23] More details may be found in (Lütkepohl, 1993).

[24] For all considered residual series Ljung-Box Q-statistics provided no evidence of autocorrelation. Complete results of these tests are available from authors upon request.

normal distribution of error vector $\begin{pmatrix} \varepsilon_{y,t} \\ \varepsilon_{x,t} \end{pmatrix}$) provided strong support for claiming that considered residuals are not normally distributed (p-value<10^{-6}). Similar result was obtained for *CPU* and *RWSE-RDIJA* variables (p-value<10^{-6}). However, these findings do not exclude possibility of application of asymptotic variant of Wald test since the latter assumes error vector to be white noise only (normality is not required). Thus, it seemed obvious that we should test residual series resulting from both considered VAR models for the presence of heteroscedastic structures. We had run some typical tests (with null hypothesis referring to homoscedasticity). Results are presented in table 6:

INSERT TABLE 6 AROUND HERE

After analyzing outcomes presented in table 6 it is easy to see that all considered residual time series exhibit significant heteroscedastic structures. With this thought in minds, we have also conducted some standard tests to investigate possible presence of both unidimensional and multivariate ARCH structures. [25] We found that residual vectors resulting from both considered VAR models exhibit presence of statistically significant two-dimensional ARCH structures. Furthermore, significant univariate ARCH effects were also reported for all considered residual time series, confirming that the variance of examined error terms depends conditionally on their past values. All these facts provided solid basis for claiming that in our case the application of standard linear Granger causality test (even in the asymptotic variant) may lead to spurious conclusions.

Since standard linear causality analysis is sensitive to presence of heteroscedastic structures in error term the obtained results forced us to use some alternative methods. One of possible solutions is the application of bootstrap method. This method is used for estimating the distribution of test statistics by resampling considered data. At this place we shall underline some important facts. Firstly, the estimated distribution depends only on available data set, therefore none of assumptions required for parametric methods has to be fulfilled for proper application of bootstrap technique. Secondly, the size and power properties of causality test

[25] Complete results and test technicalities are not presented here to save the space. This data is available from authors upon request.

based on bootstrap techniques remain relatively good even in cases of nonstationarity[26] and various schemes of error term structure (including heteroscedasticity, autocorrelation etc.).[27]

In this paper we applied bootstrap technique based on resampling leveraged residuals. The leverages were used to modify regression raw residuals in order to stabilize their variance.[28] To throw some light on discussed approach let us study the case of VAR model constructed for $\{x_t\}=\{CCU_t\}$ and $\{y_t\}=\{RSMI_t-RDJIA_t\}$ variables (the case of Poland is analogous). Suppose that we are interested in testing for Granger causality in direction from $\{y_t\}$ to $\{x_t\}$ (analogous procedure for testing causality in the opposite direction). In the initial step suitable VAR model (4) is estimated through OLS methodology with the null hypothesis assumed (that is: $\{y_t\}$ does not Granger cause $\{x_t\}$). Thereafter, let $\overline{\varepsilon}_t := \begin{pmatrix} \overline{\varepsilon}_{y,t} \\ \overline{\varepsilon}_{x,t} \end{pmatrix}$ stand for the two-dimensional vector of error term resulting from restricted VAR model and let T denote the sample size. In the next step we use leverage transformation of regression raw residuals (vector of modified residuals will be denoted as $\overline{\varepsilon}_i^m$ for $i=1,\ldots,T$). Finally, the following algorithm is conducted:

- Drawing randomly with replacement (each point has probability measure equal to $\frac{1}{T}$) from the set $\{\overline{\varepsilon}_i^m\}_{i=1,\ldots,T}$ (as a result we get the set $\{\overline{\varepsilon}_i^{**}\}_{i=1,\ldots,T}$);
- Subtracting the mean vector to guarantee the mean of bootstrap residuals is zero (this way we create the set $\{\overline{\varepsilon}_i^{*}\}_{i=1,\ldots,T}$);
- Generating the simulated data $\{y_i^*\}_{i=1,\ldots,T}, \{x_i^*\}_{i=1,\ldots,T}$ through the use of original data ($\{y_i\}_{i=1,\ldots,T}, \{x_i\}_{i=1,\ldots,T}$), coefficient estimates from the regression of restricted VAR model and the bootstrap residuals $\{\overline{\varepsilon}_i^{*}\}_{i=1,\ldots,T}$);
- Calculating the Wald test statistics (for simulated data).

