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THE STUDY ON THE NON-LINEAR DYNAMIC CAUSAL RELATIONSHIPS BETWEEN CONSTRUCTION INDEX AND ITS MATERIALS INDEXES

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Key words: asymmetric threshold co-integration model, stock market, construction index, cement index, steel index.

ABSTRACT

This paper aims to examine the short-run and long-run non-linear dynamic relationship between indexes of construction and cement or steel in the Taiwan stock markets over the 1995-2011 periods. In addition to traditional linear co-integration tests, the threshold co-integration and asymmetric threshold error-corrrection models (TECM) suggested by Enders and Siklos (2001) are used. Linear co-integration tests reveal no co-integration between the construction index and either of the cement and steel indexes, while threshold co-integration tests show existence of the co-integration relationship and asymmetric adjustment. Further analysis from TECM Granger causality tests finds evidence of a bi-directional causality between cement index and construction index, and a uni-directional causality going from steel index to construction index. These findings have important implications for the investors in the Taiwan stock markets.

I. INTRODUCTION AND LITERATURE REVIEW

The construction industry occupies an important position in contributing to the international competitiveness and economic prosperity of a country, and has been called industrial locomotive for an extended time. The activity of this industry is highly integrated with national infrastructure and creates many employment opportunities, thus construction industry is a vital sector for most countries. Over the past decade, the construction sector happens to be one of the fastest growing sectors in many countries because of real-estate boom. Meanwhile, the construction activities have triggered off and fuelled demand in many important sectors like cement, steel, paints and chemicals, etc. Therefore, understanding the linkages between construction index and its related materials indexes attracts great attention from many stock investors who invest in at least one of these stocks.

The interrelations among stock indexes have been examined extensively scholarly literature after the October 1987 stock market crash. Most researchers focus on the interrelationship among international stock indexes and suggest that there is strong linkage between them. For example, Lin et al. (1994) show bi-directional cross-market interdependence in returns and volatilities between the US and Japan markets. Investigating return and volatility spillovers from Japan and the US to seven Asian markets, Miyakoshi (2003) finds that the volatility of the Asian market is mainly influenced by Japan than by the US. Ozdemir and Cakan (2007) focus on the non-linear dynamics between stock indexes of the US, Japan, France and the UK. They find that there is a strong bi-directional non-linear causal relationship between the US and the others. While the US stock market Granger causes significantly the other considered stock markets, Japan and France do not Granger cause the US, but just the UK does. Recently, Gupta and Guidi (2012) use co-integration methodology to explore links between the Indian stock market and three developed Asian markets (Hong Kong, Japan and Singapore), and find a short-run relationship and absence of a strong long-run relationship among these markets. However, existing empirical evidence on the relationship between construction index and other indexes in a specific country is relatively limited.

In a related study, Guo (2007) applies linear co-integration and Granger causality tests to investigate the relationship among the indexes of construction, steel and cement industries. The results find a long-term equilibrium relationship among

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these indexes and a unidirectional Granger causality from construction to cement index. However, their empirical findings depend on the linear econometric model which might ignore non-linear relation between variables and asymmetric adjustment mechanism toward equilibrium and therefore lead low testing power.

In fact, the past two decades have witnessed increasing non-linear linkage among stock prices in the literature (Masih and Masih, 2001; Ozdemir and Cakan, 2007; Beine, 2008; Qiao et al., 2011). These non-linearities are normally attributed to factors such as non-linear transaction costs, the role of noise traders, infrequent trading and regime shifts. To investigate the possible non-linear dynamics among variables, various non-linear analysis tools have been developed in the literature. Among these tools, the threshold autoregression model is considered as an enormously influential and useful one in the economics and finances.[1] Especially, this type of model provides more complete explanations for short-run and long-run dynamic causal relation between variables and allows for asymmetric adjustment to their long-run equilibrium relation.

This paper contributes to existing empirical literature by analyzing the short-run and long-run non-linear dynamics between indexes of construction and cement or steel in the Taiwan stock market. Understanding the dynamics, there might be potential benefits in considering these indexes for a possible investment portfolio. The paper has twofold objectives. First, this paper examines whether construction index and cement/steel index are co-integrated in the long term and their asymmetric adjustment process to this long-run relationship. The work provides us a more detailed understanding of the long-run relation behavior among the above indexes and their appropriate response to stock market shock. Second, this paper detects the short-term and long-run non-linear causal associations between these indexes. To achieve this goal, this paper constructs the joint behavior of the involved index series using the asymmetric threshold co-integration and threshold error-corrrection models (TECM) of Enders and Siklos (2001), then performing an TECM-based non-linear Granger causality test. Identifying the dynamic causality can help investors design investment portfolio and risk management. Unlike previous research, this paper especially focuses on the non-linear interrelation between construction index and steel or cement index. This paper attempts to provide further insight into long-run relationship, adjustment behavior and dynamic causality between these indexes.

The empirical results illustrate the importance of testing for asymmetric and non-linear dynamics between construction index and its material indexes. First, although the linear co-integration test fails to find co-integration relation, the threshold co-integration test identifies the existence of threshold co-integration and asymmetric adjustment. The presence of threshold co-integration relationship suggests that both prices of construction index and either of cement and steel indexes tend to move together in the long run. Second, further results from causality tests show that non-linear Granger causality between construction index and cement index is bi-directional but steel index exerts non-linear impact on construction indexes both in the long run and short run. These findings demonstrate that no matter how long or short the investment period is, cement and steel indexes are useful in predicting construction index, while construction index only can be used to predict cement index in Taiwan stock market. Therefore, investors could construct investment portfolio to earn potential gains by applying the co-integrated and causal information of the above results.

The remainder of this paper proceeds as follows. Section 2 briefly presents traditional linear co-integration test and Enders-Siklos (2001) approach to asymmetric threshold co-integration testing used here. Section 3 describes the data and provides the empirical results of the application of linear and non-linear co-integration tests to weekly cement, steel and construction indexes and examines the extent to non-linear causality of these indexes. The final section concludes.

II. METHODOLOGIES

This paper mainly utilizes both conventional linear and advanced non-linear techniques to analyze the short-term and long-term interrelationships between construction index and its material indexes in Taiwan, respectively. Several econometric techniques are used in this paper. These techniques are introduced as follow.

