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Modelling official and parallel exchange rates in Colombia under alternative regimes: a non-linear approach

Costas Milas^{a,*}, Jesús Otero^{b,1}

^a*Department of Economics and Finance, Brunel University, Uxbridge, UK*

^b*Facultad de Economía, Universidad del Rosario, Bogotá, Colombia*

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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. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

During the last three decades Colombia has witnessed the operation of two different exchange rate regimes. Between the late 1960s and November 1991, the country adopted a crawling peg regime, during which the Central Bank (Banco de la República) varied the exchange rate once or twice per week with the aim of

* Corresponding author. Tel.: +44-1895-816268; fax: +44-1895-203384.

E-mail address: costas.milas@brunel.ac.uk (C. Milas).

¹ E-mail address: jotero@claudio.urosario.edu.co.

neutralising domestic and foreign inflation differences. Nevertheless, 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. From December 1991 onwards, the monetary authorities favoured a 'crawling band' regime (see Williamson, 1996) which allows for a wide band for fluctuation of the exchange rate.

A parallel market for foreign exchange exists in Colombia. This is mainly for US dollars, as most foreign exchange transactions take place in this currency. We use the term 'parallel market' rather than 'black market' to reflect a type of '... intermediate position of legality in that it is illegal but also conspicuously public and, it would appear, officially tolerated' (see Dornbusch et al., 1983, p. 26). During the crawling peg period, the parallel market was the result of strict foreign exchange controls that concentrated all foreign exchange transactions at the central bank. By 1992, following a series of major liberalising reforms including the abolition of exchange controls, foreign currency operations were decentralised. Despite the reforms, the parallel market is still in operation due to the presence of agents involved in illegal activities, and for this reason it is not able to trade in the official market.

In portfolio balance theories (see e.g. Dornbusch et al., 1983), asset market conditions drive the parallel market rate, and the current account affects the parallel rate through its impact on the stock of parallel dollars. This implies the existence of a proportional equilibrium relationship between the parallel and official rates (i.e. a parallel market premium). Assuming a fixed stock of parallel foreign currency in the short run, the short-run premium follows a saddle path behaviour. This implies that the contemporaneous impact of the short-run official rate on the parallel rate is less than proportional, that is, the premium drops following a surprise devaluation (see e.g. Moore and Phylaktis, 2000; for a survey of theoretical models connecting parallel and official exchange rates see e.g. Phylaktis, 1997). Our paper examines the empirical relationship between the Colombian parallel and official exchange rates. It differs from earlier papers (see e.g. Booth and Mustafa, 1991, for Turkey; Phylaktis and Kassimatis, 1994, for the Pacific basin countries; Cárdenas, 1997, for Colombia; and Ashworth et al., 1999, for Nigeria) in two ways. First, the Colombian experience allows us to examine whether the relationship between the parallel and official exchange rates has varied depending upon regime. Second and more important, following Teräsvirta (1994) and more recently Van Dijk and Franses (2000), we discuss tests for linear vs. non-linear adjustment of the error correction model by looking at different non-linear functional forms of the disequilibrium error.

We characterise the behaviour of the exchange rates using Smooth Transition Error Correction (STEC) models. These are regime-switching models, where the transition from one regime to the other occurs in a smooth way. Furthermore, the transmission mechanism between regimes is a function of the explanatory variables. Modelling exchange rates in Colombia within the STEC context can be motivated by the fact that the last decade has witnessed a transition period from direct official intervention in the foreign-exchange market to a more flexible environment. Assuming that the transition mechanism is controlled by the parallel

market premium, we can differentiate between the impact of the parallel market premium on the exchange rates during periods when the premium is positive, as access to the official foreign exchange market is limited, and its impact on exchange rates during periods when the premium is negative, as commercial banks are not allowed to buy foreign currency without proper identification of its origin. Therefore, there is a laundering charge individuals are willing to incur when offering for sale foreign currency they have no right to possess.

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 both for linear and non-linear adjustment, and Section 4 provides conclusions and some policy implications.