After repeating considered bootstrap procedure N times it is possible to create the empirical distribution of Wald test statistics and get empirical critical values (bootstrap critical values) next. Finally, to test for Granger causality one should calculate the Wald statistics (for original data) and compare this value with critical values of bootstrap distribution. The suitable procedure written in Gretl is available from authors upon request.

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[26] For more details see (Dolado and Lütkepohl, 1996), (Mantalos, 2000).
[27]For more details see (Hacker and Hatemi, 2006).
[28] For more details on this issue see (Davison and Hinkley, 1999).

The establishment of number of replications is one of key decisions in every application of bootstrap technique. This number varied significantly in previous studies concentrated on bootstrapping (from less than 100[29] to over 1000[30]). The impact of increase of number of replications on performance of Wald test is still a matter of academic discussion.[31] In this paper we used N=100, N=250 and N=500 replications for each performed causality test.

As we had already mentioned beside the bootstrap–based linear causality test we also used nonlinear test of Granger causality. The motivation for use of nonlinear techniques is a consequence of two main facts. Firstly, standard linear Granger causality tests tend to have extremely low power in detecting certain kinds of nonlinear relationships.[32] Secondly, since the traditional linear approach is based on testing the statistical significance of suitable parameters only in mean equation the causality in higher-order structure (for example causality in variance) can not be explored.[33] The application of nonlinear approach may be a solution to this problem as it allows exploring complex dynamic links between variables of interest.

The foundations of considered nonlinear technique were laid by Baek and Brock (1992). This leading method was thereafter modified by Hiemstra and Jones (1994). In order to present a brief outline of the idea of considered nonlinear technique let us assume that we are interested in testing whether time series $\{X_t\}$ Granger causes time series $\{Y_t\}$ (testing for causality in the opposite direction requires analogous analysis). In the beginning we should define for t=1, 2… the $L_X + L_Y + 1-$dimensional vector $W_t := (X_{t-L_X}^{L_X}, Y_{t-L_Y}^{L_Y}, Y_t)$. The null hypothesis that $\{X_t\}$ does not Granger cause $\{Y_t\}$ may be written in the following form:

$$\begin{aligned} f_{X,Y,Z}(x,y,z) = f_{X,Y}(x,y) f_{Z|X,Y}(z \mid x,y) = \\ = f_{X,Y}(x,y) f_{Z|Y}(z \mid y) \end{aligned} \tag{5}$$

where $f_W(x)$ denotes the probability density function of random vector W at point x, $X = X_{t-L_X}^{L_X}$, $Y = Y_{t-L_Y}^{L_Y}$, $Z = Y_t$ for $t = 1,2,...$. The last equation may be presented in more convenient forms, namely:

[29] For more details see (Horowitz, 1994).
[30] For more details see (MacKinnon, 1992).
[31] For more details see (Horowitz, 1995).
[32] For more details see (Brock, 1991), (Gurgul and Lach, 2009).
[33] For more details see (Diks and DeGoede, 2001).

$$\frac{f_{X,Y,Z}(x,y,z)}{f_{X,Y}(x,y)} = \frac{f_{Y,Z}(y,z)}{f_Y(y)} \tag{6}$$

and

$$\frac{f_{X,Y,Z}(x,y,z)}{f_Y(y)} = \frac{f_{X,Y}(x,y)}{f_Y(y)} \frac{f_{Y,Z}(y,z)}{f_Y(y)} \tag{7}$$

