TESTING MONETARY EXCHANGE RATE MODELS WITH PANEL COINTEGRATION TESTS

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Abstract: *The monetary exchange rate models explain the long run behaviour of the nominal exchange rate. Their central assertion is that there is a long run equilibrium relationship between the nominal exchange rate and monetary macro-fundamentals. Although these models are essential tools of international macroeconomics, their empirical validity is ambiguous. Previously, time series testing was prevalent in the literature, but it did not bring convincing results. The power of the unit root and the cointegration tests are too low to reject the null hypothesis of no cointegration between the variables. This power can be enhanced by arranging our data in a panel data set, which allows us to analyse several time series simultaneously and enables us to increase the number of observations. We conducted a weak empirical test of the monetary exchange rate models by testing the existence of cointegration between the variables in three panels. We investigated 6, 10 and 15 OECD countries during the following periods: 1976Q1-2011Q4, 1985Q1-2011Q4 and 1996Q1-2011Q4. We tested the reduced form of the monetary exchange rate models in three specifications; we have two restricted models and an unrestricted model. Since cointegration can only be interpreted among non-stationary processes, we investigate the order of the integration of our variables with IPS, Fisher-ADF, Fisher-PP panel unit root tests and the Hadri panel stationary test. All the variables can be unit root processes; therefore we analyze the cointegration with the Pedroni and Kao panel cointegration test. The restricted models performed better than the unrestricted one and we obtained the best results with the 1985Q1-2011Q4 panel. The Kao test rejects the null hypotheses – there is no cointegration between the variables – in all the specifications and all the panels, but the Pedroni test does not show such a positive picture. Hence we found only moderate support for the monetary exchange rate models.*

Keywords: monetary exchange rate models; cointegration; empirical testing; OECD countries; Pedroni panel cointegration test; Kao panel cointegration test

JEL codes: F31; F41; C33

1. Introduction

The long run equilibrium relationship between the nominal exchange rate and monetary macro-fundamentals is described by the monetary exchange rate models. These models are essential theoretical tools; even so, their empirical validity is doubtful. The majority of empirical analyses cannot confirm that these models provide a good explanation for the long run behaviour of nominal exchange rates. Many empirical tests using time series analysis have failed to find evidence for the empirical validity of these models. (Meese, 1986; Sarantis, 1994; Rapach and Wohar, 2002; Upadhyaya and Pradhan, 2006).

However, these results do not indicate that the theoretical models are inapplicable. Among others, Groen (2000) and Rapach and 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 and 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 macro-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 following periods: 1976Q1-2011Q4, 1985Q1-2011Q4 and 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. We obtain the reduced form in the sense of Groen (2000) and Basher and Westerlund (2009): take the money market equilibrium as the point of origin when the real money supply is equal to the real money demand:

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

the same equilibrium exists abroad:

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

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:

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

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:

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

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

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

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):

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

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

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

2.2. Testing strategy

The monetary exchange rate models assume a long run equilibrium relationship between the nominal exchange rate and 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 asterisks indicate the foreign country, which is the US dollar in all cases, therefore the foreign variables have only t subscript. The literature usually tests this restricted model when assuming that the coefficients 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:

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

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 and Juselius, 2000) In this paper the existence of the cointegration between the nominal exchange rate and monetary macro-fundamentals will be tested with panel cointegration tests, so we conduct a weak test of the monetary exchange rate models. This kind of cointegration test has greater power than the time series tests.

To reveal the long run equilibrium relationship between the examined variables we use Pedroni and Kao panel cointegration tests. Both tests use the idea of the Engle and Granger (1987) time series cointegration test in the sense that they are residual-based tests; both tests include the null hypothesis of no cointegration among the examined variables. Pedroni (2000, 2004) proposes several tests to examine the cointegration in panels. The tests can be divided into two groups: 1) there are tests which average the test statistics of the individual time series across the cross section units, 2) other tests are based on averaging not the test statistics as a whole, but make separate averages for the numerator and for the denominator terms. The tests also differ in terms of the assumption of the time series autoregressive structure, i.e. some tests assume an identical autoregressive structure of the examined time series and other tests allow different autoregressive structures. Since the assumption of identical autoregressive structures is far from realistic, we use only tests which allow enough heterogeneity. Because these tests are also sensitive to the modelling of the time series, all the model possibilities – i.e. the time series a) includes an intercept, b) includes a constant and a trend, and c) includes none of the former – were investigated. (Pedroni, 2000, 2004; Baltagi, 2008) The Kao test also has DF and ADF tests, but we only use the ADF test statistics. There is only one modelling possibility: the time series including an intercept. (Kao, 1999; Baltagi, 2008) In both cases the residuals are obtained from the panel fixed effects estimation.

