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Testing monetary exchange rate models with the Westerlund panel cointegration test

Szabó Andrea: A monetáris árfolyammodellek tesztelése Westerlund panel kointegrációs teszttel

Összefoglaló

A monetáris árfolyammodellek idősoros tesztelése a legtöbb esetben nem támasztotta alá az elméleti modellek feltevéseit. Így az irodalom egyre inkább a panel technikák alkalmazása felé fordult a monetáris árfolyammodellek tesztelése során, mivel a panel kointegrációs teszteknek nagyobb az erejük, mint a sima idősoros kointegrációs teszteké. A következőkben Westerlund 2007 panel kointegrációs teszttel vizsgáljuk meg a monetáris árfolyammodellek érvényességét 15 OECD ország dollár árfolyamán keresztül az 1996Q1 és a 2011Q4 közötti periódusban. Az eredmények mérsékelten igazolják a monetáris árfolyammodellek érvényességét.

Kulcsszavak: monetáris árfolyammodellek, empirikus tesztelés, OECD-országok, panel kointegrációs teszt

ABSTRACT

Time series testing of long-run monetary models of exchange rate determination in most cases fails to support the conjectures of the theory. The empirical literature increasingly uses the panel technique when testing monetary exchange rate models because the power of the panel unit root and panel cointegration tests seems higher than the pure time series tests. In this paper we examine the validity of the monetary exchange rate models over the period 1996Q1-2011Q4 for US dollar exchange rates of 15 OECD countries using Westerlund's 2007 panel cointegration tests. We found moderate empirical support for monetary exchange rate models.

Keywords: monetary exchange rate models, empirical testing, OECD countries, panel cointegration test

1. INTRODUCTION

Monetary exchange rate models are one of the standard analytical tools of international open-macroeconomics. Even so, the empirical validity of the theoretical models is doubtful. The majority of the empirical analyses cannot

confirm that these models explain the long run behaviour of nominal exchange rates well. In the seventies and eighties, and in the first half of the nineties time series tests were principally used, i.e. exchange rate behaviour was investigated on a country-by-country basis. The results usually do not show cointegration between the nominal exchange rate and the monetary macro-fundamentals [Frankel 1984; Meese 1986; Sarantis 1994; Rapach – Wohar 2002; MacDonald – Taylor 1992].

However these results do not indicate that the theoretical models are inapplicable. Among others, Groen 2000 and Rapach – Wohar 2004 attributed the failure of the empirical testing of monetary exchange rate models to the short sample length. In such circumstances the power of the unit root and the cointegration tests are too low to reject the null hypothesis of no cointegration between the variables. Others [Shiller and Perron 1985; Otero and Smith 2000] showed that the power of the unit root and the cointegration tests is influenced by the length of the sample, not the frequency of the data. To increase the power of the tests we can use the panel technique instead of applying only a single time series. In this way we have

more observations which can increase the precision of the unit root and the cointegration tests [Taylor-Taylor 2004]. Since the power of the pure time series cointegration tests is lower than the power of the panel cointegration tests, the literature increasingly uses the panel technique by testing monetary exchange rate models. Groen 2000 is one of the early analyses, which succeeded in supporting the validity of monetary exchange rate models by using the panel technique. Further success was achieved in detecting cointegration between the nominal exchange rate and monetary fundamentals by Mark and Sul 2001, Rapach and Wohar 2004, and Basher and Westerlund 2009.

The results show that the panel analyses are more successful than the country-by-country basis analyses in testing the monetary exchange rate models. In this paper we also apply the panel technique to test the monetary exchange rate models during the period 1996Q1-2011Q4.

2. METHODOLOGY

2.1. The model

There are three versions of the monetary exchange rate models: 1) the flexible price monetary exchange rate model [Frenkel 1976; Bilson 1978], 2) the sticky price monetary exchange rate model [Dornbush 1976] and 3) the real interest rate differential model [Frankel 1979]. These models stress the role of the money supply and the money demand in the determination of the exchange rate. All three models assume that the uncovered interest parity and the purchasing power parity (PPP) are held stable. The central statement of these models is that there is a long run equilibrium relationship between the nominal exchange rate and the monetary macro-fundamentals which appear in the models.