2. The empirical model: long-run behaviour

We use a set of $p = 2$ endogenous variables, $y = [ep, eo]'$, where ep and eo refer to the logarithm of the exchange rate in the parallel and official markets for US dollars, respectively. The data are monthly observations from 1979:1 to 1998:12. The data set is taken from the Banco de la República (1998) and is available from the authors upon request.²

We write a p -dimensional Vector Error Correction (VEC) model as:

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

where y_t is the set of $I(1)$ variables discussed above; $\varepsilon_t \sim \text{iid}(0, \Sigma)$; μ is a drift parameter, and Π is a $(p \times p)$ matrix of the form $\Pi = \alpha\beta'$, where α and β are both $(p \times r)$ matrices of full rank, with β containing the r cointegrating vectors and α carrying the corresponding loadings in each of the r vectors (see also Johansen, 1988, 1995).

Fig. 1 plots ep , eo and their difference, that is the parallel market premium (in percentage terms). The graph indicates a substantial difference between the two rates in 1983–1985 and a persistent discount starting in 1991. This is further discussed after estimating the non-linear models in Section 3.3 below.

Preliminary analysis of the data using the Augmented Dickey–Fuller (ADF) tests suggested that the levels of both series are $I(1)$ with a drift during the two sub-periods and the full sample.

The equations for ep and eo in the unrestricted VAR model Eq. (1) are initially estimated over the whole sample period 1979:1–1998:12, using a lag length of $k = 12$ (estimations are done in PcGive and PcFiml 9.0; see Hendry and Doornik, 1997). The lag length is obtained by the Akaike Information Criterion (AIC). The

² Data on the parallel exchange rate are based on a daily survey of a sample of the Bureaux of Change in the city of Bogota. Both exchange rates are monthly averages.

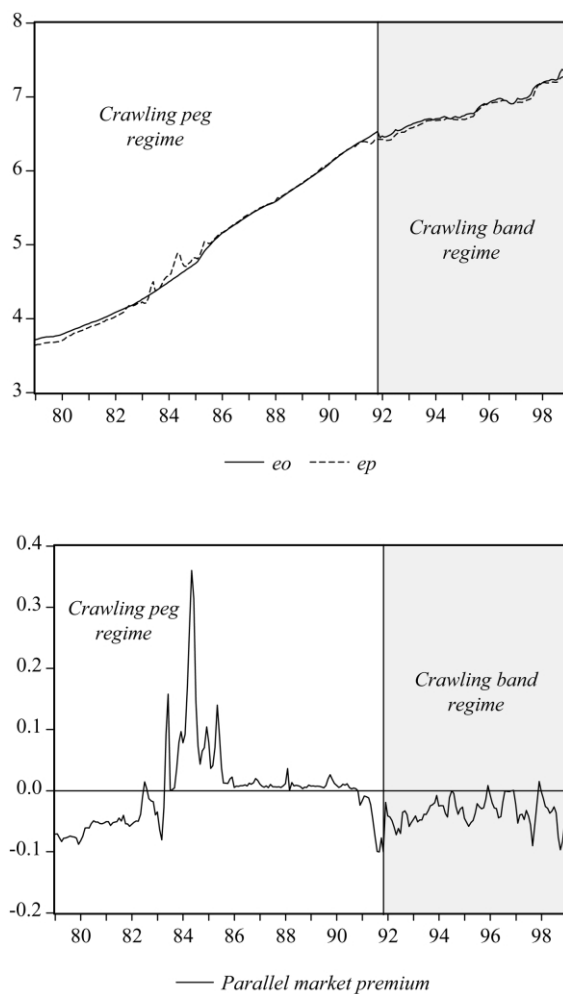


Fig. 1. Logarithm of the peso/dollar official (*eo*) and parallel (*ep*) exchange rates and parallel market premium (in %) terms.

intercept term (i.e. μ) enters the model unrestrictedly, since the series have a drift term. The VAR model fails normality, ARCH and heteroscedasticity, making it seriously misspecified (see Table 1). Recursive estimation by means of one-step residuals ± 2 standard errors and forecast Chow tests (figures are available upon request), reveals non-constancy of the estimated models, in particular at approximately 1991:12 when the monetary authorities abandoned the crawling peg regime. Given the evidence of model misspecification over the whole sample period, we estimate two VAR 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). Columns

