Does Policy Uncertainty Have a Bright Side in Carbon Markets?

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Abstract

Using the New Zealand Emissions Trading Scheme (NZ ETS) as the policy setting I find that, contrary to the irreversible investment and growth option investment perspectives, policy uncertainty, proxied for by the volatility of the carbon price, exhibits a positive relationship with irreversible investments and a negative relationship with growth option investments in carbon markets. The results are explained by the marginal abatement cost curve and demonstrate that the effects of policy uncertainty not only depend on the type of investment but also the policy setting.

JEL Classification: O13, G31, O33, Q53

Key words: carbon markets, carbon price, volatility, emissions, investment

1 Introduction

Recent work by Atanassov et al. (2024) has advanced our understanding of the policy uncertainty-investment relationship by providing empirical evidence which suggests differential effects. A sizable portion of the empirical literature has asserted a negative relationship between policy uncertainty and investment; Atanassov et al. (2024) show, however, that while this relationship holds for irreversible fixed asset investments, it becomes positive when growth option investments such as R&D are considered. They show that despite the uncertainty they face, firms may go ahead with R&D investments because of the optionality to abandon the project without the need for further capital commitment other than the initial startup capital. I build on this finding by examining whether the irreversible investment perspective or the growth option perspective applies to carbon markets which are designed to spur firms to invest in abatement and decarbonization of their operations through the carbon price signal. I follow Atanassov et al. (2024) in distinguishing between two types of investments, namely, irreversible investment and growth option investment. Treating the volatility of the carbon price as a measure of policy uncertainty and conditioning on economic policy uncertainty and climate policy uncertainty, I examine its impact on both types of investments using macro-level data.

A growing body of empirical evidence appears to indicate that carbon pricing mechanisms are effective in reducing carbon emissions and spurring investment in abatement. An assessment of the European Union Emissions Trading Scheme (EU ETS), the world's oldest and largest carbon market, establishes a positive correlation between firms' trading profits within the ETS and the reduction in their emissions (Guo et al., 2020; Dechezlepretre et al., 2018). Similarly, research from Sweden provides compelling evidence of the impact of carbon pricing on emissions reduction at the firm level. Using panel regressions spanning 26 years and data from 4,000 firms, Martinson et al. (2024) demonstrate that carbon pricing has indeed led to reductions in carbon emissions within the Swedish manufacturing sector and that the reductions were achieved by investments made by firms in decarbonising their operations. Earlier work by Brown et al. (2022) also shows that increased taxes on manufacturing emissions lead to increased R&D spending by firms. Using thermal power enterprises involved in the Chinese emisisons trading scheme, Wei et al. (2022) also presented evidence that a certain price of carbon significantly increases technological innovation within these firms.

An appealing argument made for carbon pricing is that it acts as a strong signal which incentivizes investment in emissions mitigation and low-carbon technology innovation (Boyce, 2018; Tvinnereim and Mehling, 2018) leading to reduced emissions. This argument is grounded in the theoretical literature on directed technical change (Acemoglu et al., 2012; Acemoglu et al., 2016) and does seem to be supported by the emerging empirical evidence (Colmer et al., 2022; Guo et al., 2020; Best et al., 2020; Kumar, 2023; Martinson et al., 2024) but does this theoretical signalling mechanism still operate in an environment of volatile carbon prices?

Carbon price volatility introduces a significant degree of uncertainty and is often related to regulatory and policy uncertainty particularly within the context of emission trading schemes. In keeping with the predictions of real options theory, policy uncertainty has been found to be negatively related to a firm's decision around investment (Baker et al., 2016,) and more recently with venture capital investment decisions (Tian et al., 2023) and disposal of assets (Campello et al., 2024). According to real options theory, economic actors delay investments under conditions of uncertainty due to the increased option value of waiting (Dixit and Pindyck, 1994). Real options theory, therefore, predicts that investment in clean technology should be hindered in an environment of policy uncertainty.

While theoretical and empirical studies demonstrate that firms postpone abatement investments (Fuss et al., 2009; Kettunen et al., 2011) and reduce green investments (Wang et al., 2023) during periods of policy uncertainty, conflicting evidence has emerged which suggests that despite uncertainty, firms actually accelerate abatement activity resulting in reduced emissions (Hoffman, 2005; Delmas and Montes-Sancho, 2010; Delmas and Toffel, 2008). A more recent study by Wang (2023) presents robust evidence that climate policy uncertainty has a causal effect on increased adoption of abatement technology and reduced pollutant emissions by firms. The theoretical explanation for why firms might behave contrary to the predictions of real options theory rely on a resource-based view of the firm (Barney, 1991; Wernerfelt, 1984) and argues that during periods of policy uncertainty, firms take a proactive environmental approach as a way of building their competitive advantage (Aragon-Correa and Sharma, 2003).

