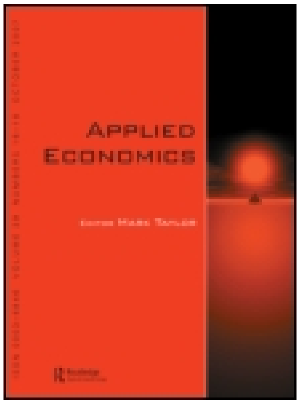

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The dynamic relationship between the prices of ADRs and their underlying stocks: Evidence from the threshold vector error correction model

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The dynamic relationship between the prices of ADRs and their underlying stocks: evidence from the threshold vector error correction model

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This paper sets out to estimate the dynamic relationship that exists between the prices of ADRs and their underlying stocks, in both the short run and the long run, using a number of recent developments of the threshold cointegration framework. The empirical results support the notion of nonlinear mean reversion of the prices of ADRs and their underlying stocks.

I. Introduction

The relationship between nonlinear error correction models and the concept of cointegration has attracted considerable attention in recent years. Applications of the threshold cointegration, introduced by Balke and Fomby (1997), are especially popular, evidenced by the many references reviewed in Hansen and Seo (2002) on multivariate threshold vector error correction model (hereafter, VECM). More recently, Peel and Taylor (2002) used univariate threshold autoregressive model and multivariate threshold VECM to investigate the covered interest rate arbitrage in the interwar period and found strong support for the Keynes–Einzig conjecture. Enders and Chumrusphonlert (2004) applied a threshold cointegration methodology to explore the properties of long-run purchasing power parity in the Pacific nations and found that asymmetric adjustments of nominal exchange rates play an important role in eliminating deviations from long-run PPP.

Most studies on price transmission using threshold models tend to use either one threshold to separate the adjustment process into two regimes (Balke and Fomby, 1997; Enders and Granger, 1998; Abdulai, 2002; Deidda and Fattouh, 2002; Escribano and Mira, 2002; Hansen and Seo, 2002; Cook, 2003; Cook and Manning, 2003; Sephton, 2003; Oscar *et al.*, 2004) or two thresholds to separate the adjustment process into three regimes (Obstfeld and Taylor, 1997; Goodwin and Piggott, 2001; Serra and Goodwin, 2002; Seo, 2003). This paper aims to propose a two-regime threshold VECM for ADR and its underlying stock price.

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Given the increasing global competition, many companies have chosen to raise capital in the USA by issuing American Depositary Receipts (ADRs) in order to diversify their capital market risk, whilst also reducing the overall cost of capital and promoting the firm's reputation in the global market. Through the purchase of ADRs, investors can also indirectly invest in foreign securities as a means of circumventing foreign exchange barriers and various investment regulations. Thus, for both foreign investors and issuing companies alike, ADRs have become one of the most popular financial instruments currently in use.

Over the past decade several researchers have examined the direct and indirect causal transmissions among ADRs and their underlying stocks. Among others, Alaganar and Bhar (2001) have examined, within the developed markets, whether arbitrage opportunities exist between ADRs and their underlying stocks, while Rabinovitch *et al.* (2003) have investigated this issue within the emerging markets. However, these studies generally found that the prices of both the ADRs and their underlying stocks were the same, leaving little, if any, opportunities for arbitrage.

Under perfect market assumptions, the ADR and its underlying stock price are closely related according to the law of one price. However, in practice, deviations from this no-arbitrage relation are usually observed because of market imperfections such as transaction costs and price uncertainty due to noisy trader risk. Using the VECM, Kim *et al.* (2000) examine the dynamic price relationship of American Depositary Receipt (ADR) price to exchange rate and underlying stock price. As arbitrage activities only occur when the spread between an ADR and its underlying stock price is larger enough to cover trading costs, the use of threshold VECM could be potentially more meaningful in characterizing their price dynamics.

To the best of our knowledge, no study has yet been published characterizing the price dynamics between ADRs and their underlying stocks through the use of the threshold VECM. Therefore, this paper sets out to explore in two parts, the existence of various arbitrage regimes and causal linkages between the prices of ADRs and their underlying stocks. This paper begins, first of all, by identifying the location of possible thresholds and then exploring the relationship leading to the determination of the error correction term in a two regime strategy. This paper then estimates a threshold cointegration framework in both the short run and the long run, and finds that a significant threshold effect exists in the error correction term of the prices of ADRs and their underlying stocks.