Table 1
VAR diagnostics

Statistic	Full sample 1979:1–1998:12 ($k = 12$ lags)		Crawling peg regime 1979:1–1991:11 ($k = 12$ lags)		Crawling band regime 1991:12–1998:12 ($k = 3$ lags)	
	<i>ep</i>	<i>eo</i>	<i>ep</i>	<i>eo</i>	<i>ep</i>	<i>eo</i>
F ar	1.36 [0.190]	1.25 [0.249]	1.31 [0.224]	1.62 [0.098]	0.85 [0.603]	1.31 [0.235]
F arch	4.77 [0.000]	0.52 [0.898]	2.43 [0.009]	1.45 [0.157]	3.90 [0.000]	2.52 [0.011]
χ^2 nd	282.37 [0.000]	500.90 [0.000]	123.7 [0.000]	0.74 [0.691]	7.06 [0.029]	18.97 [0.000]
F het	2.48 [0.000]	1.74 [0.006]	1.94 [0.006]	1.49 [0.063]	3.44 [0.001]	0.93 [0.528]

F ar is the LaGrange Multiplier F -test for residual serial correlation of up to 12th order. F arch is the 12th order Autoregressive Conditional Heteroscedasticity F -test. χ^2 nd is a Chi-square test for normality. F het is an F test for heteroscedasticity. Numbers in square brackets are the probability values of the test statistics.

four to seven of Table 1 report the diagnostics of the VAR model Eq. (1) for the two regimes, using $k = 12$ lags in the first regime and $k = 3$ lags in the second one. Notice the significant improvement in all diagnostic tests by comparing the results of the VAR models estimated for each sub-period with those of the model estimated for the whole sample period. Recursive OLS estimation (not reported here) suggests that fitting separate models for the two exchange regimes improves substantially the constancy of the equations. The normality failures of our models are not so serious for the cointegration tests reported below (see e.g. Cheung and Lai, 1993, who find that the tests perform reasonably well in the presence of excess kurtosis, and Johansen, 1995, p. 29, who points out that although the cointegration analysis is based on Gaussian likelihood, the asymptotic properties only depend on the assumption that the errors are *i.i.d.*). In addition, the ARCH effects reported in our models are also not very serious for the cointegration analysis (see e.g. Lee and Tse, 1996).

Cointegration tests (see Johansen, 1988) are shown in Table 2, which reports the λ_i eigenvalues, the λ -max and the trace statistics. Both statistics are adjusted for degrees of freedom to take into account the small sample bias and lag structure (see Reimers, 1992). Both statistics show evidence of one cointegrating vector for both regimes.^{3,4} We normalise on the parallel rate and test the unit coefficient on

³ The results should be interpreted with some caution as the evidence of cointegration is weaker during the second period, which is much shorter (i.e. it covers only 7 years) than the first one.

⁴ 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.

Table 2
Eigenvalues, test statistics and critical values

λ_i	H_0	H_1	λ -Max statistic	H_0	H_1	λ -Trace statistic
Sample period 1979:1–1991:11						
0.151	$r = 0$	$r = 1$	19.49 ^c	$r = 0$	$r \geq 1$	20.34 ^c
0.007	$r < 1$	$r = 2$	0.85	$r < 1$	$r > 2$	0.85
Sample period 1991:12–1998:12						
0.172	$r = 0$	$r = 1$	14.35 ^b	$r = 0$	$r \geq 1$	14.51 ^a
0.002	$r \leq 1$	$r = 2$	0.16	$r \leq 1$	$r > 2$	0.16

The number of cointegration vectors is denoted by r . The λ -max and λ -trace statistics have been adjusted by degrees of freedom following Reimers (1992), and their corresponding critical values are taken from Osterwald-Lenum (1992).

^aStatistical significance at the 10% level.

^bStatistical significance at the 5% level.

^cStatistical significance at the 1% level.

the official rate, so that the residuals from the cointegrating vector can be interpreted as the logarithm of the parallel market premium. The restriction is accepted for both regimes (the p values are equal to 0.364 and 0.766, respectively; see Table 3).⁵ The finding of cointegration does not support the view that the parallel market for foreign exchange in Colombia is informationally efficient, since cointegration implies that it is possible to forecast the parallel rate. 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.⁶ Cointegration between the two rates also 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).

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; see Table 3) 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. Nevertheless, we proceed by assuming 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

⁵ Crdenas (1997) also finds cointegration between the two rates for Colombia using the Johansen approach. However, he does not estimate the short-run model, nor does he look at the possibility of non-linear short-run adjustment depending upon regime, which is what we do below.

⁶ 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.