In the next step we shall define correlation integral $C_W(\varepsilon)$ (symbol W stands for multivariate random vector) by the following expression:

$$C_W(\varepsilon) = P\left(\left\|W_1 - W_2\right\| \le \varepsilon\right) = \iint I(\left\|s_1 - s_2\right\| \le \varepsilon) f_W(s_1) f_W(s_2) ds_2 ds_1 \tag{8}$$

where symbols W_1, W_2 stand for independent multivariate random vectors which distributions are in the equivalence class of distribution of vector *W*, letter *I* denotes the indicator function,[34] $\|x\| = \sup\{|x_i| : i = 1,...,d_W\}$ stands for the supremum norm[35] and $\varepsilon > 0$. As noted by Hiemstra and Jones (1994), equations (6) and (7) may be equivalently rewritten in following forms:[36]

$$\frac{C_{X,Y,Z}(\varepsilon)}{C_{X,Y}(\varepsilon)} = \frac{C_{Y,Z}(\varepsilon)}{C_Y(\varepsilon)} \tag{9}$$

and:

$$\frac{C_{X,Y,Z}(\varepsilon)}{C_Y(\varepsilon)} = \frac{C_{X,Y}(\varepsilon)}{C_Y(\varepsilon)} \frac{C_{Y,Z}(\varepsilon)}{C_Y(\varepsilon)}, \tag{10}$$

where ε is a positive number. According to mentioned authors, the next step of considered nonlinear procedure is testing whether left-hand- and right-hand-side ratios in equation (9) and (10) differ significantly or not. Since in empirical applications it is impossible to calculate exact values of correlation integral the following expression was recommended as its estimator:

[34] This function is equal to one if the condition in brackets holds true, otherwise it is equal to zero.
[35] Symbol d_W denotes the dimension of sample space *W*.
[36] Considered paper does not contain proof of this equivalence.

$$C_{W,n}(\varepsilon) = \frac{2}{n(n-1)} \sum_{i<j} \sum I_{ij}^{W} \tag{11}$$

where $I_{ij}^{W} = I(\|W_i - W_j\| < \varepsilon)$.

After few years Diks and Panchenko[37] proved that condition expressed in equation (9) or (10) is generally not equivalent to the null hypothesis of Granger non-causality. Furthermore, they found exact conditions under which the HJ (Hiemstra-Jones) test is a useful tool for causality analysis and they managed to bypass the above mentioned problem of testing for an incorrect hypothesis. Additionally, their article contains the asymptotical theory of the modified test statistic.

In this article we use nonlinear causality test proposed by Diks and Panchenko.[38] The application of this nonparametric method may significantly reduce problems resulting from model misspecification. Furthermore, this test performs relatively well even in cases of untypical (impossible to filter out by any (G)ARCH[39] model) heteroscedastic structures.[40] In our research we decided to use some typical values of bandwidth parameter (ε), setting it at the level of 0.5, 1 and 1.5 for all conducted tests.[41] We have also decided to use the same lags for every pair of time series being analyzed (L_X=L_Y), establishing this lag at the order of 1, 2 and 4.[42]

We performed our calculations on the basis of residual time series resulting from the appropriate VAR model. The application of residual time series is justified by the fact that they reflect strict nonlinear dependencies[43] (the structure of linear dependences had been filtered out with application of suitable VAR models). The time series of residuals were both standardized, thus they shared a common scale parameter. Finally we must note that we used one-side test rejecting whenever calculated test statistics was too large. There are at least two main reasons justifying this choice. Firstly, in practice one-sided test is often found to have

[37] For more details see (Diks and Panchenko, 2005).
[38] For more details see (Diks and Panchenko, 2006).
[39] In empirical research (especially performed for some financial data) the (G)ARCH filtering is usually an important part of preliminary analysis.
[40] For more details see (Diks and Panchenko, 2006). Authors reported that in this case (i.e. nonstandard heteroscedastic structure) GARCH(1,1)-filtration significantly improves size properties of considered nonlinear technique.
[41] These values were commonly used in previous studies, see e.g. (Hiemstra and Jones, 1994), (Diks and Panchenko, 2005), (Diks and Panchenko, 2006).
[42] More details about meaning of considered technical parameters and the form of test statistics may be found in (Diks and Panchenko, 2006).
[43] For more details see (Baek and Brock, 1992), (Chen and Lin, 2004).

larger power than a two-sided one.[44] Secondly, although significant negative values of test statistics also provide basis for rejecting the null hypothesis of Granger non-causality, they additionally indicate that the knowledge of past values of one time series may aggravate the prediction of another one. In contrast, the causality analysis is usually conducted to judge whether this knowledge is helpful (not aggravating) for prediction issues or not.