The remainder of this paper is organized as follows. Section II introduces the econometric models, followed, in Section III, by a description of the data and the empirical results. A brief summary, along with the conclusions drawn from this study, are provided in Section IV.

II. Econometric Methods

VECM has been the major model for the analysis of macroeconomic dynamic or the causal relationships of stock prices. Examples of the applications of VECM include Agrawal (2001) and Calza *et al.* (2003). For the case of ADR and its underlying stock (UND) price, the existence of transaction costs and other market imperfection factors might cause the error correction effects on the price adjustment be significant only when the deviation of price between ADR and UND is larger than a certain threshold. While previous studies, such as Enders and Chumrusphonlert (2004), employed a univariate threshold model to explore the properties of purchasing power parity, this paper follows the Hansen and Seo's (2002) model to develop a multivariate threshold VECM. The model is employed to estimate the threshold parameters, to construct asymptotic confidence intervals for the threshold parameters, and to develop new tests for the threshold effects of ADRs and their underlying stocks (UNDs) prices.

Estimation of the threshold parameters

Let x_t be a p-dimensional $I(1)$ time series, with n observations, with l as the maximum lag length. A linear VECM of order $l+1$ can be written briefly as

$$\Delta x_t = A' X_{t-1}(\beta) + u_t \qquad (1)$$

where

$$X_{t-1}(\beta) = [1 \quad w_{t-1}(\beta) \quad \Delta x_{t-1} \quad \Delta x_{t-2}, \ldots, \Delta x_{t-l}]'$$

and Δ is the first-order difference operator; the repressor $X_{t-1}(\beta)$ is $k \times 1$; A is $k \times p$; and $k = pl + 2$. The error term, u_t is assumed to be a vector Martingale difference sequence with finite covariance matrix $\Sigma = E(u_t u_t')$. Note that $w_{t-1}(\beta) = \beta' x_{t-1}$ is an $I(0)$ error correction term. For the bivariate case of ADR and UND price, Δx_t corresponds to $[\Delta \text{ADR}_t \ \Delta \text{UND}_t]$.

Consider now an extension of Equation 1, provided by:

$$\Delta x_t = \begin{cases} A_1' X_{t-1}(\beta) + u_t, & \text{if } \left| w_{t-1}(\beta) \right| \le \gamma \\ A_2' X_{t-1}(\beta) + u_t, & \text{if } \left| w_{t-1}(\beta) \right| > \gamma \end{cases}$$

where γ is the threshold parameter. Note that this paper uses the absolute value of error correction term as a threshold variable. In addition to the merit of parsimony in the modeling of threshold effect, the assumption is reasonable since transaction costs tend to be symmetric for either long or short position in the ADR for its arbitrage. Alternatively, this may be written as

$$\Delta x_t = A_1' X_{t-1}(\beta) \mathrm{d}_{1t}(\beta, \gamma) + A_2' X_{t-1}(\beta) \mathrm{d}_{2t}(\beta, \gamma) + u_t, \tag{2}$$

where

$$\mathrm{d}_{1t}(\beta, \gamma) = 1(\left| w_{t-1}(\beta) \right| \le \gamma),$$
$$\mathrm{d}_{2t}(\beta, \gamma) = 1(\left| w_{t-1}(\beta) \right| > \gamma),$$

and 1(.) denotes the indicator function. The existence of the threshold effect is confirmed if $0 < P(|w_{t-1}(\beta)| \le \gamma) < 1$, otherwise the model simplifies to linear cointegration.

The threshold VECM of ADRs and UNDs can be estimated using the maximum likelihood method proposed by Hansen and Seo (2002). Under the assumption that the errors u_t are *iid* Gaussian, the likelihood function is

$$L_n\left(A_1, A_2, \sum, \beta, \gamma\right) = -\frac{n}{2} \log|\Sigma| - \frac{1}{2} \sum_{t=1}^{n} u_t(A_1, A_2, \beta, \gamma)' \times \sum^{-1} u_t(A_1, A_2, \beta, \gamma), \tag{3}$$

where

$$u_t(A_1, A_2, \beta, \gamma) = \Delta x_t - A_1' X_{t-1}(\beta) \mathrm{d}_{1t}(\gamma) - A_2' X_{t-1}(\beta) \mathrm{d}_{2t}(\gamma).$$