Table 3
Estimated cointegrating vectors β and weights α in parentheses

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

adjustment coefficient is very small.⁷ Hence, the weak exogeneity tests show some evidence that short-run deviations from the one-by-one relationship between the two exchange rates do not cause the monetary authorities to adjust the value of the official rate.

3. Modelling the short-run dynamics

3.1. Linear error correction models for the parallel rate

Table 4 reports the parsimonious linear error correction (EC) models for Δep during the crawling peg and crawling band regimes, respectively. The point estimates of Rcv_{t-1} (i.e. $Rcv_{t-1} = ep_{t-1} - eo_{t-1}$) suggest a faster speed of convergence to equilibrium during the crawling band regime (i.e. –0.237) compared to the crawling peg regime (i.e. –0.161). 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. The contemporaneous effect from the official rate is statistically less than one (i.e. 0.408, with a standard error of 0.049) in the crawling band regime, pointing to a saddle path behaviour of the parallel premium as predicted by portfolio theories; see e.g. Moore and Phylaktis (2000). The equation estimated for the crawling peg regime passes the LM(12) test for residual serial correlation, but fails the ARCH, normality and heteroscedasticity tests. The estimated equation for the crawling band period fails normality and heteroscedasticity. Failure of the diagnostic tests provides the motivation for considering the possibility of a non-linear rather than a linear type of adjustment. Non-linear adjustment is also attractive from an economic point of view, as it allows for the parallel exchange rate to adjust differently to

⁷ However, some caution is needed here. If there is not exogeneity, the estimation method could be inefficient if not invalid. We thank an anonymous referee for raising this point.

Table 4

Linear error correction models for the parallel exchange rate Δep (OLS estimates)

Variable	Crawling peg regime		Crawling band regime	
	Coeff.	HCSE	Coeff.	HCSE
Constant	−0.018	0.007	−0.007	0.002
Δep_{t-1}	0.369	0.074	0.527	0.082
Δep_{t-7}	0.160	0.071		
Δep_{t-11}	0.439	0.072		
Δeo_t			0.408	0.049
Δeo_{t-1}	1.904	0.440	−0.116	0.108
Δeo_{t-4}	−2.037	0.758		
Δeo_{t-5}	3.326	1.030		
Δeo_{t-6}	−2.194	0.725		
Rcv_{t-1}	−0.161	0.036	−0.237	0.051
Obs.	142		83	
σ	0.02263		0.00856	
F ar	1.55	[0.12]	0.57	[0.86]
F arch	2.66	[0.00]	1.30	[0.25]
χ^2 nd	138.47	[0.00]	7.31	[0.03]
F het	3.34	[0.00]	9.92	[0.00]

We use heteroscedastic consistent standard errors (HCSE) by White (1980) as both equations fail homoscedasticity. Numbers in square brackets are the probability values of the test statistics. σ is the standard error of the regression. Rcv is the restricted cointegrating vector, i.e. $Rcv_{t-1} = ep_{t-1} - eo_{t-1}$. The diagnostic tests are discussed in the notes of Table 1.

positive or negative and to large or small deviations from its long-run equilibrium level.

3.2. A brief theory of non-linear smooth transition error correction models

Van Dijk and Franses (2000) consider non-linear models where non-stationary variables cointegrate and adjustment towards equilibrium is based on a Smooth Transition Error Correction (STEC) mechanism as follows:

$$y_t + \beta x_t = z_t, \quad z_t = (\rho_1 + \rho_2 F(z_{t-d}))z_{t-1} + \varepsilon_t$$

where y_t and x_t cointegrate with vector $(1, \beta)'$; $F(z_{t-d})$ is a continuous and bounded between 0 and 1 transition function; $d \in (1, 2, \dots)$ is the delay parameter; $\varepsilon_t \sim \text{iid}(0, \sigma_\varepsilon^2)$; and z_t follows a Smooth Transition Autoregressive (STAR) model (see e.g. Granger and Teräsvirta, 1993; Teräsvirta, 1994). There are three popular choices for the transition function $F(z_{t-d})$. The first one is the ‘logistic’ function:

$$F(z_{t-d}) = \{1 + \exp[-\gamma(z_{t-d} - c_1)]\}^{-1}, \quad \gamma > 0 \quad (2)$$

which assumes asymmetric adjustment to positive and negative deviations relative to a threshold c_1 . The second one is the ‘exponential’ function:

$$F(z_{t-d}) = 1 - \exp\{-\gamma(z_{t-d} - c_1)^2\}, \quad \gamma > 0$$

which assumes asymmetric adjustment to small and large equilibrium errors. The third choice derives from the fact that the ‘exponential’ model above becomes linear if either $\gamma \rightarrow 0$ or $\gamma \rightarrow \infty$. To avoid this, Jansen and Teräsvirta (1996) suggest the following ‘quadratic logistic’ function:

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

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

Step 1: Specify a linear EC model. This is the parsimonious linear model reported in Table 4 for the two different regimes. The model will be tested against a STEC model of the form:

$$\Delta y_t = \pi'_1 w_t + \pi'_2 w_t F(z_{t-d}) + \eta_t \quad (4)$$

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

$$\Delta y_t = \phi' w_t + \phi'_1 \tilde{w}_t z_{t-d} + \phi'_2 \tilde{w}_t z_{t-d}^2 + \phi'_3 \tilde{w}_t z_{t-d}^3 + \eta_t \quad (5)$$

where $\eta_t \sim iid(0, \sigma_\eta^2)$; w_t are the regressors in the linear EC model of Step 1; and $\tilde{w}_t$ are the w_t regressors excluding the constant. Eq. (5) has to be estimated for different d values and then test the null hypothesis $H_0: \phi'_1 = \phi'_2 = \phi'_3 = 0$. This is an LM-type test of linearity against non-linearity for different values of d . From all non-linear models (associated with the different d values) in Eq. (5), select the one associated with the strongest rejection of H_0 .

Step 3: Select the appropriate form of the transition function $F(z_{t-d})$, that is, select between the ‘logistic’ function Eq. (2) and the ‘quadratic logistic’ function Eq. (3). This is done by running a sequence of LM tests nested within the non-linear Eq. (5) of Step 2, namely:

$$\begin{aligned} H_{03}: \phi'_3 &= 0, \\ H_{02}: \phi'_2 &= 0 | \phi'_3 = 0 \\ H_{01}: \phi'_1 &= 0 | \phi'_3 = \phi'_2 = 0 \end{aligned} \quad (6)$$

The decision rule is to select the ‘quadratic logistic’ function Eq. (3) if the p value associated with the H_{02} hypothesis is the smallest one, otherwise select the ‘logistic’ function Eq. (2). Having done that, proceed by estimating the STEC

model Eq. (4), with the transition function specified based on the sequence of tests in Eq. (6). Van Dijk and Franses (2000) and Van Dijk et al. (2000) suggest estimating the STEC model using both transition functions and then choose the appropriate model using other criteria such as how well determined the parameters are.

3.3. Empirical smooth transition error correction models for the parallel rate

To clarify the connection between the non-linear models Eq. (4) and Eq. (5) above with the empirical models of the Colombian parallel rate for the two regimes, let $\Delta y_t = \Delta p_t$, $z_{t-d} = Rcv_{t-d}$ and w_t be the RHS regressors in the linear EC models of Table 4. The empirical results of the LM-type tests (Steps 2 and 3 in Section 3.2 above) are reported in Table 5. We set d equal to 1–6 (results are not affected even if we go up to $d = 12$). Focusing on the crawling peg period first (see the first panel of Table 5), 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 Eq. (6) refers to H_{02} (i.e. P value = 0.00001). Therefore, we select Eq. (3) as the appropriate transition function. However, following Van Dijk and Franses (2000) and Van Dijk et al. (2000), Table 6 reports the NLS estimates of the parsimonious non-linear model Eq. (4) for the parallel rate during the crawling peg period using both the transition function Eq. (2)) (see left panel of Table 6) and the transition function Eq. (3) (see the right panel of Table 6). The non-linear model using the function Eq. (2) has less well determined parameters, a higher residual standard deviation and worse diagnostic tests (the only exception being the LM test for residual serial correlation) compared to the non-linear model using the function Eq. (3). For this reason, we proceed by discussing only the model that adopts the transition function Eq. (3).

