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Modelling official and Parallel Exchange Rates in Colombia under Alternative Regimes: A Non-Linear Approach

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MODELLING OFFICIAL AND PARALLEL EXCHANGE RATES IN COLOMBIA UNDER ALTERNATIVE REGIMES: A NON-LINEAR APPROACH

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ABSTRACT

We examine the long-run relationship between the parallel and the official exchange rate in Colombia over two regimes; a crawling peg period and a more flexible crawling band one. The short-run adjustment process of the parallel rate is examined both in a linear and a non-linear context. We find that the change from the crawling peg to the crawling band regime did not affect the long-run relationship between the official and parallel exchange rates, but altered the short-run dynamics. Non-linear adjustment seems appropriate for the first period, mainly due to strict foreign controls that cause distortions in the transition back to equilibrium once disequilibrium occurs.

JEL classifications: C32, F31, O54.

Keywords: Parallel market, cointegration, non-linear error correction models, Colombia

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1. Introduction

During the last three decades Colombia has witnessed the operation of two different exchange rate regimes. In 1967, the country adopted a crawling peg regime, which was maintained until November 1991. Under the crawl, the Central Bank (Banco de la República) varied the exchange rate once or twice per week with the aim of neutralising the difference between domestic and foreign inflation. In practice, however, purchasing power parity was not maintained in the strict sense of the term, since the crawling peg system was also targeting the real exchange rate.[1] In December 1991 the crawling peg system was abandoned, as it proved inconsistent with the price stability clause defined in the constitutional reform of that year. Since then, the monetary authorities have favoured the introduction of a more flexible regime, adopting a target zone that allows the trend depreciation of the central exchange rate (or parity), and a wide band for fluctuation of the actual exchange rate. Williamson (1996) refers to such a system as a "crawling band" regime.[2]

Like many other developing countries, Colombia has been characterised by the existence of a parallel market for foreign exchange, in particular for US dollars, as most foreign exchange transactions in the country take place in this currency. During the crawling peg period, the parallel market emerged as the result of strict foreign exchange controls, that concentrated all sales and purchases of foreign exchange at the central bank. By 1992, following a series of major liberalising reforms including the abolition of

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[1] In the early 1980s, for example, the monetary authorities accelerated the rate of crawl as part of a stabilisation programme. Steiner (1987) discusses the objectives of the crawling peg in Colombia, and Edwards (1986) discusses the determinants of the rate of crawl.

[2] Williamson (1996) and Cárdenas (1997) discuss the transition between the two regimes.

exchange controls, foreign currency operations were decentralised to financial intermediaries other than the central bank. As a result, Colombians could freely buy and sell foreign exchange. Despite the liberalisation measures, however, the parallel market has still been in operation due to the presence of agents involved in illegal activities and for this reason not able to trade in the official market.

This paper investigates the relationship between the parallel and official exchange rates under the crawling peg and crawling band regimes, respectively. The paper differs from existing work applying cointegration techniques in the context of the official and parallel exchange rates (see e.g. Booth and Mustafa, 1991, for Turkey; Baghestani and Noer, 1993, for India) in at least three ways. First, the Colombian experience allows us to examine the long-run properties over the two regimes. Second, one might argue that the short-run relationship between the parallel and official exchange rates might have varied depending upon regime. This is examined in the present paper. Third, we allow for the possibility of non-linear adjustment back to equilibrium by looking at different non-linear functional forms of the disequilibrium error.

The outline of the paper is as follows. Section 2 presents the cointegration properties of our empirical model. Section 3 discusses the short-run dynamics allowing for linear and non-linear adjustment to take place, and Section 4 discusses conclusions and some policy implications.

2. The empirical model: Long-run behaviour

Our model uses a set of $p = 2$ endogenous variables, $y = [ep, eo]'$, where *ep* and *eo* refer to the exchange rate in the *parallel* and *official* markets for US dollars, respectively.[3] The data are monthly observations from 1979:1 to 1998:12, and the variables are in logarithms.

