New Zealand's Emission Trading Scheme: A Financial Perspective

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Abstract

New Zealand Emissions Trading Scheme (NZ ETS) is an intensity based system and the second oldest national ETS. It is unique in that it is highly international (has allowed unlimited use of offsets/imported Kyoto allowances) and it incorporates forestry. We provide the first empirical analysis of the determinants of allowance prices on NZ ETS. Our results indicate that imports of offsets rather than fundamentals have been the major price determinant. Moreover, the pricing of New Zealand Units (NZUs) can be placed into three distinct periods as delineated by two structural breaks. The first is when the system is autarkic; in the second period, as international offset prices drop below NZU's, the system becomes a 'price take'; in the final period following some policy interventions the system regains some independence. The case of NZ ETS shows both the power of tacitly linking ETSs' and the dangers of doing so.

JEL Classification: G12, G14, Q52, Q53, Q54, Q58

KEYWORDS: Emissions trading; NZ ETS; Carbon Markets; Carbon Finance; Emissions permit markets; Asset Pricing

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1. Introduction

> "*Except for New Zealand, no system allows more than 20% of emissions to be covered with offsets, and few allow more than 10%.*" Ranson and Starvins (2015,p.8)

International emission trading schemes are considered an important market-based mechanism to mitigate greenhouse gas (GHG) emissions. Of the schemes in existence, the EU ETS is the largest and most high profile, as reflected in a large literature examining the scheme from a financial (asset pricing) perspective (for instance Alberola, *et al.* 2008; Benz & Trück , 2009; Hintermann 2010; Mansanet-Bataller *et al.* 2007). By way of contrast, there have been no discernable empirical analyses of the New Zealand Emissions Trading Scheme (NZ ETS) from a financial perspective. The absence of an analysis of trading on NZ ETS is surprising since it has been in existence since 2008 and its design and context make it unique in several respects. NZ ETS is an intensity based system, it covers all six Kyoto greenhouse gases, it is highly international (has allowed unlimited use of offsets/imported Kyoto allowances) and it incorporates forestry, while the original intention was for it to be an economy-wide scheme that incorporated agriculture.

Despite its comprehensive ambitions, the merits of NZ ETS have been the subject of much debate since New Zealand Unit (NZU) prices have been low. The low prices of NZUs have been attributed in part to the 'transition rules' introduce by the incoming National government in 2009 (the scheme has been enacted by the outgoing Labour administration in 2008) which effectively blunted the impact of the scheme in a number of ways, including a more liberal allocation policy, capping the price of NZUs and delaying indefinitely the introduction of the agricultural sector.[1] Moreover, it has been argued that the declines in NZU prices are the result of NZ ETS allowing

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[1] The 'transition rules' were extended indefinitely in 2012 though the scheme is likely to be reviewed in 2015/6. See Section 2 for a fuller discussion of the 'transition rules'.

unlimited imports of offsets (Ranson and Starvins 2015). From mid-2011 as the international price for carbon (CERs) fell below domestic NZU prices, it is claimed NZ ETS became a ‘price taker’ (WB, 2014; Sopher and Mansell 2014). The subsequent collapse of CERs was attributed with ‘dragging down’ NZU prices and leading to a glut of imported international units surrendered for obligation (WB, 2014). These assertion have not, however, been subjected to empirical scrutiny.

Accordingly, this paper explores the determinants of price of New Zealand Units (NZUs). More specifically, using NZU price data and data from the NZ Emissions Unit Registry and a range of econometric techniques (tests for structural breaks, VAR models, test of Granger causality and ARCH & GARCH analyses) we explore how fundamental (energy prices, weather conditions and economic conditions), policy changes and imported offsets affect prices of NZUs. Our principal contributions is empirical; we provide the first financial analysis of NZ ETS and thereby contribute to the understanding of the asset pricing of emissions units in a highly international emissions trading scheme. Our results indicate that unlike in EU ETS, imports of offsets rather than fundamentals have been the major price determinant. Moreover, the pricing of NZUs can be placed into three distinct periods as delineated by two structural breaks (1) a period up to 2011 when the system is autarkic; (2) a period between June 2011 and February 2013 when NZ ETS does indeed become a ‘price take’ and; (3) a period post February 2013 when the system regains some independence following policy intervention to ban the importation of offsets of dubious provenance (e.g. allowances related to the HFC-23 scandal). The case of NZ ETS highlights both the power of tacitly linking ETSs’ and the dangers of doing so. In the latter case, distortions such as ‘hot air’ misallocation or problems such as dubious HFC-23 allowances from other markets are in effect ‘imported’ to the domestic market. This can undermined the credibility of the domestic ETS and dampen its environmental effectiveness.

The rest of the paper is structured as follows: Section 2 introduced NZ ETS, Section 3 develops asset pricing hypothesis based economic theory and the extant NZETS literature, Section 4 outlines the data and econometric models employed, Section 5 outlines the results, while in Section 6 we provide some concluding remarks.

2. New Zealand Emissions and Emissions Trading Scheme

The challenge of mitigating New Zealand's GHG emissions can be observed from the change in emissions since 1990 base levels, shown in Table 1 (Panel A) and Figure 1. New Zealand's gross GHG emissions increased by 25.4% between 1990 and 2012. However, it is expected that New Zealand will meet its Kyoto Protocol Commitment Period 1 (CP1) obligations of cutting GHG emissions to 1990 levels as a result of forestry removals (Referred to as land use, land-use change and forestry or LULUCF) (MfE, 2014a.).

[INSERT TABLE 1 AND FIGURE 1 ABOUT HERE]

New Zealand's GHG emissions profile compared to other Annex I countries is dramatically difference, as shown in Table 1 (Panel B). New Zealand's agriculture sector is responsible for the greatest proportion of emissions; 49% compared to 12% for other developed countries (MfET, 2007). Particularly, methane emission from livestock has a global warming potential 21 times that of CO_2 (Jiang, et al., 2009). The energy sector contributes a relatively low percentage, 43%, compared other developed countries as New Zealand has high levels of renewable energy sources: particularly, hydro and geothermal (MfET, 2007).

In 2008, New Zealand established its Emissions Trading Scheme (NZ ETS) through the 'Climate Change Response (Emissions Trading) Amendment Act (2008). NZ ETS was to ultimately encompass all sectors[2] of the economy and all six Kyoto greenhouse gases[3] (GHG). New Zealand is unique in that is it is the only country in the world that planned to include forestry and agriculture in their ETS (Moyes, 2008; Adams & Turner, 2012; Bullock, 2012). The NZ ETS was not designed as a cap-and-trade, nor credit-based scheme, but a system of mandatory surrender of carbon credits issued by the government to cover emissions (Richter & Mundaca, 2013). Government also provided free

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[2] Sectors included: (1) energy, (2) industrial processes, (3) solvent and other product use, (4) agriculture, (5) land use, land-use change and forestry (LULUCF), and (6) waste (MfE, 2014b)

[3] Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons ($PFCs$), and sulphur hexafluoride (SF_6). While emissions and removals from direct GHGs are reported and accounted for under climate change convention and Kyoto Protocol, indirect GHGs: carbon monoxide (CO), sulphur dioxide (SO_2), oxides of nitrogen (NO_X) and non-methane volatile organic compounds ($NMVOCs$) are also included (MfE, 2014b).

allocation of units to at-risk sectors, designed to reduce damage from output reduction, ease adjustment into the system, and compensate participants for losses (Kerr & Zhang, 2009). All sectors were expected to be phased into the scheme by 2013, with sector participants expected to surrender one New Zealand Units (NZUs) for each tonne of carbon dioxide equivalents (CO_2-e) emitted. Unlike other ETSs (e.g. European Union Emissions Trading Scheme [EU ETS]), the NZ ETS also has had no restrictions on the amount of overseas carbon credits that could be surrendered for obligation, including: Certified Emissions Reduction Units (CERs) from clean development mechanisms (CDMs), Emission Reduction Units (ERUs) from joint implementations (JIs), and Removal Units (RMUs) from carbon sink activities.

In 2009, the newly elected National government amended the framework of the NZ ETS amidst concerns from business, agricultural and consumer groups that the scheme would to burdensome economically. The amendments came in the Climate Change Response (Moderated Emissions Trading) Amendment Bill. The 2009 bill was designed to ensure a smooth transition for industries into the NZ ETS during the economic downturn.

The 2009 amendments introduced a 'transition phase' for the NZ ETS between 01 July 2010 and 31 December 2012. The transition phase has three features. First, participants from the liquid fossil fuel, stationary energy, forestry, and industrial processes sectors are only required to submit one emissions unit per two tonnes of CO_2-e emitted (known as 'one-for-two'). Second, ETS participants could pay a NZ$25 fixed-price per tonne of CO_2-e – implying that participants could purchase unlimited NZUs. Combined with 'one-for-two', the carbon price cannot logically exceed $12.50 per tonne of CO_2-e emitted (MfE, 2011; Sinclair, 2011; MfE, 2012a; Bullock, 2012). Finally, non-forestry NZUs could not be converted to international Assigned Amount Units (AAUs) for sale offshore during the transition period – this prevented arbitrage while carbon emission prices were capped (MfE, 2011; Bullock, 2012). Beyond these features, the amendments also changed entry dates for sectors; most sectors now entered the scheme on 01 July 2010, with the exception of agriculture – delayed initially to 01 January 2015 but this has subsequently been extended indefinitely. Further, National government also switched to an intensity-based allocation of allowances, allocating units based on average industry emissions between 2006 and 2008. This model was criticized as industries were effectively ‘compensated’ for emissions. Importantly, the intensity-based system, without a volume cap and unrestricted import of international units, allowed gross emissions to continue increasing (Bullock, 2012; Richter & Mundaca, 2013).

Persistently low prices of NZU following these changes has led to a debate as to merits of the scheme. The debate has centered on three themes; whether to include agriculture; the role of forestry in the scheme; and the impact of cheap imported allowances and related policy changes.

2.1. Agriculture

Opponents to the inclusion of the agriculture sector suggest it would lead to a loss in competitiveness, since their global competitors do not face similar schemes. The competitiveness of New Zealand’s agricultural sector is of great importance to the economy as agricultural exports accounts for 47% of New Zealand’ total export income (Bullock, 2012). Dairy and meat exports represent the two largest exports for New Zealand: 24.91% and 10.97% of total merchandise export, respectively (Statistics New Zealand, 2012). However, meaningful emissions reductions are unlikely to occur until the introduction of the agricultural sector, when large methane and nitrous oxide emissions enter the scheme (see Jiang, et al., 2009 and Table 1, Panel A & B). The delayed entry of agriculture has been negatively received by some stakeholders, who want a more liquid market and equitable treatment of all sectors by facing at least some level of obligation to the ETS (Richter & Mundaca, 2013). Nevertheless and as noted above, entry of the sector by the National government has been delayed indefinitely.

2.2. Forestry

Forestry has an important role in New Zealand’s emission profile, with forestry participants being the only sector that receive and generate sellable credits by recapturing carbon emissions (Sinclair, 2011). Over the first commitment period, New Zealand projected to generate around 79 million tonnes of forest sink credits (MfET, 2007). Selling the surplus units overseas was expected to generate NZ$430 million, at prevailing prices, for New Zealand's economy; making the NZ ETS a net contributor to the economy financially (MfE, 2005). Initially this recapture of carbon resulted in a viable economic incentive to encourage afforestation in New Zealand, with forestry NZUs historically accounting for a 63.79% of surrendered units in 2010 (MfE, 2013b). However, as the price of NZUs have declined, so have the financial incentive of maintaining or converting land to forestry. Indeed, with prices of NZUs being low and a push for greater farming intensification there was net deforestation (Net change in planted forest area = Afforestation - Deforestation) in 2013, the first time that had been the case since 2009 (EPA 2013).