$MLE(\hat{A}_1, \hat{A}_2, \hat{\Sigma}, \hat{\beta}, \hat{\gamma})$ are the values which maximize $L_n(A_1, A_2, \Sigma, \beta, \gamma)$ in order to maximize the log-likelihood, to hold (β, γ) fixed, and to compute the constrained *MLE* for (A_1, A_2, Σ). This is just *OLS* regression:

$$\hat{A}_1(\beta, \gamma) = \left(\sum_{t=1}^{n} X_{t-1}(\beta) X_{t-1}(\beta)' \mathrm{d}_{1t}(\beta, \gamma) \right)^{-1} \times \left(\sum_{t=1}^{n} X_{t-1}(\beta) \Delta x_t' \mathrm{d}_{1t}(\beta, \gamma) \right), \tag{4}$$

$$\hat{A}_2(\beta, \gamma) = \left(\sum_{t=1}^{n} X_{t-1}(\beta) X_{t-1}(\beta)' \mathrm{d}_{2t}(\beta, \gamma) \right)^{-1} \times \left(\sum_{t=1}^{n} X_{t-1}(\beta) \Delta x_t' \mathrm{d}_{2t}(\beta, \gamma) \right), \tag{5}$$

$$\hat{u}_t(\beta, \gamma) = u_t(\hat{A}_1(\beta, \gamma), \hat{A}_2(\beta, \gamma), \beta, \gamma),$$

and

$$\hat{\sum}(\beta, \gamma) = \frac{1}{n} \sum_{t=1}^{n} \hat{u}_t(\beta, \gamma) \hat{u}_t(\beta, \gamma)'. \tag{6}$$

Note that Equations 4 and 5 are the *OLS* regressions of Δx_t on $X_{t-1}(\beta)$ for the samples of which $|w_{t-1}(\beta)| \le \gamma$ and $|w_{t-1}(\beta)| > \gamma$, respectively.

$$L_n(\beta, \gamma) = L_n(\hat{A}_1(\beta, \gamma), \hat{A}_2(\beta, \gamma), \hat{\sum}(\beta, \gamma), \beta, \gamma) = -\frac{n}{2} \log\left| \hat{\sum}(\beta, \gamma) \right| - \frac{np}{2}. \tag{7}$$

From the grid search procedure, the model with the lowest value of $\log|\hat{\sum}(\beta, \gamma)|$ is used to provide the $MLE(\hat{\beta}, \hat{\gamma})$, while the limitation of β is $\pi_0 \le P(|w_{t-1}(\beta)| \le \gamma) \le 1 - \pi_0$, where $0 < \pi_0 < 1$ is a trimming parameter; this paper sets $\pi_0 = 0.05$. This paper employs the grid-search algorithm developed by Hansen and Seo (2002) to obtain the parameter estimates, with the $MLE(\hat{A}_1, \hat{A}_2)$ being $\hat{A}_1 = \hat{A}_1(\hat{\beta}, \hat{\gamma})$ and $\hat{A}_2 = \hat{A}_2(\hat{\beta}, \hat{\gamma})$.

Tests for threshold effects

Let H_0 represent the class of linear VECM in Equation 1, and H_1 represent the class of two regime threshold VECM in Equation 2. These models are nested, with the constraint H_0 being the models in H_1 which gratify $A_1' = A_2'$. Our test will compare H_0 (linear cointegration) with H_1 (threshold cointegration).

In order to assess the evidence, both linearity and the threshold VECM are tested by using the Lagrange Multiplier (*SupLM*) test developed by Hansen and Seo (2002). The LM statistic employed is:

$$\mathrm{LM}(\beta, \gamma) = \mathrm{vec}(\hat{A}_1(\beta, \gamma) - \hat{A}_2(\beta, \gamma))' \times (\hat{V}_1(\beta, \gamma) + \hat{V}_2(\beta, \gamma))^{-1} \times \mathrm{vec}(\hat{A}_1(\beta, \gamma) - \hat{A}_2(\beta, \gamma)) \tag{8}$$

$$\mathrm{SupLM} = \sup_{r_L \le r \le r_U} \mathrm{LM}(\tilde{\beta}, \gamma) \tag{9}$$

where $\tilde{\beta}$ is the null estimate of β. The bootstrap method proposed by Hansen and Seo's (2002) is employed to calculate the asymptotic critical values and p-values.