In most cases the literature tests the reduced form of the monetary exchange rate models (nominal exchange rate, nominal money supply, real income). We obtain the reduced form in the sense of Groen 2000 and Basher -

Westerlund 2009: take the money market equilibrium as the point of origin when the real money supply is equal to the real money demand:

$$m - p = \phi y - \lambda i, \quad (1)$$

the same equilibrium exists abroad:

$$m^* - p^* = \phi y^* - \lambda i^*, \quad (2)$$

where m and m^* are the logarithms of the domestic and foreign nominal money supply, p and p^* are the logarithms of the domestic and foreign price levels, y and y^* are the logarithms of the domestic and foreign real income, and i and i^* are the domestic and foreign interest rates. It is assumed that the PPP holds in the markets:

$$e = p - p^*, \quad (3)$$

where e is the logarithm of the spot exchange rate (define the price of foreign currency in terms of domestic currency). Express the domestic and the foreign price level from equation (1) and (2), then substitute these into PPP (3). Thus we get the equilibrium value of the exchange rate:

$$e = (m - m^*) - \phi(y - y^*) + \lambda(i - i^*). \quad (4)$$

It is also assumed that bonds are perfect substitutes, so the uncovered interest parity holds:

$$E_t(e_{t+1}) - e_t = i_t - i_t^*, \quad (5)$$

where E_t is the conditional expectation operator on the information set available at time t , and $E_t(e_{t+1}) - e_t$ the expected rate of depreciation. Substitute this equation (5) into equation (4):

$$e = (m - m^*) - \phi(y - y^*) + \lambda(E_t(e_{t+1}) - e_t). \quad (6)$$

In the long run the exchange rate converges to its long run equilibrium value ($e_t = e_{t+1} = \bar{e}$), thus the expected rate of depreciation will be zero: $E_t(e_{t+1}) - e_t = \bar{e} - \bar{e} = 0$. Then we obtain the reduced form of the monetary exchange rate models:

$$e = (m - m^*) - \phi(y - y^*). \quad (12)$$

2.2. Testing strategy

The monetary exchange rate models assume a long run equilibrium relationship between the nominal exchange rate and the monetary macro-fundamentals and this can be captured by revealing the cointegration between these variables. We test the reduced form of the monetary exchange rate models:

$$e_{it} = \beta_0 + \beta_1(m_{it} - m_t^*) + \beta_2(y_{it} - y_t^*) + u_{it},$$

where e_{it} is the logarithm of the nominal exchange rate of the i -th country at time t , m_{it} is the logarithm of the money supply of the i -th country at time t , y_{it} is the logarithm of the real income of the i -th country at time t and u_{it} is white noise. The asterisk indicate the foreign country that is the US dollar, in all cases, therefore the foreign variables have only t subscript. The literature usually tests this restricted model when assuming the coefficient of the domestic and foreign variables are equal. We also assume that the proportionality hypothesis is realized, i.e. any changes in the money supplies (in our case changes in the difference between the money supplies) appear as one hundred percent in the exchange rate, thus $\beta_1 = +1$. We assume the same with the difference in real incomes, i.e. $\beta_2 = -1$. In this paper we do not estimate the model, but only test the existence of the cointegration among the variables, even though the restrictions in connection with the coefficients of the variables are important. Beyond this specification we test another two specifications. Either of them has a stricter restriction when handling the monetary macro-fundamentals as a single "composite" variable:

$$e_{it} = \beta_0 + \beta_1[(m_{it} - m_t^*) - (y_{it} - y_t^*)] + u_{it},$$

where the literature would expect that $\beta_1 = +1$. This kind of testing method was taken from Rapach and Wohar 2002. The third

specification is an unrestricted model, which relaxes the previous restrictions. So it is not assumed that the domestic and foreign variables influence the nominal exchange rate to the same extent:

$$e_{it} = \beta_0 + \beta_1 m_{it} + \beta_2 m_t^* + \beta_3 y_{it} + \beta_4 y_t^* + u_{it}.$$

2.3. The testing procedure

The long run equilibrium relationship between the examined variables can be captured by the cointegration. The variables are cointegrated if there exists a linear combination of them, which is stationary. [Hendry – Juselius 2000] In this paper the existence of the cointegration between the nominal exchange rate and the monetary macro-fundamentals will be tested with a panel cointegration test. This kind of test has greater power than the time series tests. The majority of the panel cointegration tests use the idea of the Engel – Granger 1987 time series cointegration test in the sense that they are residual-based tests. These tests have a great disadvantage; they assume that the long- and short-run coefficients are equal, which can reduce the power of the tests considerably. [Westerlund 2007] Thus we applied the tests developed by Westerlund 2007 instead of residual-based tests.

