Analyzing the Law of One Price and Volatility in the New Zealand Emissions Trading Scheme using NZUs, CERs and ERUs

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A B S T R A C T

In late 2012, New Zealand announced the opt-out of the second phase of the Kyoto Protocol. It has been decided that after 31 May 2015 overseas Kyoto units were no longer acceptable for surrender within the NZ ETS.

If the market is efficient, the law of one price has significant meanings because it would reduce search cost regarding proper carbon price, provide opportunity for arbitrage among markets and decrease transaction cost by increasing market liquidity. Hence, the law of one price in NZ ETS is the main issue to be discussed in this study. This study also evaluates the trivariate error correction modeling and causality testing for NZ ETS price volatility using daily price data on NZUs, CERs and ERUs.

The central result show that NZUs, CERs and ERUs affect each other significantly through the vector autoregression model and react quite rapidly to shocks to themselves and each other though the impulse response function analysis in a whole period. Most importantly, three price series are found to be cointegrated but differently for periods, with international credits leading the price discovery process in the long-term through the vector error correction mechanism.

Keywords: New Zealand Emission Trading Scheme (NZ-ETS), New Zealand Unit (NZU), Certified Emission Reduction (CER), Emissions Reduction Units (ERU), Forest Carbon Credits,

1. Introduction

New Zealand decided to opt out of the second phase of the Kyoto Protocol. In November 2012 the New Zealand government announced that it would not proceed with the second commitment period of the Kyoto Protocol, and future linking became uncertain. It was decided that NZ ETS participants could continue to use Kyoto Protocol first commitment period Certified Emission Reduction units (hereafter, CERs), Removal Units (hereafter, RMUs) and Emission Reduction Units (hereafter, ERUs) to account for surrender obligations up until 31 May 2015, after which these units would no longer be eligible. Participants were not allowed to surrender international units for NZ ETS compliance after mid-2015.

From 2012 through to mid-2015, participants predominantly met their NZ ETS obligations by purchasing overseas Kyoto units at a low cost. Since then, there has been a "money-go-round," with the polluters and the forest owners making money and profiting.

Although there are several ETSs, the ETS is an important topic for research, because the ETSs could be consolidated into one market if the law of one price among markets were set up (Mo *et al.*, 2005). If the market is efficient, the law of one price has significant meaning, because it would reduce the cost of searching for the proper carbon price, provide opportunity for arbitrage among markets, and decrease transaction cost by increasing market liquidity. However, legislative amendments to moderate the system's impact, combined with an oversupply of units in the international market, contributed to low domestic emission prices in recent years, and policy uncertainty has obscured the system's long-term price signal.

Considering the above policy changes, we set up three periods for analysis. The whole period is from 31st October 2011 to 29th May 2015. The first period is called period A, from 31st October 2011 to 31st December 2012; and the second period is period B, from 2nd January 2013 to 29th May 2015.

The daily price data of three credits in New Zealand were used: the NZU spot price and the CER and ERU prices from trades on international futures markets, with prices converted to New Zealand dollars using that day's exchange rates.

2. Methods

2.1. Wald test

If there is a law of one price between NZUs and overseas credits (ERUs and CERs), these credits' price is the same in NZ ETS. The following equations, (1) and (2), show the null hypothesis that H_0: $\alpha = 0,\ \beta = 1$.

$$NZU_t = \alpha + \beta \cdot ERU_t \tag{1}$$

$$NZU_t = \alpha + \beta \cdot CER_t \tag{2}$$

Based on the result of OLS estimation and the Wald test, we can see whether the law of one price can be applied to NZ-ETS. NZU_t is the NZU's price, ERU_t is the ERU's price, and CER_t is the CER's price, at time *t*.

2.2. Trivariate Granger causality

We tested for Granger causality, by following a trivariate vector error-correction model (hereafter, VECM).

According to Engle and Granger (1987), the error-correction model is of the following form. Equations (12) to (14) show how NZU_t, CER_t, and ERU_t change in response to stochastic shocks (represented by $\varepsilon_{NZUt}, \varepsilon_{CERt}$, and ε_{ERUt}) and to the previous period's deviation from the long-run equilibrium (represented by ECT_{t-1}), where Δ stands for first difference, the ECT_{t-1} is the lagged error-correction term. The $\varepsilon_{NZUt}, \varepsilon_{CERt,}$ and ε_{ERUt} are premised on the assumption of constant variance, zero mean, and normal distribution.

The *s* and *r* are the number of lags for ΔNZU_t, ΔCER_t, and ΔERU_t. In determining the optimal values of *r* and *s* in each of equations (12) to (14), we choose the lag length that produces the smallest value of the Akaike Information Criterion (hereafter, AIC).