Following Johansen (1988, 1995), we write a p-dimensional Vector Error Correction (VEC) model as:

$$\Delta y_t = \sum_{i=1}^{k-1} \Gamma_i \Delta y_{t-i} + \Pi y_{t-1} + \mu + \varepsilon_t, \quad t = 1,\ldots,T \qquad (1)$$

where Δ is the first difference operator, y_t is the set of $I(1)$ stochastic variables discussed above, $\varepsilon_t \sim niid(0,\Sigma)$, μ is a drift parameter, and Π is a (p x p) matrix of the form $\Pi = \alpha\beta'$, where α and β are both (p x r) matrices of full rank, with β containing the r cointegrating relationships and α carrying the corresponding loadings in each of the r vectors.

Preliminary analysis of the data using the Augmented Dickey-Fuller (ADF) tests suggested that both series are $I(1)$ with a drift when considered in levels. The presence of a unit root in the exchange rate series is also confirmed by the Phillips-Perron tests, and by the visual inspection of their correlograms.[4]

The levels of the two equations in the unrestricted VAR model (1) are initially estimated over the whole sample period 1979:1 to 1998:12, using a lag length of k = 12. The intercept term (i.e. μ) enters the model unrestrictedly, since the series have a drift term.[5]

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[3] Data on the parallel rate come from surveys carried out by the Banco de la República. The official rate is taken from various issues of the Revista del Banco de la República. The data set is available from the authors upon request.

[4] A detailed Appendix on these tests is available from the authors upon request.

[5] All estimations are obtained using PcGive and PcFiml 9.0 (Hendry and Doornik, 1997). The lag length is selected by starting with twelve lags on each variable, and sequentially testing down using an F-test. The same number of lags is obtained by the Akaike Information Criterion (AIC).

The inclusion of twelve lags in the model seems adequate as both equations pass the Lagrange Multiplier LM[12] test for residual serial correlation: $ep_{\text{LM(12)}} = 1.356$ (*p. value* 0.190), and $eo_{\text{LM(12)}} = 1.254$ (*p. value* 0.250). However, the VAR model fails all other diagnostic tests (i.e. normality, ARCH and heteroscedasticity), making it seriously misspecified. Further, recursive estimation as a way of evaluating the model's constancy by means of 1-step F-tests, break-point F-tests and forecast F-tests, reveals non constancy of the two exchange rate equations, in particular around the time when the monetary authorities abandoned the crawling peg regime (i.e. 1991(12)).

Based on the evidence of model misspecification and parameter instability over the whole sample period, we proceed by estimating two models, one for the crawling peg period (i.e. 1979:1-1991:11) and the other one for the crawling band period (i.e. 1991:12-1998:12). The VAR model (1) is then estimated using a lag length of $k = 12$ in the first regime, and $k = 3$ in the second one. Again, the intercept term (i.e. μ) enters unrestrictedly, and the order of the VAR models seems appropriate as the LM(12) test shows no evidence of residual serial correlation in the equations of either model.[6] The empirical evaluation of the constancy of both models is again performed with recursive OLS estimation, and the results (not reported here) suggest that fitting separate models for the two exchange rate regimes improves substantially the constancy of the estimated equations.

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[6] During the first regime, the equation for *eo* (but not the equation for *ep*) passes the ARCH(12), normality and heteroscedasticity tests. During the second regime, the equation for *eo* passes the ARCH(12) and heteroscedasticity tests, but fails normality. The equation for *ep*, on the other hand, passes normality but fails the ARCH(12) and heteroscedasticity tests. As indicated by Johansen (1995), although the cointegration analysis is based on Gaussian likelihood, the asymptotic properties only depend on the assumption that the errors are *i.i.d.*. Hence, the normality failure is not so important for the conclusions, but the ARCH effect may be. The results of the diagnostic tests are not reported here, but

Next we test for cointegration based on the maximal eigenvalue (λ-*max*) and the trace (λ-*trace*) tests. Cointegration results are shown in Table 1, which reports the l_i eigenvalues, the λ-*max* and the *trace* statistics, and the 95% critical values. The λ-*max* and the *trace* statistics show evidence of one cointegrating vector for both regimes.[7] Normalising on the parallel rate and imposing the restriction of a unit coefficient on the official rate leads to a one-by-one relationship between the two rates over the two regimes (see Table 2).[8]

The finding of cointegration does not support the view that the parallel market for foreign exchange in Colombia is informationally efficient, at least during the period under consideration, since cointegration implies that it would be possible to forecast the parallel rate. The concept of market efficiency is based on the notion that market participants are well informed and use all available information, so that no variable should provide useful information for forecasting the parallel exchange rate.[9] Further, cointegration between the parallel and official exchange rates implies that one has to reject the view that the official rate is irrelevant in the presence of a parallel market for foreign exchange (see also Kouretas and Zarangas, 1998).

