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Price transmission dynamics between ADRs and their underlying foreign securities

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Abstract

This paper extends previous research by considering three pricing factors for American Depository Receipts (ADRs): the price of the underlying shares in the local currency, the relevant exchange rate, and the US market index. Using both a vector autoregressive (VAR) model with a cointegration constraint and a seemingly-unrelated regression (SUR) approach, we examine the relative importance of, and the speed of adjustment of ADR prices to, these underlying factors. Our results show that while the price of the underlying shares is most important, the exchange rate and the US market also have an impact on ADR prices. While the bulk of the shocks to the pricing factors are reflected in the ADRs within the same calendar day, there are indications that the adjustments are not completed until the following day. Curiously, the ADRs appear to initially overreact to the US market index but underreact to changes in underlying share prices and exchange rates. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

We study the dynamics of international transmission between American Depository Receipts (ADRs) and their underlying foreign securities in this paper. Earlier studies on international capital market relationships focus mainly on the interdependence of price movements across different countries (see, e.g., Grubel, 1968; Hilliard, 1979). They generally find that the correlations among different national equity markets are very low, and, thus, that security returns are determined by domestic factors. Other studies, however, tend to find integration of international equity markets. They pay more attention to the dynamics of the transmission mechanism across different national markets. For example, Eun and Shim (1989) and Koch and Koch (1991) examine major international stock indexes by using vector autoregressive and simultaneous equations models, respectively. They generally support the notion that international equity markets are informationally efficient on a daily basis.

Studies of the Crash of 1987 also provide evidence of strong international equity market linkages (Roll, 1988; Aderhold et al., 1988; Bennet and Keller, 1988). Kasa (1992) uses Johansen's (1991) multivariate cointegration tests and finds that a common stochastic trend drives equity markets of the US, Japan, UK, Germany, and Canada. This implies that, in the long run, the gains from international equity diversification would be minor because these markets are closely related.

As an extension of these studies, we examine the transmission of stock price movements between ADRs and their respective underlying foreign markets. ADRs provide a unique opportunity to investigate transmission channels in that they are traded in the US markets but represent ownership of foreign underlying securities. As an alternative vehicle for international diversification, ADRs have become popular in the US market. The dollar volume of ADRs traded on the major US securities exchanges has grown dramatically in recent years. By the end of 1996, more than 1000 ADRs were available in US markets, up 14% from the previous year.

Because ADRs are quoted in dollars, the price of an ADR reflects not only changes in the value of its underlying foreign security but also currency shifts against the US dollar. Less obviously, US market conditions may also affect the price of an ADR for two reasons. First, investors may evaluate the systematic risk of ADRs with reference to US market indices. Second, ADRs are traded in the US during North American trading hours, during all or part of which the markets for their underlying securities are closed. If foreign market returns on the following day are positively correlated with current day US market returns (as many previous studies have found), then we would expect a positive contemporaneous relationship between ADR returns and US market index returns.

The purpose of this paper is two-fold. First, we investigate informational efficiency between markets for ADRs and their underlying foreign shares.

Rosenthal (1983) finds that ADR prices are fairly consistent with weak-form efficiency, as abnormal returns cannot be earned from any price dependence. Kato et al. (1991) and Wahab et al. (1992) try to find arbitrage opportunities between the prices of ADRs and underlying foreign securities. They generally support the notion that, after transactions costs, few profitable opportunities exist in these markets, implying that both markets are efficient. We study this issue further from a different perspective by examining the dynamics of price transmission mechanisms between two markets (Mathur et al., 1998). Specifically, we examine how a shock in one market is transmitted to the other market and how long the shock persists.

Second, we study different pricing factors for ADRs. One can assume á priori that the underlying prices mainly explain the movements of the ADRs because ADRs are based on these foreign securities, and thus both securities should be priced in the same way. However, due to a recent history of volatile foreign exchange markets, exchange rate movements may allow ADRs to perform more strongly (or weakly) for US investors than do the underlying securities for holders in their home market. In addition, as noted earlier, movements in US stock market indices may also have an impact on ADR prices. One empirical question not addressed in previous studies is to what extent each of these factors actually leads the ADR prices. Therefore, we examine how three different shocks (shocks in the underlying prices, the exchange rates, and the US index) are transmitted to the prices of ADRs. By studying the behavior of the three pricing factors for ADRs, we hope to explain the ADR price structure more clearly.

We utilize a vector autoregression (VAR) model to study the dynamics of the price transmission between ADRs and underlying foreign securities. Specifically, we calculate the impulse response functions to examine how a shock in one market is transmitted to the other market. Through variance decomposition, the VAR model also allows us to assess the relative weight of each variable in the system in generating unexpected variations of its own and other variables. In addition, we test a possible cointegration relationship among the prices via the multivariate procedures outlined by Johansen (1988, 1991) and Johansen and Juselius (1992). The cointegrating constraints are explicitly considered in the analysis of the impulse response functions to capture the long-as well as the short-run dynamics among the variables. Finally, to shed further light on the degree of predictability (if any) of ADR returns based on predetermined pricing factors, we estimate regressions of ADR returns on contemporaneous and lagged underlying security, exchange rate and US market index returns.

2. ADR pricing factors

One aspect of the ADRs is that ADR owners can convert the shares into the foreign currency-denominated underlying shares subject to cancellation and conversion fees. By the same token, holders of underlying shares can convert the shares into ADRs if they exist in the US markets. Therefore, an investor who compares the ADR price with the dollar price of the underlying share can get a riskless profit if the price differential is sufficient to cover the transactions costs. This arbitrage force would keep the price of ADRs in line with the dollar price of underlying shares. Under an assumption of constant foreign exchange rates over time, an upward (a downward) movement of the underlying share in the foreign market would move up (down) the price of the ADR in the US market. Within the same calendar day, the Asian markets close first, the Europeans are next, and the US market is the last one to close. (See Fig. 1 for the trading times of six markets included in this study.) Therefore, if the markets are fully efficient and the prices of underlying shares truly affect the prices of ADRs, a shock from the underlying shares should be reflected in the prices of ADRs by the same calendar day.

Currency movements against the US dollar are also transmitted to the price of ADRs indirectly. Typically, profits from foreign equity investments are subject to exchange rate risk because investors hold foreign currency denominated shares. Although ADRs, being US dollar-denominated, do not bear explicit exchange rate risk, there is an implicit exchange risk in their price due to the convertiblity between ADRs and the underlying shares. Even if the price of the underlying share remains unchanged for a period, changes in the exchange rate against the US dollar would make the price of ADRs adjust to avoid arbitrage profits. For example, under an assumption of constant underlying share price over time, an appreciation (a depreciation) of the Japanese yen against the dollar will force the prices of Japanese ADRs to move up (down) until arbitrage profits due to foreign exchange movements disappear.