III. Data and Empirical Results

The ADRs and UNDs series are tested for stationarity in this paper using unit root tests; followed by an examination of the cointegration test between the two series. If they are cointegrated, the threshold VECM is then applied to determine the short-run dynamics and the long-run equilibrium between the ADR and the UND markets.

The daily returns of three locally-traded Argentinean firms provide the data for analysis in this study, with Table 1 providing the basic description of their respective NYSE-traded ADRs. Although the ADRs are priced in US dollars, UNDs in the home stock market are priced in Argentinian pesos. The prices of ADRs are calculated into the Argentinian peso price using the daily closing exchange rate. ADRs prices, the prices of UNDs, and the exchange rates used in this study were obtained from Datastream.

The log-price of the ADRs and the UNDs are used to carry out our empirical analysis, with the returns of ADRs and UNDs being calculated, first of all, by taking the difference in the log-price. Table 2 presents the results of the unit root and cointegration tests; the unit root test uses the null hypothesis versus the alternative of stationarity in the variables for the results of the Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests. The results thus cannot reject the null hypothesis of a unit root; the variables in the levels are $I(1)$ for each of the ADR price and for those of UND. The variables in the first difference are integrated of order zero; the null hypothesis of unit root is rejected at the 5% level for the price difference series. These results indicate that the two price series are integrated in the first difference, and thus validates the use of the cointegration test.

Given that all the variables of the same order are integrated, this paper uses two Johansen multivariate

Table 1. Data description

Symbol	Company	Industry	Shares per DR	Sample period	Number of observations
YPF	YPF, S.A.	Oil and gas operator	1	7 Jul 93–31 Jul 04	2888
TEO	TELECOM ARGENTINA STET-FRANCE TELECOM, S.A.	Telecoms	5	12 Dec 94–31 Jul 04	2516
TGS	TRANSPORTADORA DE GAS DEL SUR, S.A.	Oil and gas operator	5	2 Jan 95–31 Jul 04	2500

Table 2. Unit root and cointegration tests for log-prices of ADRs and their underlying stocks

		Augmented Dickey–Fuller test		Phillips–Perron test	
Unit root test		Levels	First differences	Levels	First differences
YPF	ADR	−0.112758	−51.53653**	−0.091492	−51.49286**
	UND	−0.138284	−48.78652**	−0.126952	−48.83657**
TEO	ADR	−1.679652	−45.80010**	−1.635612	45.39878**
	UND	−1.624543	−45.71221**	−1.579939	−45.34922**
TGS	ADR	−2.256933	−38.23152**	−1.811293	−51.83980**
	UND	−1.898783	−47.40127**	−1.897981	−47.33906**
Cointegration tests		Trace test	5% CV	Max-eigenvalue test	5% CV
YPF	None	78.15789**	15.41	78.15465**	14.07
	One at most	0.003231	3.76	0.003231	3.76
TEO	None	77.81962**	15.41	77.81962**	14.07
	One at most	2.827981	3.76	2.827981	3.76
TGS	None	111.4459**	15.41	107.8217**	14.07
	One at most	3.624222	3.76	3.624222	3.76

Notes: Total number of sample observations is 2888 for YPF, 2516 for TEO and 2500 for TGS. UND represents the price of underlying stock.
**Indicates significance at the 5% level.

cointegration tests to determine whether the variables in each respective series are cointegrated. The maximum likelihood estimation procedure provides a likelihood ratio test, referred to as a trace test, with the likelihood ratio test being the test for maximum eigenvalue. The likelihood ratio statistics reject the null hypothesis of no cointegration at the 5% level. A feature of this approach is that the VECM contains an error correction term which reflects the current error in achieving long-run equilibrium. Therefore, the VECM can be used to jointly estimate the long-run relationship with short-run dynamics, a process which has been proven to be more effective than Granger causality.

Table 3 provides the estimates of the linear model. In order to address the issue of linear, or nonlinear, adjustment to the long-run equilibrium, this study estimates a linear VECM, given by Equation 1, with our selection of the lag length being based upon the AIC and BIC criteria. As a comparison, this paper first of all estimates the linear VECM for the price series of the ADR and underlying stock, reporting the results of the linear VECM estimation in Table 3. The estimated coefficients of the error correction term on the equations of the underlying stock are all significant at the 5% level.