The estimate of γ is rather high indicating that the transition from $F(z_{t-1}) = 0$ to $F(z_{t-1}) = 1$ is rapid when the disequilibrium error $z_{t-1} = Rcv_{t-1}$ is above and

Table 5
LM-type test for smooth transition error correction (probability values)

Null	d					
	1	2	3	4	5	6
Crawling peg regime						
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						
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

Table 6

Non-linear ECM for the first difference of the parallel exchange rate during the crawling peg regime (NLS estimates)

Variable	With the transition function Eq. (2) in main text		With the transition function Eq. (3) in main text	
	Coeff.	S.E.	Coeff.	S.E.
Constant	−0.002	0.016	−0.003	0.005
Δep_{t-1}	0.359	0.073	0.306	0.057
Δep_{t-7}				
Δep_{t-11}	1.487	0.482	0.217	0.075
Δeo_{t-1}	0.794	1.344	1.675	0.353
Δeo_{t-4}	−2.318	2.086	−1.648	0.584
Δeo_{t-5}	3.740	2.158	1.501	0.814
Δeo_{t-6}	−2.669	1.704	−0.749	0.562
Rcv_{t-1}				
Constant	−0.007	0.018	−0.098	0.043
Δep_{t-1}				
Δep_{t-7}	0.180	0.07	2.686	0.425
Δep_{t-11}	−1.073	0.487	0.715	0.128
Δeo_{t-1}	1.175	1.421	−1.622	3.475
Δeo_{t-4}	0.052	2.279	18.652	13.466
Δeo_{t-5}	−0.161	2.488	19.517	8.195
Δeo_{t-6}	0.099	1.885	−35.646	14.366
Rcv_{t-1}	−0.192	0.044	−0.246	0.0870
γ	13.067	60.412	7.977	6.351
c_1	−0.017	0.005	−0.081	0.008
c_2			0.104	0.004
Obs.	142		142	
σ	0.02253		0.01698	
F ar	1.05	[0.41]	1.96	[0.03]
F arch	2.01	[0.03]	1.53	[0.12]
χ^2 nd	113.35	[0.00]	53.42	[0.00]
F het	2.32	[0.00]	1.13	[0.32]

Non-linear ECM refers to the STEC model Eq. (4) in the main text. S.E. refers to the standard errors. The diagnostic tests are discussed in the notes of Table 1.

below the thresholds (see Fig. 2).⁸ Notice in Table 6 the rather large standard error associated with the estimate on γ (i.e. t -ratio = 1.256). Teräsvirta (1994) and Van Dijk et al. (2000) point out that this should not be interpreted as evidence of weak non-linearity. To estimate γ accurately, many observations in the immediate

⁸ Following Tersvirta (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 γ is a scale free-parameter.

neighbourhood of c_1 and c_2 are needed. The estimates of the thresholds c_1 and c_2 are equal to -0.081 and 0.104 , respectively. Interpreting $Rcv_{t-1} = ep_{t-1} - eo_{t-1}$ as a term premium, one could say that Δep falls sharply when $Rcv_{t-1} > c_2$, that is, when there is a positive premium in excess of 0.104 . On the other hand, Δep increases rapidly when $Rcv_{t-1} < c_1$, that is when a negative premium below -0.081 is observed. Dornbusch et al. (1983) relate a negative parallel market premium to a laundering charge individuals are willing to incur when offering for sale foreign currency they have no right to possess.

The error variance of the non-linear model is much lower than that of the linear model (i.e. $\sigma_{NL}^2/\sigma_L^2 = 0.56$), so that the non-linear model has a much better fit. The non-linear model captures the ARCH and heteroscedasticity effects that were present in the linear model. There is a considerable improvement in the test for normality (although the test still fails) and significant evidence for serial correlation at the 5% (but not at the 1%) level.

Fig. 3 shows the evolution of the estimated smooth transition function over time. 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 fell rapidly 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 1980s restricted the country's access 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 real exchange rate became overvalued and the premium of the parallel rate over the official one increased sharply.⁹ In late 1991, and just before the abandonment of the crawling peg regime by the authorities, the non-linear function picks up two observations in the lower regime (although from Fig. 3 it appears that the non-linear part is active only for two observations; some other observations are quite close to the threshold defining the lower regime). At that time, and unlike the episode of the mid-1980s, the premium of the parallel over the official rate was negative.