Taken together, an upward (a downward) movement of the underlying share coupled with an appreciation (a depreciation) of local currency against the dollar will exert even greater pressure on the firm's ADR to move up (down). If, however, the underlying shares and the exchange rate move in opposite directions with the same magnitude, the effect is netted out, and the ADR price should remain the same. Therefore, any attempt to investigate market effi-

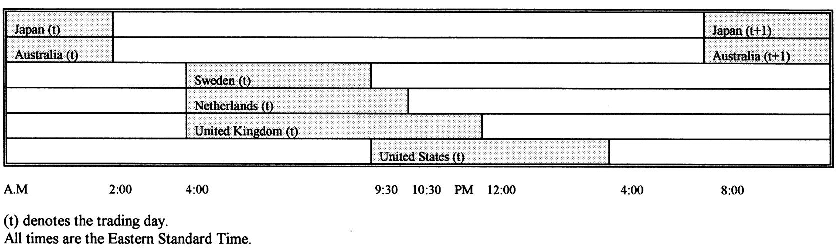

Fig. 1. Trading hours of different securities exchanges.

ciency or arbitrage opportunities between the ADRs and the underlying foreign markets should consider exchange rate movements as well as share price movements. In addition, given non-synchronous trading times between the US and foreign markets, ADR prices may also be affected by an innovation in the US market. As shown in Fig. 1, within one calendar day, the US market is the last one to close. Therefore, if markets are efficient, the ADRs should react to new information in the US while foreign markets are closed, and the movement is transmitted to the prices of underlying foreign stocks by the next calendar day.

3. Data

For this study, we identify those foreign securities whose daily prices are reported in the *Wall Street Journal*, and whose ADRs trade in the US. To be included in the sample, the prices of both the ADR and the underlying security had to be available for each firm. This procedure resulted in identifying 21 Japanese, 21 British, 5 Dutch, 5 Swedish, and 4 Australian firms for the period January 4, 1988 to December 31, 1991. We obtain daily closing prices of ADRs from the CRSP tape. All ADRs included in this study trade on either the New York Stock Exchange, the American Stock Exchange or the NASDAQ. The daily closing prices for the underlying foreign securities are compiled from the *Wall Street Journal*. If there are stock splits or stock dividends, the prices are adjusted accordingly. The spot foreign exchange rates against the US dollar are based on New York interbank closing rates, and are obtained from Knight Ridder Financial Publishing, Inc. except for the Swedish krona, which are compiled from the *Wall Street Journal*. The S&P 500 index is used as a measure of general movements of the US stock market; daily closing prices are obtained from Knight Ridder.

4. Methodology

4.1. Stationarity and multivariate cointegration tests

We first test whether each of the ADRs, their underlying prices, the appropriate exchange rates, and the S&P 500 index are stationary. The Augmented Dickey–Fuller (ADF) tests are used to test for unit roots in the time series. A sufficient number of lagged differences is included so that the residual series is approximately white noise.

If, as expected, each variable is integrated of order one, $I(1)$, then the next step would be to test for cointegration among the variables, for which we utilize the test specification provided by Johansen (1988, 1991) and Johansen and Juselius (1992). The test is designed to test for the number of linearly independent cointegrating vectors existing among the variables (Barnhart and Szakmary, 1991; Schwarz and Szakmary, 1994).

4.2. VAR test

After determining the cointegrating relationships among the variables, we calculate the impulse response function (IRF) of the VAR system for each firm under the cointegrating constraints. The average IRF for each country is calculated based on each firm's IRF. The IRF traces the impact of a shock in a variable onto the system over a time period. Thus, we can measure how rapidly information is transmitted across different markets. By construction of the VAR equations, the error terms are serially uncorrelated but they may be contemporaneously correlated. This implies that an innovation in one variable may also work through the contemporaneous correlations of innovations of different series. This ambiguity in decomposing variance into components attributable to each innovation is resolved by using a transformation of the error terms that makes them contemporaneously uncorrelated. The transformation is achieved by orthogonalizing the innovations so that the orthogonalized innovations form an identity covariance matrix and are uncorrelated both serially and contemporaneously.

4.3. Regression test

Normally, because cointegration implies predictability, the existence of a cointegrating relationship among a set of asset prices requires at least some degree of inefficiency in at least one of the markets. However, this implication does not necessarily hold in our study, because the closing price of the underlying security is not observed simultaneously with the ADR price and the other pricing factors. Thus, the influence of the underlying security, the exchange rate, and the US index on the ADR is also examined by estimating the following regression model:

$$\mathrm{ADR}_{i,t} = a_i + \sum_{j=0}^{2} b_{ij}\mathrm{UND}_{i,t-j} + \sum_{j=0}^{2} c_{ij}\mathrm{EXG}_{i,t-j} + \sum_{j=0}^{2} d_{ij}\mathrm{SP}_{i,t-j} + e_{i,t}, \quad (1)$$

where $\mathrm{ADR}_{i,t}$ is the return on the ith ADR on day t, $\mathrm{UND}_{i,t}$ the underlying security return on day t, $\mathrm{EXG}_{i,t}$ the exchange rate return (appreciation of the foreign currency) on day t, and $\mathrm{SP}_{i,t}$ the return on the S&P 500 index on day t.

Because the error terms across firms are likely to be contemporaneously correlated, the regressions are estimated as a seemingly-unrelated system of equations on a country-by-country basis, i.e., all of the UK firms are estimated jointly, the Japanese firms are estimated jointly, etc. The regressions are used primarily to shed further light on whether the prices of ADRs efficiently incorporate innovations in the underlying pricing factors. As explained previously, given the daily trading hour differences in the markets, we would expect coefficients on the same-day underlying factors to be positive. However, since ADR prices are observed contemporaneously with or after all of the independent variables, the coefficients on lagged underlying security returns, exchange rate returns, and US market returns should be zero if ADR prices instantaneously incorporate information on their underlying pricing factors.

4.4. Regression-based trading rule

Because we find that lagged variables as described above frequently have significant coefficients in the regression tests, we test whether an ADR trading rule based on the regressions can earn excess returns over a "buy–hold" strategy. If excess returns are possible, then we also determine the maximum level of one-way trading costs that would eliminate the excess returns. To execute these tests, we use the estimated regression coefficients and daily observations on the lagged underlying security, exchange rate and US market returns to compute predicted ADR returns for each day. We evaluate a trading rule that takes a long position in the ADR on all days for which the predicted return is greater than or equal to zero, and a neutral position when the predicted ADR return is less than zero. We do not take short positions. To determine the excess trading profits relative to buy–hold, we use the *X*-statistic developed by Sweeney (1988):

$$X = \overline{R_{\mathrm{T}}} - \overline{R_{\mathrm{BH}}} + (N_{\mathrm{out}}/N_{\mathrm{tot}})\overline{R_{\mathrm{BH}}}, \qquad (2)$$

where $\overline{R_{\mathrm{T}}}$ is the trading rule mean return, $\overline{R_{\mathrm{BH}}}$ the buy–hold strategy mean return, N_{out} the number of days out of the ADR with the trading rule, and N_{tot} the total number of days within the test period.

For comparison purposes we assume that the investor could have engaged the buy–hold strategy over N_{tot} days. The investor uses the predicted ADR returns to make purchase and sale decisions, and in doing so owns the ADR for N_{in} days and does not own it for N_{out} days. As shown by Sweeney, the *X*-statistic measures profits per day, in excess of buy–hold, for each of the N_{tot} days.