The estimation results of the threshold VECM, and the test for the hypothesis of linearity versus the threshold effect of non-linearity, provided by Equation 9, are presented in Tables 4, 5 and 6, under the application of the *SupLM* test for the complete bivariate specification. The *p*-values of the results supporting the threshold cointegration hypothesis were calculated using both the fixed repressor and a residual bootstrap experiment, with 1 000 simulation replications. The estimated threshold VECM was provided by Equation 2, with our selection of the lag length being based upon the AIC and BIC criteria; it was also considered in this study that the cointegrating vector $\hat{\beta}$ should be estimated. Standard errors were calculated from the heteroscedasticity-robust covariance estimator, with the parameter estimates being calculated by the minimization of Equation 7 over a 300×300 grid on the parameters (β, γ).

Table 4 reports the threshold VECM results for ADR with ticker symbol 'YPF' along with UND. In this study, this paper selected a lag length of $l = 3$, with the estimated cointegrating relationship being $w_{t-1} = \mathrm{ADR}_{t-1} - 1.00123\mathrm{UND}_{t-1}$, quite close to a unity coefficient. This paper also conducted analyses for the case where a unity coefficient is imposed, with the results being very similar. The estimated threshold parameter was $\gamma = 0.000368$, indicating that the first regime corresponded to $|\mathrm{ADR}_{t-1} - 1.00123UND_{t-1}| \leq 0.000368$. This first regime, which comprised of 78% of all of the observations in the sample, is referred to in this study as

Table 3. Linear VECM estimations for log-prices of ADRs and their underlying stocks

	YPF		TEO		TGS	
	$\Delta\mathrm{ADR}_t$	$\Delta\mathrm{UND}_t$	$\Delta\mathrm{ADR}_t$	$\Delta\mathrm{UND}_t$	$\Delta\mathrm{ADR}_t$	$\Delta\mathrm{UND}_t$
w_{t-1}	−0.044*	0.035**	−0.037	0.150***	−0.082**	0.035**
	(0.026)	(0.016)	(0.028)	(0.036)	(0.039)	(0.016)
Constant ($\times 10^{-3}$)	0.242	0.781**	−4.299	17.368	−2.754**	1.335*
	(0.414)	(0.380)	(3.418)	(14.260)	(1.332)	(0.736)
$\Delta\mathrm{ADR}_{t-1}$	0.022	0.214***	−0.671***	−0.117**	−0.072	0.056**
	(0.038)	(0.046)	(0.130)	(0.052)	(0.044)	(0.027)
$\Delta\mathrm{ADR}_{t-2}$	0.068	−0.053	−0.036	−0.614***	0.182***	0.019
	(0.045)	(0.049)	(0.027)	(0.063)	(0.054)	(0.038)
$\Delta\mathrm{ADR}_{t-3}$	−0.009	0.084**	−0.513***	−0.091		
	(0.051)	(0.038)	(0.137)	(0.062)		
$\Delta\mathrm{UND}_{t-1}$	−0.030	−0.063*	−0.030	−0.429***	−0.098**	0.061**
	(0.043)	(0.038)	(0.019)	(0.064)	(0.043)	(0.027)
$\Delta\mathrm{UND}_{t-2}$	0.018	0.044	−0.245**	−0.104	0.050	−0.076**
	(0.040)	(0.029)	(0.113)	(0.085)	(0.050)	(0.035)
$\Delta\mathrm{UND}_{t-3}$	−0.049	−0.022	−0.015	−0.226***		
	(0.036)	(0.035)	(0.011)	(0.054)		
Cointegration vector estimate	0.998549		1.19591		1.041	
AIC	−22529.2		−4510.15		−18063.0	
BIC	−22505.9		−4487.76		−18046.2	

Notes: Values in parentheses are Eicker–White standard errors.
***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Table 4. Threshold VECM estimations of YPF for log-prices of ADRs and their underlying stocks