1. Traditional Linear Unit Root Tests

Since Granger and Newbold (1974) suggested spurious regressions, various unit root tests are developed to check the stationary of time series in the literature. Among different testing methods, first, we tested the for stationarity of each variable by employing three traditional unit root test techniques, namely, ADF (Dickey and Fuller, 1981), PP (Phillips and Perron, 1988), and KPSS (Kwiatkowski et al., 1992). Since the estimation might be biased if the lag length and bandwidth are pre-designated without rigorous determination, based on the ‘‘principle of parsimony’’. The Akaike information criterion (AIC) for the ADF test and the Bartlett kernel based criterion proposed by Newey and West (1994) for the PP and KPSS tests are utilized to determine the optimal number of lags and optimal bandwidth, respectively.

2. Advanced Non-linear KSS Unit Root Test

It was suggested that the stock indices might exhibit non-linear behavior, and thus traditional unit root tests have lower power in detecting their mean reverting equilibrium

[1] A recent review on the threshold autoregression model and its application in the economics and finances see Hansen (2011).

tendency. We therefore employ a newly developed ''non-linear'' stationary test advanced by Kapetanios et al. (2003) (henceforth, KSS) to determine whether the underlying series are non-linear stationary.

The KSS test is to detect the presence of non-stationarity against a non-linear but globally stationary exponential smooth transition autoregressive (ESTAR) process. The model is expressed as below:

$$\Delta Y_t = \gamma Y_{t-1}[1-\exp(-\theta Y_{t-1}^2)] + \nu_t, \quad t = 1, 2, ..., T \quad (1)$$

where Y_t is the data series at time t, $\theta \geq 0$ is the transition parameter of the ESTAR model that governs the speed of transition, and ν_t is an independent and identically distributed (i.i.d.) error with zero mean and constant variance. We are interested in testing the null hypothesis of $\theta = 0$ against the alternative of $\theta > 0$. Under the null hypothesis, Y_t follows a linear unit root process, but under the alternative, Y_t follows a non-linear but globally stationary ESTAR process assumed that $-2 < \gamma < 0$. However, the parameter γ is not identified under the null hypothesis. To overcome this problem, Kapetanios et al. (2003) followed Luukkonen et al. (1988) to compute a first-order Taylor series approximation to the $[1-\exp(-\theta Y_{t-1}^2)]$ under the null hypothesis of $\theta = 0$ and derive a t-statistic for the null $\delta = 0$ (non-stationarity) against the alternative $\delta < 0$ (non-linear ESTAR stationarity) in the following auxiliary regression with the p augmentations:

$$\Delta Y_t = \delta Y_{t-1}^3 + \sum_{i=1}^{p-1} \beta_i \Delta Y_{t-i} + \nu_t \quad (2)$$

where δ and β_i are estimated parameters and p is lag length of the model. After estimating the model, the t statistic for $\delta = 0$ against $\delta < 0$ can be obtained as

$$t = \hat{\delta} / \mathrm{se}(\hat{\delta}) \quad (3)$$

where $\hat{\delta}$ is the OLS estimate of δ and $\mathrm{se}(\hat{\delta})$ is the standard error of $\hat{\delta}$. Although the t statistic does not have an asymptotic normal distribution but its asymptotic critical value can be found in Kapetanios et al. (2003).

3. Johansen's Co-integration Tests

This paper employs co-integration tests for the long run co-movement among the underlying stock indexes. The methodology employed here is the more powerful Johansen multivariate maximum likelihood method in fully specified error correction model (ECM) and the Johansen (1994) idea of determining the co-integration rank in the presence of a linear trend and a quadratic trend.

The elaborate works developed by Johansen (1988, 1990, 1994) have five vector autoregression (VAR) models with ECM, which are presented in the following forms:[2]

$$\mathrm{H}_0(\mathrm{r}): \Delta X_t = \Gamma_1 \Delta X_{t-1} + ... + \Gamma_{k-1} \Delta X_{t-(k-1)} + \alpha\beta' X_{t-1} + \Psi D_t + \in_t \quad (1988) \quad (4)$$

$$\mathrm{H}_1^*(\mathrm{r}): \Delta X_t = \Gamma_1 \Delta X_{t-1} + ... + \Gamma_{k-1} \Delta X_{t-(k-1)} + \alpha(\beta', \beta_0)(X'_{t-1}, 1)' + \Psi D_t + \in_t \quad (1990) \quad (5)$$

$$\mathrm{H}_1(\mathrm{r}): \Delta X_t = \Gamma_1 \Delta X_{t-1} + ... + \Gamma_{k-1} \Delta X_{t-(k-1)} + \alpha\beta' X_{t-1} + \mu_0 + \Psi D_t + \in_t \quad (1990) \quad (6)$$

$$\mathrm{H}_2^*(\mathrm{r}): \Delta X_t = \Gamma_1 \Delta X_{t-1} + ... + \Gamma_{k-1} \Delta X_{t-(k-1)} + \alpha(\beta', \beta_1)(X'_{t-1}, t)' \mu_0 + \Psi D_t + \in_t \quad (1994) \quad (7)$$

$$\mathrm{H}_2(\mathrm{r}): \Delta X_t = \Gamma_1 \Delta X_{t-1} + ... + \Gamma_{k-1} \Delta X_{t-(k-1)} + \alpha\beta' X_{t-1} + \mu_0 + \mu_1 t + \Psi D_t + \in_t \quad (1994) \quad (8)$$

where Γ_t and Ψ are coefficient matrices, α are adjustment parameter matrices, β are cointegrating matrices, D_t are deterministic dummies, and μ_0 and μ_1 are vectors of constant and trend coefficients, respectively. The error terms $\in_t$ are assumed to be i.i.d. N(0, Ω) where Ω is variance-covariance matrix.

The Johansen analysis provides two different likelihood ratio (LR) tests, the trace test and the maximum eigenvalue test, to determine the number of co-integrating relations or vectors (q). The hypothesis of the two tests can be specified in terms of the rank of the long run impact matrice $\prod$, where $\prod = \alpha\beta'$. The trace test takes the null hypothesis that rank($\prod$) $\leq q$ against a general alternative. The maximum eigenvalue test examines the null hypothesis of rank($\prod$) $= q$ against the specific alternative of rank($\prod$) $= q + 1$. It should be noted that the trace and maximum eigenvalue statistics depend on the sample size and the number of lags in the VAR models. To avoid the problem of size distortion, this paper uses critical values for the Johansen's co-integration tests from Osterwald and Lenum (1992). As to the optimal number of lags, it is usually chosen by model selection criterion such as the Akaike information criterion (AIC) or Schwarz Bayesian criterion (SBC).