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are available on request.

[7] Siklos and Granger (1997) have recently proposed the concept of regime-sensitive cointegration to identify those cases where the underlying series are cointegrated only during certain periods. Our finding of cointegration for both the crawling peg and crawling band regimes, however, does not support this view.

[8] Our finding of cointegration is consistent with previous results by Booth and Mustafa (1991) for Turkey, Baghestani and Noer (1993) for India, and Chica and Ramírez (1990) and Cárdenas (1997) for Colombia. All authors, except Cárdenas (1997), use the Engle and Granger two-step procedure and so the standard errors cannot be used to test the hypothesis of a one-by-one relationship between the two rates. Cárdenas (1997), on the other hand, uses the Johansen approach but does not formally test this hypothesis either.

[9] Booth and Mustafa (1991), however, argue that the existence of cointegration does not necessarily rule out market efficiency, since the presence of constraints on official transactions may render the exploitation of possible arbitrage opportunities impossible. A review of studies on the market efficiency hypothesis can be found in Maddala and Kim (1999, p.234).

From Table 2 we can see that the adjustment coefficient (α) associated with the official rate is rather small for both periods (i.e. 0.028 in the first period and 0.018 in the second one) and is tested for weak exogeneity. The weak exogeneity test (not reported here) indicates that the official rate is weakly exogenous during the crawling band period, but not during the crawling peg one. In what follows, however, we assume weak exogeneity of the official rate under both periods. In any case, the effect of the exchange rate market disequilibrium on the short-run equation for the official rate during the crawling peg regime has to be negligible as the corresponding adjustment coefficient is very small. Further, if we want to provide a full account of the behaviour of the official rate, we need to include in the model other factors like money, output and interest rates. This is far beyond the scope of the present paper.

Overall, cointegration with a unit coefficient between the two rates implies that the exchange rate set in the parallel market is strongly influenced by movements in the official rate. Further, based on the weak exogeneity tests, there is some evidence that short-run deviations from the one-by-one relationship between the two rates do not cause the monetary authorities to adjust the value of the official rate. From Table 2, it is also notable that the speed of convergence of the parallel rate towards the long-run equilibrium is much quicker during the crawling band regime (i.e. -0.232) compared to the crawling peg regime (i.e. -0.108). This is somewhat expected as the introduction of more flexibility in the official market of buying and selling currency during the second period has also forced the parallel market to adjust faster when discrepancies occur in the relationship between the two rates.

3. Modelling the short-run dynamics

Next, we model the short-run dynamics of the parallel rate during both regimes, also examining the possibility of non-linear adjustment. The fitted linear conditional error-correction (EC) models for Δep during the crawling peg and crawling band regimes are reported in Table 3. The lag length is set equal to $k = 11$ and $k = 2$ in the first and second regimes, respectively, since we included twelve and three lags, respectively, in the VAR models of the variables in levels. The initial models proved overparameterised, therefore, in Table 3, we report the parsimonious EC models.

As can be seen from the bottom panel of Table 3, the diagnostic tests indicate serious misspecification problems in the equation estimated for the crawling peg regime. Indeed, notice that this EC model only passes the LM(12) test for residual serial correlation, but fails the ARCH, normality and heteroscedasticity tests. As to the equation estimated for the crawling band period, it passes the tests for serial correlation, ARCH and normality, but fails the test for heteroscedasticity.

The failure of the diagnostic tests in the EC model estimated for the crawling peg period provides the motivation for considering the possibility that the short-run dynamics of the parallel exchange rate might be better characterised by a non-linear type of adjustment rather than the linear one discussed above. Non-linear adjustment is also attractive from an economic point of view, as it allows for the parallel exchange rate to adjust differently to positive or negative and to large or small deviations from its long-run equilibrium level.