To determine if the *X*-statistic is significantly different from zero, we use a *t*-statistic, where the standard error is given by

$$\sigma_X = [(\sigma_{\mathrm{BH}}/N_{\mathrm{tot}})(N_{\mathrm{out}}/N_{\mathrm{tot}})(N_{\mathrm{in}}/N_{\mathrm{tot}})]^{1/2}, \qquad (3)$$

where σ_{BH} is the standard deviation of buy–hold returns.

To compute the maximum round-turn transaction cost that would eliminate excess trading profits (i.e., drive a positive *X*-statistic to zero), we proceed as follows. First, note that with transactions costs, the *X*-statistic becomes

$$X_{\text{adj}} = X - [0.5 \times (N_{\text{trad}}/N_{\text{tot}}) \times \text{RTC}], \tag{4}$$

where RTC is the round-turn transaction cost expressed as a percentage of asset value and N_{trad} is the total number of trades initiated by the trading rule. The term in square brackets can be interpreted as the average daily transaction cost. Setting Eq. (4) equal to zero and solving for RTC gives

$$\text{RTC} = \frac{K}{0.5 \times (N_{\text{trad}}/N_{\text{tot}})}. \tag{5}$$

Clearly, Eq. (5) yields a meaningful result only if the unadjusted X-statistic is greater than zero. Intuitively, (5) shows that the regression-based trading rule's practical usefulness depends both on the quality of the signals it generates and the required trading frequency.

5. Results

5.1. Stationarity and multivariate cointegration tests

The stationarity properties of variables are estimated by performing the ADF tests. Specifications for these tests are provided in Table 1, which reports the results for the ADRs and their underlying foreign shares for 21 UK firms. The results for the ADRs based on underlying firms in the other countries are similar, and are available from the authors on request. The ADF test results for each country's exchange rate and for the S&P 500 index are presented in Table 2. The tables report the t-statistics for the hypothesis that $\eta = 0$ in the regression equations. Throughout the tests, the lag length is chosen just large enough so that the Ljung–Box Q-statistic at 36 lags indicates absence of autocorrelation in the residuals. The asymptotic critical values are taken from Davidson and Mackinnon (1993).

Tests for the presence of one unit root in the price series of ADRs and their underlying foreign shares fail to reject the null hypothesis in most cases, except for four firms (out of 56) at the 10% level. On the other hand, tests for two unit roots reject the null hypothesis at the 1% level, suggesting that first differencing is enough to obtain stationarity. The results also show that the ADRs and their corresponding foreign shares tend to have similar temporal properties. This is as expected because in a perfectly frictionless market they will be priced identically. Consistent with the findings of previous studies, the results for currencies and the S&P 500 index prices also show that they are $I(1)$. Given these findings, we take the first difference of each price series in estimating the impulse response functions from the vector autoregressive models.

Next, we perform Johansen's multivariate cointegration test. The test re-captures any long-run trend that might be lost due to the first differencing of

Table 1
Augmented Dickey–Fuller unit root tests[a] – United Kingdom:
One unit root – $\Delta y_t = \delta_1 + \eta_1 y_{t-1} + \sum_{i=1}^{K} \phi_{1,i} \Delta y_{t-i} + \epsilon_{1,t}$.
Two unit roots – $\Delta^2 y_t = \delta_2 + \eta_2 \Delta y_{t-1} + \sum_{i=1}^{K} \phi_{2,i} \Delta^2 y_{t-i} + \epsilon_{2,t}$

Firms[b]	ADR		Underlying	
	One UR	Two UR	One UR	Two UR
1	−2.559	−35.842***	−2.461	−22.132***
2	−1.245	−13.821***	−1.725	−19.753***
3	−1.652	−14.873***	−1.823	−12.694***
4	−2.235	−15.985***	−1.927	−13.346***
5	−1.985	−26.879***	−1.969	−28.566***
6	−2.237	−27.522***	−1.878	−25.997***
7	−2.334	−20.464***	−1.200	−23.489***
8	−2.652*	−30.435***	−2.800*	−29.833***
9	−1.287	−10.156***	−2.382	−14.489***
10	−1.823	−26.372***	−1.014	−21.788***
11	−1.021	−27.825***	−1.087	−19.482***
12	−1.934	−29.225***	−2.425	−27.125***
13	−2.324	−13.223***	−1.894	−12.854***
14	−1.997	−17.325***	−1.823	−16.478***
15	−1.333	11.528***	−1.458	−37.311***
16	−1.223	−10.285***	−1.253	−18.244***
17	−1.11	−16.742***	−2.182	−33.245***
18	−1.559	−14.522***	−1.285	−17.354***
19	−2.678*	−22.485***	−2.677*	−15.660***
20	−1.546	−14.266***	−1.024	−14.266***
21	−2.364	−22.333***	−1.625	−24.757***

[a] y denotes the price of the ADR or the underlying stock. Each number represents the t-statistic for the hypothesis that $\eta = 0$ in the regressions listed. Asymptotic critical values are from Davidson and Mackinnon (1993). Lag length K is chosen such that the Q-statistic at 36 lags indicates absence of autocorrelation in the residuals. Estimation period is Jan. 4, 1988–Dec. 31, 1991.
[b] The names of firms are available from the authors.
* Significant at the 10% level.
*** Significant at the 1% level.

the variables. Table 3 presents the results of tests for 21 UK firms with four variables: ADRs, corresponding foreign shares, the value of the Pound against the US dollar, and the S&P 500 index. Again, similar results were obtained for the Japanese, Swedish, Dutch and Australian firms (in each case with reference to the appropriate currency), so these results are not reported in order to conserve space. For each firm, the lag length k is chosen by Sims' likelihood ratio test. Both trace and eigenvalue tests indicate that for all fifty-six firms estimated, there exists at least one cointegrating relationship among the variables. Fourteen firms have at least two and twelve firms at least three cointegrating relationships. Each firm's cointegrating vector is calculated and incorporated in the VAR model estimation to capture the long-run equilibrium relationship.

Table 2
Augmented Dickey–Fuller unit root tests[a] – exchange rates and the S&P 500 index:
One unit root – $\Delta y_t = \delta_1 + \eta_1 y_{t-1} + \sum_{i=1}^{K} \phi_{1,i} \Delta y_{t-i} + \epsilon_{1,t}$.
Two unit roots – $\Delta^2 y_t = \delta_2 + \eta_2 \Delta y_{t-1} + \sum_{i=1}^{K} \phi_{2,i} \Delta^2 y_{t-i} + \epsilon_{2,t}$

Variables	One unit root	Two unit roots
British Pound	−1.625	−19.124***
Japanese Yen	−1.334	−18.254***
Swedish Krona	−1.045	−11.552***
Netherlands Guilder	−0.925	−10.002***
Australian Dollar	−1.026	−10.987***
S&P 500 index	−2.115	−20.254***

[a] Each number represents the t-statistics for the hypothesis that $\eta = 0$ in the regressions listed. Asymptotic critical values are from Davidson and Mackinnon (1993). Lag length K is chosen such that the Q-statistic at 36 lags indicates absence of autocorrelation in the residuals. Estimation period is Jan. 4, 1988–Dec. 31, 1991.
*** Significant at the 1% level.