4. Threshold Co-integration and Asymmetric Adjustment

Bierens (1997) indicates that the conventional tests for the unit root and co-integration, whether proposed by Engle and Granger (1987) or Johansen (1988), are misspecified when the

[2] The 1990 equations (4 and 5) are from Johansen and Juselius (1990).

true nature of the adjustment process is non-linear and the speed of adjustment varies with the magnitude of the disequilibrium. This paper thus employs the asymmetric threshold co-integration techniques elaborated by Enders and Granger (1998) and Enders and Siklos (2001). This is indeed a residual-based two-stage estimation as developed by Engle and Granger (1987). The differences between them are addressed on the formulation of linearity and non-linearity from their second stage of the unit root test. The equation is expressed as the following in the first stage.

$$Y_{1,t} = \alpha + \beta Y_{2,t} + \mu_t \tag{9}$$

where $Y_{1,t}$ and $Y_{2,t}$ are both $I(1)$ series of stock indexes. α and β are estimated parameters and μ_t is the disturbance term that may be serially correlated.

The second stage focuses on the coefficient estimates of ρ_1 and ρ_2 in the following regression:

$$\Delta\mu_t = I_t \rho_1 \mu_{t-1} + (1 - I_t)\rho_2 \mu_{t-1} + \sum_{i=1}^{p-1} \gamma_i \Delta\mu_{t-i} + \varepsilon_t \tag{10}$$

where μ_t is extracted from Eqn. (8), γ_i are autoregressive coefficients, ρ_1 and ρ_2 are the speed of adjustment coefficients, and ε_t is the white-noise disturbance. The term I_t is the Heaviside indicator function such that $I_t = 1$ if $\mu_{t-1} > \tau$ and $I_t = 0$ if $\mu_{t-1} \le \tau$, where τ denotes the unknown threshold value. A necessary condition for $\{\mu_t\}$ to be stationary is: $-2 < (\rho_1, \rho_2) < 0$.

Eqn. (9) represents the threshold autoregressive (TAR) model of the disequilibrium error, where the test for the threshold behavior of the disequilibrium error is termed the threshold co-integration test for variables in Eqn. (8). Assuming the system is convergent, $\mu_t = 0$ can be considered as the long-run equilibrium value of the sequence. We test the null of $\rho_1 = \rho_2 = 0$ for the co-integration relationship, and the rejection implies the existence of a co-integration relationship between variables. The finding of $\rho_1 = \rho_2 = 0$ enables us to proceed with a further test for symmetric adjustment (i.e., H_0: $\rho_1 = \rho_2$) by using a standard F-test. When the coefficients of regime adjustment are equal (symmetric adjustment), Eqn. (9) converges the prevalent ADF test. Rejecting both the null hypotheses of $\rho_1 = \rho_2 = 0$ and $\rho_1 = \rho_2$ implies the existence of threshold co-integration and the asymmetric adjustment.

Instead of estimating Eqn. (9) with the Heaviside indicator depending on the level of μ_{t-1}, the decay could also be allowed depending on the change in μ_{t-1} in the previous period. The Heaviside indicator could then be specified as $I_t = 1$ if $\Delta\mu_{t-1} > \tau$ and $I_t = 0$ if $\Delta\mu_{t-1} \le \tau$, where τ is the unknown threshold value. As noted by Enders and Granger (1998), this model is especially valuable when the adjustment is asymmetric such that the series exhibits more momentum in one direction than the other. This model is termed the momentum threshold autoregressive (M-TAR) model. The TAR model is used to capture a deep cycle process if, for example, positive deviations are more prolonged than negative ones. On the other hand, the M-TAR model allows the autoregressive decay to depend on $\Delta\mu_{t-1}$. As such, the M-TAR representation may capture sharp movements in a sequence. As there is generally no presumption as to whether to use the TAR or M-TAR model, the recommendation is to select the adjustment mechanism by a model selection criterion such as AIC or SBC.

5. TECM and M-TECM Granger Causality Test

Based on the estimation of TAR or M-TAR model, the corresponding TECM or momentum TECM (M-TECM) can be expressed as the following:

$$\Delta Y_{it} = \alpha_i + \gamma_1 Z_{t-1}^{+} + \gamma_2 Z_{t-1}^{-} + \sum_{t=1}^{\kappa_1} \delta_i \Delta Y_{1t-i} + \sum_{t=1}^{\kappa_1} \theta_i \Delta Y_{2t-i} + v_{it} \ ,$$

$$i = 1, 2 \tag{11}$$

where α_i is intercept, δ_i and θ_i are estimated coefficients, v_{it} is white-noise disturbance. Here, $Z_{t-1}^{+} = I_t \hat{u}_{t-1}$ and $Z_{t-1}^{-} = (1 - I_t)\hat{u}_{t-1}$, given $I_t = 1$ if $\hat{u}_{t-1} \ge \hat{\tau}$ and $I_t = 0$ if $\hat{u}_{t-1} < \hat{\tau}$ for TECM and $I_t = 1$ if $\Delta\hat{u}_{t-1} \ge \hat{\tau}$ and $I_t = 0$ if $\Delta\hat{u}_{t-1} < \hat{\tau}$ for M-TECM, where $\hat{u}_{t-1}$ is obtained from Eqn. (8) and $\hat{\tau}$ is estimated threshold value.

From this formulation, the Granger-Causality tests are employed to examine whether all the coefficients of ΔY_{1t} or ΔY_{2t} are jointly statistically different from zero in the short run and/or whether the γ_j coefficients of the error-correction term are significant in the long run with a standard F-test. Due that Granger causality tests are very sensitive to the selection of lag length, various model selection criterions could be applied to determine the appropriate lag length ex ante.

III. DATA AND EMPIRICAL RESULTS

1. The Data

The data consists of the weekly closing prices of construction index and its materials indexes, cement and steel indexes, traded on the Taiwanese Stock Exchange (TSE). The sample period covers from August 12, 1995 to July 4, 2011, with a total of 827 observations. The data are obtained from the database of Taiwan Economic Journal (TEJ). In the following analysis, the three weekly indexes are expressed in natural logarithm. The evolution of these considered logarithmic series is shown in Fig. 1.