The Westerlund tests have the null hypothesis of no cointegration among the examined variables. The adjustment parameter of a conditional panel error-correction model is analyzed to see whether it is zero or not. If the adjustment parameter is zero, there is no cointegration among the examined variables; if it is less than zero, the variables are cointegrated. The test not only allows the heterogeneity of the short-run parameters but can also manage cross section dependence. Westerlund 2007 constructed four tests, which can be divided into two groups on the grounds of their alternative hypotheses. Two tests (P_τ , P_α) investigate whether the panel cointegrated as a whole, the alternative hypothesis of the other two tests (G_α , G_τ) is

that at least one unit in the panel is cointegrated.

However, the cointegration can only be interpreted among non-stationary processes; therefore we must investigate the order of the integration of our variables before testing the cointegration. Since the unit root tests are, in general, very sensitive, we applied more tests to check the robustness of our results: Im, Pesaran, Shin (IPS), Fisher-ADF, Fisher-PP and Hadri tests [Im et al. 2003; Maddala – Wu 1999; Hadri 2000]. The Hadri test is the only one which has the null hypothesis of stationarity; the other three tests are panel unit root tests. The selection of the tests was influenced by their assumptions. There are tests which presume there is an identical autoregressive structure at each cross section unit, but this assumption is far from realness. The selected tests have no such an assumptions, they permit the different autoregressive structure of the pooled time series, with the exception of the Hadri test (but this is the only panel stationarity test which is supported by software packages). Previously, in the case of the panel analysis, it was typical to assume the cross section independence of the residuals but this does not apply in several cases. This is mainly true with large cross section units (i.e. with more than 10 cross section units). [Pesaran 2004] In our case, it is not only the somewhat restricted number of the cross section units, but the application of the US dollar as the anchor currency which can be the origin of the cross section dependence. [O'Connell 1998] Therefore we also analyzed the extent of the possible cross section dependence between the residuals and the variables. We used the Pesaran 2004 CD test based on the average of pair-wise correlation coefficients. We obtained the residuals from the pooled mean-group estimation of the panel, which is a typical cointegrated panel estimation method. [Pesaran et al. 1999] In the presence of cross section dependence the distribution of the Westerlund test statistics is changed hence running the tests again we report bootstrapped p -values. Then we assess

the results of the panel cointegration tests by the bootstrapped p -values.

3. RESULTS

3.1. Data

To collate our data we applied the OECD Statistics database. The dollar exchange rates of the following 15 OECD countries (regions) were analyzed using quarterly data over the period 1996Q1-2011Q4: Australia, Canada, Czech Republic, Denmark, the euro area, Hungary, Japan, Korea, Mexico, Norway, Poland, Sweden, Switzerland, Turkey and the United Kingdom. During the sample period the exchange rate policy of the examined countries is characterized primarily by floating exchange rates. We tested the reduced form of the monetary exchange rate models thus our variables are the nominal exchange rate, the nominal money supply and the industrial production index. The exchange rates are average period values, the nominal money supplies are the end of period data, containing both seasonally adjusted and unadjusted items. In general they are M3, but in some cases we have M2 and M4. All the industrial production indices are seasonally adjusted. The data selection was influenced by the availability of the data. We applied the industrial production index because real GDP can be reached in a shorter time period, and the majority of the studies also use this kind of data to proxy the real income. Eviews and Stata programmes were used to test our model.

3.2. Results of the panel unit root tests

The order of the integration of the variables was examined by three panel unit root tests and one panel stationarity test: IPS, Fisher-ADF, Fisher-PP and Hadri tests. In the interest of the robustness of the results, all model possibilities were tested. In the case of the IPS and the Fisher-ADF tests the number of the lags in the auxiliary regression was determined by the Schwarz information criterion. The other tests use the kernel method to correct the feasible

autocorrelation; thus in the case of the Fisher-PP and Hadri tests, the Bartlett kernel was applied. The results are heterogeneous (Table 1).