5.2. Decomposition of forecast error variance

Table 4 presents the decomposition of average forecast error variance from the four-variable VAR system for the firms from the five countries. Each number in the table denotes the percentage of 5-day ahead average forecast error variance of the left-hand side variables explained by innovations in the variables on the top. Among the four variables in the VAR system, each country's exchange rate and the US market turn out to be most exogenous in that most of their 5-day ahead forecast error variances are explained by their own innovations. For example, Japanese yen innovations account for 98.62% of its own variance, and innovations in US market explain 96.83% of its own variance. The next most exogenous variable is each country's underlying shares. Their error variances are affected by innovations in the US market and in their corresponding ADRs.

As expected, innovations from each country's underlying shares explain substantial portion of innovations in the corresponding ADRs; 58.61% for Japan, 60.24% for UK, 64.89% for Sweden, 60.78% for Netherlands, and 67.86% for Australia. The influence of innovations in the US market are relatively small compared to those from the underlying shares; 5.33% for Japan, 6.23% for UK, 1.23% for Sweden, 2.11% for the Netherlands, and 5.94% for Australia. Innovations from each country's currency market account for a somewhat larger amount of ADR innovations; 9.19% for Japan, 11.28% for UK, 10.25% for Sweden, 11.43% for Netherlands, and 9.36% for Australia.

One implication of these findings is that US investors in ADRs might realize substantial gains or losses on their share values depending on the foreign currency's value against the US dollar. In other words, US investors bear exchange rate risk even though ADRs are denominated in the US dollar. Another

Table 3
Johansen multivariate cointegration tests[a] – United Kingdom: $\Delta Y_1 = \Gamma_1 \Delta Y_{t-1} + \cdots + \Gamma_{k-1}\Delta Y_{t-k+1} + \Pi Y_{t-k} + \mu + U_t$

Firms[b]	Trace test				Maximal eigenvalue test			
	$\Pi = 0$	$\Pi \leqslant 1$	$\Pi \leqslant 2$	$\Pi \leqslant 3$	$\Pi = 0$	$\Pi \leqslant 1$	$\Pi \leqslant 2$	$\Pi \leqslant 3$
1	91.22***	21.28	2.95	1.04	70.11***	10.09	1.89	1.04
2	52.18***	12.45	6.06	1.25	36.37***	10.65	4.75	1.25
3	68.02***	20.24	5.79	0.50	84.67***	12.34	5.00	0.50
4	105.24***	28.45*	7.64	1.25	96.77***	19.65*	6.75	1.25
5	45.33*	11.02	1.24	0.37	39.32***	9.88	1.05	0.37
6	163.26***	32.84**	9.75	3.94	141.21***	27.87***	13.25***	3.94
7	85.24***	19.45	2.25	1.00	66.47***	10.65	1.75	1.00
8	150.33***	30.02*	8.24	3.54	120.32***	20.78*	6.45	3.54
9	49.23**	12.02	1.29	0.98	29.32**	9.78	9.24	0.98
10	50.24**	13.45	1.54	1.08	46.37**	10.65	3.25	1.08
11	190.33***	38.02***	18.24**	3.99	145.31***	28.88**	11.48	3.99
12	96.96***	21.84	3.00	1.52	72.50**	12.09	2.69	1.52
13	150.24***	30.00*	7.34	3.24	120.22***	20.74*	5.45	3.24
14	199.43***	42.02***	19.24***	4.57	150.32***	38.99***	18.45**	4.57
15	153.33***	31.25**	8.66	3.25	125.43***	21.27**	5.75	3.25
16	81.43***	21.34	5.24	2.08	52.45***	17.24	3.78	2.08
17	210.24***	68.24***	21.78**	4.02	139.32***	34.28***	16.27**	4.02
18	62.96***	13.11	1.75	0.99	42.11***	10.09	1.29	0.99
19	49.24**	9.92	1.24	0.61	27.88**	8.45	1.05	0.61
20	120.33***	24.91	6.24	2.01	84.56***	15.74	3.45	2.01
21	173.86***	33.24**	8.03	4.06	121.54***	33.34***	10.49	4.06

[a] The cointegration equation is based on four variables: (1) UK ADRs, (2) UK underlying shares, (3) British pound spot exchange rates, and (4) the S&P 500 index cash prices. Estimation period is Jan. 4, 1988–Dec. 31, 1991.
[b] The names of firms are available from the authors.
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

implication is that it might be difficult to realize any abnormal arbitrage profits from the price disparity between an ADR and its corresponding underlying share because movements in both the underlying share and the exchange rate would be incorporated in the ADR price. This issue will be examined further in the next section by investigating the speed of the price adjustments.

5.3. Analysis of impulse response functions

The impulse response function traces the effect and persistence of one market's shock to other markets, which tells us how fast information transmits across the markets. Table 5 reports the average impulse responses for UK's ADRs to a unit innovation in corresponding exchange rates against the US dollar, underlying shares, and the S&P 500 index. Table 6 reports similar

Table 4
Decomposition of 5-day ahead average forecast error variance[a]

County	Variables explained[b]	Japanese Yen	By innovations in Underlying stock	S&P 500	ADR
Japan	Japanese Yen	98.62	2.23	0.44	−0.71
	Underlying stock	0.57	87.95	4.45	7.02
	S&P 500 index	0.67	2.44	96.83	0.05
	ADR	9.19	58.61	5.33	26.86
		British Pound	Underlying stock	S&P 500	ADR
UK	British Pound	96.25	3.24	1.45	2.69
	Underlying stock	1.24	82.24	9.35	10.24
	S&P 500 index	0.96	2.24	97.11	0.47
	ADR	11.28	60.24	6.23	23.46
		Swedish Krona	Underlying stock	S&P 500	ADR
Sweden	Swedish Krona	98.71	4.82	0.81	0.87
	Underlying stock	1.09	86.46	4.6	7.19
	S&P 500 index	0.96	2.24	97.11	0.47
	ADR	10.25	64.89	1.23	30.64
		Netherlands Guilder	Underlying stock	S&P 500	ADR
Netherlands	Netherlands Guilder	95.98	0.87	0.99	0.67
	Underlying stock	1.34	86.46	4.6	7.19
	S&P 500 index	0.96	2.24	97.11	0.47
	ADR	10.25	64.89	1.23	30.64
		Australian Dollar	Underlying stock	S&P 500	ADR
Australia	Australian Dollar	95.96	0.8	1.51	1.71
	Underlying stock	1.14	86.38	4.78	7.55
	S&P 500 index	1.99	2.91	94.92	0.63
	ADR	9.36	57.86	5.94	26.84

[a] The numbers reported denote the percentage of 5-day average forecast error variance of the left-hand side variables (I) explained by innovations in the variables (j) on the top. They are

$$\left[\sum_{k=0}^{4} B_{ij,k}^{2} \Big/ \sum_{j=0}^{4}\sum_{k=0}^{4} B_{ij,k}^{2}\right] 100,$$

where $b_{ij,k}$ is calculated from the orthogonalized moving average transformation of 4×1 vector. Estimation period is Jan. 4, 1988–Dec. 31, 1991.