2.3. Linking and policy changes

The low prices of NZUs have been attributed in part to the 'transition rules' introduce by the National government (including the 'one for two' deal, see above) which were due to come to an end in 2012 and have subsequently been extended indefinitely. Moreover, it has been argued that the declines in NZU prices are the result of NZ ETS allowing unlimited imports of offsets or imported Kyoto allowances. The NZ ETS operates within the framework of a broader global market in emissions and it is acknowledged that there are strong financial and political benefits from linking international carbon schemes (Ellerman & Decaux, 1998; Flachsland, et al., 2009; Diaz-Rainey, et al., 2014). Linking should benefit small markets like New Zealand since it will aid market liquidity and act as a safety valve on price (MfET, 2007; Flachsland, et al., 2009). However, it has been argued that from mid-2011 as the international price for carbon (CERs) fell below domestic NZU prices, NZ ETS became a 'price taker' (WB, 2014; Sopher and Mansell 2014). The subsequent collapse of CERs was attributed with 'dragging down' NZU prices and leading to a glut of imported international units surrendered for obligation. As noted in the earlier, these assertion have not, however, been subjected to empirical scrutiny.

On 24 December 2011 and 18 December 2012, the government introduced bans on various international CERs and ERUs purportedly to strengthen the credibility of the NZ ETS and advance discussions on linking the NZ ETS with other major international ETSs but it is clear that concerns about the environmental integrity[4] of some imported units were a major consideration (MfE, 2014b). Despite its inclusion in the Kyoto protocol's CP1, New Zealand has decided that it will no longer commit to an emission reduction target under the second commitment period (CP2) (Mundaca & Richter, 2013). The declining price of carbon is also argued to be a reason why New Zealand withdrew from CP2 (Mundaca & Richter, 2013). Importantly, countries which do not sign up to CP2 will be unable to access the international offset market after the 'true-up' period (the formal international process to close off CP1), expiring in 2015.[5] This lack of international access should increase demand for domestic NZUs. A review of NZ ETS is expected at some stage in 2015/2016 but the review is not likely to be completed before the United Nations Framework Convention on Climate Change (UNFCCC) conference in Paris 2015 (COP21). In the run-up to COP21 the government announced its Intended Nationally Determined Contribution (INDC) of a 30% reduction in emissions relative to 2005 levels by 2030 – this is equivalent to 11% below 1990 levels excluding LULUCF.[6] The expectation is that the NZ ETS will remain the government's main instrument in achieving these targets going forward.

3. Literature Review and Hypotheses

The majority of literature to date focuses on the *ex-ante* impact of the NZ ETS on specific sectors, with forestry (Adams and Turner, 2012) and agriculture (Jiang et al, 2009; Kerr and Zhang, 2009) being the most prominent sectors investigated. There is also a small body of literature

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[4] The European Union and other nations moved to ban HFC-23 carbon credits of Chinese (and other nation) origin(s) amongst claims of perverse incentives created by these credits in the CDM. The large sums paid for HFC-23 offsets have led to factories in China (and elsewhere) to manufacture more HCFC-22 and HFC-23 by-products than necessary during operations, with the aim of earning extra carbon credits for destroying it (The New York Times, 2012; Motherboard, 2013). In 2011, one tonne of HFC-23 could be destroyed for just €0.17; the destruction of one CO_2-e tonne generated one CER, which has historically been sold for an average of €12 (Environmental Investigation Agency, 2011). As HFC represent approximately 11,000 carbon credits, credit revenue could represent up to half of the manufacturer's total revenue. (Environmental Investigation Agency, 2011; The New York Times, 2012).

[5] See http://www.epa.govt.nz/e-m-t/reports/Pages/True-up-process.aspx#whathappening [cited 18 October 2015]

[6] See https://www.climatechange.govt.nz/reducing-our-emissions/targets.html [cited 18 October 2015]

specifically focusing on the forecasted impact of linking the NZ ETS into international ETSs.[7] To date, there are no empirical papers, especially from a financial perspective, which attempt to decompose NZU price dynamics from an asset pricing perspective.

The driving factors behind the supply, demand and price of carbon allowances can be categorized into: (i) policy related issues, such as trading rules, linking ETSs into international markets, and government allocations of units; and (ii) market fundamentals which govern the production of GHGs, such as: weather, fuel price, and economic growth (Jiang, et al., 2009; Diaz-Rainey, et al., 2014). Due to the lack of NZ ETS empirical literature, we draw on the EU ETS literature to develop testable hypotheses. This is facilitated by the fact that EU Emissions Allowances (EUAs) are identical to NZUs. First, we address fundamentals, then policy impacts.

3.1. Fundamentals

There is a large body of research which demonstrates that the price of commodities such as oil, coal, natural gas, and electricity are fundamental determinants of EUAs prices. There is evidence to suggest that the former three commodities are major determinants of carbon prices due to the additional cost of carbon emissions (Benz & Trück, 2006; Mansanet-Bataller, et al., 2007; Hintermann, 2010). This is particularly important to the energy sector, which are able to switch fuel in the short-term to benefit from economic price differentials (Söderholm, 2001). Energy utilities have an economic incentive to purchase the cheapest fuel, however carbon emissions between fuels differ – the most carbon intensive fuels will require additional carbon allowances. Further, the price of the electricity produced will also determine carbon prices. Overall, high (low) energy prices should contribute to increases (decreases) in carbon prices (Alberola, et al., 2008).

The empirical evidence finds no clear consensus on the impact of each fundamental. Empirical analysis by Mansanet-Bataller et al. (2007) show that oil and natural gas prices are important determinants of CO_2 prices. Counterintuitively, coal, the most carbon intensive fuel, appeared have

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[7] See Benwell (2008; 2009); Jiang et al. (2009); Richter and Mundaca (2013) also provide an ex-post assessment of how obligated parties under the scheme take advantage of the flexibilities granted to reduce compliance costs.

no significant impact on carbon prices. Alberola et al. (2008) find that natural gas and electricity prices positively impact EUA prices, coal negatively impacts EUA prices, while oil was not statistically significant – with oil's impact possibly captured by natural gas. The increasing price of coal provides an incentive to switch to gas, therefore reducing CO_2 emissions and reducing allowance price. Importantly, Alberola et al. (2008) found that the relationship between CO_2 prices and fundamentals varied over multiple periods, defined by structural breaks. Thus, overall, the impact of each commodity is still debated, and may be dependent on a country's infrastructure, political factors, and emissions profile. With regards to the NZ ETS, the energy sector only accounts for 43% of gross emissions in New Zealand due to the reliance of renewable energies (MfET, 2007). Therefore, energy commodities may have less importance in determining carbon prices.

There is much research which suggests that weather conditions such as temperature, precipitation, and wind are expected to influence the price of carbon, with some researchers showing support and others finding a lack of significant evidence (Christiansen, et al., 2005; Mansanet-Bataller, et al., 2007; Benz & Trück, 2006; Alberola, et al., 2008; Benz & Trück, 2009; Hintermann, 2010). Dry climates are arguably the most important weather condition for New Zealand. Dry climates will decrease output from hydroelectric plants and increase reliance on emission-intensive power plants (Benz & Trück, 2006; Benz & Trück, 2009). Beyond drought, extreme weather conditions may also affect the pricing of EUAs. The literature suggests that extreme hot and cold weather conditions lead to increased end-user energy consumption from air conditioning or space heating units, increasing CO_2 emissions through power and heat generation, therefore increasing demand for carbon allowances (Christiansen, et al., 2005; Alberola, et al., 2008; Benz & Trück, 2009). In response, energy generators must increase their supply – demanding more fossil fuels, which must increase carbon emissions and demand for allowances. To their surprise, Alberola et al. (2008) find no statistically significant relationship between extreme weather and carbon prices, contradicting previous literature. However, there may still be a relationship between carbon and weather in New Zealand which is heavily reliant on electricity.

3.2. Policy Impacts

Policy elements may also determine the pricing dynamics of NZUs. It has been noted that the transition period of the NZ ETS doubles the utility of each NZU, allowing one unit to be surrendered for every two tonnes of CO_2-e emitted (Moyes, 2008). However, the greatest policy impact is likely to be linking the NZ ETS into international ETSs, particularly from the liquidity induced by the abundance of international units.

One body of research which provides some economic and financial theoretical grounding for linking systems focuses on the measurement of Marginal Abatement Cost (MAC) Curves (Ellerman & Decaux, 1998). Linking systems creates an incentive for permit sellers (low-damage countries) to relax their cap in order to sell even more permits – relevant to New Zealand's forest sink sector. Since, in compensation, permit buyers (high-damage countries) tend to choose to have stringent caps on their emissions, a distributional shift in favor of seller countries is created. If emission trading is possible, the MAC can be used to determine the supply and demand for any given market. For any region, if the market price is lower than the autarkic[8] marginal price, then the region becomes a net importer. Conversely, if the market price is higher than the autarkic marginal price, then the region abates more and becomes an exporter (Ellerman & Decaux, 1998).

Ellerman and Decaux (1998) demonstrate that New Zealand (as part of a subset) would stand to make a small profit from the marginally higher 'shadow carbon' price by exporting carbon units. However, if countries which have lower MACs than New Zealand are included in trading, New Zealand becomes a net importer of allowances and gains from cheaper imports. In comparison to their 1990 emissions levels, the Former Soviet Union (FSU) and eastern European countries (EEC), covered in the Kyoto protocol, are already considerably lower than their target emissions. The 'excess' allowances allocated to the FSU ad EEC, the difference between its current emissions levels and [higher] emission targets, are commonly referred to as 'hot air' and distort the global price of carbon (Ellerman & Decaux, 1998). The marginal cost of these allowances is zero, therefore FSU and

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[8] An autarkic market is a self-sufficient market, where carbon prices would be determined domestically.

EEC must be net exporters – marking the shadow price of carbon marginally lower than domestic NZUs. Further, the additional allowances generated regarding HFCs from China and India's manufacturing processes[4] also result in an excess supply of units. As such, the excess supply will further decrease the international price of carbon. We posit that when the international price of carbon drops below NZUs, New Zealand switches from being a net exporter to a net importer. Accordingly, there will be a structural shift in the price dynamics of NZUs as New Zealand becomes a price taker and follows international carbon prices. This leads to the first testable hypothesis:

> ***H_1: Domestic NZU prices will experience a negative structural shift in returns during the period at which international CER prices become relatively cheaper and are eligible for surrender obligations.***

Contemporary New Zealand based research by Richter and Mundaca (2013), which echoed Ellerman and Decaux's (1998) proposition, argued that the price of international units fell below NZUs due to more supply coming from the international market and the EU financial crisis – which reduced emissions, EU domestic demand for offsets, and led to an excess supply of unused carbon credits. Richter and Mundaca (2013) highlight that the price of units is influenced not only by domestic supply on the market and demand, but also the price and availability of international units which are eligible for compliance under the NZ ETS.

Similar to the NZ ETS, the EU ETS allowed the surrender of project-based units – such as CERs from CDMs. In 2006, about 90% of EU ETS project based units came from CDM activities, where China was the main supplier and UK firms were the main buyers. Supply was ample and demand was high as prices in the project based market was typically €10-15 less than EUAs (Jiang, et al., 2009). There is at least some indication that this may be the case in New Zealand, as Richter and Mundaca (2013) find that interview respondents claimed to buy units at spot prices as they were needed, while other participants purchased more units in anticipation of the expiry of the one-for-two rule and increased obligations. We refrain from estimating the direction between demand and CER price as the matter is complex and dependent on NZ participants' objectives.