Using the New Zealand Emissions Trading Scheme (NZ ETS) as the policy setting, I first present detailed analysis of the time series behavior of the New Zealand Unit (NZU) carbon price and model its return and volatility using a AR(1)-GARCH(1, 1) model. I further present exploratory investigations which examine the determinants of the carbon price and carbon price volatility within the NZ ETS.

In addition, I examine the relationship between carbon price volatility and aggregate level investment and obtain results which contradict both the irreversible investment perspective and the growth option perspective. I find instead that, at the aggregate level, firms continue to make irreversible investments and are reluctant to pursue R&D investments under conditions of carbon price volatility suggesting that other factors, such as the marginal abatement cost curve and proactive environmental strategies, are influencing their decisions; I confirm these results using instrumental variable analysis where I instrument my measure of carbon price volatility with elections held in New Zealand. Elections, which are exogenously determined, result in significant uncertainty for firms and therefore serve as a reasonable instrument of general policy uncertainty (Julio and Yook, 2012). I further contribute to elucidating the mechanisms through which firms achieve their emissions reduction when subjected to carbon pricing. While several studies have demonstrated that carbon pricing under the EU ETS has an effect in driving firms to reduce emissions (Martinson et al., 2024; Colmer et al., 2022), less is known about whether reductions are achieved through changes in production or investments in capital expenditure and R&D. To study which mechanism is at play in the NZ ETS, I examine the relationship between emissions, irreversible investments and growth option investments and obtain results which suggest that emissions reductions under the NZ ETS are achieved through R&D investments.

Previous studies on carbon price volatility have focused on its asset pricing implications (Feng et al., 2011; Ibrahim et al., 2016; Dai et al, 2022). I differ from these studies by focusing on carbon price volatility as a regulatory signaling mechanism which proxies for policy uncertainty. I advance previous work on carbon price volatility by studying its impact on decisions around production changes and abatement investments as mechanisms for emissions reductions. The aforementioned studies have focused exclusively on the EU ETS and as such this paper also contributes to adding evidence on carbon pricing and emissions from the NZ ETS which is a less studied jurisdiction despite being the second oldest ETS in the world.

In a more recent study, Fuchs et al.(2024) introduce the Carbon VIX and Carbon Implied Volatility (CIV) as measures to capture carbon price volatility within the European Union Emissions Trading Scheme (EU ETS). The authors aimed to quantify expected volatility in carbon markets, deriving a market-based metric similar to the CBOE VIX for stock price volatility. This approach involved estimating volatility through out-of-the-money options prices, which reflect market expectations for short-term fluctuations in carbon allowances. The Carbon VIX, therefore, serves as a proxy for carbon price uncertainty, which Fuchs et al.(2024) relate to firms' decarbonization investments. However, several weaknesses in this approach limit its efficacy in fully capturing the drivers and implications of carbon price volatility.

A significant limitation in the Fuchs et al.(2024) approach is that, the reliance on short-term market volatility metrics may obscure underlying regulatory and economic drivers. For instance, their approach does not differentiate between volatility arising from temporary market sentiment shifts and that caused by structural policy changes, both of which could yield different responses from firms regarding investment in emissions reduction. Additionally, focusing on aggregate volatility in the EU ETS does not account for sector-specific drivers of volatility. Various industries within the EU ETS experience unique regulatory pressures, technological challenges, and energy dependencies that likely affect their sensitivity to carbon price fluctuations differently. This lack of granularity may lead to overly broad conclusions about firms' decarbonization responses and limit the applicability of the results across industries.

I addresses these limitations by introducing a more nuanced analysis of carbon price volatility within the New Zealand Emissions Trading Scheme (NZ ETS). I present a model which incorporates both general economic policy uncertainty (EPU) and climate-specific policy uncertainty (CPU) to assess their impact on carbon price volatility. This approach provides a clearer distinction between price fluctuations due to policy actions and those resulting from economic or market conditions. Additionally, I employ a longitudinal AR(1)-GARCH(1,1) model to capture the persistence of volatility patterns over time, examining the determinants of volatility at both the sectoral and aggregate levels. This sectoral approach clarifies how different industries react to carbon price changes based on their regulatory exposure and decarbonization pathways.