Table 1 presents the descriptive statistics for the weekly indexes of construction, cement, and steel. The three indexes exhibit a positive mean with significant skewness and kurtosis, suggesting fat-tailed behavior and possibly some extreme values in the sample. The Jarque-Bera (JB) tests for normality indicate these weekly indexes are not normally distributed.

Table 1. Summary statistics for variables.

	Construction	Cement	Steel
Mean	5.2991	4.2736	4.3593
Max.	6.3496	5.1725	5.1455
Min.	4.0328	3.1764	3.3407
Std. Dev	0.6076	0.4584	0.3674
Skewness	-0.3670	-0.4250	-0.4401
Kurtosis	2.1081	2.5243	2.9569
Jarque-Bera	45.9818***	32.6981***	26.7639***
	(0.000)	(0.000)	(0.000)
L-B Q(24)	45.368***	31.495	51.889***
	(0.005)	(0.140)	(0.001)
Obs.	827	827	827

Notes: 1. All observations are taken logarithms in this study.
2. *, ** and *** denote significance at 10%, 5% and 1% significance level, respectively.
3. Jarque-Bera is the statistic of normal test. It are computed to test the null hypotheses H_0: X~Normal distribution, $JB = \frac{T-n}{6}\left(s^2 + \frac{1}{4}(k-3)^2\right)$, where T is the number of parametric estimated, n is the number of observations, s is skewness, k is kurtosis.
4. L-B Q is the statistics of Ljung-Box Q.

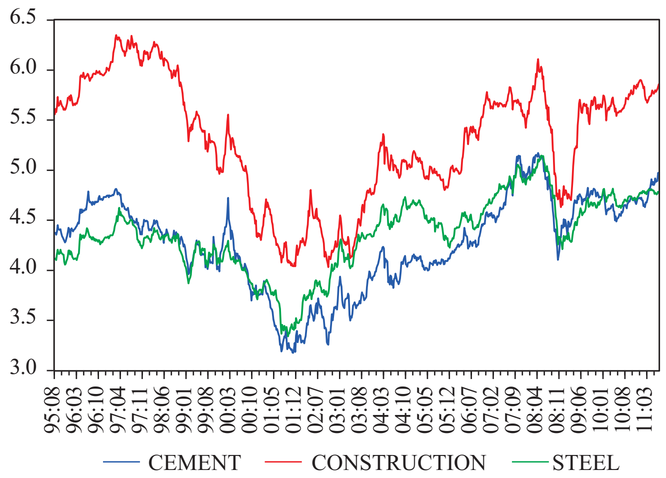

Fig. 1. Time series of the construction, cement and steel indexes.

The Ljung-Box Q statistics with 24 lags show strong autocorrelation in the indexes of construction and steel. The significant autocorrelations demonstrate the existence of nonlinear dependence in these two indexes.

2. Results of Unit Root Tests

This paper mainly uses co-integration and Granger causality techniques to examine the relationship between the construction index and its material indexes. Before performing co-integration tests, it is necessary to examine whether each stock index to be considered is stationary. The stationary characteristic of the underlying index is checked by applying three different unit root tests: ADF, PP and KPSS tests. The ADF and PP tests share the null hypothesis that a given series has a unit root, while the KPSS has a reversed null hypothesis of stationarity. The KPSS test is conducted to check the robustness of the other two unit root tests.

For the sake of parsimony, this paper uses the Akaike information criterion (AIC) with lag length up to 20 for ADF and PP tests to gauge the optimal number of lags, the Bartlett kernel-based criterion (proposed by Newey and West (1994)) for KPSS test to determine the optimal bandwidth.

Table 2 lists the results of various unit root tests for the level and the first difference of weekly construction, cement, and steel indexes. The ADF and PP tests reject the null hypothesis of a unit root at the 5% significance level for the three indexes. The KPSS test confirms the results from the above two tests by rejecting the null hypothesis of stationary for these indexes. After first differencing, however, all unit root tests suggest there is no unit root for construction, cement, and steel indexes.

Besides the above three conventional linear unit root tests, this paper further applies the non-linear KSS unit root test suggested by Kapetanios et al. (2003) to detect the appearance of non-linear unit root. The results of KSS unit root test listed in Table 3 suggests there is a non-linear unit root in each of the construction, cement and steel indexes since the corresponding t statistic is insignificant at the 10% level. Together with the results of linear and non-linear unit root tests, we therefore conclude that all the construction, cement, and steel stock indexes are non-stationary and integrated of order one, I(1).

3. Results of Linear Co-integration Tests

Given the results of unit root test, this paper next explores the existence of co-integration relationship between construction index and its material indexes by applying well-known co-integration test developed in Johansen (1988, 1990, 1994). The Johansen co-integration test provides two types of LR tests, the trace test and the maximum eigenvalue test. Notably, the outcome of Johansen co-integration test is related to the lag structure of the data and the deterministic components in the co-integrating equation. In this paper, the optimal lag length for the Johansen test is selected by AIC with a maximum lag length of 8 lags. To evaluate the sensitivity of the Johansen test to the deterministic component, this paper adopts five model specifications in Eqns. (4)-(8).

Table 4 lists the results of Johansen co-integration test for cement index and construction index. In the Table, the third rows report the results of the trace test and maximum eigenvalue test, respectively. The results from the two tests illustrate no evidence of co-integration between cement index and construction index. The LR statistics for trace test cannot reject the null of no co-integration (r = 0) at the 5% significance level for all model specifications regarding the deterministic components. The LR statistics for the maximum eigenvalue test produce similar results for all five models. The

Table 2. Results of various unit root tests.

	Level			First difference		
	ADF	PP	KPSS	ADF	PP	KPSS
Construct	-1.5605(2)	-1.5558	0.6576**	-12.6481(3)***	-27.5005***	0.1862
Cement	-1.0505(1)	-1.0840	10.8904***	-14.8772(2)***	-29.6902***	0.1966
Steel	-1.6172(3)	-1.4272	9.2547***	-12.7397(3)***	-26.6105***	0.0746

Notes: 1. ** and *** denote significance at the 5% and 1% significance level, respectively; the numbers in the parentheses are the appropriate lag-lengths selected by minimizing AIC.