Jiang et al. (2009) argues that if demand for permits exceeds the supply of NZUs, a formal link between the NZ ETS and international ETSs is likely to prevail, with an effective price floor implicitly set by the international price of carbon which can also be used for surrender obligations. Therefore, we expect interdependencies between NZU and CER prices – with CER prices leading and NZUs becoming price takers. Further, we may expect that the increased demand for cheap international units will result in increasing net import of units, further decreasing domestic NZU prices[9]. We develop two further hypotheses:

H_2: There will be an interdependent relationship between the NZU and CER returns, with CERs leading and NZUs following.

H_3: Increasing net import of units will negatively impact NZUs returns.

4. Methodology

The following sections outline the methodology of the paper. Section 4.1 presents the data for domestic and international carbon prices, and variables specified as carbon price fundamentals. Section **Error! Reference source not found.** outlines the econometric models of the paper, including tests of structural change breakpoints, Vector Auto Regression (VAR), Granger Causality tests, and ARCH and GARCH analysis of volatility.

4.1. Data

As we are interested in the price dynamics of NZUs, we conduct an analysis which includes determinants of NZU returns. Accordingly, daily spot prices for NZUs between 01 July 2010 and 31 December 2013 are used, representing 914 daily observations. We calculate daily return (r_t) as the log-first difference of price. Due to the lack of available spot price data, futures prices for CERs are

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[9] Karpoff (1987) outlines a large number of historical empirical papers which demonstrate a positive relationship between price changes and volume of trade.

used as a proxy for international carbon price; extracted from the ICE (2014) database. Importantly, futures with the shortest strips are used to better represent daily spot price dynamics. As the price of international carbon is quoted in Euros, prices are converted to New Zealand dollars (NZ$) to better represent the import and export costs to NZ ETS participants and account for fluctuations in currency. We calculate first log-difference of CER price as a measure of return (CER_r).

As determinants of carbon fundamentals, we include energy and electricity returns, identified as the first log-difference of: oil (Oil_t in NZ$/barrel), natural gas ($Gas_t$in NZ$/MWh), coal ($Coal_t$ in NZ$/ton), and electricity ($Elec_t$ in NZD$/MWh). To capture the fundamental impact of extreme weather, following Mansanet-Bataller et al. (2007) and Alberola et al. (2008), we include the changes in temperature ($Temp_t$) and also calculate deviations from seasonal averages[10] to identify extreme weather conditions. We calculate extreme deviations as the upper 95% and lower 5% quintiles, creating two dummy variable series: 'extreme hot' (Hot_t) and 'extreme cold'[11] ($Cold_t$). Regarding the impact on volume from linking the NZ ETS into international markets, the models include daily aggregated transaction data from the New Zealand Emission Unit Register (NZ EUR), generously provided by the Environmental Protection Authority (EPA). We combine daily incoming and outgoing transactions of AAU, RMU, CER and ERU (from AAU) units to create a net import variable[12] ($NetImport_t$). This represents the most comprehensive record of New Zealand transactions to date.

4.2. Structural Breakpoint Tests

As mentioned, Alberola et al. (2008) found that the relationship between CO_2 prices and fundamentals varied over time. The first hypothesis predicts that there will be a negative structural shift in NZUs when CERs become relatively cheaper and are eligible for NZ ETS surrender purposes.

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[10] Seasonal averages are calculated over the previous decade.

[11] We refrain from using Alberola et al.'s (2008) term 'unanticipated', as such weather conditions may be anticipated days before such event – the impact on carbon prices is expected to be derived from the increased end-user energy consumption. Weather data is recorded in Auckland.

[12] All international transactions are subject to a 24-hour window where the two parties of the transactions approve the transaction; further, there is an additional 2-hour window where the NZ EUR can also approve the transaction. Therefore, the volume data will be tested for contemporaneous and lagged relationships.

The analysis of multiple structural change models follow Bai and Perron (BP) (2003) who developed the algorithm and tested structural breaks in U.S. real interest rates. The BP algorithm obtains global minimizers of the sum of squared residuals, based on dynamic programming, which requires at most least-squares operations of order $O(T^2)$ for any number of breaks. Of interests to this paper is the presence of abrupt structural changes in NZU returns. As such, we specify a mean equation of NZU returns with only an intercept as a regressor. Based on evidence of heteroskedasticity and autocorrelation, we specific Newey-West heteroskedasticity and autocorrelation consistent (HAC) standard errors for the coefficient covariance matrix and allow error distribution to differ across breaks. The HAC coefficient covariance matrix is fixed at 1 lag and allows for serial correlation in the errors, therefore is specified using quadratic spectral kernels based on HAC covariance estimations using prewhitened residuals. The kernel bandwidth is automatically determined using Andrew's AR(1) method. The BP (double maximum) tests the null of no structural break against an unknown number of globally determined breaks, given the upper bound M, using LWZ criterion from Liu et al (1997) (Bai & Perron, 2003). The information criterion is set to allow a maximum of 5 structural breaks, and employs a trimming percentage of 15% - as the dataset consists of 914 observations, the trimming value implies that regimes must have at least 137 observations to be considered a structural break. Consideration must be given to the noise data in daily time series – an issue we also address.

4.3. Vector Autoregression and Granger Causality Tests

The second and third hypotheses focus on the inter-relationships between NZUs, CERs, and Net Imports. To address these questions, we required econometric models which can estimate the causal relationships and feedback mechanisms among variables. We identify VAR and Granger causality tests as suitable cross-spectral methods which are implemented simultaneously. This methodology was also implemented by Chevallier (2010), identifying the interrelationships between EUAs and CERs. The cross-spectral methods provide a useful description of the relationship between two (or more) variables when one is causing another (Granger, 1969). Further, the models allow interpretation whether NZUs or CERs or are the leaders in long-term price discovery. For VAR, let $Z_t = \begin{pmatrix} X_t^1 \\ X_t^2 \end{pmatrix}$ be the vector process formed of the stationary NZU and CER prices. The VAR(p) model is:

$$Z_t = C + \Gamma_1 Z_{t-1} + \cdots + \Gamma_p Z_{t-p} + \epsilon_t \tag{1}$$

where $C = \begin{pmatrix} C^1 \\ C^2 \end{pmatrix}$ is a constant vector, $\Gamma_1, \ldots, \Gamma_p$ are 2×2 matrices and the vector process $\epsilon_t = \begin{pmatrix} \epsilon_t^1 \\ \epsilon_t^2 \end{pmatrix}$ is formed of independent random variables following a centered bi-variate normal distribution $N(0, \Sigma)$. The VAR test will identify lagged relationships between dependent variables and lags of independent variables; where the inter-relationships between NZU, CER and Net Import are the primary variables of interest. Based on the structure of NZ EUR[12] and the lag between international transactions, we implement a VAR(2) model to capture two orders of lags. Oil, gas, coal, electricity, temperature, and extreme hot and cold deviations are included as additional exogenous variables.

The second test focuses on causality among the variables. Granger causality determines whether one time series is useful in forecasting another. Suppose that a vector set consists of only two series, X_t and Y_t, and that all other information is irrelevant[13]. First, let's assume that $P_t(X|\bar{X})$ is the optimum predictor of X_t using all information available[14] $(\bar{X})$. Then $\sigma^2(X|\bar{X})$ denotes the minimum predictive error variance of X_t using only past X_t, while $\sigma^2(X|\bar{X},\bar{Y})$ denotes the minimum predictive error variance of X_t using past X_t and Y_t. If $\sigma^2(X|\bar{X}) > \sigma^2(X|\bar{X},\bar{Y})$ then Y_t is said to cause X_t. The best linear predictor of X_t, using only past X_t and past Y_t will take the form

$$P_t(X|\bar{X},\bar{Y}) = \sum_{j=1}^{\infty} a_j X_{t-j} + \sum_{j=1}^{\infty} b_j Y_{t-j} \tag{2}$$

where a_j and b_j are chosen to minimize $\sigma^2(X|\bar{X},\bar{Y})$. We can state that a process Y "Granger-causes" X at the order of p if it can be shown, in a linear regression on lagged values of Y (and lagged values of X), that at least one regression coefficient of Y values is statistically different from zero. The concept behind Granger causality is that information on past values of prices of Y are relevant to

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[13] Such a definition does not account for confounding variables. As such, the selection of X_t and Y_t must be based on theory; particularly if an exogenous variable could affect both – resulting in spurious correlations.

[14] Granger (1969) revises this universal definition to only include relevant information.

forecasting X at future time t. Importantly, the flow of time plays a central role in this definition, where the *cause* happens prior to the *effect* (Granger, 1969). The definition in (2) can be extended to a cross-spectral model, illustrated using two-variables. Again, let X_t, Y_t be two stationary time series with zero means:

$$\begin{aligned} X_t &= \sum_{j=1}^{m} a_j X_{t-j} + \sum_{j=1}^{m} b_j Y_{t-j} + \varepsilon_t, \\ Y_t &= \sum_{j=1}^{m} c_j X_{t-j} + \sum_{j=1}^{m} d_j Y_{t-j} + \eta_t, \end{aligned} \tag{3}$$

where ε_t, η_t are two uncorrelated white-noise series. The definition of causality given implies that Y_t is causing X_t so long at least one b_j statistically different from zero. Further, X_t is causing Y_t so long as at least one c_j is statistically different from zero. If at least one coefficient from both b_j and c_j are statistically significant then there is said to be a feedback relationship between X_t and Y_t. The above definition, (3), also represents a VAR specification by allowing more than one evolving variable over time; explaining its evolution based on its own lags and the lags of other model variables. Granger causality is examined by testing the null hypothesis that coefficients for Y on X are null; a p-value lower than 0.05 results in a rejection of the null.

4.4. ARCH and GARCH Analysis

Autoregressive Conditional Heteroskedasticity (ARCH) and *Generalized Autoregressive Conditional Heteroskedasticity* (GARCH) models, developed by Engle (1982) and Bollerslev (1986), respectively, are designed to deal with changing variance across time, providing a volatility measure that can be used in financial decisions which concern risk analysis (Engle, 2001). The standard ARCH model states that innovations (y_t) are a function of random error terms (ε_t) and conditional variances (h_t), and conditional variance themselves are a linear function of past squared innovations.

$$y_t = \varepsilon_t h_t^{1/2},$$

where

$$h_t = \alpha_0 + \alpha_1 y_{t-1}^2, \tag{4}$$

and $V(\varepsilon) = 1$. Engle (1982) adds the assumption of normality to the ARCH model, expressed directly in terms of ψ_t, representing the availability of the information set at time *t.* Using conditional densities:

$$y_t | \psi_{t-1} \sim N(0, h_t),$$

where

$$h_t = \alpha_0 + \alpha_1 y_{t-1}^2 \tag{5}$$

However, the limitation of ARCH alone is that an arbitrary linear declining lag structure of conditional variance to account for the long-memory (Bollerslev, 1986). Bollerslev (1986) proposes the GARCH model to allow the incorporation of a longer memory and more flexible lag structure. This formulation generalizes the ARCH model by allowing non-zero β_i's (Engle & Bollerslev, 1986). The GARCH (*p, q*) is given by:

$$\varepsilon_t | \psi_{t-1} \sim N(0, h_t),$$

$$h_t = \alpha_0 + \sum_{k=1}^{q} \alpha_k \varepsilon_{t-k}^2 + \sum_{i=1}^{p} \beta_i h_{t-i}$$

$$= \alpha_0 + A(L)\varepsilon_t^2 + B(L)h_t, \tag{6}$$

where:

$$p \geq 0, \quad q > 0$$

$$\alpha_0 > 0, \quad \alpha_k \geq 0, \quad k = 1, \ldots, q,$$

$$\beta_i \geq 0, \quad i = 1, \ldots, p.$$

Again, let h_t denote the conditional variance function, ε_t denote the real-valued discrete-time stochastic process, and ψ_t the information set through time *t* with normal distribution (Engle, 1982; Bollerslev, 1986). The ARCH coefficient is noted as α_k, while the GARCH coefficient is noted as β_i. The GARCH (*p, q*) in equation (6) represents the simplest GARCH model, where *p* measures the number of autoregressive lags for the ARCH term, and the q to how many moving average lags are specified for the GARCH terms (Bollerslev, 1986; Engle, 2001). If $p = 0$ the process reduces to an ARCH (q) process, and for $p = q = 0$ ε_t becomes white noise as there is no covariance with either the past variances or past conditional variances. The advantage of ARCH and GARCH models is that they consider relative weightings of the whole dataset, giving more relevance and weight to the most recent data which specifically accounts for changing volatility over time (Engle, 2001). Further, the inclusion of lagged conditional variances indicates an adaptive learning mechanism (Bollerslev, 1986).