In the second panel of Table 5, 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 5% but not the 1% level of statistical significance) against linearity only for $d = 1$. Given $d = 1$, the sequence of tests in Eq. (6) for the selection of the transition function points to the 'logistic' function Eq. (2) as the appropriate one. Notice, however, that the resulting P values are not as low as those obtained for the model of the first period. In fact, when estimating non-linear models [using both functions Eq. (2) and Eq. (3)] for the crawling band regime,

⁹ Otero (1999) discusses the overvalued real exchange rate in terms of the world price of coffee, the stock of foreign debt, import tariffs and the ratio of central government's current expenditure to total expenditure.

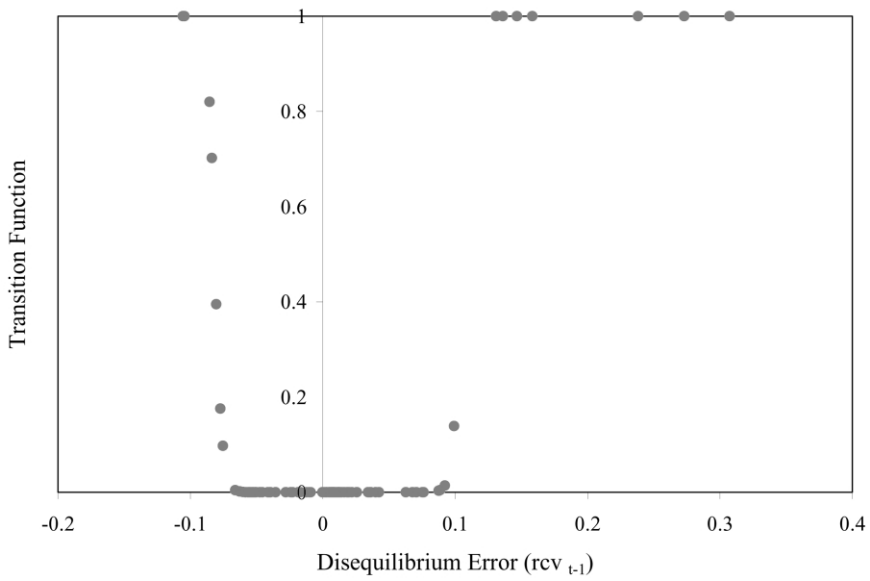


Fig. 2. Transition function vs. disequilibrium error (lagged once).

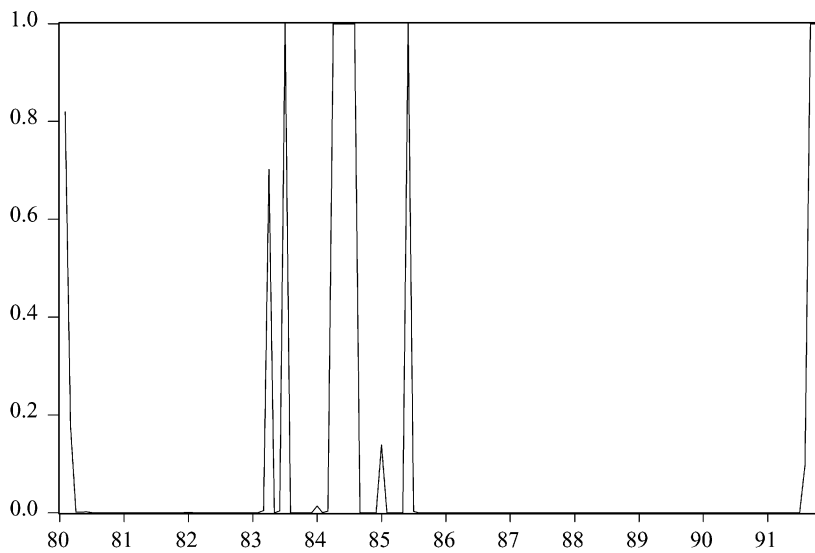


Fig. 3. Transition function (vertical axis) vs. time (horizontal axis).

the terms appearing in the non-linear part of the equation turn out to be insignificant. Hence, the linear specification captures sufficiently the short-run behaviour of the parallel rate. For this reason, the non-linear model is not reported.

4. Conclusions

This paper looks 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. Cointegration between the two rates supports 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.

The linear short-run estimates suggest that the removal of distortions in the official market has also forced the parallel market to adjust faster when discrepancies occur in the relationship between the two rates. Furthermore, 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.