Since former research provided solid basis for claiming that the nonlinear causality test tend to over-reject in cases of presence of heteroscedastic structures[45] we have also decided to re-run nonlinear causality tests for GARCH(1,1)-filtered residual time series.[46] However at this place we shall note that this type of filtering shall be carried out carefully as it sometimes may lead to loss of power of the test, which derives from possible misspecification of conditional heterocedasticity model.[47]

5. Analysis of empirical results

This paragraph contains the results of both linear and nonlinear short-run causality tests. These findings are helpful in describing the dynamic relationships between considered exchange rates and stock returns for Switzerland and Poland in the period under study. Since considered economies represent different levels of development conducted analysis of dynamic links may be helpful in judging whether the structure of causal relationships between variables of interest depends on advancement and size of the market.

The following table contains *p*-values obtained from testing for linear Granger causality in case of VAR model constructed for the *CCU* and *RSMI-RDIJA* variables. In order to make the presentation of these results more transparent we decided to use the bold face (shaded area) to indicate results supporting the hypothesis of the existence of linear Granger causality in the considered direction at 10% significance level (1% significance level):[48]

INSERT TABLE 7 AROUND HERE

[44] For more details see (Skaug and Tjøstheim, 1993).
[45] For more details see (Diks and Panchenko, 2006).
[46] In this case we divided residual series by conditional standard deviation estimated through application of GARCH(1,1) model (instead of dividing by sample standard deviation).
[47] For more details see (Diks and Panchenko, 2006).
[48] This way of reporting was used in case of all tables containing results of causality analysis.

After analyzing results contained in table 7 one can easily see that bootstrap-based linear causality analysis provided strong support for claiming that past fluctuations of performance of Swiss stock market with respect of US stock market are helpful in predicting current and future values of percentage change of exchange rate of Swiss franc to the United States dollar. It is worth mentioning that this relationship was found to be extremely strong since the obtained *p*-values were no greater than 0.001 despite the number of replications used in computation. This result confirms that short-term speculative capital inflows and long-term structural capital investments together Granger cause the exchange value of the Swiss franc to the US dollar.

On the other hand, despite the value of *N* parameter results of Wald test (with bootstrap distribution) conducted to test for causality in opposite direction provided no reason to reject the null hypothesis of Granger noncausality. Thus, results of linear causality tests provided strong support for claiming that Hypothesis 1 is true. In other words, the portfolio approach was found to be the proper model to reflect the relationship between stock market and exchange rate in case of Swiss economy. These findings support the hypothesis that past values of considered exchange rate are not useful in predicting current and future performance of Swiss stock market.

The next table contains results of linear Granger causality tests conducted for analogous variables related to Polish economy:

INSERT TABLE 8 AROUND HERE

The analysis of outcomes presented in table 8 also leads to many interesting conclusions. Firstly, similarly to previous case results of considered variant of linear causality test strongly point at existence of causal link from performance of Polish stock market with respect of US stock market to the percentage change of exchange rate of Polish złoty to the United States dollar. This finding was indicated despite the number of replications used in computation. However, the results of testing for causality in the opposite direction provided evidence of significant difference in respect to previous case. This time bootstrap-based Wald test provided evidence of existence of linear causal relationship at 5% significance level (despite the value of *N*), which means that both the traditional and portfolio approaches are suitable models for Polish economy. All these findings provided no basis for the rejection of Hypothesis 2. On the other hand, analysis of results contained in table 7 and 8 leads to the conclusion that Hypothesis 3 should be rejected.