2. The critical value for the 10%, 5% and 1% significance level of ADF, PP and KPSS are (-2.567894, -2.863559, -3.435176), (-2.567891, -2.863552, -3.435161) and (0.3470, 0.4630, 0.7390).

3. The null hypothesis of ADF and PP are non-stationary (unit root); the null hypothesis of KPSS is stationary (no unit root).

Table 3. Results of the non-linear unit root test – KSS test.

	t Statistics on $\hat{\delta}$	
	Level	First difference
Construction	-1.5686(1)	-12.1309(2)***
Cement	-1.3020(1)	-12.0465(3)***
Steel	-1.6429(2)	-11.8993(1)***

Notes: 1. The numbers in the parentheses are the appropriate lag-lengths selected by minimize AIC.

2. The simulated critical values for the KSS tests are tabulated in Kapetanios et al. (2003).

3. *, ** and *** denote significance at the 10%, 5% and 1% significance level, respectively.

Table 4. Results of johansen co-integration test for cement index and construction index.

	Model 1		Model 2		Model 3		Model 4		Model 5	
	H_0		H_1^*		H_1		H_2^*		H_2	
Rank	$T_0(r)$	$C_0(5\%)$	$T_1(r)$	$C_1^*(5\%)$	$T_1(r)$	$C_1(5\%)$	$T_2(r)$		$T_2(r)$	$C_2(5\%)$
r = 0	5.2530	12.3209	7.1930	20.2618	6.9724	15.4947	12.9304	25.8721	11.7961	18.3977
r ≤ 1	0.0549	4.1299	1.9940	9.1646	1.8465	3.8415	3.2261	12.5180	2.1336	3.8415

Notes: 1. $T_0(r)$, $T_1^*(r)$, $T_1(r)$, $T_2^*(r)$, and $T_2(r)$ denote the LR test statistics for all the nulls of $H(r)$ vs. the alternative of $H(p)$ of Johansen's five models.

2. $C_0(5\%)$, $C_1^*(5\%)$, $C_1(5\%)$, $C_2^*(5\%)$, and $C_2(5\%)$ are the 5% LR critical value for Johansen's five models, which are extracted from Osterward-Lenum (1992).

3. The model selection follows Nieh and Lee's (2001) decision produce, diagnosing models one by one until the model that can not be rejected for the null.

4. VAR lag-length is 3 for all the models, which is selected based on minimize numbers of AIC.

Table 5. Results of johansen co-integration test for steel index and construction index.

	Model 1		Model 2		Model 3		Model 4		Model 5	
	H_0		H_1^*		H_1		H_2^*		H_2	
Rank	$T_0(r)$	$C_0(5\%)$	$T_1(r)$	$C_1^*(5\%)$	$T_1(r)$	$C_1(5\%)$	$T_2(r)$	$C_2^*(5\%)$	$T_2(r)$	$C_2(5\%)$
r = 0	3.531	12.321	6.565	20.262	6.255	15.495	10.649	25.872	9.673	18.398
r ≤ 1	0.109	4.130	2.590	9.165	2.528	3.842	2.954	12.518	2.005	3.842

Notes: see the ones in Table 2.

absence of co-integration indicates that there is no a stable long-run relationship between cement index and construction index.

The results of Johansen co-integration test for steel index and construction index are listed in Table 5. Both the trace and maximum eigenvalue tests show no evidence of co-integration between the two indexes. For all five model specifications regarding the deterministic components, the LR statistics for the trace and maximum eigenvalue tests cannot reject the null of no co-integration at the 5% significance level. The findings demonstrate that there is also no long-run relationship between steel index and construction index.

Table 6. Results of the enders-siklos test for asymmetric threshold co-integration for cement index and construction index.

	TAR	MTAR	TAR-T	MTAR-T
ρ_1	0.00143	-0.00325	0.00245	-0.00298
ρ_2	-0.02491**	-0.01657**	-0.02378***	-0.03946***
F_C	3.7163	3.0813	4.5897	**6.4405***
F_A	3.0982*	1.8349	4.8358**	**8.5177*****
r	0	0	0.23251	**-0.03103**
lag	3	2	1	2
AIC	387.667	388.938	385.923	**382.240**

Notes: 1. The lag-length of difference Ks selected by minimizing AIC; r is the estimated threshold value.
2. F_C and F_A denote the F-statistics for the null hypothesis of no co-integration and symmetric adjustment. Critical values are taken from Enders and Siklos (2001).
3. *, ** and *** denote significance at the 10%, 5% and 1% significance level, respectively.
4. The threshold values of the TAR-T model and the MTAR-T model are 0.23251 and -0.03103.

Overall, the empirical results from Johansen co-integration test indicate that no long-run equilibrium relationship exists between construction index and either of the cement index and steel index. The results might not help investors decide on an optimal investment strategy. However, Johansen's technique relies on the linear assumption which implies the constant adjustment speed despite that stock market is uptrend or downtrend. This paper therefore turns to study the co-integration relationship with asymmetric adjustment speed using the advanced threshold co-integration test of Enders and Siklos (2001).

4. Results of Threshold Co-integration Tests

Tables 6 and 7 present the results of the estimation and test of threshold co-integration model for construction index and cement index or steel index, respectively. Based on the 'Principle of Parsimony', AIC suggests that the most applicable threshold model is MTAR-T (MTAR model with threshold value) for construction index and cement index and TAR-T (TAR model with threshold value) for construction index and steel index, where the threshold values are found to be -0.031 and 0.472, respectively, based on Chan's (1993) method. Table 6 provides the results for construction index and cement index. Here this paper focuses on the case of the best fitted MTAR-T model in the final column. For the model, the value of F_C statistic (6.44) indicates that the null hypothesis of no co-integration ($\rho_1 = \rho_2 = 0$) is rejected at the 5% significance level, while the value of F_A statistic (8.54) indicates the hypothesis of symmetric adjustment ($\rho_1 = \rho_2$) is strongly rejected at the 1% significance level. Therefore, construction index and cement index are co-integrated and their adjustment toward equilibrium appears to be asymmetric. The results for construction index and steel index are listed in Table 7. Since the TAR-T model is best fitted for the two indexes, this paper turns to observe the result of this model. As shown in the third column, the values of both F_A and F_C statistics (5.96 and 5.55) indicate that there also exists a significant threshold co-integration relationship and asymmetric adjustment between construction index and steel index. Overall, the above results demonstrate the existence of a non-linear threshold co-integration relationship and asymmetric adjustment behavior between indexes of construction and cement or steel. For investors, these findings might be helpful in their investment decision and portfolio management.