Van Dijk and Franses (2000) consider a type of models where non stationary variables are linked by linear long-run equilibrium relationships, and adjustment towards equilibrium can be modelled by means of Smooth Transition Error-Correction (STEC) models. Following the notation in Van Dijk and Franses (2000), a STEC model can be introduced by considering the bivariate system:

$$y_t + bx_t = z_t , \qquad z_t = (r_1 + r_2 F(z_{t-d}))z_{t-1} + e_t ,$$

and

$$y_t + ax_t = w_t , \qquad w_t = w_{t-1} + h_t ,$$

where $F(z_{t-d})$ is a transition function, which is continuous and bounded between 0 and 1, $d \in (1,2,...)$ denotes the delay parameter, $a \neq b$, and

$$\begin{pmatrix} e_t \\ h_t \end{pmatrix} \sim i.i.d(0,\Sigma), \quad \Sigma = \begin{pmatrix} 1 & qs \\ qs & s^2 \end{pmatrix}.$$

In the system defined above, y_t and x_t cointegrate with vector $(1, b)'$, and z_t is assumed to follow a Smooth Transition Autoregressive (STAR) model (see e.g. Granger and Teräsvirta 1993, Teräsvirta 1994). The form of the transition function $F(z_{t-d})$ varies depending on the type of adjustment. In particular, asymmetric adjustment to positive and negative deviations relative to a threshold *c*, can be obtained by setting $F(z_{t-d})$ equal to the 'logistic' function:

$$F(z_{t-d}) = \{1 + \exp[-g(z_{t-d} - c)]\}^{-1}, \quad g > 0, \tag{2}$$

whereas asymmetric adjustment to small and large equilibrium errors can be obtained by setting $F(z_{t-d})$ equal to the 'exponential' function:

$$F(z_{t-d}) = 1 - \exp\{-g(z_{t-d} - c)^2\}, \quad g > 0 .$$

Van Dijk and Franses (2000) argue that one possible drawback of the exponential function is that the model becomes linear if $g \to 0$ or $g \to \infty$. To overcome this drawback, they suggest specifying $F(z_{t-d})$ as the 'quadratic logistic' function:

$$F(z_{t-d}) = \{1 + \exp[-g\,(z_{t-d} - c_1)(z_{t-d} - c_2)]\}^{-1}, \quad g > 0. \tag{3}$$

In this case, the adjustment is stronger for $z_{t-d} < c_1$, or $z_{t-d} > c_2$, and weaker when z_{t-d} is between the thresholds c_1 and c_2, i.e. $c_1 < z_{t-d} < c_2$. The specification of a STEC model follows three steps:

<u>Step 1</u>: Start by specifying a standard linear EC model. In our case, this is simply the parsimonious linear model reported in Table 3 for the two different regimes. This will be tested against a STEC model of the form:

$$\Delta y_t = p'_1 w_t + p'_2 w_t F(z_{t-d}) + h_t. \tag{4}$$

Equation (4) involves a linear part (i.e. $p'_1 w_t$) given by the parsimonious EC model, and a non-linear part given by the product of the regressors in w_t, times the transition function $F(z_{t-d})$.

<u>Step 2</u>: To test the linear EC model against model (4), $F(z_{t-d})$ is replaced by a third-order Taylor approximation, that is, we define the following non-linear model:

$$\Delta y_t = f' w_t + f'_1 \tilde{w}_t z_{t-d} + f'_2 \tilde{w}_t z^2_{t-d} + f'_3 \tilde{w}_t z^3_{t-d} + h_t, \tag{5}$$

where $\Delta y_t = \Delta ep_t$, f' refers to a vector of parameters associated with w_t (i.e. all regressors in the linear EC model of *Step 1*), f'_1 refers to a vector of parameters associated with $\tilde{w}_t z_{t-d}$ (i.e. the product of the regressors in the linear EC model of *Step 1* excluding the constant, times the EC term lagged d times), and so on. Model (5) consists of the linear part introduced in *Step 1*, that is, $f' w_t$, and a non-linear part of the form

$f'_1\,\tilde{w}_t z_{t-d} + f'_2\,\tilde{w}_t z_{t-d}^2 + f'_3\,\tilde{w}_t z_{t-d}^3$, as a proxy for $F(z_{t-d})$.

The non-linear model (5) has to be estimated for different values of *d*. For each of these non-linear models, the null hypothesis to test is $H_0: f'_1 = f'_2 = f'_3 = 0$. This is a test of linearity against non-linearity for different values of the delay parameter *d*. The test is an LM-type test. From all non-linear models (associated with the different values of *d*) in (5), the decision rule is to select the one associated with the strongest rejection of H_0, that is, the lowest *p. value*.