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 further tests to check the robustness of our results: Im, Pesaran, Shin (IPS), Fisher-ADF, Fisher-PP and Hadri tests (Im, Pesaran and Shin, 2003; Maddala and Wu, 1999; Hadri, 2000). The Hadri test is the only one which has the null hypothesis of stationarity (the alternative hypothesis is that a few cross section units contain a unit root, but not all do so); the other three tests are panel unit root tests. The IPS *t*-statistics are the average of the individual ADF tests; the null hypothesis is that all the time series contain a unit root, and the alternative hypothesis is that a few cross section units contain a unit root (Im, Pesaran and Shin, 2003). The Fisher type tests combine the *p*-value of the individual unit root tests across the cross sections. Their null hypothesis is also the conjecture of the unit root in the time series (Maddala and Wu, 1999; Baltagi, 2008). In the interest of the robustness of the results, all model possibilities were tested, i.e. the time series a) includes an intercept, b) includes a constant and a trend, and c) includes none of the formers. The selection of the tests was influenced by the assumptions made regarding each test. Panel unit root tests also include tests which presume an identical autoregressive structure at each cross section unit and which allow a heterogeneous autoregressive structure. The selected tests 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).

3. Results

3.1. Data

To collate our data we applied the OECD Statistics database. Three panels were constructed because of the absence of data. The shortest panel (1996Q1-2011Q4) has 15 cross section units: Australia, Canada, the Czech Republic, Denmark, the euro area, Hungary, Japan, Korea, Mexico, Norway, Poland, Sweden, Switzerland, Turkey and the United Kingdom; the longest (1976Q4-2011Q4) panel has 6 cross section units: Australia, Canada, Denmark, Norway, Sweden, Switzerland; and the intermediate length (1985Q1-2011Q4) has 10: Australia, Canada, Denmark, Japan, Mexico, Norway, Sweden, Switzerland, Turkey and the United Kingdom. The dollar exchange rates were analyzed using quarterly data. 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 data selection was influenced by the availability of the data.

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 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 variables of the USA can also be examined by time series unit root tests, because in each equation there is the same time series as 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 results are heterogeneous (Table 1, Table 2). The US nominal money supply and the US real income seems to be integrated of order one (it needs once differencing to be stationary), the nominal exchange rate and the nominal money supply of the OECD countries examined is *I(1)* or *I(0)*, and the real income of the examined OECD countries also seems to be *I(1)*.

3.3. Results of the Pedroni and Kao panel cointegration tests

The results are not too convincing, but show some degree of support for the monetary exchange rate models (Table 3, Table 4 and Table 5). These tests do not have too much power, so probably they will be sensitive to the length of the sample, the number of the observations and the modelling of the time series. Our hypothesis is that the results will be improved with samples with longer time horizons, and with samples with a relatively high number of observations. Our panels differ in the length of the sample and also in the number of the cross section units examined, so the results are also different for each panel. The Kao test rejects the null hypotheses – no cointegration between the variables – for all the specifications and all the panels. In the case of the first (Table 3) and the second (Table 4) panel at the 1% significance level, in the case of the third panel (Table 5) by the two- and three-variable specification at the 5% significance level, and by the five-variable specification again at the 1% significance level. From among the three test statistics of the Pedroni test it is the ADF test which rejects the null hypotheses the most often. We can also see that in the case of the restrictive models, i.e. the two- and three-variable models, we have better results. With the five-variable specification the null hypothesis is only rejected in the case of the second panel by the Pedroni test. The best results were obtained by the second panel (1985Q1-2011Q4), where we found evidence for the monetary exchange rate models in all the specifications. Presumably the reason for this is the greater number of observations compared to the other two panels.

4. Conclusion

The long run monetary exchange rate models are essential theoretical tools of international macroeconomics; nonetheless, their empirical validity is ambiguous. Previously, the time series testing was prevalent in the literature, but it did not bring convincing results. The power of the unit root and the cointegration tests are too low to reject the null hypothesis of the tests. This power can be enhanced by arranging our data in a panel data set, which ensures that we analyse several time series simultaneously and enables us to increase the number of observations.

We conducted a weak empirical test of the monetary exchange rate models by testing the existence of the cointegration between the variables in three panels. The reduced form of the monetary exchange rate models was investigated in three specifications. We examined the order of the integration of the variables with IPS, Fisher-ADF, Fisher-PP and Hadri tests, then ran Pedroni and Kao panel cointeration tests. The restricted models performed better than the unrestricted one; however we found only moderate support for the monetary exchange rate models.