Table 7. Results of the enders-siklos test for asymmetric threshold co-integration for steel index and construction index.

	TAR	MTAR	TAR-T	MTAR-T
ρ_1	0.00288	-0.00375	0.00411	-0.00376
ρ_2	-0.01779**	-0.00725	-0.01788***	-0.01607*
F_C	3.0825	1.64061	**5.9571***	2.3822
F_A	3.1596*	0.2864	**5.5505****	1.7642
r	0	0	**0.4717**	-0.03435
lag	2	2	1	1
AIC	392.252	395.144	**389.703**	393.655

Notes: The threshold values of the TAR-T model and the MTAR-T model are 0.47170 and -0.03435.

5. Results of TECM Granger Causality Tests

Given the threshold co-integration results found in the previous subsection, the next step proceeds with the Granger causality test using the advanced TECM (or M-TECM) model. Table 8 presents the estimated results of M-TECM model and the Granger causality tests based on the M-TECM for cement index and construction index.[3] The optimal lag length for the M-TECM model is 2 determined by AIC. The autoregressive conditional heteroskedasticity (ARCH) tests for model residuals show that the M-TECM model is desirable. For the adjustment speed toward equilibrium, there are approximately -45.2 percent and -51.3 percent in the cement index and the construction index, respectively, when change in the previous disequilibrium error are in the higher regime (above the threshold value of -0.031). In the lower regime (below the threshold of -0.031), the adjustment seed for the cement index is only approximately -3.4 percent and that for the construction index is approximately -21.1 percent. Except in the case of the cement index under the lower regime, the other adjustment speeds is statistically significant at the 10% level.

[3] Since the best fitted threshold model for the two indexes is the M-TAR, their ECM representation is the M-TECM.

Table 8. Results of the M-TECM model and granger causality test for cement index and construction index.

	Cement	Construction
Constant	0.0024 (1.125)	0.0015 (1.021)
$Cement_{t-1}$	0.8931 (5.852)***	**-0.7630 (-4.376)*** **
$Cement_{t-2}$	0.5187 (5.133)***	**-0.0823 (-3.291)** **
$Construct_{t-1}$	0.4637 (4.288)**	0.8911 (7.125)***
$Construct_{t-2}$	0.0726 (1.016)	0.6715 (7.216)***
Z^{+}_{t-1}	**-0.4524 (-5.131)*** **	**-0.5130 (-6.129)*** **
Z^{-}_{t-1}	-0.0341 (-1.235)	**-0.2111 (-2.983)* **
H_0: $\gamma_1 = \gamma_2 = 0$	7.1147***	8.8986***
H_0: $\theta_1 = \theta_2 = 0$	4.2147**	
H_0: $\delta_1 = \delta_2 = 0$		7.8873***
H_0: $\theta_1 = \theta_2 = \gamma_1 = 0$	6.1891**	
H_0: $\theta_1 = \theta_2 = \gamma_2 = 0$	2.1108	
H_0: $\delta_1 = \delta_2 = \gamma_1 = 0$		11.8141***
H_0: $\delta_1 = \delta_2 = \gamma_2 = 0$		5.0152**
H_0: $\gamma_1 = \gamma_2 =$ (Cement)	6.3156**	
H_0: $\gamma_1 = \gamma_2 =$ (Construction)		6.4512**
AIC	-221.9417	-217.6714
ARCH(4)	0.223 [0.782]	0.698 [0.443]

Notes: 1. *, ** and *** denote significance at the 10%, 5% and 1% significance level, respectively.
2. Numbers in parentheses and bracket are the t statistics and their *p*-values, respectively.

These results indicate that cement and construction indexes exhibit asymmetric adjustment pattern toward their equilibrium relationship. Moreover, since half the adjustment speed is insignificant for the cement index, the effectiveness of investors' trading strategy might be affected when cement stocks are incorporated into investment portfolio.

The presence of asymmetric adjustment behavior in the cement and construction indexes is also uncovered by the significance of both the null hypotheses of $\gamma_1 = \gamma_2$ for cement index and construction index. This evidence is consistent with the finding of the previous MTAR-T co-integration model which shows asymmetric adjustment in the co-integration relationship.

The results from M-TECM Granger causality test show that a bidirectional short-run causality exists between cement index and construction index because both the null hypotheses of $\theta_1 = \theta_2 = 0$ and $\delta_1 = \delta_2 = 0$ are rejected at the 5% significance level. This indicates that cement index causes construction index and vice versa in the short run. In terms of the long-run situation, there exists a bidirectional long-run causality in the higher regime (above the threshold value of -0.031) and a unidirectional long-run causality running from cement to construction index in the lower regime (below the threshold value of -0.031). In the higher regime, both the null hypotheses of $\delta_1 = \delta_2 = \gamma_1 = 0$ and $\theta_1 = \theta_2 = \gamma_1 = 0$ are statistically significant at the 5% level. In the lower regime, the null hypothesis of $\theta_1 = \theta_2 = \gamma_2 = 0$ is statistically significant but that of $\delta_1 = \delta_2 = \gamma_2 = 0$ is statistically insignificant at the 5% level. These results provide evidence of regime dependence in the long-run causality between cement index and construction index. These findings illustrate that, from long-run point of view, cement index and construction index cause toward each other in the higher regime and cement index cause construction index but not vice versa in the lower regime.

The estimations and Granger causality tests of the TECM model for steel index and construction index are reported in Table 9. The AIC determines the optimal lag length of 2 for the model. The ARCH test for model residuals indicates that the TECM model is appropriate for the data. For the adjustment speed toward equilibrium, it is statistically significant and approximately -27.2 percent and -25.2 percent in the steel and construction indexes, respectively, when the previous disequilibrium errors are in the higher regime (above the threshold value of 0.232). In contrast, the adjustment speed for the two indexes is relatively small and insignificant when the previous disequilibrium errors are in the other regime (below the threshold value of 0.232). This seems to be evidence of asymmetric adjustment behavior in the steel and construction indexes. Moreover, it should be noted that insignificant adjustment speeds in the lower regime below the given threshold value might limit the effectiveness of investors' trading strategy.