<u>Step 3</u>: Having selected the appropriate non-linear model (5) in *Step 2*, proceed by selecting the appropriate form of the transition function $F(z_{t-d})$, that is, select between the 'logistic' function (2) and the 'quadratic logistic' function (3). To do that, we need to run a sequence of LM tests nested within the non-linear model of *Step 2*, namely:

$$\begin{aligned} &H_{03}: f'_3 = 0, \\ &H_{02}: f'_2 = 0 \mid f'_3 = 0 \\ &H_{01}: f'_1 = 0 \mid f'_3 = f'_2 = 0. \end{aligned} \qquad (6)$$

In this case, the decision rule is to select the 'quadratic logistic' function (3) if the *p. value* associated with the H_{02} hypothesis is the smallest one, otherwise select the 'logistic' function (2). Having done that, we are now ready to form the STEC model that will be used for inference on the behaviour of the parallel rate. This is simply the non-linear model (4), with the transition function specified using the sequence of tests in (6).

The empirical results of the LM-type test for smooth transition error-correction (*Steps 2* and *3*) are reported in Table 4. We set *d* equal to 1 through 6 (although the results are the same even if we go up to $d = 12$). Focusing on the crawling peg period first (see the first panel of Table 4), the linearity test (i.e. H_0) is rejected most strongly at $d = 1$. Given $d = 1$, the strongest rejection of the sequence of tests in (6) refers to H_{02} (i.e. *p. value* = 0.00001). Therefore, we select the 'quadratic logistic' model (3) as the appropriate transition function. Using the transition function in (3), Table 3 reports the NLS estimates of the parameters in the non-linear model (4) for the parallel rate during the crawling peg period. The results for the non-linear model appear next to the linear version of the model (after dropping some insignificant terms to obtain a more parsimonious structure).

The estimates of the thresholds c_1 and c_2 are equal to –0.081 and 0.104, respectively. The estimate of γ is such that the transition from $F(z_{t-1}) = 0$ to $F(z_{t-1}) = 1$ is quite rapid once the disequilibrium error (lagged once) is above and below the thresholds (see Figure 1).[10] The error variance of the non-linear model is considerably less than that of the linear model (i.e. $s^2_{NL} / s^2_{L} = 0.56$), so that the non-linear model has a much better fit. In addition, the non-linear specification seems to capture the ARCH effects that were present in the linear specification of the model, and White's test no longer suggests the presence of heteroscedasticity. There is a considerable improvement in the test for normality (although the test still fails). The LM test for residual serial correlation is passed at the three per cent level of statistical significance.

Figure 2 shows the evolution of the estimated smooth transition function over

[10] Following Teräsvirta (1994) and Van Dijk and Franses (2000), we have standardised the exponent of $F(z_{t-d})$ by dividing it by the variance of Rcv_{t-1}, so that g is a scale free-parameter. Notice in Table 3 the rather large standard error associated with the estimate on g (i.e. *t*-ratio = 1.256). As Teräsvirta (1994) points out, accurate estimation of γ is not always feasible as it requires many observations close to c_1 and c_2.

time. As can be seen from Figure 2, the non-linearity mainly helps explain the behaviour of the parallel exchange rate during the 1983-1985 period as well as in late 1991. The first period is associated with the foreign exchange crisis that affected the Colombian economy. In the early 1980s, export revenues declined considerably due to a sharp reduction in the price of coffee (i.e. the country's main commodity export), and the government ran increasing budget deficits which substantially reduced foreign reserves. The international debt crisis of the eighties restricted the access of the country to foreign borrowing, despite the fact that Colombia was the only Latin American country to avoid any formal rescheduling of its external debt. As a result, the official exchange rate became overvalued and the premium of the parallel rate over the official one increased considerably. In late 1991 and just before the monetary authorities decided to abandon the crawling peg regime, the non-linear function picks up two observations in the lower regime (although from Figure 2 it appears that the non-linear part is active only for two observations, some other observations are quite close to the threshold that defines the lower regime). At that time, and unlike the episode of the mid eighties, the premium of the parallel over the official rate was negative.[11]

In the second panel of Table 3, we report the empirical results for smooth transition error-correction (*Step 2* and *Step 3*) for the crawling band period. There is some weak evidence (at the five but not the one per cent level of statistical significance)