The significance of the *t*-statistics for the ECT_{t-1} indicates the presence of a long-run causal relationship between the variables. Short-run causality is suggested by the significance of the *F*-statistic of the lagged variables (Solarin, 2013). From equations (12) to (14), given the use of VECM structure, all variables are treated as endogenous.

This paper assesses the possible direction of causations within the series with the Granger causality test, after establishing any long-run relationship. If there is cointegration, Granger causality is conducted within the framework of the trivariate VECM as follows:

$$\Delta NZU_t = \alpha_1 + \alpha_{1j} ECT_{t-1} + \sum_{j=1}^{r} \alpha_{1j} \Delta NZU_{t-j} + \sum_{j=1}^{s} \alpha_{1j} \Delta CER_{t-j} + \sum_{j=1}^{q} \alpha_{1j} \Delta ERU_{t-j} + \varepsilon_{1t} \tag{12}$$

$$\Delta CER_t = \alpha_2 + \alpha_{2j} ECT_{t-1} + \sum_{j=1}^{r} \alpha_{2j} \Delta NZU_{t-j} + \sum_{j=1}^{s} \alpha_{2j} \Delta CER_{t-j} + \sum_{j=1}^{q} \alpha_{2j} \Delta ERU_{t-j} + \varepsilon_{2t} \tag{13}$$

$$\Delta ERU_t = \alpha_3 + \alpha_{3j} ECT_{t-1} + \sum_{j=1}^{r} \alpha_{3j} \Delta NZU_{t-j} + \sum_{j=1}^{s} \alpha_{3j} \Delta CER_{t-j} + \sum_{j=1}^{q} \alpha_{3j} \Delta ERU_{t-j} + \varepsilon_{3t} \tag{14}$$

If there is no cointegration, we can use a vector autoregression model (hereafter, VAR). VAR models are used for multivariate time series. The structure is that each variable is a linear function of past lags of itself and past lags of the other variables. Each variable is a linear function of the lag values for all variables in the set. Like Sim (1980), suppose that we measure three different time-series variables, denoted by NZU_t, CER_t, and ERU_t.

Let $NZU_t = (NZU_{1t}, NZU_{2t}, \dots, NZU_{nt}$, $CER_t = (CER_{1t}, CER_{2t}, \dots, CER_{nt})'$, $ERU_t = (ERU_{1t}, ERU_{2t}, \dots, ERU_{nt})'$ denote an $(n \times 1)$ vector of time-series variables. The trivariate VAR model has the form

$$NZU_t = C_1 + \prod_j \sum_{j=1}^{p} NZU_{t-j} + \varepsilon_{1t} \tag{15}$$

$$CER_t = C_2 + \prod_j \sum_{j=1}^{p} CER_{t-j} + \varepsilon_{2t} \tag{16}$$

$$ERU_t = C_3 + \prod_j \sum_{j=1}^{p} ERU_{t-j} + \varepsilon_{3t} \tag{17}$$

where $t = 1, \dots, T$, Π_j are $(n \times n)$ coefficient matrices, and ε_t is an $(n \times 1)$ unobservable zero-mean white-noise vector process (serially uncorrelated or independent) with a time-invariant covariance matrix $\sum$.

3. Empirical Results

3.1. Wald test and least-squares results

We can reject the null hypothesis(H_0: $\alpha = 0$, $\beta = 1$) from equations (1) and (2). In this result, it looks like the law of one price cannot be applied to the New Zealand ETS (See Table 1). However, for the whole period, the coefficient is over 0.5 and is close to 1 in 2013. Prices go to the opposite direction after 2013.

Table 1 Wald Test Results

Period	Equation	Test statistic	Value	Probability
Whole Period	NZU_t	F-Statistic	1862.427	0.0000
(31st Oct. 2011	$= \alpha + \beta \cdot ERU_t$	Chi-Square	3724.853	0.0000

~ 29th May 2015)	$NZU_t = \alpha + \beta \cdot CER_t$	F-Statistic Chi-Square	1473.559 2947.118	0.0000 0.0000
Period A (31st Oct. 2011 ~ 31st Dec. 2012)	$NZU_t = \alpha + \beta \cdot ERU_t$	F-Statistic Chi-Square	59.459 118.9187	0.0000 0.0000
	$NZU_t = \alpha + \beta \cdot CER_t$	F-Statistic Chi-Square	125.998 251.996	0.0000 0.0000
Period B (2nd Jan. 2013 ~ 29th May 2015)	$NZU_t = \alpha + \beta \cdot ERU_t$	F-Statistic Chi-Square	3233.955 6467.910	0.0000 0.0000
	$NZU_t = \alpha + \beta \cdot CER_t$	F-Statistic Chi-Square	1606.218 3213.436	0.0000 0.0000

Table 2 presents the results of the least squares, which are very pertinent to players in the realm of NZUs, CERs, and ERUs. In period A, our computed coefficients are 0.960 and 0.933, which are very close to 1 and greater than the upper critical bound at 1% levels and, respectively. That is, the domestic NZU price is remarkably similar in period A to the international unit prices.