5. Results

5.1. Descriptive Results

[INSERT FIGURE 2, FIGURE 3, FIGURE 4 & FIGURE 5]

Simple descriptive evidence of the impact of importing international allowances on NZUs can be observed in Figure 2 and Figure 3. Figure 2 illustrates that from mid-2011 the international price for carbon (CERs) fell below domestic NZU prices. Further, Figure 2 and Figure 3 show increases in both net import of international units and international units surrendered for obligation. From Figure 3 it is clear that the number of domestic NZUs surrendered decreases from 2011 while there is an increase use of international CERs, ERUs, and RMUs. Collectively, these three imported unit types comprised 1.60% of surrendered units in 2010, 70.85% of surrendered units in 2011, and 95.52% of surrendered units in 2012.

Figure 4 shows NZU returns, CER returns, and Net Imports across all three periods. A brief glance at the NZU returns would suggest that some time periods are riskier than others as the magnitude of returns vary, and that these risky periods are not randomly scattered; often there is a great degree of autocorrelation in the returns, with small and large magnitudes of returns are clustered together.

The impact of cheap, international units can also be observed from unit import and export data, shown in Figure 5. During 2009, New Zealand was a net exporter of 1.13 million units; mainly AAU and ERU (from AAU) units. In 2010, despite an increase in imported CERs, New Zealand continued to export AAUs and ERUs (from AAUs) – net position was 1.75 million units outgoing. In contrast, when the price of international units fell below domestic units in 2011, New Zealand began to import a large number of international RMUs and CERs with little growth in exports – net position was 4.03 million incoming. In 2012, when international carbon prices declined further, New Zealand also began importing ERUs (from AAUs) which resulted in a net position of 30.36 million units imported. Finally, 2013 witnessed a large growth in international ERU (from AAUs) imports – New Zealand's net position was 95.99 million units incoming. The descriptive results show evidence of New Zealand becoming a net importer during a period where the international price of carbon fell below the price of domestic NZUs.

5.2. Structural Breaks

There are two expected structural breaks during the time series. The first can be identified from Figure 2. We expect the first structural break to occur when the price of international CERs fell below the price of domestic NZUs for extended periods – beginning 21 June 2011. The second structural break is expected to occur soon after New Zealand banned the surrender of international CERs[4]. A small ban (24 units) occurred on 24 December 2011 - predominantly from China (54.17%) and India (20.83%) – which is unlikely to have an impact. A much larger ban occurs on 18 December 2012, banning a further 641 CERs and ERUs from surrender obligations - the majority of bans were from China (78.47%). The impact may be delayed, as there was an agreed 'true-up' period to account for contracts entered into before the ban. Forward contracts must be registered with the NZ EUR by 11 February 2013 (MfE, 2012b). The ban on particular units will affect the surrender dynamics; it will also affect the import of international units and therefore the price of NZUs through changing supply and demand. To empirically address the structural breaks, we implement the BP multiple structural change test.

The results of the Bai-Perron multiple structural change test on daily data are shown in Panel A of Table 2, suggesting no statistically significant breaks across the entire time series. However, Figure 2 illustrates that NZUs prices experienced large declines from mid-2011 in tandem with CER prices. Further, the p value is relatively close to significance; we posit that the lack of statistically significant inference may be due to a large amount of noise in daily NZU returns.

[INSERT **ERROR! REFERENCE SOURCE NOT FOUND.** 2 AND FIGURE 6 ABOUT HERE]

We repeat the Bai-Perron breakpoint test using monthly NZU returns to examine whether structural breaks could be identified using data which contained less noise; the results are shown in Panel B of Table 2 and Figure 6. The results show that the Bai-Perron breakpoint test identified two statistically significant structural breaks, separating the time series into three distinct periods: August 2010 to June 2011, July 2011 to February 2013, and March 2013 to December 2013. During the second period, July 2011 to February 2013, there is a statistically significant intercept (-0.1263) which shows that returns decreased by an average of 12.63% each month. There were no statistically significant intercepts during the first or third period, suggesting that prices remained relatively stable during these periods on a monthly basis.

Based on the findings of the monthly data, we perform a further breakpoint test using daily NZU returns, constraining the model to automatically identify two (unknown) structural breaks using Global Information Criterion (GIC) tests; results are shown in Panel C of Table 2. The result of the GIC test, which automatically detects two breakpoints, estimates the breakpoints to be 20 June 2011 and 19 February 2013; similar to the dates outlined in Panel B of Table 2 and our expected breakpoints. The results show a statistically significant intercept (-0.006), suggesting an average daily decline of 0.6% during the second period[15]; there are also no statistically significant intercepts for the first and third periods. Based on the results of the breakpoint tests, we adopt the two identified breakpoints for further analysis, separating the sample into three sub-periods: 01 July 2011 to 19

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[15] Note that a negative daily return of -0.6% produces a negative monthly return of -12.40% over a 22 day month; $-0.1240 = (1 - 0.006)^{22} - 1$. The small difference between the monthly and daily estimates may be due to the precise location of the breakpoints, affecting the average daily return estimate during the second period.

June 2011 (First Period), 20 June 2011 to 18 February 2013 (Second Period), and 19 February 2013 to 31 December 2013 (Third Period).

Overall, the results from Table 2 show support for $\boldsymbol{H_1}$, a significant negative structural shift begins the day before CER prices fall below NZU prices. The negative shift continues to February 18, which occurs 2 months after the ban on 641 CERs is announced and 7 days after the deadline to register all forward contracts for exemption. All analyses focuses on the interrelationships among variables, delineating the time series into the full time period and the three smaller sub-periods to control for the structural breaks in returns.

5.3. Vector Autoregression

In this section we present the results of the VAR analysis. The VAR results in Table 3 provide an in-depth analysis of the interrelationships and variable dynamics, controlling for fundamentals. We address each time period individually.

[INSERT TABLE 3]

Over the full period, 01 July 2010 to 31 December 2013, the results show a statistically significant relationship between the contemporaneous NZU returns and the first-lag of NZU returns (0.0894). NZU prices also show positive coefficients with two lags of CER returns ([L1]0.0520; [L2]0.0274) and a small positive coefficient with one lag of Net Imports ([L1]0.0060). Over the full period, the fundamental factors had no impact. Regarding CERs, the results show that the CER returns have large mean-reversion dynamics, with a large negative coefficient for one lag of CER returns (-0.1920) but small positive coefficient for two lags (0.0772). The major determinant of CER returns was the return on coal (1.0554) – the most carbon-intensive fuel. For Net Imports, result show a large positive coefficient with the two day lag on CERs (1.0554) and a positive intercept (0.0925). Over the entire time period, results suggest that NZU are responding to: past NZU returns, past CER returns, and demand for units (Net Imports). CERs returns primarily determined by previous CER returns and are independent to NZUs, but Net Imports, which proxies for New Zealand’s unit demand, has a small impact on CER returns. The relationship between Net Imports and CERs may be due the NZ ETS participants who are buying cheap CERs in anticipation of increased surrender obligations and expiration of the two-for-one rule, noted by Richter and Mundaca (2013).

During the first period, 01 July 2010 to 17 June 2011, the results show that NZU returns have a large negative coefficient with their first lag (-0.1744) suggestion mean reversion. During this period CER prices are generally higher than NZU prices; there is little demand for CERs and New Zealand ETS is largely independent to relatively expensive international units. As the NZ ETS is infrequently traded during its first year since inception, prices remain relatively stable and fluctuate between $18.20-21.42. International CERs are also independent to NZU, with the returns on coal being the only statistically significant fundamental variable (0.6030). Further, Net Imports show a statistically significant coefficient for one lag of Net Imports (0.1657), suggesting a position relationship between today's and yesterday's demand for allowances. Moreover, the dummy variable for extreme hot weather is positive and statistically significant (0.0163). For the first period, the extreme hot weather primarily occurred between December 2010 and March 2011 which overlaps with the December 2010 surrender deadline. At the same time, there was a brief period in December 2010 when international CERs temporarily fell below NZU prices. The combination of relatively cheap international units and the surrender requirement would result in the temporary increase in Net Imports observed.

During the second period, 20 June 2011 to 18 February 2013, the price of international CERs falls below NZU; both prices begin at approximately $20 and decline in tandem to $1.45 for NZUs and $0.22 for CERs. During the second period, NZU returns lose their autoregressive characteristic observed during the first period. Instead, NZU returns have statistically significant relationship with: the first and second lag of international CER returns ([L1]0.1265; [L2]0.0654), New Zealand electricity (-0.0204) and a significant intercept (-0.0048). This suggests that CERs were price leaders and NZUs become price takers - responding to short-term international unit price movements and moving in the same direction – with some minor adjustment for domestic energy demand. Economically, there is no incentive for an NZ ETS participant to buy expensive domestic NZUs when there is a supply of cheap, and identical, international CERs which can be used for NZ ETS compliance. For CERs, the major determinant of returns is international coal prices; however there is some feedback[16] between CER returns and NZU returns, with CER returns moving in the opposite direction to NZU returns. This finding is expected, and similar to Chevallier (2010). For Net Imports, there are no significant fundamentals, while the intercept is statistically significant.

During the third period, 19 February 2013 to 31 December 2013, the NZU prices remain above CERs. This period occurs soon after the ban on international units. As such, the results show that lagged CER returns do not have a statistically significant impact on NZU returns. Instead, NZUs have only one statistically significant coefficient - one lag of NZU returns (0.1858). During the third period, NZU prices experience a small but positive increase to approximately $3. CER prices remain low through the majority of the third period, with a peak of $1.16. Coal returns provide a statistically significant coefficient (2.6766) for CER returns, while one lag of CER returns provides a statistically significant negative coefficient (-0.2774), suggesting prices mean revert during this period. Net Imports have a statistically significant intercept (0.2253) and positive coefficient for two lags of CER returns (1.3569). The third period is primarily a period of unit importing; this result is confirmed in Figure 2. Intuition would suggest a negative coefficient between Net Imports and CERs, as falling CER prices would encourage New Zealand participants to purchase more. However, international CER prices remain below domestic NZU prices, therefore providing economic incentive for New Zealand participants to import cheap international units and bank domestic NZUs, again supporting the

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[16] The feedback can be explained through the behaviour of NZU and CER prices during the second period. First, note that CER prices are lower than NZU prices for the majority of the second period. CER returns are also primarily determined by coal returns. If CER returns are the major determinant of NZU returns, then we'd expect CER innovations to occur first at time t and NZU innovations respond on the following lags. The VAR estimation calculates the covariance of CER returns based on *lagged* NZU returns (and vice versa). The results show that CERs have a significant negative relationship with one lag of NZUs, but NZUs have a significant positive relationship with two lags of CERs – showing that NZUs are slower to incorporate innovations. If CER innovations lead, while NZUs respond in the following lags, then we would expect there to be a negative coefficient between CER_t and NZU_{t-1} as today's CER price deviates away from yesterday's NZU. In response, NZUs follow CERs in the following two lags; therefore move in the same direction – explaining the positive coefficients for NZUs.

argument of participants purchasing unit in anticipation of increased obligation (Richter & Mundaca, 2013).