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[11] One could also interpret the period of exchange rate crisis as aberrant and treat these observations as outliers. Hence, one might as well settle for a linear model with a dummy variable for the exchange rate crisis period. In fact, we have estimated the linear model of Table 3, also allowing for a shift dummy taking the value of one from 1983:3 to 1985:3 (these years are considered difficult for the Colombian economy because of the exchange rate crisis period). The dummy variable in that model (not reported here) was significant but that linear model still failed normality and heteroscedasticity significantly compared to the non-linear one.

against linearity only for $d = 1$. Given $d = 1$, the sequence of tests in (6) for the selection of the transition function points to the 'logistic' function (2) as the appropriate one. Notice, however, that the resulting *p. values* are not as small as those obtained for the model of the first period. In fact, when estimating the non-linear version of the model for the crawling band regime, the terms appearing in the non-linear part of the equation turn out to be insignificant, suggesting that the linear specification is sufficient enough to capture the short-run behaviour of the parallel rate. For this reason, the non-linear model is not reported here.

4. Conclusions

In this paper we look at the long-run relationship between the parallel and the official exchange rate in Colombia over two regimes; a crawling peg period and a more flexible crawling band one. The existence of cointegration between the parallel and official exchange rates in Colombia is consistent with previous findings for other developing economies, and offers support for the view that the parallel market for foreign exchange is not informationally efficient, because past values of the two rates (and of the disequilibrium error) could be used for forecasting the parallel exchange rate. The fact that the parallel rate cointegrates with the official one also implies that the latter has a role to play in the evolution of the former. This should be kept in mind when the monetary authorities affect with their decisions the behaviour of the official exchange rate.

Further, we look at the short-run adjustment process of the parallel rate both in a linear and a non-linear context. According to the empirical results, there is strong evidence in favour of non-linear adjustment over the crawling peg but not over the crawling band period.

This should not come as a surprise. The first period has witnessed the operation of strict foreign controls that have caused distortions in the transition back to equilibrium, once disequilibrium has occurred. The non-linear adjustment reported in the paper, provides an empirical evidence of the complicated structure under which the exchange rate market operated. With the abolition of exchange rate controls and the introduction of more flexibility in the exchange rate market over the second period, these distortions have gradually been eliminated. As a result, the transition back to equilibrium does not longer seem to exhibit any complicated non-linear structure. Thus, the modelling exercise has showed that the change from the crawling peg exchange rate regime to a crawling band one did not affect the long-run equilibrium relationship between the official and parallel exchange rates in Colombia, but changed radically the short-run dynamics.

Table 1. Eigenvalues, test statistics, and critical values

Sample period 1979:1 – 1991:11								
	λ-*max*				λ-*trace*			
λ_i	H_0	H_1	Statistic	95%	H_0	H_1	Statistic	95%
0.151	$r = 0$	$r = 1$	23.42	14.07	$r = 0$	$r \geq 1$	24.44	15.41
0.007	$r \leq 1$	$r = 2$	1.02	3.76	$r \leq 1$	$r \geq 2$	1.02	3.76
Sample period 1991:12 – 1998:12								
	λ-*max*				λ-*trace*			
λ_i	H_0	H_1	Statistic	95%	H_0	H_1	Statistic	95%
0.172	$r = 0$	$r = 1$	15.48	14.07	$r = 0$	$r \geq 1$	15.66	15.41
0.002	$r \leq 1$	$r = 2$	0.18	3.76	$r \leq 1$	$r \geq 2$	0.18	3.76

Notes: r denotes the number of cointegration vectors. The critical values of the λ-*max* and λ-*trace* statistics are taken from Osterwald-Lenum (1992).