However, the result of period B suggests that CERs and ERUs have a negative and statistically significant effect on NZUs. A one-unit decrease in ERUs increases NZUs by 1.714, whereas a one-unit decrease in CERs increases NZUs by 1.038, with both coefficients being statistically significant at the 1 percent level. It is interesting to note that the domestic NZU price was not essentially the same as international unit prices in period B.

Table 2 Least-squares results

Period	Equation	Variables	Coefficient	F-Statistic
Whole Period (31st Oct. 2011 ~ 29th May 2015)	$NZU_t = \alpha + \beta \cdot ERU_t$	C ERUs	3.469* 0.560*	1670.540*
	$NZU_t = \alpha + \beta \cdot CER_t$	C CERs	3.167* 0.555*	1448.757*
Period A (31st Oct. 2011 ~ 31st Dec. 2012)	$NZU_t = \alpha + \beta \cdot ERU_t$	C ERUs	0.578* 0.933*	3777.703*
	$NZU_t = \alpha + \beta \cdot CER_t$	C CERs	0.431* 0.960*	1658.498*
Period B		C	4.279*	157.500*

(2^{nd} Jan. 2013 ~ 29^{th} May 2015)	$NZU_t = \alpha + \beta \cdot ERU_t$	ERUs	-1.714*	
	$NZU_t = \alpha + \beta \cdot CER_t$	C	4.595*	46.408*
		CERs	-1.038*	

*: significantly valued ($p < 0.01$)

3.2. Unit Root Test Results

Table 3 contains the ADF test of the null hypothesis that a unit root exists in the raw series as well as in the first differences of the series. Clearly, the null hypothesis of a unit root in raw levels cannot be rejected, implying that each of the three variables, while the null hypothesis of the other unit root is rejected. Hence, we conclude that these series are characterized as I(1). Hence this series has a stochastic trend. This evidence is consistent with the prevalent view that most time series are characterized by a stochastic rather than deterministic nonstationarity (Serletis, 2012; Nelson and Plosser, 1982).

Table 3 Unit Root Test Results

Period	Series	ADF
Raw series		
Whole Period (31^{st} Oct. 2011 ~ 29^{th} May 2015)	NZUs	-2.456
	CERs	-1.304
	ERUs	-1.768
Period A (31^{st} Oct. 2011 ~ 31^{st} Dec. 2012)	NZUs	-4.226
	CERs	-3.274
	ERUs	-3.492
Period B (2^{nd} Jan. 2013 ~ 29^{th} May 2015)	NZUs	-3.127
	CERs	-2.618
	ERUs	-2.655
First differences of the series		
Whole Period (31^{st} Oct. 2011 ~ 29^{th} May 2015)	NZUs	-6.546*
	CERs	-7.457*
	ERUs	-7.854*
Period A	NZUs	-5.060*

(31st Oct. 2011 ~ 31st Dec. 2012)	CERs	-16.000*
	ERUs	-13.000*
Period B (2nd Jan. 2013 ~ 29th May 2015)	NZUs	-7.315*
	CERs	-15.665*
	ERUs	-10.216*

Note: Results are reported for an ADF statistic of order 20, 15, and 18 each period. The 99% critical value for the ADF test statistics is -3.971, -3.989, and -3.973 for each period for the "with trend" and intercept version of the test. An asterisk indicates significance at the 1% level.

3.3.Cointegration results

The estimated results in Table 4 indicate that there is a cointegration vector among the variables. Two statistics are used to test for the number of cointegrating vectors: the trace and maximum eigenvalue (λ_{max}) test statistics. The two statistics give similar results.

In particular, the hypothesis that there were one or no cointegrating relations had to be rejected for the whole period and period A. Thus, the three variables form two cointegrating relationships or, alternatively, they are driven by only one common trend.

Hence, the law of one price was identified between domestic and overseas credits in these two periods. The same underlying stochastic components presumably affect all NZ ETS markets. We may conclude that there is cointegration between the series for long-run relationships during these two periods studied, in the case of New Zealand.

However, for period B, in contrast, none of the hypotheses can be rejected. There is no cointegration. In this period, there is no long-run relationship and one common trend.

Table 4 Results of the Johansen-based cointegration test

	Whole Period (31st Oct. 2011 ~ 29th May 2015)		Period A (31st Oct. 2011 ~ 31st Dec. 2012)		Period B (2nd Jan. 2013 ~ 29th May 2015)		Critical values	
							Trace	λ_{max}
No. of coint. eqn.	Trace	λ_{max}	Trace	λ_{max}	Trace	λ_{max}	95%	95%
None	63.027*	38.454*	30.974*	25.343*	22.522	16.560	29.797	21.131
At most 1	24.573*	22.368*	16.300*	14.674*	5.962	4.523	15.495	14.265
At most 2	2.206	2.206	3.450	3.450	1.438	1.438	3.841	3.841

Notes: * denotes rejection of the hypothesis at the 0.05 level. Critical values are sourced from Johansen and Juselius (1990). The optimal lag structure is determined by AIC. The optimal lag used in VAR is that whole period is 7, period A is 7, and period B is 6.