5.4. Granger Causality

Table 4 present the results of the pairwise-Granger causality tests. Results show that both CERs and Net Imports Granger-cause NZU prices across the entire time period. CERs had a greater impact than Net Imports, especially in the second period when lagged CERs were the major determinant of future NZU prices.

[INSERT TABLE 4]

Net imports appear to have a small impact on CER prices over the entire period. Further, NZUs also provide a small impact on future CER prices in the second period. This particular finding is of importance as it suggested that the prices are inter-related. Naturally, our results mirror those of Chevallier (2010); both units represent the same emission asset and can be used for arbitrage purposes for NZ ETS compliance, therefore the two assets should be inter-related and impact each other. Further, this appears to be consistent with Granger's (1969) definition of feedback, where the past prices of NZUs and CERs help predict future prices of both series.

Finally, results show that CERs impact Net Imports across the entire time series, with a major impact occurring in the third period. Upon further inspection of the data, there is a large increase in ERUs imported during the third period after the New Zealand ban on certain CERs[17]. Results would suggest that NZ participants substituted banned CERs with alternative (inexpensive) international carbon units. Further, the international price of carbon had fallen to near zero while NZUs fluctuates between $3-5. The spread between the relatively expensive NZUs and cheap ERU alternatives resulted in a large increase in imports.

The results of the VAR and Granger causality tests show significant support for ***H*₂**. Both models provide evidence of CER returns being the major determinant of NZU returns during the

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[17] Such results are congruent with the comments provided by Nigel Brunel, Director of OM Financial, who highlighted that the ban on CERs resulted in NZ ETS participants switching to importing international ERUs. A lack of complete ERU data prevented empirical analysis of this proposition.

second period – as defined by the BP test which coincides with CER prices falling below NZU prices until the ban. Importantly, there is an interdependence among the carbon unit returns, suggesting that the systems are linked. Interestingly, we identify the significant results which are opposite to ***H₃*** and counterintuitive to expectations. Results showed a positive relationship between Net Imports and CER returns[18] – however, this result would be congruent with Richter and Mundaca's (2013) claims of NZ ETS participants banking domestic NZUs and continuing to buy international units at spot prices.

5.5. ARCH and GARCH analysis

To identify ARCH effects, we perform an ARIMA model on NZU returns with two autoregressive lags; results shown in Panel A Table 5. Results show statistically significant coefficient with one autoregressive lag. The standard deviation of the white-noise disturbance is also statistically significant. For robustness, we also implement Engle's Lagrange Multiplier test for the presence of autoregressive conditional heteroskedasticity on the residuals of the ARIMA specification; shown in Panel B Table 5. Results show statistically significant ARCH effects for up to 15 lags –rejecting the null hypothesis of no ARCH effects. The jump from zero lags to one lag provides a X^2 of 15.626, while the second lag onwards provides little change in X^2, suggesting that an ARCH(1) model is the appropriate specification[19].

[INSERT TABLE 5 & TABLE 6]

The ARCH(1) and GARCH(1,1) results are provided in Table 6. For the full period, the mean equation's intercept shows that NZU returns were generally negative over time – decreasing price. The results show that the conditional variance has significant coefficients with lagged squared

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[18] As a post-hoc test, we regress Net Imports against NZU-CER price spread; correcting for heteroskedasticity in the full, first, and second period (no heteroskedasticity detected in the third period). This was based on the logical proposition that cheaper CERs would provide an economic incentive to import units. The results showed a significant positive relationship during the full and first period, yet no significance during the second and third period – when CERs became cheaper than NZUs. Results omitted for brevity.

[19] There is little difference between the X^2 or one and two lags, while the jump from two lags to three lags is a difference of $X^2 = 1.351$; a two-tailed X^2, with 1 df, provides $p \cong 0.2451$. The significant X^2 values up to 15 lags indicate that there may be some GARCH effects.

residuals (0.1356; ARCH effects) and lagged conditional variance (0.8579; GARCH effects). The sum of the two coefficients is close to one (0.9935), suggesting the process slowly mean reverts and has persistent volatility across the entire sample. The intercept is statistically significant, but contributes a very small amount of conditional variance beyond the specified parameters.

For the first period, the intercept for the mean equation is statically insignificant, showing no significant shift in returns. There are statistically significant ARCH (0.0545) and GARCH (0.5879) coefficients which sum to 0.6424 , suggesting that volatility has relatively quick mean reversion, with the major determinant of volatility persistence being covariance with past conditional variance values. The statistically significant intercept suggests a small increase in conditional variance during the first period which is exogenous to the specified parameters.

For the second period, the mean equation's intercept is statistically significant and negative, showing negative returns over the period at a rate of -0.59% each day. The GARCH(1,1) specification was unsuitable for the second period, failing to find any statistically significant GARCH effects and no covariance with lagged conditional variance values. This suggests that the GARCH effect is not statistically different from zero. Instead, we fit an ARCH(1) specification, which shows statically significant ARCH effects (0.1351) and significant intercept (0.0014). The ARCH effect is of relatively similar magnitude to the full period window. The intercept suggests that a variable beyond those specified increased conditional variance during this period.

For the third period, the mean equation's intercept was statistically insignificant, suggesting that returns were not significantly different from zero over the third period. There are statistically significant ARCH (0.4225) and GARCH (0.5242) effects, which sum to 0.9467 – indicating slow mean reversion and persistent volatility over the third period. The large ARCH and GARCH coefficients show that although the GARCH effect is still the greatest determinant of conditional variance, the ARCH effect (covariance with lagged unexpected innovations) has a relatively greater role compared to the ARCH effects found in the first and second periods. The statistically significant intercept suggests a small increase in conditional variance from exogenous variances beyond those specified.

6. Conclusions

We provide the first financial analysis of NZ ETS and thereby contribute to the understanding of the asset pricing of emissions units in a highly international emissions trading scheme. Our results indicate that unlike in EU ETS, imports of offsets rather than fundamentals have been the major price determinant. Moreover, the pricing of NZUs can be placed into three distinct periods as delineated by two structural breaks (1) a period up to 2011 when the system is autarkic; (2) a period between June 2011 and February 2013 when NZ ETS does become a 'price take' and; (3) a period post February 2013 when the system regains some independence following policy intervention to ban the importation of offsets of dubious provenance (e.g. allowances related to the HFC-23 scandal).

The case of NZ ETS highlights both the power of tacitly linking ETSs' and the dangers of doing so. In the latter case, distortions such as 'hot air' misallocation or problems such as dubious HFC-23 allowances from other markets are in effect 'imported' to the domestic market. This can undermine the credibility of the domestic ETS and dampen its environmental effectiveness. Linking ETSs', whether formally or tacitly through the offset markets, is clearly a double edge sword. Whether small and international ETSs' could be designed with *ex ante* 'circuit-barkers' for imported offset/allowances remains an open question and potentially a valuable avenue for theoretical modelling. Such *ex ante* rules are likely to be preferable to *ex post* interventions that add to market uncertainty, as was the case in NZ ETS. Price based circuit-barkers are common in stockmarkets so this experience may provide some insight into how imported 'volume' base circuit-barkers might be implemented.

References

Adams, T. & Turner, J. A., 2012. An investigation into the effects of an emissions trading scheme on forest management and land use in New Zealand. *Forest Policy and Economics*, 15(1), pp. 78-90.

Alberola, E., Chevallier, J. & Chèze, B., 2008. Price drivers and structural breaks in European carbon prices 2005–2007. *Energy Policy*, 36(2), pp. 787-797.

Bai, J. & Perron, P., 2003. Computation and analysis of multiple structural change models. *Journal of Applied Econometrics*, 18, pp. 1-22.

Benwell, R., 2008. Linking as leverage: emissions trading and the politics of climate change. *Cambridge Review of International Affairs*, 21(4), pp. 545-562.

Benwell, R., 2009. Voluntary aspects of carbon emissions trading. *International Journal of Environmental Studies*, 66(5), pp. 605-618.

Benz, E. & Trück, S., 2006. CO2 emission allowances trading in Europe – specifying a new class of assets. *Problems and Perspectives in Management*, 4(3), pp. 30-40.

Benz, E. & Trück, S., 2009. Modeling the price dynamics of CO2 emission allowances. *Energy Economics*, 31(1), pp. 4-15.

Bollerslev, T., 1986. Generalized autoregressive conditional heteroskedasticity. *Journal of Econometrics*, 31(3), pp. 307-327.

Bullock, D., 2012. Emissions trading in New Zealand: development, challenges and design. *Environmental Politics*, 21(4), pp. 657-675.

Chevallier, J., 2010. EUAs and CERs: vector autoregression, impulse response function and cointegration analysis. *Economics Bulletin*, 30(1), pp. 558-576.

Christiansen, A., Arvanitakis, A., Tangen, K. & Hasselknippe, H., 2005. Price determinants in the EU emissions trading scheme. *Climate Policy*, 5(1), pp. 15-30.

Diaz-Rainey, I., Finegan, A., Ibikunle, G. & Tulloch, D. J., 2014. Institutional investment in the European Union emissions trading scheme. In: J. P. Hawley, et al. eds. *Cambridge Handbook of Institutional Investment and Fiduciary Duty*. Cambridge: Cambridge University Press, pp. 127-145.

Ellerman, A. D. & Decaux, A., 1998. Analysis of post-Kyoto CO2 emissions trading using marginal abatement curves. MIT Joint Program on the Science and Policy of Global Change, Report 40, Cambridge, Massachusetts, pp. 1-33.

Engle, R. F., 1982. Autoregressive conditional heteroscedasticity with estimates of the variance of United Kingdom inflation. *Econometrica*, 40(4), pp. 987-1007.

Engle, R., 2001. GARCH 101: The use of ARCH/GARCH models in applied econometrics. *The Journal of Economic Perspectives*, 15(4), pp. 157-168.

Engle, R. F. & Bollerslev, T., 1986. Modelling the persistence of conditional variances. *Econometric Reviews*, 5(1), pp. 1-44.

Environmental Investigation Agency, 2011. CAuthorityhina's greenhouse gas vent threat in bid to extort billions. [Online] Available at: http://eia-international.org/china-threat-to-vent-super-greenhouse-gases-in-bid-to-extort-billions [Accessed 08 January 2015].

EPA 2013. The New Zealand Emissions Trading Scheme: ETS 2013 - Facts and figures, Wellington: Environmental Protection Authority.

Flachsland, C., Marschinski, R. & Edenhofer, O., 2009. To link or not to link: benefits and disadvantages of linking cap-and-trade systems. *Climate Policy*, 9(4), pp. 358-372.

Granger, C. W., 1969. Investigating causal relations by econometric models and cross-spectral methods. *Econometrica*, 37(3), pp. 424-438.

Hintermann, B., 2010. Allowance price drivers in the first phase of the EU ETS. *Journal of Environmental Economics and Management*, 59, pp. 43-56.

ICE, 2014. ICE Report Centre - Data. [Online] Available at: https://www.theice.com/marketdata/reports/94 [Accessed 18 December 2014].

Jiang, N., Sharp, B. & Sheng, M., 2009. New Zealand's emissions trading scheme. *New Zealand Economic Papers*, 43(1), pp. 69-79.

Karpoff, J. M., 1987. The relationship between price changes and trading volume: a survey. *Journal of Financial and Quantitative Analysis*, 22(1), pp. 109-126.

Kerr, S. & Zhang, W., 2009. Allocation of New Zealand units within agriculture in the New Zealand emissions trading scheme. *Motu Working Paper*, 9(16), pp. 1-82.