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Appendix

Table 1: The results of the IPS and the Fisher-ADF panel unit root tests

Variables	**IPS test**		**Fisher-ADF test**		
	A	**B**	**A**	**B**	**C**
Variables of the USA 1996Q1–2011Q4					
m_t*	5.775	-1.070	2.159	29.279	0.000
Δm_t*	-17.650***	-15.942***	324.396***	258.702***	23.213
y_t*	-6.156***	-5.664***	89.212***	80.431***	3.005
Δy_t*	9.524***	-7.779***	149.323***	111.733***	221.771***
Variables of the OECD countries 1996Q1-2011Q4					
e_{it}	-0.211	-2.643***	33.298	47.306**	31.274
Δe_{it}	-18.199***	-17.273***	342.912***	292.416***	488.164***
m_{it}	-0.446	-0.394	93.110***	46.102**	0.146
Δm_{it}	-12.177***	-11.853***	215.837***	198.698***	91.979***
y_{it}	-0.099	-2.495***	36.660	50.798**	7.378
Δy_{it}	-20.908***	-20.258***	378.870***	324.774***	867.538***
Variables of the OECD countries 1985Q1-2011Q4					
e_{it}	-5.615***	-2.276***	83.403***	46.307***	52.457***
Δe_{it}	-20.414***	-20.652***	372.337***	338.429***	604.651***
m_{it}	0.249	-1.524*	27.922	39.878***	0.430
Δm_{it}	-10.993***	-9.632***	173.074***	138.489***	208.871***
y_{it}	-0.624	0.526	24.693	22.455	1.519
Δy_{it}	-25.392***	-26.342***	458.793***	412.013***	1043.56***
Variables of the OECD countries 1976Q1-2011Q4					
e_{it}	-1.778**	-0.321	18.548	11.368	14.082
Δe_{it}	-20.012***	-20.309***	315.071***	288.102***	677.397***
m_{it}	-0.374	-1.968**	10.893	21.154**	0.020
Δm_{it}	-6.497***	-6.873***	70.656***	70.661***	29.195***
y_{it}	0.590	1.276	10.199	9.367	0.172
Δy_{it}	-22.589***	-23.643***	340.211***	313.644***	825.119***

Notes: A) the time series includes intercept, B) includes trend and intercept, C) includes none; the stars are the significance level of rejection: * 10%, ** 5%, *** 1%

Table 2: The results of the Fisher-PP panel unit root and the Hadri stationary test

Variables	**Fisher-PP test**			**Hadri test**	
	A	**B**	**C**	**A**	**B**
Variables of the USA 1996Q1–2011Q4					
m_t*	1.745	17.118	0.000	22.167***	10.246***
Δm_t*	328.176***	262.335***	88.701***	-2.704	-0.320
y_t*	83.622***	31.108	1.777	11.091***	9.555***

Δy_t^*	100.963***	61.457***	171.216***	1.691**	0.002
$\Delta^2 y_t^*$	–	–	–	-2.868	-3.176
Variables of the OECD countries 1996Q1–2011Q4					
e_{it}	43.237	30.525***	38.954	10.108***	8.716***
Δe_{it}	310.789***	252.381***	444.651***	2.264**	3.761***
$\Delta^2 e_{it}$	–	–	–	3.480***	17.343***
m_{it}	110.402***	41.010*	0.000	21.537***	9.652***
Δm_{it}	248.988***	232.567***	152.661***	5.762***	7.199***
$\Delta^2 m_{it}$	–	–	–	1.742**	10.486***
y_{it}	28.806	27.426	6.957	14.499***	7.405***
Δy_{it}	389.091***	338.235***	873.100***	-0.135	-1.468
Variables of the OECD countries 1985Q1–2011Q4					
e_{it}	74.012***	41.911***	54.072***	8.620***	8.653***
Δe_{it}	406.379***	368.626***	693.699***	2.193**	4.586***
$\Delta^2 e_{it}$	–	–	–	1.398*	10.549***
m_{it}	77.732***	28.123	0.000	20.811***	9.579***
Δm_{it}	277.577***	256.229***	368.856***	3.613***	5.280***
$\Delta^2 m_{it}$	–	–	–	-0.030	5.777***
y_{it}	29.419*	15.914	0.937	17.089***	9.410***
Δy_{it}	508.485***	418.303***	1273.48***	2.960***	2.944***
$\Delta^2 y_{it}$	-	-	-	-0.009	6.051***
Variables of the OECD countries 1976Q1–2011Q4					
e_{it}	14.473	7.292	12.755	5.815***	6.081***
Δe_{it}	305.985***	276.040***	632.390***	0.722	-0.995
m_{it}	26.043**	16.403	0.000	20.101***	11.052***
Δm_{it}	322.044***	303.089***	580.949***	3.921***	4.122***
$\Delta^2 m_{it}$	–	–	–	-0.949	-0.379
y_{it}	9.820	9.013	0.115	18.664***	7.878***
Δy_{it}	431.623***	391.834***	1211.08***	2.178**	1.071
$\Delta^2 y_{it}$	-	-	-	0.065	4.051***