[b] The ordering in the VAR estimation is set (1) Currency, (2) underlying share, (3) S&P 500 index, and (4) ADR. The ADR variables are set to be the last ones because it would be reasonable to assume that ADRs are influenced by the other factors in the system. We perform the same tests with different orderings of the first three variables. The results are not materially different from those reported here.

Table 5
Average impulse responses of UK ADRs to a unit shock in each pricing factor[a]

A unit shock in	Year	Days after shock											
		0	1	2	3	4	5	6	7	8	9	10	20
British Pound	Whole	0.274	0.095	0.022	−0.030	0.020	0.002	0.000	0.002	0.049	−0.001	0.001	−0.007
	1988	0.126	0.112	0.020	−0.024	−0.025	0.022	0.096	−0.003	−0.083	−0.012	−0.069	0.018
	1989	0.312	0.063	−0.025	−0.038	0.005	−0.056	0.022	0.021	−0.011	0.019	0.024	0.013
	1990	0.352	0.032	−0.016	−0.002	−0.054	0.017	0.032	0.016	0.000	0.000	0.012	0.000
	1991	0.361	0.163	−0.063	−0.008	−0.016	0.024	0.002	0.017	0.000	0.002	0.011	0.002
Underlying stock	Whole	0.655	0.023	0.100	−0.078	−0.071	0.032	0.043	−0.017	0.068	0.032	0.043	−0.017
	1988	0.753	0.018	0.090	0.079	0.054	0.064	0.024	−0.012	−0.021	0.001	0.022	0.036
	1989	0.552	0.020	0.057	0.036	0.032	−0.037	−0.092	−0.024	0.093	0.025	−0.011	−0.013
	1990	0.644	0.016	0.152	−0.037	0.023	−0.024	0.093	0.025	−0.011	−0.013	0.024	−0.012
	1991	0.608	0.006	−0.112	0.099	0.025	−0.006	−0.002	0.009	0.015	−0.029	0.077	−0.001
S&P 500 index	Whole	0.303	0.048	−0.021	0.036	−0.032	−0.04	0.069	0.026	−0.041	0.03	0.002	0.019
	1988	0.353	−0.026	0.048	−0.040	0.069	0.026	−0.041	0.030	0.089	0.108	0.058	0.018
	1989	0.335	0.005	0.040	0.013	−0.042	−0.034	−0.122	0.095	0.044	0.069	0.042	0.013
	1990	0.258	0.178	−0.001	0.049	−0.023	−0.028	−0.015	0.003	0.005	0.031	0.009	0.000
	1991	0.293	−0.011	0.027	0.009	0.015	−0.029	0.077	0.017	−0.033	0.005	−0.004	0.008

[a] The numbers reported are the normalized average impulse responses of twenty one UK ADRs on the ith day to an unit innovation in the British pound spot exchange rate, UK underlying shares and the S&P 500 index cash prices, respectively. They are represented by B_{ij} in the orthogonalized moving average transformation of Y_t:

$$\Delta Y_t = \sum_{k=0}^{\infty} \zeta_{t-k},$$

where Y_t is a vector of four variables in the system. Each B_{ij} is divided by its standard error for proper comparison.

Table 6
Average impulse responses of Japanese ADRs to a unit shock in each pricing factor[a]

A unit shock in	Year	Days after shock											
		0	1	2	3	4	5	6	7	8	9	10	20
Japanese Yen	Whole	0.302	0.085	−0.049	−0.030	−0.018	0.038	0.000	0.002	0.049	−0.001	0.001	0.007
	1988	0.061	0.134	0.020	−0.023	0.124	−0.021	0.096	−0.003	−0.083	−0.012	−0.069	0.018
	1989	0.377	0.114	−0.005	−0.038	−0.135	0.087	−0.039	0.038	0.148	0.032	0.170	−0.003
	1990	0.434	0.032	−0.016	−0.046	−0.052	0.016	−0.034	0.062	0.051	0.031	−0.119	−0.023
	1991	0.342	0.141	−0.166	−0.078	0.076	0.178	0.079	0.008	0.065	−0.071	0.011	−0.039
Underlying stock	Whole	0.772	0.013	0.005	0.002	−0.051	−0.018	−0.040	−0.066	0.036	0.080	0.015	0.009
	1988	0.804	0.019	0.190	0.079	0.054	0.064	−0.021	0.009	−0.004	−0.037	−0.102	0.013
	1989	0.837	−0.044	0.057	0.036	−0.053	−0.121	−0.034	−0.068	0.009	0.145	−0.069	0.019
	1990	0.753	0.017	−0.012	−0.053	−0.119	−0.076	−0.027	−0.122	0.094	0.148	0.080	0.013
	1991	0.648	−0.017	−0.112	−0.032	0.026	0.140	−0.037	−0.054	−0.021	0.141	0.093	0.053
S&P 500 index	Whole	0.226	0.008	−0.021	−0.045	0.029	0.005	−0.048	0.027	−0.036	0.048	−0.040	−0.018
	1988	0.273	−0.013	−0.015	−0.019	−0.020	−0.047	−0.015	0.098	−0.143	−0.077	0.128	0.022
	1989	0.167	0.005	0.040	0.103	−0.042	−0.034	−0.122	0.095	0.044	0.069	−0.103	0.013
	1990	0.178	0.178	−0.001	−0.155	0.145	0.021	−0.046	−0.081	−0.064	0.065	−0.028	−0.030
	1991	0.310	−0.011	0.027	−0.005	0.023	0.042	−0.089	0.027	−0.025	0.050	−0.098	−0.006

[a] The numbers reported are the normalized average impulse responses of twenty one Japanese ADRs on the *i*th day to an unit innovation in the Japanese yen exchange rate, Japanese underlying shares and the S&P 500 index cash prices, respectively. They are represented by B_{ij} in the orthogonalized moving average transformation of Y_t:

$$\Delta Y_t = \sum_{k=0}^{\infty} B_k \zeta_{t-k},$$

where Y_t is a vector of four variables in the system. Each B_{ij} is divided by its standard error for proper comparison.

results for Japanese ADRs, Table 7 for Swedish ADRs, Table 8 for Netherlands ADRs, and Table 9 for Australian ADR's. Each impulse response represents a moving average coefficient normalized by its standard error. This normalization is necessary to compare the impulse responses across variables that have different variations. Therefore, each impulse response reported in Table 5 is the average impulse response of UK ADRs to a unit shock in other variables in the VAR system. Tables 6–9 report similar averages across firms for other countries' ADRs.

Most responses occur on day 0, which is the same calendar day. This is as expected because on a given calendar day the US market, where ADRs are traded, is the last one to close. However, the magnitude and persistence of ADR's responses to innovations in other markets are quite different. First of all, shocks from foreign underlying markets (UND in Tables 5–9) are reflected in the prices of ADRs on day 0 most strongly, and then diminish sharply afterward. On day 0 and day 1 they are respectively 0.772, 0.013 for Japan, 0.655, 0.023 for the UK, 0.824, 0.032 for Sweden, 0.833, 0.094 for the Netherlands, and 0.804, 0.094 for Australia. The complete response on day 0 is especially true in the Japanese and UK ADR markets, implying these markets are more efficient in processing new information.