Variables	IPS test	Fisher-ADF test	Fisher-PP test	Hadri test
<i>Variables of the USA 1996Q1-2011Q4</i>				
m_t^*	$I(1)$	$I(1)$	$I(1)$	$I(1)$
y_t^*	$I(0)$	$I(1)$ or $I(0)$	$I(1)$ or $I(0)$	$I(1)$ or $I(2)$
<i>Variables of the OECD countries 1996Q1-2011Q4</i>				
e_{it}	$I(1)$ or $I(0)$	$I(1)$ or $I(0)$	$I(1)$ or $I(0)$	$I(3)$
m_{it}	$I(1)$	$I(0)$	$I(0)$	$I(3)$
y_{it}	$I(1)$ or $I(0)$	$I(1)$ or $I(0)$	$I(1)$	$I(1)$

Table 1

The results of the IPS, the Fisher-ADF, the Fisher-PP and the Hadri panel unit root and panel stationarity tests

The variables of the USA can be examined by time series unit root tests too, because in each equation there is the same time series of the USA. In order to test all the variables with the same methodology, the four selected panel unit root tests were eventually used for the US variables too. The US nominal money supply is unambiguously integrated of order one. The US real income is $I(1)$ or $I(0)$, but the second order integration also emerged from the Hadri test. The nominal exchange rate of the examined OECD countries is also $I(1)$ or $I(0)$ and the Hadri test shows an unrealistic $I(3)$. The results of the nominal money supply of the examined OECD countries are similar, but in this case two tests show that the process is stationary, one that it is a unit root process, while the Hadri again shows $I(3)$. We have better results in the case of the real income of the examined OECD countries; according to the Fisher-PP and Hadri tests it is $I(1)$, and only the IPS and Fisher-ADF tests are uncertain whether the process is $I(1)$ or

$I(0)$. The graphs of the time series can offer a little help in evaluating the results. It seems from the graphs that the majority of the time series have a trend, so in almost all cases we can exclude the possibility that the examined processes are stationary. Some outlier values and sometime possible breakpoints also appeared, which may be the cause of the uncertainty of the Hadri test.

Although we cannot make an unambiguous decision about the integration order of the variables, the examined processes can in all cases be considered unit root processes. So we can analyze whether a long run equilibrium relationship exists between the examined variables, i.e. whether the central statement of the monetary exchange rate models is fulfilled or not.

3.3. Results of the Westerlund panel cointegration tests

We examined three specifications of the reduced form of the monetary exchange rate models: a two-, a three- and a five-variable model (Table 2).

statistics	Two-variable model		Three-variable model		Five-variable model	
	value	p-value	value	p-value	value	p-value
G_t	-2.221	0.028	-2.567	0.013	-3.100	0.004
G_a	-8.964	0.097	-11.241	0.096	-6.961	0.999
P_t	-8.221	0.004	-9.923	0.001	-10.688	0.014
P_a	-7.729	0.001	-10.302	0.001	-8.021	0.744

Table 2

The results of the Westerlund panel cointegration test in respect to the monetary exchange rate models

We can see that the restricted models perform better. In case of the P tests the null hypothesis (that there is no cointegration) can be rejected at a 1% significance level by the two- and three-variable model against the alternative hypothesis that the panel is cointegrated as a whole. In the case of the G tests the null hypothesis can be rejected at the 5% and 10% significance levels by both restricted models against the alternative that there is at least one unit which is cointegrated. We cannot reject the null hypothesis in the case of the five-variable unrestricted model, nor by the G_α neither by the P_α test, but it can be rejected by the G_τ and the P_τ test at the 1% and 5% significance levels. The first results of the tests are relatively positive. Still, we found

evidence for the hypothesis that the panel is cointegrated as a whole. The results of the two- and three-variable model unambiguously confirm that a long run equilibrium relationship exists between the nominal exchange rate and the monetary macro-fundamentals, and the unrestricted model also offers moderate support for the empirical validity of the monetary exchange rate models. Nevertheless, we must examine whether our results are robust or not. Since we applied the US dollar as an anchor currency, there is a great chance that there exists cross section dependence between the residuals of the panel units. We analyzed the cross section dependence with the Pesaran 2004 CD test between both the residuals and the variables for all the three specifications (Table 3).