Additionally, we shall note that in all cases results of standard Wald tests (with χ^2 distribution) were generally in line with outcomes of residual-based approach except for testing causality from *RWSE-RDJIA* to *CPU* (standard test provided evidence of existence of causality, but not at 1% significance level). This may somehow prove that results of linear tests based on asymptotic distribution theory may lead to spurious results in case of presence of heteroscedastic structures in the error term.[49]

As we had already noted the analysis of causal links between variables of interest with application of linear methods only is incomplete and has got some serious drawbacks. Therefore, to complete the analysis of dynamic relationships between exchange rate and stock market for both considered countries we have conducted suitable nonlinear causality tests. Since for both examined VAR models each residual time series exhibited significant heteroscedasticity we have also decided to present results of nonlinear tests conducted for GARCH(1,1)-filtered data. Tables 9-12 contain *p*-values obtained from testing for nonlinear Granger causality in considered directions. Similarly to linear cases, we decided to use the bold face and shaded areas to indicate results supporting the hypothesis of the existence of nonlinear Granger causality in the considered direction at 10% and 1% significance levels.

In tables 9-12 symbol ε stands for bandwidth parameter and l ($l=L_X=L_Y$) denotes considered lag parameter. We shall start our considerations from the presentation of results obtained for unadjusted series of residuals. In the first instance we present results of nonlinear causality tests conducted for suitable variables describing Swiss economy:

INSERT TABLE 9 AROUND HERE

[49] For more details see (Hacker and Hatemi, 2006).

The analysis of outcomes presented in table 9 leads to some important conclusions. It is not difficult to see that these findings differ from corresponding results obtained with application of linear methods. Namely, in contrast to Wald test the nonlinear technique provided strong support for claiming that for *CCU* and *RSMI-RDJIA* variables causality runs in both directions. It is also worth mentioning that for both considered directions suitable *p*-values reached values no greater than 0.01 for relatively large number of pairs of parameters ε and l, which may convince about existence of strong causal links between variables of interest. Finally, the existence of relatively strong nonlinear causalities provides basis for claiming that Hypothesis 4 is false.

Let us now move to the presentation of results of nonlinear causality analysis performed for Polish economy. The following table contains results of suitable nonlinear tests conducted for *CPU* and *RWSE-RDJIA* variables:

INSERT TABLE 10 AROUND HERE

In contrast to previously presented results (Table 9) these outcomes provided quite convincing support for claiming that for *CPU* and *RWSE-RDJIA* variables there is no nonlinear Granger causality in any direction. One should note that for all considered values of parameters ε and l suitable *p*-values were greater than 0.10, which helps to interpret test results in relatively undoubted way. It may also be important for researcher to compare these results with outcomes gained with application of bootstrap-based linear Granger causality tests. After analyzing outcomes presented in tables 8 and 10 it is easy to see that for Poland there exists strict linear Granger causality between fluctuations of exchange rate and stock return differentials in both directions.

As it was already mentioned considered nonlinear Granger causality test is sensitive to the presence of heteroscedastic structures in examined time series, which may lead to significant over-rejection. Since we had found our data to exhibit significant autoregressive conditional heteroscedasticity we decided to use GARCH(1,1)-filtration of considered residual time series and then repeat nonlinear causality analysis. At this place we must underline some important facts since in the initial analysis we examined existence of ARCH effects only. Firstly, for every considered residual series all GARCH(1,1) coefficients were statistically significant[50] except residuals resulting from *CPU* equation. In that case we found that ARCH(1) model fits better to the data. However, results of suitable nonlinear tests were in line with those gained after GARCH filtration, thus in this case we found no particular reason to present results of tests conducted for ARCH-filtered series separately. In the first instance we present results of nonlinear causality tests conducted for filtered variables referring to Swiss economy:

INSERT TABLE 11 AROUND HERE

Outcomes contained in table 11 provided a bit weaker support for claiming that the nonlinear causality runs in both directions than it was in case of results contained in table 9. Moreover, these findings may prove that in case of existence of (G)ARCH structures in examined data, considered test statistics indeed tends to take significantly too large values (over-rejection). Therefore, Hypothesis 5 can not be rejected. However, for each examined direction the results of test provided relatively significant evidences of the existence of causality for almost half of all possible values of parameters ε and l. Furthermore, if we take into consideration the fact that (G)ARCH filtering may cause serious loss of power of considered test then outcomes presented in table 11 may indeed provide relatively strong support for claiming that there exist causal links in both directions for *CCU* and *RSMI-RDJIA* variables. In other words these results provided significant reasons to state that Hypothesis 4 is indeed false.

It may be interesting how the GARCH(1,1) filtration may influence results of nonlinear causality analysis for *CPU* and *RWSE-RDJIA* variables. The following table contains suitable data:

INSERT TABLE 12 AROUND HERE

It seems obvious that results presented in table 12 should be analyzed together with outcomes presented in table 10. In contrast to previous case (Table 11), the results of (G)ARCH

[50] All estimated GARCH processes were found to be stationary.

filtration generally did not have significant impact on test results. Although, in general, *p*-values have changed in comparison to corresponding numbers contained in table 10, they all are still significantly greater than 0.10. The latter may be interpreted as extremely strong proof of hypothesis that for *CPU* and *RWSE-RDJIA* variables there is no nonlinear Granger causality in any direction.

In general the results of nonlinear causality test were unchanged after GARCH(1,1) filtering in case of both considered countries. Therefore, the nonlinear causality analysis provided relatively convincing support for claiming that in case of Swiss economy the portfolio as well as the traditional approach may be used to describe the links between movements on stock and currency markets. On the other hand, neither the traditional or portfolio approach was found to be the right pattern for Polish economy (based on results of nonlinear causality analysis only).

6. Concluding remarks

The relationship between stock prices and exchange rates has some important implications. First of all, this relationship is often used by fundamental investors to predict future trends in both considered markets. Secondly, both variables play an important role as factors having an impact on the development of emerging markets. This concerns particularly those countries which have rapidly growing corporate sectors with listed firms and expanding tradable sectors which are sensitive to exchange rate policies. The third point is that, theoretically, stock prices might influence or might be influenced by exchange rates. The traditional approach based on the interest parity condition implies that changes in exchange rates should give an impulse to rise of stock price. On the other hand portfolio approach suggests that changes in stock prices lead changes in exchange rates.

The aim of this paper was the examination of the nature of causal links between exchange rate and stock market performance of two countries, namely Switzerland (which was representing advanced markets) and Poland (representing emerging markets). We used daily data from period 2001.03.01 to 2008.08.29 to perform linear (bootstrap-based) as well as nonlinear causality tests. We used exchange rates of both considered domestic currencies to the US dollar and we measured performance of Swiss and Polish stock market in respect to US stock market (by the application of stock return differentials).

Our findings indicate strong linear causal relationship in direction from stock market to exchange rate for Switzerland. The linear causality in opposite direction was not reported. On the other hand, the results of nonlinear causality analysis (for unadjusted data of Swiss economy) provided strong basis for claiming that for considered variables nonlinear causality runs in both directions. This result was just a bit less convincing after GARCH(1,1) filtration. All these facts together confirmed the hypothesis, that in case of Switzerland the portfolio approach seems to be proper method to describe the dynamic interactions between stock and currency markets. However, we can not forget about evidences of nonlinear causality running in opposite direction (traditional approach).

In contrary to previous case, the results of linear causality analysis for Polish economy provided strong basis to claim that in this case each of considered variables have dynamic impact on the other one. Therefore, both the traditional as well as the portfolio models seem to be applicable in examination of causal links between stock market and exchange rate. It is worth to underline the fact that mentioned interactions were found to have strictly linear nature, as the results of nonlinear analysis provided absolutely no evidence of existence of causality in any direction (for unadjusted as well as for GARCH(1,1)-filtered data).