The magnitude of currency shocks (the first block in Table 5) is smaller compared to that of underlying shares' shocks. The currency shocks, however, persist one day longer. For example, on average, UK ADRs' response to a unit shock in the pound/dollar exchange rate is 0.274 on day 0, followed by 0.095 on day 1. For Japanese ADRs, the response to a unit exchange rate shock is 0.302 on day 0, followed by 0.085 on day 1, while for Australian firms, the exchange rate response is 0.232 on day 0 and 0.126 on day 1. For Swedish and Dutch firms, both the day 0 and day 1 response is somewhat smaller. In all cases, the ADR reactions to exchange rate shocks are uniformly small after day 1.

That currency shocks last longer compared to other shocks may be due to uncertainty of information content, rather than market inefficiency. In other words, at an early stage, ADR market participants may not be sure about the content of a shock that has caused unexpected movements in the currency markets. Consequently, they under react to the initial currency shock, and as the content of the shock becomes clearer afterward the full reaction eventually occurs.

It is also worth noting that in the more recent years the magnitude of the currency shock seems to grow whereas the underlying share's shock seems to diminish. This phenomena is more pronounced in the Japanese and UK ADR markets. For instance, in the UK ADRs, the responses to the currency shocks increase to 0.361 in 1991 from 0.126 in 1988 while those to underlying shares' shocks decrease to 0.608 in 1991 from 0.753 in 1988. This may reveal a growing trend of volatile currency markets.

Table 7
Average impulse responses of Swedish ADRs to a unit shock in each pricing factor[a]

A unit shock in	Year	Days after shock											
		0	1	2	3	4	5	6	7	8	9	10	20
Swedish Krona	Whole	0.173	0.035	0.024	0.017	−0.033	0.005	−0.004	−0.088	0.066	0.085	−0.007	0.000
	1988	0.146	0.100	−0.016	−0.031	−0.021	0.089	−0.061	−0.024	−0.004	0.015	−0.021	0.018
	1989	0.136	0.062	−0.015	−0.032	0.049	−0.023	−0.028	−0.015	0.003	0.005	0.031	0.009
	1990	0.192	0.032	0.033	−0.024	−0.004	0.015	−0.021	0.022	0.018	−0.037	0.023	0.004
	1991	0.182	−0.112	0.064	−0.022	0.061	0.134	0.020	−0.023	0.021	−0.021	0.096	−0.003
Underlying stock	Whole	0.824	0.032	0.067	0.020	−0.023	0.124	−0.021	0.096	−0.003	−0.083	−0.012	−0.069
	1988	0.793	0.016	0.090	0.062	0.070	−0.026	0.029	0.050	−0.290	0.001	0.022	0.000
	1989	0.885	0.020	0.062	0.036	−0.026	0.029	0.050	−0.029	−0.021	−0.006	−0.011	−0.011
	1990	0.783	0.018	−0.024	0.054	0.064	−0.021	0.009	−0.004	−0.037	−0.102	−0.082	−0.017
	1991	0.803	0.016	0.052	0.099	0.054	0.064	−0.021	0.009	−0.004	−0.037	0.062	0.013
S&P 500 index	Whole	0.152	0.012	−0.021	0.003	0.007	−0.062	0.006	−0.031	0.073	0.016	0.047	0.012
	1988	0.123	0.010	0.048	0.024	−0.156	−0.074	−0.023	0.082	−0.034	−0.146	0.029	0.014
	1989	0.164	0.011	−0.026	0.013	−0.016	−0.012	−0.029	0.010	0.027	0.041	0.015	0.013
	1990	0.097	0.018	−0.010	0.079	0.119	0.056	−0.011	−0.129	−0.019	−0.017	−0.036	0.002
	1991	0.183	0.013	0.027	0.014	−0.046	−0.129	0.023	0.001	0.046	−0.085	0.001	−0.003

[a] The numbers reported are the normalized average impulse responses of twenty one Swedish ADRs on the *i*th day to an unit innovation in the Swedish krona spot exchange rate, Swedish underlying shares and the S&P 500 index cash prices, respectively. They are represented by B_{ij} in the orthogonalized moving average transformation of Y_t:

$$\Delta Y_t = \sum_{k=0}^{\infty} B_k \zeta_{t-k},$$

where Y_t is a vector of four variables in the system. Each B_{ij} is divided by its standard error for proper comparison.

Table 8
Average impulse responses of Netherland ADRs to a unit shock in each pricing factor[a]

A unit shock in	Year	Days after shock											
		0	1	2	3	4	5	6	7	8	9	10	20
Netherlands Guilder	Whole	0.157	0.046	0.025	−0.002	−0.082	0.015	0.098	0.098	0.048	0.014	−0.082	−0.058
	1988	0.124	0.102	0.016	−0.064	0.008	0.068	−0.076	0.013	0.067	0.021	0.098	0.038
	1989	0.112	−0.072	0.026	−0.032	0.049	−0.023	−0.028	−0.015	0.017	0.005	0.031	0.012
	1990	0.190	0.032	−0.035	−0.024	−0.004	−0.012	0.012	−0.037	0.029	0.012	0.023	0.004
	1991	0.180	0.116	0.002	−0.022	0.061	−0.039	−0.039	0.000	−0.025	−0.056	−0.005	−0.003
Underlying stock	Whole	0.833	0.094	0.057	0.030	−0.046	−0.008	0.143	0.030	0.073	−0.096	0.024	−0.046
	1988	0.633	0.056	0.090	0.062	0.070	−0.025	0.130	−0.021	0.011	−0.007	0.104	0.013
	1989	0.902	0.090	0.062	0.036	−0.026	0.029	0.074	0.076	0.045	0.099	−0.007	−0.002
	1990	0.886	0.083	−0.024	0.054	0.064	−0.021	0.013	0.042	0.033	−0.094	0.077	−0.143
	1991	0.872	0.020	0.052	0.099	0.054	0.064	−0.063	0.027	0.007	−0.185	−0.021	0.010
S&P 500 index	Whole	0.142	0.011	−0.021	0.002	0.016	−0.081	−0.185	0.053	−0.007	0.075	−0.043	0.027
	1988	0.113	0.009	0.048	0.060	0.072	0.075	0.017	−0.051	0.032	−0.095	0.011	0.027
	1989	0.182	0.016	−0.026	−0.018	0.008	−0.019	0.004	−0.001	0.003	−0.009	0.008	−0.001
	1990	0.093	0.008	0.010	0.023	0.171	−0.103	0.073	−0.030	−0.038	0.017	−0.088	−0.032
	1991	0.092	0.010	−0.002	0.013	0.058	−0.002	0.377	0.114	−0.005	−0.038	−0.135	0.087

[a] The numbers reported are the normalized average impulse responses of twenty one Netherland ADRs on the ith day to an unit innovation in the Netherland guilder spot exchange rate, Netherland underlying shares and the S&P 500 index cash prices, respectively. They are represented by B_{ij} in the orthogonalized moving average transformation of Y_t:

$$\Delta Y_t = \sum_{k=0}^{\infty} B_k \zeta_{t-k},$$

where Y_t is a vector of four variables in the system. Each B_{ij} is divided by its standard error for proper comparison.