Liu, J., Wu, S., & Zidek, J. V., 1997. On segmented multivariate regression. *Statistica Sinica*, 7(2), pp. 497-525.

Mansanet-Bataller, M., Pardo, A. & Valor, E., 2007. CO_2 prices, energy and weather. *The Energy Journal*, 28(3), pp. 73-92.

MfE, 2005. Review of Climate Change Policies, Wellington: Ministry for the Environment.

MfE, 2011. Report on The New Zealand Emissions Trading Scheme, Wellington: Ministry for the Environment.

MfE, 2012a. The New Zealand Emissions Trading Scheme: NZ ETS 2011 - Facts and figures, Wellington: Ministry for the Environment.

MfE, 2012b. Guidance on the use of Emission Reduction Units and Certified Emission Reduction units in the ETS, Wellington: Ministry for the Environment.

MfE, 2013b. The New Zealand Emissions Trading Scheme: ETS 2012 - Facts and figures, Wellington: Ministry for the Environment.

MfE, 2014a. New Zealand's Greenhouse Gas Inventory 1990-2012, Wellington: Ministry for the Environment.

MfE, 2014b. Regulations banning the use of certain international units in the ETS. [Online] Available at: http://climatechange.govt.nz/emissions-trading-scheme/building/regulatory-updates/restricting-cers.html [Accessed 25 November 2014].

MfET, 2007. A Framework for a New Zealand Emissions Trading Scheme, Wellington: Ministry for the Environment and The Treasury.

Motherboard, 2013. How Producers of Super Greenhouse Gases Are Blackmailing the Planet. [Online] Available at: http://motherboard.vice.com/blog/how-producers-of-super-greenhouse-gases-are-blackmailing-the-planet [Accessed 08 January 2015].

Moyes, T. E., 2008. Greenhouse gas emissions trading in New Zealand: trailblazing comprehensive cap and trade. *Ecology*, 35, pp. 911-966.

Mundaca, L. & Richter, J. L., 2013. Challenges for New Zealand's Carbon Market. *Nature Climate Change*, 5, 1006-1008.

Ranson, M., & Stavins, R. N. (2015). Linkage of greenhouse gas emissions trading systems: Learning from experience. *Climate Policy*, (ahead-of-print), 1-17

Richter, J. L. & Mundaca, L., 2013. Market behaviour under the New Zealand ETS. *Carbon Management*, 4(4), pp. 423-438.

Sinclair, G., 2011. The New Zealand emissions trading scheme: off to a good start. In: J. Peetermans, ed. Greenhouse Gas Market Report 2011 - Asia and Beyond: The Roadmap to Global Carbon & Energy. Genève: International Emissions Trading Association, pp. 12-17.

Sopher, P. and Mansell, A.. 2014. N*ew Zealand - The World's Carbon Markets: A Case Study Guide to Emissions Trading*. March, EDF & IETA

Söderholm, P., 2001. Fossil fuel flexibility in west European power generation and the impact of system load factors. *Energy Economics*, 23, pp. 77-97.

Statistics New Zealand, 2012. Overseas Merchandise Trade: June 2012. [Online] Available at: http://www.stats.govt.nz/browse_for_stats/industry_sectors/imports_and_exports/OverseasMerchandiseTrade_HOTPJun12.aspx [Accessed 20 November 2014].

The New York Times, 2012. Profits on Carbon Credits Drive Output of a Harmful Gas. [Online] Available at: http://www.nytimes.com/2012/08/09/world/asia/incentive-to-slow-climate-change-drives-output-of-harmful-gases.html [Accessed 08 January 2015].

UNFCCC, 2014. Greenhouse Gas Inventory Data - Detailed by Party. [Online] Available at: http://unfccc.int/di/DetailedByParty.do [Accessed 03 November 2014].

WB (2012). *State and trends of the carbon pricing 2014*, World Bank, Washington DC

Table 1: Ne New Zealand's GHG Emissions Profile

Panel A: Change in New Zealand's GHG Emissions Profile 1990 to 2012

Gas		**100 Year Global Warming Potential (CO_2-e)**	**1990 (Gg CO_2-e)**	**2012 (Gg CO_2-e)**	**Change from 1990**
Carbon Dioxide	CO_2	1	24,915.89	34,258.20	37.5%
Methane	CH_4	21	26,834.68	29,038.45	8.2%
Nitrous Oxide	N_2O	310	8,245.79	10,885.70	32.0%
Hydrofluorocarbons	$HFCs$	140-11,700	-	1,804.69	
Perfluorocarbons	$PFCs$	6,500-9,200	629.87	40.75	-93.5%
Sulphur Hexafluoride	SF_6	23,900	15.20	20.20	32.8%
Combined Total			**60,641.44**	**76,047.98**	**25.4%**

Sources: Adapted from Jiang et al. (2009) and UNFCCC (2014)

Panel B: GHG Emissions Profile by Gas

		NZ		**Annex I**	
GHG		**1990**	**2012**	**1990**	**2012**
Carbon Dioxide	CO_2	41.1%	45.0%	81.0%	83.1%
Methane	CH_4	44.3%	38.2%	10.5%	8.8%
Nitrous Oxide	N_2O	13.6%	14.3%	7.0%	5.9%
Hydrofluorocarbons, Perfluorocarbons and Sulphur Hexafluoride (combined)	$HFCs + PFCs + SF_6$	1.1%	2.5%	1.5%	2.3%

Source: UNFCCC (2014)

Table 2: Structural change tests

Panel A: BP Multiple Structural Change Test on Daily NZU Returns

Break type calculated using Bai-Perron test of 1 to M globally determined breaks. Dependent variable: daily NZU returns. Method: least squares with breaks. Based on 914 observations between 01 July 2010 and 31 December 2013. Break selection uses unweighted max-F (UDmax), trimming at 15%, a maximum of 5 breaks across the entire series, and a significance level at 0.05. Specified using HAC standard errors and covariance (Quadratic-Spectral kernel, Andrews' bandwidth).

R^2	0.0000	Mean dependent variable	-0.0019
Adjusted R^2	0.0000	S.D. dependent variable	0.0354
S.E. of regression	0.0354	Akaike info criterion	-3.8431
Sum squared residuals	1.1442	Schwarz criterion	-3.8378
Log likelihood	1757.2840	Hannan-Quinn criterion	-3.8411
		Durbin-Watson statistic	1.8172

Variable	Coefficient	Std. Error	t-statistic	$p \leq$
Intercept	-0.0019	0.0013	-1.50	0.1331

Panel B: BP Test on Monthly NZU Returns

Break type calculated using Bai-Perron test of 1 to M globally determined breaks. Dependent variable: monthly NZU returns. Method: least squares with breaks. Based on 41 observations between 2014M08 and 2013M03. Break selection uses unweighted max-F (UDmax), trimming at 15%, a maximum of 5 breaks across the entire series, and significance level at 0.05. Specified using HAC standard errors and covariance (Quadratic-Spectral kernel, Andrews' bandwidth).

R^2	0.2328	Mean dependent variable	-0.0430
Adjusted R^2	0.1924	S.D. dependent variable	0.1790
S.E. of regression	0.1608	Akaike info criterion	-0.7467
Sum squared residuals	0.9828	Schwarz criterion	-0.6214
Log likelihood	18.3082	Hannan-Quinn criterion	-0.7011
F-statistic	5.7645	Durbin-Watson statistic	2.2138
Prob (F-statistic)	0.0065		

Variable	Coefficient	Std. Error	t-Statistic	$p \leq$
First period: 2010M08 - 2011M06 (11 obs)				
Intercept	0.0018	0.0158	(0.11)	0.9093
Second Period: 2011M07 - 2013M02 (20 obs)				
Intercept	-0.1263	0.0254	(-4.96)	0.0000
Third Period: 2013M03 - 2013M12 (10 obs)				
Intercept	0.0742	0.0846	(0.88)	0.3862

Panel C: Global Information Criterion test

Break type calculated using 2 fixed globally determined breaks. Dependent variable: daily NZU returns. Method: least squares with breaks. Based on 914 observations between 01 July 2010 and 31 December 2013. Specified using HAC standard errors and covariance (Bartlett kernels and Newey-West fixed bandwidth).

R^2	0.0131	Mean dependent variable	-0.0019
Adjusted R^2	0.0110	S.D. dependent variable	0.0354
S.E. of regression	0.0352	Akaike info criterion	-3.8519
Sum squared residuals	1.1292	Schwarz criterion	-3.8361
Log likelihood	1763.3280	Hannan-Quinn criterion	-3.8459
F-statistic	6.0650	Durbin-Watson statistic	1.8408
Prob (F-statistic)	0.0024		

Variable	Coefficient	Std. Error	t-Statistic	Prob.
First Period: 7/01/2010 - 6/17/2011 (252 obs)				
Intercept	0.0003	0.0008	(0.46)	0.6462
Second Period: 6/20/2011 - 2/18/2013 (436 obs)				
Intercept	-0.0060	0.0020	(-3.05)	0.0023
Third Period: 2/19/2013 - 12/31/2013 (226 obs)				
Intercept	0.0034	0.0031	(1.11)	0.2670

Table 3: Vector Autoregression Models

The VAR regressions are presented in regression notation below:

(A) $r_{1,t} = \alpha_i + \sum_{j=1}^{2} \beta_{1,1}^{j} r_{1,t-j} + \sum_{j=1}^{2} \beta_{1,2}^{j} CER_{2,t-j} + \sum_{j=1}^{2} \beta_{1,3}^{j} NetImport_{3,t-j} + \beta_{1,4} Oil_{4,t} + \beta_{1,5} Gas_{5,t} + \beta_{1,6} Coal_{6,t} + \beta_{1,7} Elec_{7,t} + \beta_{1,8} Temp_{8,t} + \beta_{1,9} Cold_{9,t} + \beta_{1,10} Hot_{10,t} + \varepsilon_{1,t}$

(B) $CER_{2,t} = \alpha_i + \sum_{j=1}^{2} \beta_{2,1}^{j} r_{1,t-j} + \sum_{j=1}^{2} \beta_{2,2}^{j} CER_{2,t-j} + \sum_{j=1}^{2} \beta_{2,3}^{j} NetImport_{3,t-j} + \beta_{2,4} Oil_{4,t} + \beta_{2,5} Gas_{5,t} + \beta_{2,6} Coal_{6,t} + \beta_{2,7} Elec_{7,t} + \beta_{2,8} Temp_{8,t} + \beta_{2,9} Cold_{9,t} + \beta_{2,10} Hot_{10,t} + \varepsilon_{2,t}$

(C) $NetImport_{3,t} = \alpha_i + \sum_{j=1}^{2} \beta_{3,1}^{j} r_{1,t-j} + \sum_{j=1}^{2} \beta_{3,2}^{j} CER_{2,t-j} + \sum_{j=1}^{2} \beta_{3,3}^{j} NetImport_{3,t-j} + \beta_{3,4} Oil_{4,t} + \beta_{3,5} Gas_{5,t} + \beta_{3,6} Coal_{6,t} + \beta_{3,7} Elec_{7,t} + \beta_{3,8} Temp_{8,t} + \beta_{3,9} Cold_{9,t} + \beta_{3,10} Hot_{10,t} + \varepsilon_{3,t}$