3.4. Granger Causality Results

From the evidence provided in Table 4, we now proceed to test for Granger causality by way of the trivariate VECM formulation described by equations (12) to (14). The precondition of VECM is that variables should be nonstationary at one level, but when converted into first differences, they will become stationary. The three variables satisfy this precondition.

For period B, where we could not find evidence in favor of cointegration, the causality tests were performed by using unrestricted trivariate VAR models, using first differences of the variables involved. Given the importance of selecting the appropriate lag structure in these models, we employed a criterion based on minimizing AIC.

The summary of estimated trivariate VECMs and VARs presented in Table 5 indicates a variety of results pertaining to the causal hypothesis. We found a long-run equilibrium relationship between CERs, ERUs, and NZUs when testing Granger causality for the whole period.

Table 5 The Granger causality test results

Period	Dependent variables	Direction of causality			
		Short run			Long run
		ΔNZU_{t-j}	ΔCER_{t-j}	ΔERU_{t-j}	ECT_{t-1}
Whole Period (31st Oct. 2011 ~ 29th May 2015)	ΔNZU_t	…	15.133*	7.018*	-2.723* (-0.006*)
	ΔCER_t	2.565*	…	6.131*	-2.580* (-0.002*)
	ΔERU_t	4.733*	2.752*	…	-4.217* (-0.010*)
Period A (31st Oct. 2011 ~ 31st Dec. 2012)	ΔNZU_t	…	4.773*	3.541*	-3.414* (-0.076*)
	ΔCER_t	0.973	…	4.511*	-0.519 (-0.004)
	ΔERU_t	1.891	0.707	…	-1.386

					(-0.035)
Period B (2nd Jan. 2013 ~ 29th May 2015)	ΔNZU_t	…	0.936	0.977	…
	ΔCER_t	1.087	…	12.654*	…
	ΔERU_t	1.073	1.456	…	…

Note: * indicates statistical significance at the 1% levels.

The results from the trivariate error-correction models, reported in Table 5, confirm the evidence for joint bidirectional causality in the whole period. Since each pair of integrated markets is linked together by a bidirectional feedback relationship, the price change in one market instantaneously affects prices in the other market and vice versa (Serletis, 2012). In this study, three credits are affecting each other. Thus we conclude that there is no price leadership and that there seems to be price competition in the NZ ETS from the end of 2011 through mid-2015.

However, the international credits led domestic credit price in NZ ETS from the end of 2011 through 2012. There is short-run Granger causality running from CER to NZU, from ERU to NZU, and from ERU to CER in period A. It is interesting to note that none of the short-run channels of causality, as captured by the NZUs or the joint NZU and overseas credits in any of the equation in period A.

In period A there is evidence of long-run causality, captured by the significance of the ECT from CER and ERU to NZU, but there is no long-run Granger causality relationship running from NZU and ERU to CER and from NZU and CER to ERU.

The results from the trivariate VAR models estimated for period B are in tune with the findings of Table 5, in that there is evidence only for Granger causality running between ERU and CER even in short run. It is the only short-run unidirectional causality relationship that was found.

4. Conclusions

In this study we have investigated the law of one price and causal relationships between domestic credit and the other overseas credits for linked-emissions trading schemes period with the announcement policy.

For the whole period, there is Granger causality between CER, ERU, and NZU runs in both directions through the error-correction term in both short and long runs. This result means that NZU, CER, and ERU improve the predictive power of each other's time series. The VECM showed evidence of mutual causality between these variables for the whole period; the variance decompositions showed indications of ERU leading NZU.

In period A, we also found consistent evidence of domestic credit causing international credits and international credits causing domestic credit through the error-correction term in the long run. The finding for period A indicates that there is short-run causality running from CER and ERU to NZU, from ERU to CER. This result was, however, quite the reverse for NZU, since no short-run causality was captured by the NZU. This result means that the three variables improve the predictive power of each other's time series in the long run and that international credit improves the predictive power of the time series of domestic credit in the short run.

For period B, in which the variables were not found to be cointegrated, we found consistent evidence of ERU causing CER in the short run.

Some interesting results emerged from this analysis. Although all pairwise relationships by period shared identical univariate integrational properties, only those relationships for the whole period and period A were cointegrated. The NZU, CER, and ERU remained non-cointegrated, over the sample, for period B. Besides, our VECM indicates that the international trend led to domestic credit in the price discovery process.

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