The fact that differences in structures of dynamic links between stock and currency markets for both considered countries lie in contraries between characteristics and levels of development of their economies is rather undisputed. The existence of strong causal relationship from exchange rate to stock prices in case of Poland is worth special attention. This may be interpreted as a proof of hypothesis that in case of this country monetary and financial policy makers may have a significant influence on the performance of stock market (through the possibility of influencing the exchange rate).

However, there are some similarities in the structure of dynamic links between considered variables for Swiss and Polish economy. The existence of strong causal influence of stock market returns on fluctuations of exchange rate in both countries (especially in case of Switzerland, for which both linear as well as nonlinear causalities were found) seems to have a practical application for investors. Namely, this relationship may be used to hedge portfolios against currency movements.

We hope our effort can help to better understand the causal relationships between stock and currency markets. We believe that findings presented in this paper will become useful for other researchers, market participants and policymakers.

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LIST OF TABLES.

TABLE 1 Abbreviations for examined variables

Full name of considered variable	Shortcut name
CHF/USD exchange rate	CU
PLN/USD exchange rate	PU
Return of DJIA	RDJIA
Return of SMI	RSMI
Return of WIG i.e. main index of Warsaw Stock Exchange	RWSE

TABLE 2 Descriptive statistics of considered variables

Quantity \ Variable	CCU [%]	CPU [%]	RSMI-RDJIA[a] [ ]	RWSE-RDJIA[a] [ ]
Minimum	-2.92	-4.77	-7.33	-11.10
1st Quartile	-0.41	-0.47	-0.64	-0.89
Median	0.01	-0.05	-0.06	0.07
3rd Quartile	0.40	0.38	0.68	0.98
Maximum	4.80	2.91	10.46	7.11
Mean	-0.02	-0.01	0.05	0.03
Standard deviation	0.72	0.66	1.22	1.60
Skewness	0.33	-0.17	0.15	-0.36
Excess kurtosis	2.66	0.73	5.35	2.81

[a] realizations multiplied by 100
Source: own calculations

TABLE 3 Notation used to formulate the definition of Granger causality

Symbol	Description
$\{X_t\}$ and $\{Y_t\}$	Two scalar-valued, stationary and ergodic time series
I_{t-1}	Information set containing L_X – lagged vector of X_t ($X_{t-L_X}^{L_X}$) and L_Y – lagged vector of Y_t ($Y_{t-L_Y}^{L_Y}$)
$X_{t-L_X}^{L_X}$ and $Y_{t-L_Y}^{L_Y}$	Lagged vectors defined as follows: $X_{t-L_X}^{L_X} := (X_{t-L_X}, X_{t-L_X+1}, ..., X_{t-1})$, $Y_{t-L_Y}^{L_Y} := (Y_{t-L_Y}, Y_{t-L_Y+1}, ..., Y_{t-1})$
$F\{X_t \mid I_{t-1}\}$	Conditional probability distribution of X_t, given the bivariate information set I_{t-1}.

TABLE 4 Results of ADF test*

Variable	Optimal lag lenght	ADF test statistics
CCU	9	-28.09
CPU	2	-27.13
RSMI-RDJIA	3	-34.00
RWSE-RDJIA	1	-29.14

*critical values: -3.43 (1%), -2.86 (5%), -2.57 (10%)
Source: own calculations

TABLE 5 Results of KPSS test*

Variable	KPSS test statistics
CCU	0.06
CPU	0.19
RSMI-RDJIA	0.11
RWSE-RDJIA	0.13

*critical values: 0,739 (1%), 0,463 (5%), 0,347 (10%)
Source: own calculations

TABLE 6 Results of tests for heteroscedasticity

Variables used to construct VAR model	Test type:	Test statistics:		*p*-value:	
		CCU equation	*RSMI-RDIJA* equation	*CCU* equation	*RSMI-RDIJA* equation
CCU and *RSMI-RDIJA*	White's	62.93	198.44	$<10^{-4}$	$<10^{-4}$
	White's (squares only)	44.97	112.01	$<10^{-4}$	$<10^{-4}$
	Breusch-Pagan	16.43	61.66	0.01	<10-4
		CPU equation	*RWSE-RDIJA* equation	*CPU* equation	*RWSE-RDIJA* equation
CPU and *RWSE-RDIJA*	White's	432.23	247.56	$<10^{-4}$	$<10^{-4}$
	White's (squares only)	259.86	150.54	$<10^{-4}$	$<10^{-4}$
	Breusch-Pagan	183.90	41.22	$<10^{-4}$	$<10^{-4}$