	First regime: $\|w_{t-1}\| \leq 0.000368$ Percentage of Obs = 0.783634				Second regime: $\|w_{t-1}\| > 0.000368$ Percentage of Obs = 0.216366			
Dep	ΔADR_t		ΔUND_t		ΔADR_t		ΔUND_t	
Ind.	Estimate	Std error	Estimate	Std error	Estimate	Std error	Estimate	Std error
w_{t-1}	−0.032	0.027	0.015	0.016	−0.395**	0.200	0.442***	0.131
Constant ($\times 10^{-3}$)	0.579	0.643	−0.774	0.478	−3.324**	1.572	2.064	1.563
ΔADR_{t-1}	−0.005	0.039	0.144***	0.043	0.427***	0.138	0.217**	0.109
ΔADR_{t-2}	0.078	0.049	−0.052	0.044	−0.257*	0.141	0.106	0.115
ΔADR_{t-3}	−0.017	0.056	0.057*	0.034	0.241*	0.133	0.054	0.113
ΔUND_{t-1}	−0.018	0.045	−0.016	0.037	−0.274**	0.127	−0.112	0.098
ΔUND_{t-2}	−0.015	0.038	0.018	0.027	0.197***	0.055	0.018	0.081
ΔUND_{t-3}	−0.018	0.036	0.009	0.037	−0.238***	0.086	−0.061	0.076

Threshold estimate = 0.000368; Cointegrating vector estimate = 1.00123; AIC = −22653.1; BIC = −22606.4.

Lagrange Multiplier threshold test
Fixed regressor (asymptotic) bootstrap = 84.114*** (p-value < 0.001).
Residual bootstrap = 28.306*** (p-value < 0.001).

Wald Test
Equality of dynamic coefficients = 34.188*** (p-value < 0.001).
Equality of EC coefficients = 24.911*** (p-value = 0.008).

Notes: ***, ** and *indicate significance at the 1%, 5% and 10% levels, respectively.

Table 5. Threshold VECM estimations of TEO for log-prices of ADRs and their underlying stocks

	First regime: $\|w_{t-1}\| \leq 0.439982$ Percentage of Obs = 0.926693				Second regime: $\|w_{t-1}\| > 0.439982$ Percentage of Obs = 0.0733068			
Dep	ΔADR_t		ΔUND_t		ΔADR_t		ΔUND_t	
Ind.	Estimate	Std error	Estimate	Std error	Estimate	Std error	Estimate	Std error
w_{t-1}	−0.138	0.109	0.006	0.045	0.031*	0.018	1.069***	0.188
Constant ($\times 10^{-3}$)	28.461	29.030	−21.562*	12.326	−71.085*	40.829	−139.86	349.526
ΔADR_{t-1}	−0.669***	0.157	−0.018	0.072	−0.207***	0.056	0.317***	0.080
ΔADR_{t-2}	0.014*	0.008	−0.748***	0.079	0.011**	0.005	−0.052	0.121
ΔADR_{t-3}	−0.466***	0.163	−0.024	0.086	−0.565***	0.100	0.102	0.074
ΔUND_{t-1}	−0.002	0.011	−0.501***	0.086	0.004	0.004	−0.079	0.098
ΔUND_{t-2}	−0.197*	0.118	−0.073	0.104	−0.970***	0.117	0.369***	0.142
ΔUND_{t-3}	−0.001	0.010	−0.353***	0.078	0.003	0.002	0.001	0.069

Threshold estimate = 0.439982; Cointegrating vector estimate = 0.789472; AIC = −4740.20; BIC = −4695.41.
Lagrange Multiplier threshold test
Fixed regressor (asymptotic) bootstrap = 103.117*** (p-value < 0.001).
Residual bootstrap = 34.232*** (p-value < 0.001).

Wald test
Equality of dynamic coefficients = 24.806*** (p-value < 0.001).
Equality of EC coefficients = 26.127*** (p-value < 0.001).

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

the 'typical' regime. Conversely, the second regime, which was $|ADR_{t-1} - 1.00123 UND_{t-1}| > 0.000368$, comprised of 22% of all of the observations in the sample, and is referred to in this study as the 'extreme' regime.