	Full Period (01 Jul 2010 to 31 Dec 2013)			**First Period** (01 Jul 2010 to 17 Jun 2011)			**Second Period** (20 Jun 2011 to 18 Feb 2013)			**Third Period** (19 Feb 2013 to 31 Dec 2013)		
Specification	**(A)**	**(B)**	**(C)**	**(A)**	**(B)**	**(C)**	**(A)**	**(B)**	**(C)**	**(A)**	**(B)**	**(C)**
$RMSE$	0.0349	0.0876	0.5306	0.0138	0.0150	0.0313	0.0393	0.0688	0.3703	0.0398	0.1468	0.9275
R^2	0.0417	0.0715	0.0404	0.0679	0.2185	0.0681	0.0891	0.0488	0.0226	0.0755	0.1233	0.0768
X^2	39.6740***	70.2361***	38.4423***	18.2173	69.8801***	18.2776	42.6487***	22.3704*	10.0759	18.4465	31.7784***	18.8106
	r_t	$rCER_t$	$NetImport_t$	r_t	$rCER_t$	$NetImport_t$	r_t	$rCER_t$	$NetImport_t$	r_t	$rCER_t$	$NetImport_t$
r_{t-1}	0.0894	-0.1530	-0.1583	-0.1744	0.0305	0.0123	0.0127	-0.2048	-0.0083	0.1858	-0.2291	-0.3005
	(2.72)**	(-1.86)	(-0.32)	(-2.74)**	(0.44)	(0.09)	(0.27)	(-2.47)*	(-0.02)	(2.81)**	(-0.94)	(-0.20)
r_{t-2}	0.0203	-0.0394	-0.1077	-0.1008	-0.0943	0.0312	-0.0336	-0.0700	0.0145	0.0832	0.1494	-0.1996
	(0.62)	(-0.48)	(-0.22)	(-1.61)	(-1.39)	(0.22)	(-0.68)	(-0.81)	(0.03)	(1.31)	(0.64)	(-0.14)
$rCER_{t-1}$	0.0520	-0.1920	-0.1871	-0.0459	-0.0005	-0.1166	0.1265	-0.0157	0.0291	0.0191	-0.2774	-0.1413
	(3.97)***	(-5.84)***	(-0.94)	(-0.87)	(-0.01)	(-0.98)	(4.61)***	(-0.33)	(0.11)	(1.06)	(-4.17)***	(-0.34)
$rCER_{t-2}$	0.0274	0.0772	1.0800	0.0483	0.0705	-0.1026	0.0654	0.0150	0.1865	0.0015	0.0836	1.3569
	(2.08)*	(2.33)*	(5.39)***	(0.92)	(1.24)	(-0.87)	(2.35)*	(0.31)	(0.71)	(0.08)	(1.25)	(3.21)***
$NetImport_{t-1}$	0.0060	0.0063	0.0513	0.0455	-0.0246	0.1657	0.0086	-0.0018	0.0338	0.0044	0.0083	0.0408
	(2.79)**	(1.16)	(1.57)	(1.62)	(-0.81)	(2.62)***	(1.69)	(-0.20)	(0.71)	(1.55)	(0.80)	(0.62)
$NetImport_{t-2}$	-0.0026	0.0137	0.0193	-0.0177	-0.0452	0.0122	-0.0024	0.0061	0.0506	-0.0037	0.0159	-0.0179
	(-1.22)	(2.52)*	(0.59)	(-0.63)	(-1.49)	(0.19)	(-0.46)	(0.68)	(1.05)	(-1.32)	(1.53)	(-0.27)
Oil_t	0.1166	-0.0586	0.8950	0.0304	0.0094	0.0545	0.2167	-0.0924	-1.0526	-0.0052	-0.7690	7.3769
	(1.35)	(-0.27)	(0.68)	(0.59)	(0.17)	(0.47)	(1.45)	(-0.35)	(-0.75)	(-0.02)	(-0.83)	(1.25)
Gas_t	0.0499	-0.1872	0.0948	-0.0095	-0.0128	-0.0701	0.0493	-0.1802	0.9810	0.0850	-0.6235	-3.9479
	(1.11)	(-1.66)	(0.14)	(-0.29)	(-0.36)	(-0.94)	(0.75)	(-1.57)	(1.59)	(0.58)	(-1.15)	(-1.15)
$Coal_t$	-0.0061	1.0554	-2.0866	-0.0515	0.6030	0.1687	0.1863	0.9627	-2.3764	-0.1093	2.6766	-3.0638
	(-0.05)	(3.34)***	(-1.09)	(-0.62)	(6.74)***	(0.90)	(0.89)	(2.62)**	(-1.20)	(-0.32)	(2.11)*	(-0.38)
$Elec_t$	-0.0043	0.0007	0.0390	0.0016	-0.0023	0.0008	-0.0204	-0.0082	0.0006	-0.0059	0.0079	0.1787
	(-1.45)	(0.10)	(0.86)	(1.05)	(-1.37)	(0.23)	(-2.83)**	(-0.65)	(0.01)	(-0.78)	(0.28)	(1.02)
$Temp_t$	0.0015	0.0208	0.1056	0.0103	0.0124	0.0081	-0.0151	-0.0007	-0.0691	0.0075	0.0571	0.4329
	(0.15)	(0.82)	(0.69)	(1.32)	(1.46)	(0.46)	(-0.92)	(-0.02)	(-0.45)	(0.33)	(0.67)	(0.81)
$Cold_t$	0.0011	0.0068	-0.0141	-0.0001	0.0029	-0.0002	-0.0004	0.0054	-0.0703	0.0077	0.0164	0.0638
	(0.19)	(0.45)	(-0.15)	(-0.02)	(0.55)	(-0.02)	(-0.04)	(0.33)	(-0.81)	(0.54)	(0.31)	(0.19)
Hot_t	0.0056	-0.0177	0.0137	-0.0032	-0.0002	0.0163	0.0104	-0.0396	0.1625	0.0412	0.0517	-0.0393
	(1.00)	(-1.26)	(0.16)	(-1.02)	(-0.05)	(2.28)*	(1.05)	(-2.27)*	(1.73)	(1.73)	(0.59)	(-0.07)
α_i (*intercept*)	-0.0020	-0.0061	0.0925	0.0007	-0.0008	-0.0014	-0.0048	-0.0106	0.0753	0.0013	0.0009	0.2253
	(-1.64)	(-1.94)	(4.89)***	(0.77)	(-0.78)	(-0.67)	(-2.28)*	(-2.90)**	(3.82)***	(0.47)	(0.09)	(3.39)***

Notes: *z*-statistics show in parentheses.

*** denotes significance at $p \leq 0.001$, ** denotes significance at $p \leq 0.01$ and * denotes significance at $p \leq 0.05$.

Table 4: Pairwise Granger Causality Tests

Null Hypotheses	Full period	First Period	Second Period	Third Period
CERs do not Granger-cause NZUs	(17.3660)***	(1.5787)	(26.0900)***	(1.1721)
Net Imports do not Granger-cause NZUs	(9.0041)*	(2.7599)	(3.0063)	(4.1148)
All variables do not Granger-cause NZUs	(24.0350)***	(4.0541)	(28.4580)***	(4.7959)
NZUs do not Granger-cause CERs	(3.8807)	(2.4450)	(6.8708)*	(1.1010)
Net Imports do not Granger-cause CERs	(7.9583)*	(3.4325)	(0.4972)	(3.0091)
All variables do not Granger-cause CERs	(11.3840)*	(5.7102)	(7.1492)	(3.9141)
NZUs do not Granger-cause Net Imports	(0.1619)	(0.0509)	(0.0013)	(0.0691)
CERs do not Granger-cause Net Imports	(33.5210)***	(1.7344)	(0.5171)	(12.0520)**
All variables do not Granger-cause Net Imports	(33.6520)***	(1.7434)	(0.5497)	(12.3760)*

Notes: X^2 shown in parentheses.
*** denotes significance at $p \leq 0.001$, ** denotes significance at $p \leq 0.01$ and * denotes significance at $p \leq 0.05$.

Table 5: ARIMA Analysis

Panel A: ARIMA with autoregressive lags

The ARIMA model using daily NZU returns as the dependent variable. Results show significant autocorrelation with first lag of returns and the estimated standard deviation of the white-noise disturbance.

ARIMA specification:

$$y_t = \alpha + \rho_1 \mu_{t-1} + \rho_2 \mu_{t-2} + \epsilon_t$$

Obs		914
Log likelihood		1761.2880
$\boldsymbol{X^2}$		22.61
$\boldsymbol{p} \leq$		0.000
NZU intercept	α	-0.0019
		(-1.40)
ARMA		
L1.	ρ_1	0.0895
		(4.58)***
L2.	ρ_2	0.0196
		(0.74)
Sigma	ϵ	0.0352
		(121.39)***

Panel B: ARCH Lagrange Multiplier Test for ARIMA Residuals

lags(p)	$\boldsymbol{X^2}$	$\boldsymbol{df}$	$\boldsymbol{p} \leq$
1	15.626	1	0.0001
2	15.714	2	0.0004
3	17.065	3	0.0007
4	17.397	4	0.0016
5	17.371	5	0.0038
6	17.375	6	0.0080
7	19.037	7	0.0081
8	19.023	8	0.0147
9	19.037	9	0.0249
10	19.103	10	0.0390
11	22.059	11	0.0239
12	25.753	12	0.0116
13	25.809	13	0.0180
14	26.063	14	0.0254
15	50.094	15	0.0000

Table 6: ARCH(1) and GARCH(1,1) results for NZU Returns

ARCH(1) specification:

$$h_t = \alpha_0 + \sum_{k=1}^{q} \alpha_k \varepsilon_{t-k}^2$$

GARCH(1,1) Specification:

$$h_t = \alpha_0 + \sum_{k=1}^{q} \alpha_k \varepsilon_{t-k}^2 + \sum_{i=1}^{p} \beta_i h_{t-i}$$

	Full period	**First Period**	**Second Period**[a]	**Third Period**
Model	GARCH(1,1)	GARCH(1,1)	ARCH(1)	GARCH(1,1)
Obs	914	252	436	227
Iterations	27	12	8	12
Log Likelihood	1923.4420	732.8776	790.1576	455.2774
NZU intercept	-0.0024	0.0002	-0.0059	-0.0020
	(-2.56)*	(0.26)	(-2.81)**	(-1.08)
ARCH L1.	0.1356	0.0545	0.1351	0.4225
	(18.00)***	(4.32)***	(5.53)***	(6.75)***
GARCH L1.	0.8579	0.5879		0.5242
	(180.83)***	(8.38)***		(7.63)***
Intercept	0.0000	0.0001	0.0014	0.0002
	(19.72)***	(5.65)***	(32.58)***	(3.69)***

Notes:

[a] Results indicated that the GARCH parameter was statistically insignificant, suggesting no GARCH effects. Further, an ARCH(2) specification also resulted in lack of statistical significance. As such, an ARCH(1) model is estimated.