Source: own calculations

TABLE 7 Results of linear Granger causality tests for the percentage change of exchange rate and stock return differentials for Switzerland

Null hypothesis	Wald test (with bootstrap distribution)		
	N=100	*N*=250	*N*=500
CCU does not Granger cause *RSMI-RDJIA*	0.411	0.493	0.457
RSMI-RDJIA does not Granger cause *CCU*	0.001	0.000	0.000

Source: own calculations

TABLE 8 Results of linear Granger causality tests for the percentage change of exchange rate and stock return differentials for Poland

Null hypothesis	Wald test (with bootstrap distribution)		
	N=100	*N*=250	*N*=500
CPU does not Granger cause *RWSE-RDJIA*	**0.024**	**0.047**	**0.027**
RWSE-RDJIA does not Granger cause *CPU*	0.009	0.006	0.007

Source: own calculations

TABLE 9 Results of nonlinear Granger causality tests for the percentage change of exchange rate and stock return differentials for Switzerland (unadjusted data)

Null hypothesis	Nonlinear test			
	ε=0.5	ε=1	ε=1.5	
CCU does not Granger cause *RSMI-RDJIA*	0.27	**0.045**	0.008	*l*=1
	0.049	0.001	0.0001	*l* =2
	0.08	0.003	0.0001	*l* =4
RSMI-RDJIA does not Granger cause *CCU*	**0.043**	0.004	0.003	*l* =1
	0.41	0.01	0.001	*l* =2
	0.15	0.002	0.0002	*l* =4

Source: own calculations

TABLE 10 Results of nonlinear Granger causality tests for the percentage change of exchange rate and stock return differentials for Poland (unadjusted data)

Null hypothesis	Nonlinear test			
	ε=0.5	ε=1	ε=1.5	
CPU does not Granger cause *RWSE-RDJIA*	0.51	0.83	0.61	*l*=1
	0.37	0.52	0.56	*l* =2
	0.47	0.73	0.65	*l* =4
RWSE-RDJIA does not Granger cause *CPU*	0.98	0.93	0.83	*l* =1
	0.97	0.81	0.60	*l* =2
	0.74	0.90	0.52	*l* =4

Source: own calculations

TABLE 11 Results of nonlinear Granger causality tests for the percentage change of exchange rate and stock return differentials for Switzerland (filtered data)

Null hypothesis	Nonlinear test			
	ε=0.5	ε=1	ε=1.5	
CCU does not Granger cause *RSMI-RDJIA*	0.53	0.37	0.17	*l*=1
	0.08	**0.04**	0.01	*l* =2
	0.51	**0.03**	0.01	*l* =4
RSMI-RDJIA does not Granger cause *CCU*	0.28	**0.09**	**0.05**	*l* =1
	0.92	0.32	0.13	*l* =2
	0.15	0.002	0.0002	*l* =4

Source: own calculations

TABLE 12 Results of nonlinear Granger causality tests for the percentage change of exchange rate and stock return differentials for Poland (filtered data)

Null hypothesis	Nonlinear test			
	ε=0.5	ε=1	ε=1.5	
CPU does not Granger cause *RWSE-RDJIA*	0.72	0.81	0.60	l=1
	0.68	0.64	0.57	l =2
	0.22	0.88	0.63	l =4
RWSE-RDJIA does not Granger cause *CPU*	0.96	0.88	0.80	l =1
	0.92	0.83	0.63	l =2
	0.26	0.87	0.65	l =4

Source: own calculations