In the 'typical' regime specifically, both ΔADR_t and ΔUND_t have statistically insignificant error correction effects and minimal dynamics. They are close to white noise, which indicates that in this regime, ADR_t and UND_t are close to random walks. In contrast, in the 'extreme' regime, the asymmetry of ΔADR_t and ΔUND_t is implied, in the sense that there is an error correction effect in the ADR and UND equation being statistically

Table 6. Threshold VECM estimations of TGS for log-prices of ADRs and their underlying stocks

	First regime: $\lvert w_{t-1}\rvert \leq 0.000323$ Percentage of Obs = 0.456548				Second regime: $\lvert w_{t-1}\rvert > 0.0003231$ Percentage of Obs = 0.543452			
Dep	ΔADR_t		ΔUND_t		ΔADR_t		ΔUND_t	
Ind.	Estimate	Std error	Estimate	Std error	Estimate	Std error	Estimate	Std error
w_{t-1}	−0.056	0.043	−0.004	0.016	−0.265***	0.090	0.374***	0.083
Constant ($\times 10^{-3}$)	3.095**	1.483	−2.837***	0.920	0.705	1.247	−2.619**	1.075
ΔADR_{t-1}	−0.009	0.054	0.029	0.034	−0.095	0.070	−0.046	0.057
ΔADR_{t-2}	0.167**	0.073	0.094*	0.051	0.148**	0.075	0.060	0.063
ΔUND_{t-1}	−0.016	0.052	0.105***	0.032	−0.213***	0.053	−0.102**	0.043
ΔUND_{t-2}	0.009	0.065	−0.081*	0.046	0.108*	0.063	0.018	0.051

Threshold estimate = 0.000323; Cointegrating vector estimate = 0.993680 AIC = −18146.3; BIC = −18112.8.

Lagrange Multiplier threshold test
Fixed regressor (asymptotic) bootstrap = 20.910*** (p-value < 0.001).
Residual bootstrap = 17.305*** (p-value < 0.001).

Wald test
Equality of dynamic coefficients = 20.772*** (p-value = 0.008).
Equality of EC coefficients = 49.256*** (p-value < 0.001).

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

significant with dynamic coefficients. All in all, ADR_t and UND_t are statistically significant in the error correction effects in the 'extreme' regime, but not in the 'typical' regime.

The evidence of non-linearity appears to gain strength from the results of the Wald test diagnostics, thus the null hypothesis of linearity in error correction terms is rejected. Comparing the estimated coefficients of the error correction terms in Tables 3 and 4 shows that the linear error correction models imply very slow speed of adjustment, a result consistent to those reported in Enders and Chumrusphonlert (2004). Since the null hypothesis is of equality of the coefficients on the error correction terms and of the dynamic coefficients across the two regimes, an important finding of the estimated linear VECM and threshold VECM is that the error correction term for the ADR is negative; this result is consistent with the error correction terms. This implies specifically, that from the long-run equilibrium, the ADR adjusts to any short-run deviations. Furthermore, the negative sign of the error correction term implies that if the ADR premium is above its equilibrium level, the ADR will decline. This is as predicted in the model when the ADR overshoots its long-run equilibrium; the result is therefore just as this paper would have expected to see in this study. Details of the procedures and analyses provided above are also presented in Tables 5 and 6. The error correction term appears to be significant only in the 'extreme' regime. The estimated coefficients of the error correction terms in the extreme regime appear to be larger than those in the linear VECM. The short-run dynamic effects of ADR and UND price show significant differences between 'typical' and 'extreme' regimes.

IV. Summary and Conclusions

This paper employs the threshold VECM to investigate the dynamic price relationship between ADRs and their underlying stocks. The results provided by the LM test statistics reject the null hypothesis of no threshold effect, while the Wald test results reject the null hypothesis of the coefficients of the error correction term in the two regimes having the same value. This study therefore provides strong evidence to show that a threshold effect does exist in the prices of ADRs and their underlying stocks.

The main findings of our analyses can be summarized as follows. First of all, the results based on the threshold VECM demonstrate that linearity is rejected in favour of threshold effect nonlinearity and that the estimated two-regime threshold VECM forms a statistically sufficient representation of the data with separating regimes. Secondly, through the threshold parameters, this paper classifies the 'typical' regime and the 'extreme' regime, with only the error correction effect appearing in the 'extreme' regime being statistically significant, since it is not significant in the 'typical' regime. Finally, the negative sign of the error correction term in the 'extreme' regime implies that if the ADR's premium is above its equilibrium level, then the ADR price will decline; that is, nonlinear mean reversion is evident.

Last but not least, this study points to threshold VECM, which is consistent with the stylized fact of the error correction, and suggests that the effectiveness of the threshold cointegration model surpasses that of the linear cointegration model. Further analytical studies, using the threshold VECM model, should be undertaken in the future, with its application being targeted at predicting the achievements of ADRs and their underlying stock prices.

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