Notes: A) the time series includes intercept, B) includes trend and intercept, C) includes none; the stars are the significance level of rejection: * 10%, ** 5%, *** 1%

Table 3: The results of the Pedroni and Kao panel cointegration tests with respect to the 1976Q4-2011Q4 panel

		Two-variable model		**Three-variable model**		**Five-variable model**	
Pedroni test, presumed individual AR structure 1976Q4-2011Q4							
statistics	**model**	**value**	***p*-value**	**value**	***p*-value**	**value**	***p*-value**
rho	**A**	0.430	0.667	0.834	0.798	1.243	0.893
	B	0.906	0.818	0.770	0.779	1.949	0.974
	C	-0.101	0.460	0.999	0.841	1.122	0.869
PP	**A**	-0.024	0.490	0.339	0.633	1.046	0.852
	B	0.617	0.731	0.562	0.713	1.778	0.962
	C	-1.999	0.023	-0.325	0.373	0.535	0.704
ADF	**A**	-0.879	0.190	-0.033	0.487	-0.064	0.474
	B	-0.340	0.367	-0.310	0.378	0.315	0.624
	C	-2.010	0.022	-0.318	0.375	-0.124	0.451

Kao test 1976Q4-2011Q4							
statistics	**model**	**value**	***p*-value**	**value**	***p*-value**	**value**	***p*-value**
ADF	**A**	-2.856	0.002	-2.796	0.003	-3.447	0.000

Notes: A) the time series includes intercept, B) includes trend and intercept, C) includes none

Table 4: The results of the Pedroni and Kao panel cointegration tests with respect to the 1985Q1-2011Q4 panel

		Two-variable model		**Three-variable model**		**Five-variable model**	
Pedroni test, presumed individual AR structure 1985Q1-2011Q4							
statistics	**model**	**value**	***p*-value**	**value**	***p*-value**	**value**	***p*-value**
rho	**A**	-1.762	0.039	-0.782	0.217	-0.026	0.490
	B	-0.405	0.343	0.126	0.550	0.498	0.691
	C	-0.156	0.438	0.236	0.593	-0.096	0.462
PP	**A**	-3.115	0.001	-2.600	0.005	-1.774	0.038
	B	-1.904	0.029	-1.288	0.099	-1.268	0.103
	C	-2.459	0.007	-2.100	0.018	-2.492	0.006
ADF	**A**	-2.717	0.003	-2.740	0.003	-3.388	0.000
	B	-1.795	0.036	-1.274	0.101	-2.418	0.008
	C	-2.116	0.017	-1.693	0.045	-2.735	0.003
Kao test 1985Q1-2011Q4							
statistics	**model**	**value**	***p*-value**	**value**	***p*-value**	**value**	***p*-value**
ADF	**A**	-4.572	0.000	-4.709	0.000	-5.604	0.000

Notes: A) the time series includes intercept, B) includes trend and intercept, C) includes none

Table 5: The results of the Pedroni and Kao panel cointegration tests with respect to the 1996Q1-2011Q4 panel

		Two-variable model		**Three-variable model**		**Five-variable model**	
Pedroni test, presumed individual AR structure 1996Q1-2011Q4							
statistics	**model**	**value**	***p*-value**	**value**	***p*-value**	**value**	***p*-value**
rho	**A**	0.105	0.542	1.278	0.899	3.155	0.999
	B	1.702	0.956	2.604	0.995	3.974	1.000
	C	1.562	0.941	0.727	0.766	2.993	0.999
PP	**A**	-0.808	0.210	0.791	0.786	2.538	0.994
	B	0.208	0.582	1.882	0.970	3.391	1.000
	C	-0.871	0.192	-1.046	0.148	2.382	0.991
ADF	**A**	-1.831	0.034	-1.345	0.089	0.174	0.569
	B	-1.564	0.059	-0.020	0.492	0.292	0.615
	C	-1.044	0.148	-2.180	0.015	-0.325	0.373
Kao test 1996Q1-2011Q4							
statistics	**model**	**value**	***p*-value**	**value**	***p*-value**	**value**	***p*-value**
ADF	**A**	-2.082	0.019	-2.197	0.014	-4.569	0.000

Notes: A) the time series includes intercept, B) includes trend and intercept, C) includes none