The asymmetric adjustment behavior in the steel and construction indexes is also uncovered by observing whether both the null hypotheses of $\gamma_1 = \gamma_2 = 0$ for cement index and construction index are statistically significant. Despite there is great difference in the values of adjustment speed for the higher and lower regimes, the null hypothesis of $\gamma_1 = \gamma_2 = 0$ for steel index cannot be rejected at the 10% significant level. This result seems to contradict the finding from the previous

Table 9. Results of the TECM model and granger causality test for steel index and construction index.

	Steel	Construction
Constant	0.0032 (1.133)	0.0189 (3.012)**
$Steel_{t-1}$	0.7174 (8.312)***	**-0.5224 (-4.316)*** **
$Steel_{t-2}$	0.4651 (6.013)***	**-0.0511(-2.112)* **
$Construct_{t-1}$	0.0207 (0.382)	0.7634 (5.935)***
$Construct_{t-2}$	0.0009 (0.236)	0.3315 (5.157)***
Z^{+}_{t-1}	**-0.2717 (-1.276)**	**-0.2521 (-3.219)** **
Z^{-}_{t-1}	-0.0321 (-1.225)	-0.0583 (-1.139)
H_0: $\gamma_1 = \gamma_2 = 0$	2.1578	3.9862**
H_0: $\theta_1 = \theta_2 = 0$	2.0212	
H_0: $\delta_1 = \delta_2 = 0$		7.4673***
H_0: $\theta_1 = \theta_2 = \gamma_1 = 0$	2.7578	
H_0: $\theta_1 = \theta_2 = \gamma_2 = 0$	1.0472	
H_0: $\delta_1 = \delta_2 = \gamma_1 = 0$		4.0179**
H_0: $\delta_1 = \delta_2 = \gamma_2 = 0$		3.0114*
H_0: $\gamma_1 = \gamma_2 =$ (Steel)	2.2917	
H_0: $\gamma_1 = \gamma_2 =$ (Construction)		4.1417**
AIC	-198.8417	-200.1587
ARCH(4)	0.251 (0.771)	0.741 (0.437)

Notes: 1. *, ** and *** denote significance at the 10%, 5% and 1% significance level, respectively.
2. Numbers in parentheses and bracket are the t statistics and *p*-value, respectively.

Table 10. Results of the granger causality test.

Cement Index and Construction index	Cement	=>	Construction
	Construction	=>	Cement
Steel Index and Construction index	Steel	=>	Construction
	Construction	≠>	Steel

Notes: The symbol "=>" represents "Granger causal relationship exist", and the symbol "≠>" represents "no Granger causal relationship".

TAR-T co-integration model which displays asymmetric adjustment in the co-integration relationship. However, it can be explained that the asymmetric adjustment is mainly driven by the disequilibrium error of construction index.

The results from TECM Granger causality test show that there exists evidence of a unidirectional short-run causal relationship between steel index and construction index. At the 5% level, the null hypothesis of $\theta_1 = \theta_2 = 0$ is statistically significant but that of $\theta_1 = \theta_2 = 0$ is statistically insignificant. In terms of the long-run situation, there exists a significant unidirectional long-run causal relationship from steel to construction index regardless of the regimes above or below the threshold value of 0.472. Both the null hypotheses of $\delta_1 = \delta_2 = \gamma_1 = 0$ and $\delta_1 = \delta_2 = \gamma_2 = 0$ are statistically significant but that of $\delta_1 = \delta_2 = \gamma_1 = 0$ and $\delta_1 = \delta_2 = \gamma_2 = 0$ are statistically insignificant at the 5% level. These results indicate that the steel index causes the construction index but not vice versa in the long run.

The results from the TECM or M-TECM Granger causality tests in Tables 8 and 9 are summarized in Table 10. Overall, the test results show evidence of the existence of bidirectional causality that between cement index and construction index either in the short run or long run, suggesting these two indexes have significant short-run and long-run predictor power toward each other. Moreover, the test results also show that steel index causes construction index both in the long run and the short run, irrespective of regime above or below the given threshold value. Therefore, steel and cement stock indexes can be used to predict construction stock index while construction stock indexes only can be used to predict cement stock indexes either in the short run and/or the long run.

IV. CONCLUSIONS

This paper analyzes the short-run and long-run dynamics between indexes of construction and cement or steel in the Taiwan stock market over a seven-year period. In particular, this paper focuses on the non-linear dynamic using the asymmetric threshold co-integration and threshold error-corrrection models (TECM) of Enders and Siklos (2001). For the model specification, this paper finds that the applicable threshold mode1 is the M-TART for cement and construction indexes and the TART for steel and construction indexes. Moreover, the empirical results illustrate the importance of testing for asymmetric and non-linear dynamics between construction index and its material indexes for the following reasons. First, although Johansen linear co-integration tests show no co-integration relation between these indexes, the asymmetric threshold co-integration test identifies the presence of significant co-integration relationship between them. The result illustrates that both prices of construction index and either of cement index and steel index has a stable long-run equilibrium relationship and tend to move together in the long run. Second, this paper finds the evidence of asymmetric adjustment toward the long-run equilibrium relationship between construction index and either cement index or steel index. Third, evidence exists that non-linear Granger causality between construction index and cement index is bi-directional but steel index exerts non-linear Granger causality on construction index in both the long run and the short run.

Overall, the above findings suggest that either in the short run or the long run, cement and steel indexes are useful in predicting construction index, while construction index only can be used to predict cement index. Investors therefore obtain profit by using this information to design the proper investment strategies. In the process to formulate strategies, investors should note the existence of asymmetric adjustment behavior because this factor might considerably affect the efficiency of investment strategies. Finally, the findings of this paper also imply that investors are not able to diversity the risk by utilizing investment portfolios that holds the up- and down-stream construction stocks at the same time for the Taiwan stock markets. Since short-run and long-run causalities exist between stock indexes of construction and cement or steel, investor will encounter the external risks from political or economic factors when these stocks are inputted in one basket. One interesting extension of this paper is to examine the effect of the other factors such as financial crisis on the relationship among indexes of construction, cement and steel in a non-linear context.