Table 9
Average impulse responses of Australian ADRs to a unit shock in each pricing factor[a]

A unit shock in	Year	Days after shock											
		0	1	2	3	4	5	6	7	8	9	10	20
Australian Dollar	Whole	0.232	0.126	0.021	−0.034	−0.006	0.023	0.837	−0.044	0.057	0.036	−0.053	−0.121
	1988	0.152	0.114	0.034	0.021	−0.040	0.024	0.167	0.005	0.040	0.103	−0.042	−0.034
	1989	0.196	0.060	0.097	0.011	0.067	−0.011	0.361	−0.116	−0.036	−0.093	0.020	0.094
	1990	0.264	−0.156	−0.039	−0.038	0.148	0.032	0.170	0.088	0.002	0.002	−0.041	0.046
	1991	0.293	0.126	−0.034	−0.068	0.009	0.145	−0.069	0.045	−0.043	−0.010	−0.016	−0.058
Underlying stock	Whole	0.804	0.094	0.057	0.030	−0.046	−0.008	0.143	0.030	−0.050	−0.046	−0.026	−0.003
	1988	0.693	0.056	−0.122	0.095	0.044	0.069	−0.103	0.028	0.034	−0.090	−0.019	−0.058
	1989	0.894	0.090	−0.088	0.001	0.112	−0.015	0.092	−0.039	−0.064	−0.019	−0.028	0.019
	1990	0.856	0.042	−0.024	0.054	0.064	−0.021	0.013	0.042	0.001	0.018	0.007	0.013
	1991	0.890	0.056	0.052	0.099	0.054	0.064	−0.063	0.027	−0.031	0.020	0.005	0.007
S&P 500 index	Whole	0.112	0.010	0.012	0.012	0.068	0.122	−0.089	0.041	−0.017	−0.007	−0.002	0.000
	1988	0.096	−0.088	0.033	−0.003	−0.065	0.088	−0.017	0.124	−0.059	−0.034	0.023	−0.031
	1989	0.082	0.012	−0.092	−0.049	0.042	−0.036	0.001	−0.135	0.039	−0.016	−0.003	0.007
	1990	0.102	0.056	0.039	−0.055	0.078	−0.040	0.134	0.021	0.005	0.019	−0.074	−0.008
	1991	0.156	0.096	0.052	0.056	0.046	−0.068	0.377	0.032	−0.046	0.032	−0.005	0.132

[a] The numbers reported are the normalized average impulse responses of twenty one Australian ADRs on the *i*th day to an unit innovation in the Australian dollar spot exchange rate, Australian underlying shares and the S&P 500 index cash prices, respectively. They are represented by B_{ij} in the orthogonalized moving average transformation of Y_t:

$$\Delta Y_t = \sum_{k=0}^{\infty} B_k \zeta_{t-k},$$

where Y_t is a vector of four variables *I* the system. Each B_{ij} is divided by its standard error for proper comparison.

The contemporaneous responses of the ADRs to innovations in the US market (SP in Tables 5–9) are roughly equivalent, though usually slightly smaller, than their responses to exchange rate innovations. Unlike the currency shocks, the US market shock responses do not appear to extend beyond day 0.

5.4. Regression results

The regression results for Eq. (1) are reported in Table 10. These are estimated as systems of seemingly-unrelated regressions (SUR), and the reported t-statistics are based on White (1980) heteroskedasticity-consistent standard errors. As with the VAR results, within each country classification, we report average coefficient estimates, t-statistics and regression R-Squares. In general, the coefficients for the underlying security for day 0 are positive, large and highly significant. Surprisingly, though the coefficients are smaller in magnitude, they remain positive and highly significant for day 1 in all cases, and in

Table 10
Average coefficients from seemingly-unrelated regression estimates[a]:
$\mathrm{ADR}_{i,t} = a_i + \sum_{j=0}^{2} b_{ij}\mathrm{UND}_{1,t-j} + \sum_{j=0}^{2} c_{ij}\mathrm{EXG}_{i,t-j} + \sum_{j=0}^{2} d_{ij}\mathrm{SP}_{i,t-j} + e_{i,t}$

VAR	UK	Japan	Sweden	Netherlands	Australia
a_1	−0.00	−0.00	0.00	0.00	−0.00
	(−0.00)	(−0.00)	(0.02)	(0.00)	(−0.00)
UND_0	0.63	0.64	0.56	0.57	0.64
	(29.12)***	(41.99)***	(24.26)***	(28.30)***	(27.80)***
UND_1	0.12	0.14	0.08	0.13	0.08
	(5.51)***	(9.23)***	(3.60)***	(6.35)***	(3.23)***
UND_2	0.01	0.03	−0.02	0.06	0.03
	(0.54)	(1.65)*	(−0.89)	(30.9)	(1.39)
EXG_0	0.60	0.72	0.39	0.54	0.60
	(13.55)***	(13.27)***	(7.02)***	(13.86)***	(9.91)***
EXG_1	0.22	0.23	0.23	0.23	0.27
	(5.08)***	(4.33)***	(3.55)***	(6.13)***	(4.37)***
EXG_2	0.03	−0.03	0.03	0.05	0.05
	(0.69)	(−0.67)	(0.39)	(1.12)	(0.91)
SP_0	0.44	0.46	0.61	0.60	0.64
	(12.23)***	(11.63)	(12.90)	(19.75)	(14.14)
SP_1	−0.20	−0.19	−0.32	−0.33	−0.04
	(−5.49)***	(−5.23)***	(−6.46)***	(−10.02)***	(−7.49)***
SP_2	−0.02	−0.08**	−0.03	−0.04	−0.04
	(−0.64)	(−2.00)	(−0.54)	(−1.47)	(−0.86)
R^2	57.58%	62.19%	46.16%	49.88%	52.82%

[a] ADR, UND, EXG and SP denote daily returns on the ADR, the underlying stock, the foreign currency, and the S&P 500 index, respectively. t-statistics (given in parentheses) are based on White (1980) heteroskedasticity-consistent standard errors.
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

two cases, for Japan and for the Netherlands, they are marginally significant for day 2 also. These results, as expected, indicate that ADR returns are very sensitive to returns on the underlying security; however, not all of the adjustment in the ADR price appears to take place within the same calendar day.

Consistent with the VAR impulse responses, for all ADRs, the exchange rate coefficients for both day 0 and day 1 are also highly significant. Again, the majority of the adjustment of ADR prices to exchange rate changes appears to occur contemporaneously, but a substantial portion of the ADR price reaction is deferred until the following day.

The nature of ADR reactions to innovations in the S&P 500 Index appears to differ fundamentally from the reactions to the other pricing factors. As in the case of these other factors, for the S&P 500, the day 0 price response is large, positive and highly significant. However, this is followed by a large, significant negative price response on day 1, and a continuing (albeit largely insignificant) negative response on day 2. Thus, whereas the ADRs appear to *underreact* to innovations in the underlying security and exchange rate, they clearly *overreact* to innovations in the S&P 500 Index.