Table 2. Estimated cointegrating vectors β and weights α in parentheses

	Sample period 1979:1 – 1991: 11		*Sample period 1991:12 – 1998:12*	
Variable	β_1	β_1 restricted	β_1	β_1 restricted
ep	1 (-0.120)	1 (-0.108)	1 (-0.240)	1 (-0.232)
eo	-0.992 (0.028)	-1 (0.028)	-1.005 (0.015)	-1 (0.018)
Cointegration Restriction	$\chi^2_{(1)} =$ 0.823 *p. value* = 0.364		$\chi^2_{(1)} =$ 0.088 *p. value* = 0.766	

Table 3. Linear and non-linear error-correction models

Variable	Crawling Peg				Crawling Band	
	Linear ECM		*Non-linear ECM* *		*Linear ECM*	
	Coeff.	SE	Coeff.	SE	Coeff.	HCSE
Constant	-0.018	0.007	-0.003	0.005	-0.007	0.002
Δep_{t-1}	0.369	0.074	0.306	0.057	0.527	0.082
Δep_{t-7}	0.160	0.071				
Δep_{t-11}	0.439	0.072	0.217	0.075		
Δeo_{t}					0.408	0.049
Δeo_{t-1}	1.904	0.440	1.675	0.353	-0.116	0.108
Δeo_{t-4}	-2.037	0.758	-1.648	0.584		
Δeo_{t-5}	3.326	1.030	1.501	0.814		
Δeo_{t-6}	-2.194	0.725	-0.749	0.562		
Rcv_{t-1}	-0.161	0.036			-0.237	0.051
Constant			-0.098	0.043		
Δep_{t-1}						
Δep_{t-7}			2.686	0.425		
Δep_{t-11}			0.715	0.128		
Δeo_{t}						
Δeo_{t-1}			-1.622	3.475		
Δeo_{t-4}			18.652	13.466		
Δeo_{t-5}			19.517	8.195		
Δeo_{t-6}			-35.646	14.366		
Rcv_{t-1}			-0.246	0.0870		
γ			7.977	6.351		
c_1			-0.081	0.008		
c_2			0.104	0.004		
Obs.	142		142		83	
σ	0.02263		0.01698		0.00856	
F *ar*	1.55	[0.12]	1.96	[0.03]	0.57	[0.86]
F *arch*	2.66	[0.00]	1.53	[0.12]	1.30	[0.25]
χ^2 *nd*	138.47	[0.00]	53.42	[0.00]	7.31	[0.03]
F *het*	3.34	[0.00]	1.13	[0.32]	9.92	[0.00]

* *Non-linear ECM* refers to the STEC model (4) in the main text, using model (3) as the transition function.

F *ar* is the Lagrange Multiplier F-test for residual serial correlation of up to twelfth order. F *arch* is the twelfth order Autoregressive Conditional Heteroscedasticity F-test. χ^2 *nd* is a Chi-square test for normality. F *het* is an F test for heteroscedasticity. σ is the standard error of the regression. SE is the standard error, and HCSE is the heteroscedastic consistent standard error. Numbers in square brackets are the probability values of the test statistics.

Table 4. LM-type test for smooth transition error-correction
(probability values)

Crawling peg regime

Null	*d*					
	1	2	3	4	5	6
H_0	4.38E-10	1.16E-07	1.13E-08	3.48E-07	1.85E-08	2.26E-02
H_{03}	0.00192	0.00099	0.00002	0.01226	0.00001	0.17286
H_{02}	0.00001	0.00007	0.00001	0.00001	0.00067	0.02244
H_{01}	0.00011	0.01421	0.28589	0.02336	0.02413	0.24041

Crawling band regime

Null	*d*					
	1	2	3	4	5	6
H_0	0.01381	0.07640	0.53313	0.65664	0.60740	0.29440
H_{03}	0.00708	0.01226	0.42831	0.86311	0.92294	0.15129
H_{02}	0.09868	0.83897	0.95626	0.14667	0.13520	0.23998
H_{01}	0.60881	0.30639	0.15831	0.83327	0.68681	0.81595

Figure 1. Transition Function vs. Disequilibrium Error (lagged once)