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References

- Ashworth, J., Evans, L., Teriba, A., 1999. Structural breaks in parallel markets? The case of Nigeria, 1980–1993. *J. Dev. Economics* 58, 255–264.
- Banco de la República, 1998. Principales Indicadores Económicos 1923–1997. Banco de la República, Bogotá.
- Booth, G.G., Mustafa, C., 1991. Long-run dynamics of black and official exchange rates. *J. Int. Money Finance* 10, 392–405.
- Cárdenas, M., 1997. La Tasa de Cambio en Colombia. Cuadernos de Fedesarrollo 1. Tercer Mundo Editores, Bogotá.
- Cheung, Y.E., Lai, K.S., 1993. Finite sample sizes of Johansen's likelihood ratio tests for cointegration. *Oxf. Bull. Economics Statistics* 55, 313–328.
- Dornbusch, R., Dantas, D.V., Pechman, C., Rocha, R.R., Simoes, D., 1983. The black market for dollars in Brazil. *Q. J. Economics* 98, 25–40.
- Granger, C.W.J., Teräsvirta, T., 1993. *Modelling Nonlinear Economic Relationships*. Oxford University Press, Oxford.
- Hendry, D.F., Doornik, J.A., 1997. *Modelling Dynamic Systems Using PcFiml 9.0 for Windows*. International Thomson Business Press, London.
- Jansen, E.S., Teräsvirta, T., 1996. Testing parameter constancy and super exogeneity in econometric equations. *Oxf. Bull. Economics Statistics* 58, 735–768.
- Johansen, S., 1988. Statistical analysis of cointegration vectors. *J. Econ. Dyn. Control* 12, 231–254.
- Johansen, S., 1995. *Likelihood-based Inference in Cointegrated Vector Autoregressive Models*. Oxford University Press, Oxford.
- Kouretas, G.P., Zarangas, L.P., 1998. A cointegration analysis of the official and parallel foreign exchange markets for Dollars in Greece. *Int. J. Finance Economics* 3, 261–276.
- Lee, T.H., Tse, Y., 1996. Cointegration tests with conditional heteroskedasticity. *J. Econometrics* 73, 401–410.
- Moore, M., Phylaktis, K., 2000. Black and official exchange rates in the Pacific Basin: some tests of dynamic behaviour. *Appl. Financ. Economics* 10, 361–369.
- Osterwald-Lenum, M., 1992. A note with quantiles of the asymptotic distribution of the maximum likelihood cointegration rank test statistics. *Oxf. Bull. Economics Statistics* 54, 461–472.
- Otero, J., 1999. The real exchange rate in Colombia: An analysis using multivariate cointegration. *Appl. Economics* 31, 661–671.
- Phylaktis, K., 1997. Black market for foreign currency: a survey of theoretical and empirical issues. *Financ. Markets Institutions Instruments* 6, 102–124.
- Phylaktis, K., Kassimatis, Y., 1994. Black and official exchange rates in the pacific basin countries: an analysis of their long-run dynamics. *Appl. Economics* 26, 399–407.
- Reimers, H.E., 1992. Comparisons of tests for multivariate cointegration. *Stat. Papers* 33, 335–359.
- Siklos, P.L., Granger, C.W.J., 1997. Regime-sensitive cointegration with an application to interest-rate parity. *Macroecon. Dyn.* 1, 640–657.
- Teräsvirta, T., 1994. Specification, estimation and evaluation of smooth transition autoregressive models. *J. Am. Stat. Assoc.* 89, 208–218.
- Van Dijk, D., Franses, P.H., 2000. Nonlinear error-correction models for interest rates in the Netherlands. In: Barnett, W.A., Hendry, D.F., Hylleberg, S., Teräsvirta, T., Tjøstheim, D., Würtz, A. (Eds.), *Nonlinear Econometric Modelling in Time Series Analysis*. Cambridge University Press, Cambridge.
- Van Dijk, D., Teräsvirta, T., Franses, P.H., 2000. Smooth transition autoregressive models — a survey of recent developments. SSE/EFI Working paper series in Economics and Finance, No. 380, Stockholm School of Economics.
- White, H., 1980. A heteroscedastic-consistent covariance matrix estimator and a direct test for heteroscedasticity. *Econometrica* 48, 817–838.
- Williamson, J., 1996. *The Crawling Band as an Exchange Rate Regime: Lessons from Chile, Colombia and Israel*. Institute for International Economics, Washington, D.C.