The regression evidence is not entirely consistent with an informationally-efficient ADR market. One possible interpretation of these results is that markets are still partially segmented, i.e., US investors initially attempt to price the ADRs partly with reference to their own market, rather than to the foreign market in which the underlying shares trade. The resulting mismatches between ADR and underlying security values are eventually eliminated by arbitrageurs, but the arbitrage activity is impeded by nonsynchronous trading times and transactions costs. In the following subsection we provide evidence that a trading rule based on the regression approach does not earn returns high enough to cover the transactions costs faced by most investors.

Another potential interpretation is that, for whatever reason, ADR investors have generally overestimated the degree to which foreign markets on day $t+1$ are influenced by US market innovations on day t; consequently, they overreact to the US market return. The overreaction is corrected on the following day, when the expected price changes in the underlying shares fail to materialize. Of course, this chain of events can only provide a partial explanation of the regression findings; it does not, for example, explain why investors simultaneously under react to innovations in the underlying shares and the exchange rate.

5.5. Regression-based trading rule results

The average X-statistics from applying the regression-based trading rule, in which a long position is taken in each ADR if its predicted return (based on lagged variables only) is greater than or equal to zero, and a neutral position is maintained (i.e., a risk-free security is held) if the ADR's predicted return is less

Table 11
Regression-based ADR trading rule results[a]

	UK	Japan	Sweden	Netherlands	Australia
Average number of trades per ADR:	457	510	461	419	401
Average *X*-statistic (*t*-stat in parentheses)	0.1108% (4.4478)***	0.1174% (3.7253)***	0.0740% (2.1663)**	0.1020% (4.2233)***	0.1234% (3.8090)***
Average Round-turn transaction cost that reduces *X*-statistic to zero:	0.2765%	0.2440%	0.1633%	0.2920%	0.4067%

[a] All figures reported are averages of individual ADRs across country groupings. The *X*-statistics represent risk-adjusted excess returns per day (relative to buy–hold) on a trading rule which takes a long position in the ADR when the predicted ADR return (based on the predetermined values from regressions of ADR returns on underlying factors, reported in Table 10 is $\geqslant 0$, and a neutral position when the predicted ADR return <0. See text for *X*-statistic formula and for derivation of maximum round-turn transaction cost formula.

** Significant at the 5% level.

*** Significant at the 1% level.

than zero, are reported in Table 11. Only the average *X*-statistics are reported across country groupings. These *X*-statistics range in size from 0.0740% per day for Swedish ADRs, to 0.1234% per day for Australian ADRs. All of the *X*-statistics are significant at better than 1% except for Sweden, which is significant at 5%. Table 11 also reports the average number of trades for each ADR, by country grouping, over the four-year period, and the average round-turn trading costs that would reduce the *X*-statistics to zero, as derived in Eq. (5).

Since the *X*-statistic can be interpreted as the average risk-adjusted excess return *per day* over buy-hold, the *X*-statistics in Table 11 are large. For example, assuming 252 trading days per year, the 0.1108% per day excess return for the average actively-managed UK ADR implies a 32% annualized excess return over buy-hold. However, the most important message in Table 11 is that once transactions costs are taken into account, it is unlikely that the regression-based trading rule is worthwhile to pursue: the trading frequencies required to earn the high *X*-statistics are impractically large. Again, take the UK ADRs as an example; the trading rule would have required 457 trades over a four-year period, a trading frequency of nearly one trade every two days in which markets are open. Due to this high trading frequency, a round-turn trading cost of only 0.2765% of asset value would eliminate the excess profits derived from the trading rule.

Previous literature has documented transaction cost sizes. Bhardwaj and Brooks (1992) estimate that the average bid/ask spread alone on US stocks with market prices above $20 per share is about 0.9%. Fleming et al. (1996) estimate that bid/ask spreads faced by large institutional investors trading S&P 500 component stocks is slightly over 0.5%. Both of these estimates exceed the ceilings that eliminate excess profits on the ADR trading rule. However, as Corrado and Lee (1992) note, floor traders on the New York Stock Exchange incur considerably lower transactions costs, and might be able to employ the ADR trading rule profitably. Also, any trader who plans to purchase or sell an ADR for other reasons could use the trading rule to aid in the timing of the transaction.

6. Conclusion

We study the dynamics of information transmission between ADRs and their underlying foreign markets in this paper. ADRs provide a unique opportunity to investigate transmission channels in that they are traded in the US market but represent ownership of foreign underlying shares. Because investors in ADRs (underlying shares) are allowed to switch the shares to corresponding underlying shares (ADRs) subject to transaction costs, the ADRs are priced by arbitrage forces between the two markets. Inevitably, the currency value against the US dollar should be reflected in the ADR prices to avoid any abnormal arbitrage profits. The general movements in the US equity market may also be incorporated because ADRs are traded in the US exchanges just as ordinary US securities.

Specifically, we study the interrelationship between these pricing factors by utilizing a VAR model with cointegration constraints for the ADRs of five countries: Japan, UK, Sweden, Netherlands, and Australia. The forecast error variance and the impulse response functions from the VAR model primarily show that most responses of the ADRs to the unexpected movements of the other market occur on the same calendar day. We also document that although the most influential factor in pricing ADRs is their underlying shares, the role of foreign currency value against the US dollar has been growing, especially in recent years. Moreover, the shocks from the currency markets clearly persist beyond the same calendar day whereas those from the underlying share markets do not consistently extend beyond the same day. The influence of US market movements is also borne out, although this influence is smaller than those of the other factors, and shocks from the US market do not appear to persist beyond the same calendar day.

For the most part, results of regressions of ADR returns on underlying security, exchange rate and US market index returns accord with the VAR findings, although the regression results indicate a greater lag in the adjustment of ADRs to their underlying pricing factors. Overall, the findings of this study with respect to market efficiency are mixed. On the one hand, most price responses in the ADR market occur on the same calendar day, and the signs of the contemporaneous adjustment coefficients are consistent with a-priori expectations. There is, however, some evidence that ADR returns initially underreact to contemporaneous underlying security and especially exchange rate returns, and that they overreact to US market index returns. We conjecture that many investors may be mistakenly pricing these securities with reference to the US market index and that arbitrage activity, while obviously present, is impeded by transactions costs and the uncertainties induced by non-synchronous trading of the ADR and the underlying security. This conjecture is supported by the test of a trading rule based on the regressions, which reveals that risk-adjusted excess returns earned by the trading rule are not large enough to cover the transactions costs most traders would incur.

The regression results may have implications for investors seeking to add international exposure to their portfolios. The fact that ADRs initially overreact to changes in the US market, and underreact to foreign influences (changes in the exchange rate and underlying security) indicate that daily ADR returns are more highly positively correlated with US stock returns than are returns on the underlying foreign securities. It should be noted, however, that the overreaction to the US market is very short-term in nature, being reversed within a few days. Moreover, as shown below, the deviations in ADR prices from their fundamental values are relatively slight, too small to be exploitable in the presence of transactions costs. Thus, for US investors with time horizons of, say, one month or longer, it is not clear that ADRs are less desirable than the underlying foreign stocks.

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