	Two-variable model		Three-variable model		Five-variable model			
	CD stat.	p-value	CD stat.	p-value	CD stat.	p-value		
residuals	5.18	0.000	residuals	0.83	0.409	residuals	31.22	0.000
e_{it}	38.56	0.000	e_{it}	38.56	0.000	e_{it}	38.56	0.000
m_{it}	78.99	0.000	$m_{d,it}$	22.49	0.000	f_{it}	5.12	0.000
m_t^*	81.98	0.000	$y_{d,it}$	6.17	0.000			
y_{it}	37.34	0.000						
y_t^*	81.98	0.000						

Table 3

The results of the CD test in respect of the variables and the residuals of the estimated monetary exchange rate models

- Notes: 1) $f_{it} = [(m_{it} - m_t^*) - (y_{it} - y_t^*)]$
 2) $m_{d,it} = (m_{it} - m_t^*)$
 3) $y_{d,it} = (y_{it} - y_t^*)$

We obtain the residuals from the pooled mean-group estimation (PMG) of the panel. The null hypothesis of the CD test is that there is the cross section independence. The results are unambiguous: it can be rejected in almost all cases at the 1% significance level that the residuals and the variables are independent from each other. Only with the three-variable

specification case can we not reject the hypothesis that the residuals from the PMG estimation are independent. Since the results of the CD test show a strong cross section dependence between the units of the examined panel, the Westerlund test is run again and new p -values will be determined by the bootstrap method (Table 4).

statistics	Two-variable model		Three-variable model		Five-variable model	
	value	robust p-value	value	robust p-value	value	robust p-value
G_τ	-2.221	0.109	-2.567	0.068	-3.100	0.044
G_α	-8.964	0.095	-11.241	0.090	-6.961	0.859
P_τ	-8.221	0.081	-9.923	0.034	-10.688	0.099
P_α	-7.729	0.051	-10.302	0.031	-8.021	0.501

Table 4

The results of the Westerlund panel cointegration test in respect of the monetary exchange rate models with robust p -values

The results deteriorated but this does not influence the inferences considerably. Still, the two restricted models perform better, especially the three-variable specification, which is often tested by the literature. In the case of the G tests at 10%, and in the case of the P tests at the 5% significance level the null hypothesis – that it is no cointegration – can be rejected. With the two-variable specification, the null hypothesis only cannot be rejected in the case of the G_{τ} test; in the other cases it can be rejected at the 10% significance level. The five-variable unrestricted model performs in the same way as previously. With the G_{τ} and the P_{τ} test at the 5% and 10% significance levels the hypothesis that there is no cointegration between the examined variables can be rejected, as long as it remains impossible to reject the null hypothesis with the G_{α} and the P_{α} tests. Taking into account the cross section dependence did not fundamentally change our former assertion: i.e. that a long run equilibrium relationship exists between the nominal exchange rate and the monetary macro-fundamentals.

This is unambiguously supported by the results of the three-variable specification, and the other two specifications also serve as moderate evidence for this relationship.

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4. CONCLUSION

The most frequently applied panel cointegration tests are residual-based tests using the logic of the Engel – Granger 1987 time series cointegration test. But these tests force rigorous restrictions on the long-run and short-run parameters assuming that they are equal, and this assumption is fulfilled by all cross sections, which may reduce the power of the tests. Hence we chose a test based on a different idea, the Westerlund 2007 test, which examines whether the error-correction term in a conditional panel error-correction model is equal to zero

. This test can also handle the cross section dependence which was analyzed with the Pesaran 2004 CD test between the residuals and the variables. The monetary exchange rate models were tested in three specifications: by a two-, a three- and a five-variable model.

According to the results of the CD test there is cross section dependence in our examined panel between the residuals and the variables, too. Thus robust p -values were determined with the bootstrap method. However, the results did not fundamentally change when the new p -values were taken into consideration. We succeeded in revealing the cointegration between the examined variables, and the frequently tested three-variable model showed the best results.

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