Appendix Symbol Table

Symbol	Definition
1. ESTAR model: $\Delta Y_t = \gamma Y_{t-1}[1-\exp(-\theta Y_{t-1}^2)] + \nu_t$	
ΔY_t	the first difference of Y_t, $\Delta Y_t = Y_t - Y_{t-1}$, where Δ is difference operator
γ	the parameter determining the stationary condition for model
θ	the transition parameter governing the speed of transition
ν_t	the error term with zero mean and constant variance
2. Johansen's five co-integration model:	
	(1) : $\Delta X_t = \Gamma_1 \Delta X_{t-1} + ... + \Gamma_{k-1}\Delta X_{t-(k-1)} + \alpha\beta' X_{t-1} + \Psi D_t + \in_t$
	(2) : $\Delta X_t = \Gamma_1 \Delta X_{t-1} + ... + \Gamma_{k-1}\Delta X_{t-(k-1)} + \alpha(\beta', \beta_0)(X'_{t-1}, 1)' + \Psi D_t + \in_t$
	(3) : $\Delta X_t = \Gamma_1 \Delta X_{t-1} + ... + \Gamma_{k-1}\Delta X_{t-(k-1)} + \alpha\beta' X_{t-1} + \mu_0 + \Psi D_t + \in_t$
	(4) : $\Delta X_t = \Gamma_1 \Delta X_{t-1} + ... + \Gamma_{k-1}\Delta X_{t-(k-1)} + \alpha(\beta', \beta_1)(X'_{t-1}, t)'\mu_0 + \Psi D_t + \in_t$
	(5) : $\Delta X_t = \Gamma_1 \Delta X_{t-1} + ... + \Gamma_{k-1}\Delta X_{t-(k-1)} + \alpha\beta' X_{t-1} + \mu_0 + \mu_1 t + \Psi D_t + \in_t$
Γ_t	the coefficient matrices of ΔX_{t-i}
α	the adjustment parameter matrices of ΔX_t on X_{t-1}
β	the cointegrating matrices,
D_t	the deterministic dummies
Ψ	the coefficient matrices of D_t
μ_0	the vectors of constant coefficients
μ_1	the vectors of trend coefficients
β_0	the parameter vectors decomposed from the adjustment parameter matrices
β_1	the parameter vector decomposed from the cointegrating matrices
$\in_t$	the disturbance vectors
3. TAR model: $Y_{1,t} = \alpha + \beta Y_{2,t} + \mu_t$,	
	$\Delta\mu_t = I_t \rho_1 \mu_{t-1} + (1-I_t)\rho_2 \mu_{t-1} + \sum_{i=1}^{p-1} \gamma_i \Delta\mu_{t-i} + \varepsilon_t$,
	$I_t = \begin{cases} 1 & if\ \mu_{t-1} > \tau \\ 0 & if\ \mu_{t-1} \le \tau \end{cases}$
α	the intercept term of the co-integration equation

Appendix Symbol Table (Continued)

Symbol	Definition
β	regression coefficient of $Y_{1,t}$ on $Y_{2,t}$
μ_t	the disturbance term with zero mean and common variance
I_t	the Heaviside indicator function
τ	the unknown threshold value
ρ_1	the parameter ρ_1 is adjustment speed when the previous disequilibrium is above the threshold (i.e., $\mu_{t-1} > \tau$)
ρ_2	the parameter ρ_2 is adjustment speed when the previous disequilibrium is below the threshold (i.e., $\mu_{t-1} \le \tau$)
ε_t	the white-noise disturbance term

4. M-TAR model: $Y_{1,t} = \alpha + \beta Y_{2,t} + \mu_t$,

$$\Delta\mu_t = I_t\rho_1\mu_{t-1} + (1-I_t)\rho_2\mu_{t-1} + \sum_{i=1}^{p-1}\gamma_i\Delta\mu_{t-i} + \varepsilon_t,$$

$$I_t = \begin{cases} 1 & if\ \Delta\mu_{t-1} > \tau \\ 0 & if\ \Delta\mu_{t-1} \le \tau \end{cases}$$

the definition of symbol is as same as that in the TAR model

5. TECM model: $\Delta Y_{it} = \alpha_i + \gamma_1 Z_{t-1}^{+} + \gamma_2 Z_{t-1}^{-} + \sum_{i=1}^{\kappa_1}\delta_i\Delta Y_{1t-p} + \sum_{i=1}^{\kappa_1}\theta_i\Delta Y_{2t-i} + v_{it}$, $Z_{t-1}^{+} = I_t\hat{u}_{t-1}$,

$$Z_{t-1}^{-} = (1-I_t)\hat{\mu}_{t-1},\ I_t = \begin{cases} 1 & if\ \hat{\mu}_{t-1} > \hat{\tau} \\ 0 & if\ \hat{\mu}_{t-1} \le \hat{\tau} \end{cases}$$

Symbol	Definition
α_i	the intercept term
δ_i	the regression coefficients of ΔY_{it} on Y_{1t-j}
θ_i	the regression coefficients of ΔY_{it} on Y_{2t-j}
I_t	the Heaviside indicator function
$\hat{\mu}_{t-1}$	the pervious disequilibrium error obtained from the co-integration equation
$\hat{\tau}$	the estimated threshold value
Z_{t-1}^{+}	the pervious disequilibrium error when the error is above the estimated threshold value $\hat{\tau}$
Z_{t-1}^{-}	the pervious disequilibrium error when the error is below or equal to the estimated threshold value $\hat{\tau}$
γ_1	the adjustment parameter of ΔY_{it} on the previous disequilibrium error $\hat{u}_{t-1}$ when the error is above the estimated threshold value $\hat{\tau}$
γ_2	the adjustment parameter of ΔY_{it} on the estimated previous disequilibrium error $\hat{u}_{t-1}$ when the error is below the estimated threshold value $\hat{\tau}$.
v_{it}	the white-noise disturbance term

6.M-TECM model: $\Delta Y_{it} = \alpha_i + \gamma_1 Z_{t-1}^{+} + \gamma_2 Z_{t-1}^{-} + \sum_{j=1}^{\kappa_1}\delta_i\Delta Y_{1t-p} + \sum_{j=1}^{\kappa_1}\theta_i\Delta Y_{2t-j} + v_{it}$

$$Z_{t-1}^{+} = I_t\hat{u}_{t-1},\ Z_{t-1}^{-} = (1-I_t)\hat{u}_{t-1},\ I_t = \begin{cases} 1 & if\ \Delta u_{t-1} > \tau \\ 0 & if\ \Delta\mu_{t-1} \le \tau \end{cases}$$

the definition of symbol is as same as that in the TECM model

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