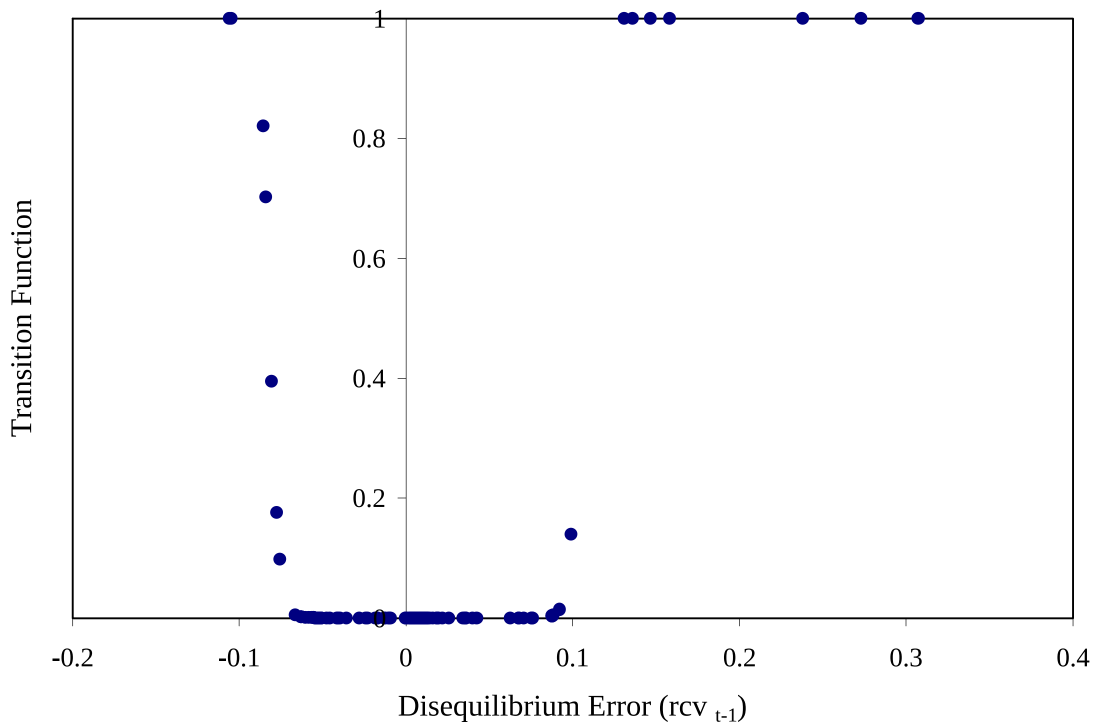
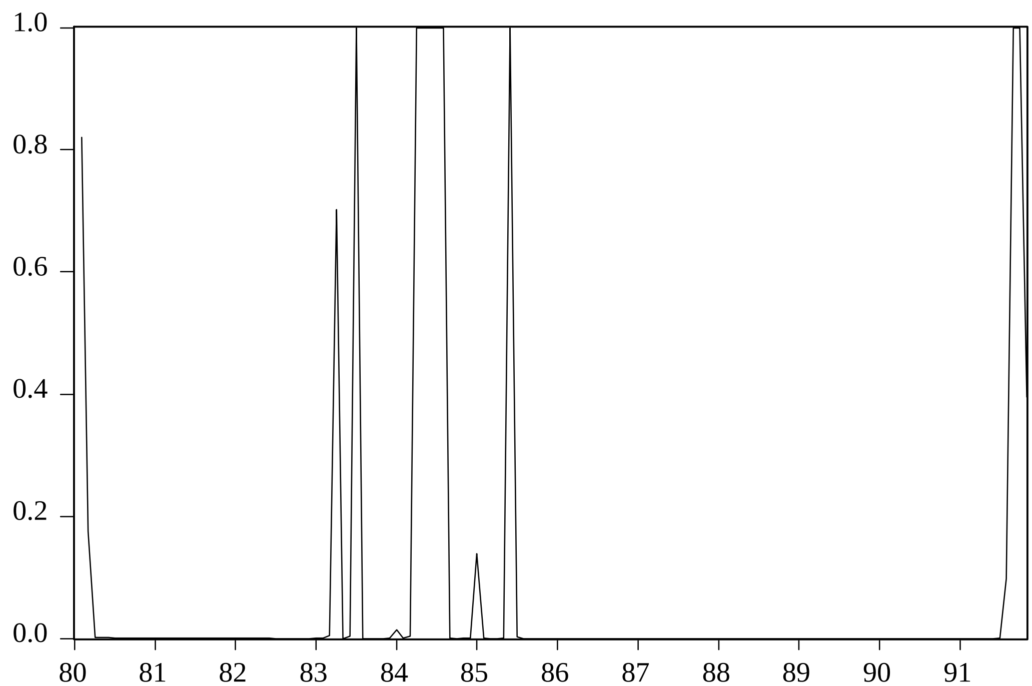


Figure 2. Transition Function (vertical axis) vs. Time (horizontal axis)



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