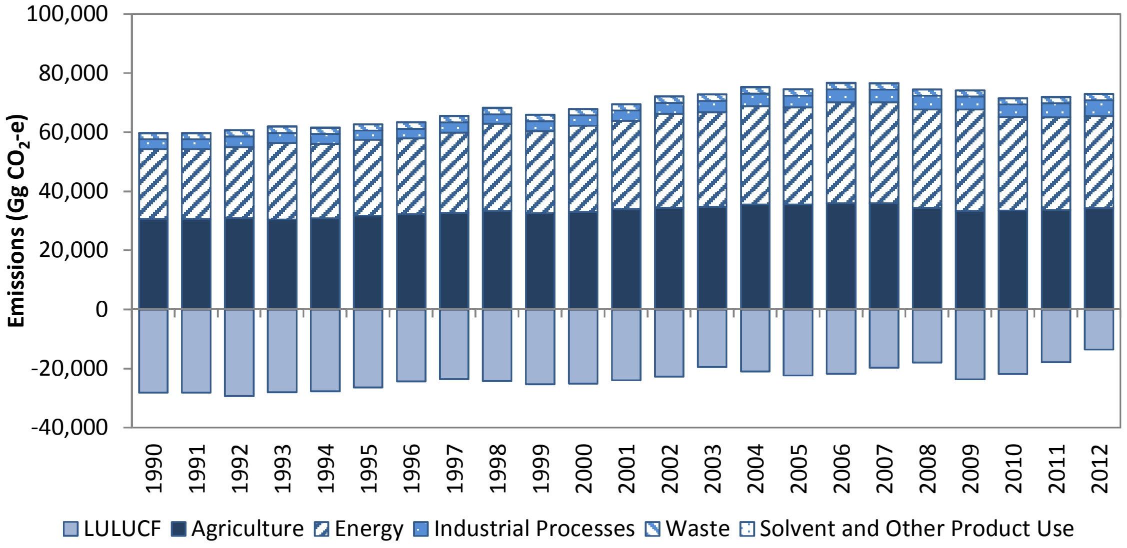

Figure 1: New Zealand's Total GHG Emissions by Sector. Adapted from UNFCCC (2014)

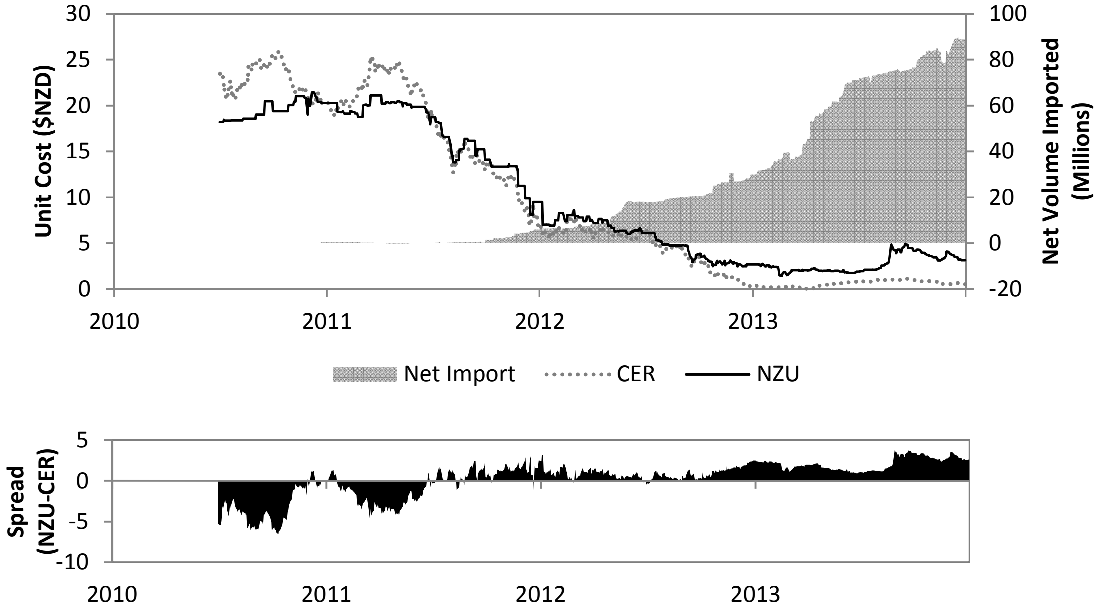

Figure 2: Daily Close Prices for NZ NZUs and CERs. Sources: ICE (2014) and the EPA**.**

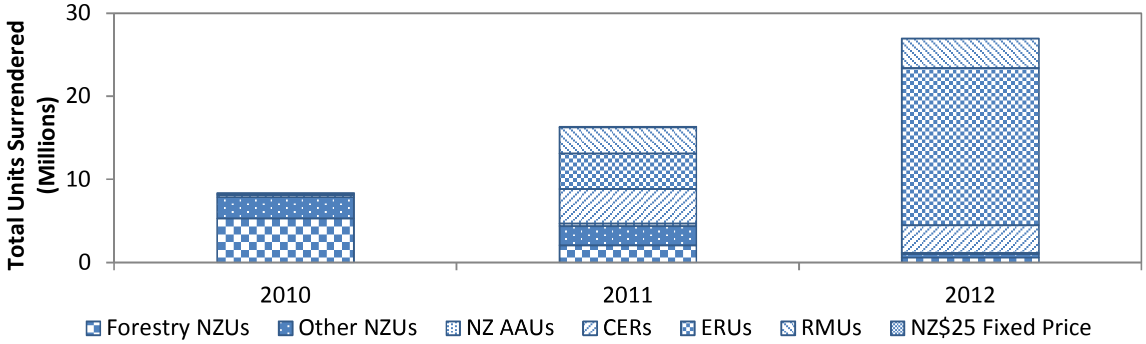

Figure 3: Total Units Surrendered by Unit Type, 2010-2012. Source: MFE (2013b). The 2010 figures relate to a six-month surrender period for non-forestry sectors, whereas 2011 and 2012 relate to emissions over a full year.

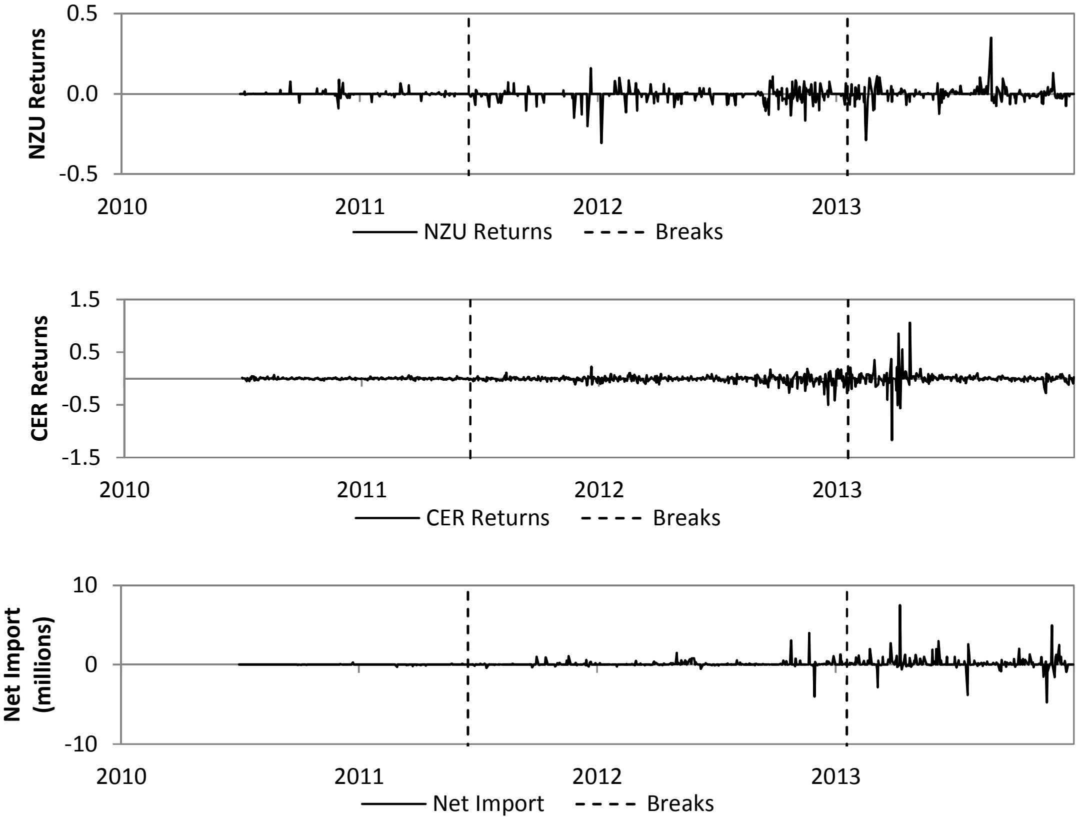

Figure 4: NZU returns, CER returns and Net imports

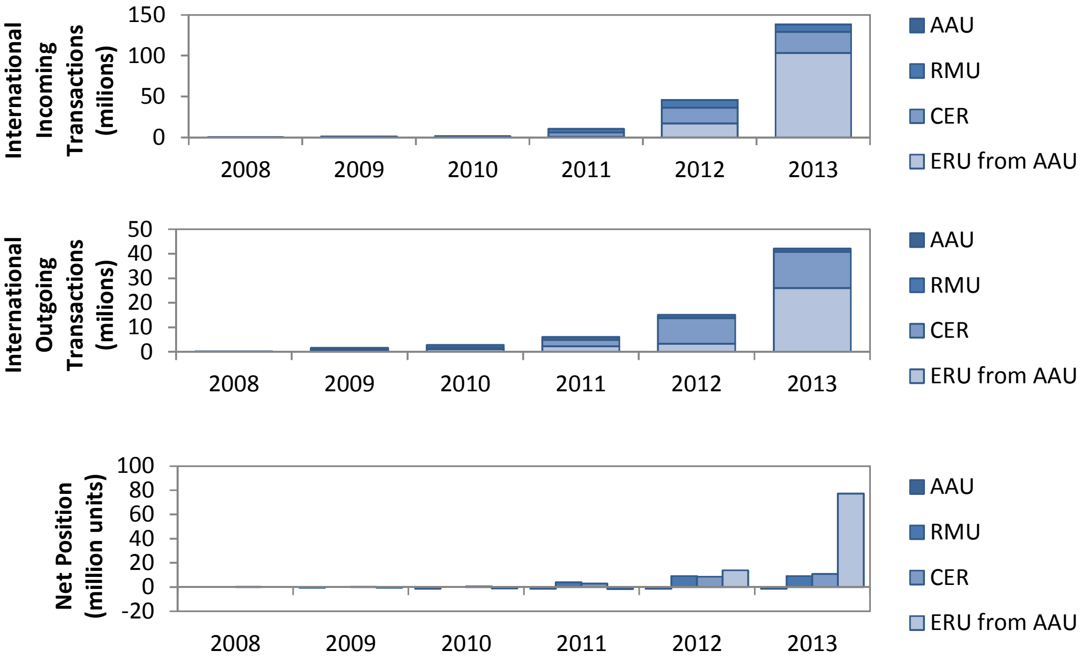

Figure 5: New Zealand Emissions Unit Register Transaction Data, 2008-2013. AAU incoming and outgoing data less than 0.02 and 1.3 million units, respectively. Compiled from daily data provided by the EPA.

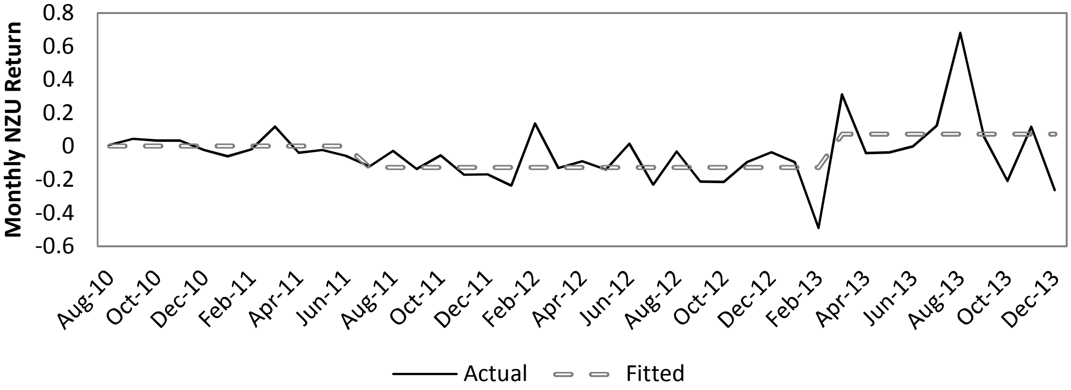

Figure 6: Actual and Fitted Monthly NZU Returns from the BP Multiple Structural Change Breakpoint Test