Furthermore, I examine the differing effects of volatility on two types of investments: irreversible investments (e.g., capital expenditure on emissions reduction technology) and growth option investments (e.g., R&D). This analysis reveals that firms reduce growth-oriented investments under high volatility conditions, contrasting with the aggregate view in Fuchs et al.(2024), where all investments are assumed to react similarly to volatility. By distinguishing between these investment types, I apply the insights from Atanassov et al.(2024) to carbon markets and in so doing deepen understanding of how policy uncertainty may impact long-term versus short-term decarbonization strategies.

Addressing the limitations in the Fuchs et al. (2024) approach is important for several reasons. First, a refined understanding of carbon price volatility's drivers aids in crafting effective carbon pricing policies that maintain credible signals for firms, encouraging stable, long-term decarbonization investments rather than reactive, short-term strategies. Second, distinguishing between market-driven and policy-driven volatility enables a better assessment of regulatory impacts, allowing policymakers to design more stable frameworks that mitigate unnecessary fluctuations due to policy uncertainty. Finally, sectoral insights provide a more targeted perspective on decarbonization, as different industries may require tailored policies that account for their unique responses to carbon price signals. By addressing the limitations in the Fuchs et al. (2024) approach, I enhance both theoretical and practical understandings of how carbon price volatility influences firm-level emissions and decarbonization investments, thereby supporting more robust and responsive climate policy frameworks.

The remainder of the paper is organized as follows. Section 2 presents a background to the NZ ETS. Section 3 describes and explores determinants of the time series behaviour of NZU price and volatility. Section 4 discusses the conceptual framework which informs subsequent analysis of NZU price volatility, carbon emissions and investment, while Section 5 describes the data and variables used. Section 6 presents the empirical results along with robustness and Section 7 concludes.

2 Background to the NZ ETS

In 2002, the Fifth Labour Government of New Zealand took a crucial step in addressing climate change by adopting the Climate Change Response Act 2002. The primary objectives were to ratify the Kyoto Protocol and fulfill obligations under the United Nations Framework Convention on Climate Change. This legislative foundation set the stage for the subsequent establishment of the New Zealand Emissions Trading Scheme (NZ ETS).

The first major milestone occurred in 2008 when the Labour Government enacted the Climate Change Response (Emissions Trading) Amendment Act 2008, incorporating the initial version of the NZ ETS into the existing legislative framework. The proposed scheme ambitiously covered all six greenhouse gases specified in the Kyoto Protocol and aimed to progressively encompass all sectors of the economy, including agriculture.

However, the political landscape shifted in 2008, with the Labour Government losing the election to a coalition led by the National Party. The new government campaigned on amending the NZ ETS, marking a turning point in the scheme's trajectory. Under the Fifth National Government, the NZ ETS underwent amendments in 2009 and 2012. Notably, until 2015, the scheme was closely tied to international carbon markets, allowing unlimited importing of most Kyoto Protocol emission units. The NZU, equivalent to one tonne of carbon dioxide, was introduced, initially allocated freely until auctions began in 2020.

Critics have raised concerns about the NZ ETS, citing generous free allocations and a perceived lack of a carbon price signal. The scheme has faced scrutiny for its effectiveness in reducing emissions, recent evidence demonstrates, however, that the ETS has been effective in reducing sectoral carbon intensity (Tao et al., 2024). A 2016 government review indicated minimal reductions in net emissions, prompting further changes in 2020, introducing rules for emissions budgets and auctions of units within price caps.

3 NZU Carbon Price Time Series Behaviour

3.1 Daily Log Price and Return Time Series

I collect daily prices for the NZUs traded in the NZ ETS betwen March 9, 2009 and November 7, 2023 from Bloomberg. I begin describing the time series behavior of the NZU carbon price by presenting graphs of its lagged daily log price and return series for the sample period. A Dickey-Fuller test estimated for both series indicates that the log price series is non-stationary while the return series is stationary.

Insert Figure 2 here

Insert Figure 3 here

The log price series, shown in Figure 2, demonstrates several distinct phases and significant movements over the analyzed period. Initially, the log price remains relatively stable from 2009 until the end of 2010. However, a sharp decline is observed starting in early 2011, reaching its lowest point in mid-2012. This period of decline coincides with global economic uncertainties and fluctuations in carbon markets. From 2013 onwards, the NZU log price begins a consistent upward trend, reflecting a recovery and increasing market stability. This upward trend continues with minor fluctuations until late 2019. Notably, from 2017 to early 2020, the log price exhibits a marked increase, possibly influenced by policy changes and growing environmental concerns that bolster the carbon market. The series also shows periods of volatility, particularly around early 2020, coinciding with the onset of the COVID-19 pandemic, which induced significant market uncertainties globally. Post-pandemic, the log price continues to rise, albeit with noticeable short-term fluctuations, indicating an overall growth trajectory but with periods of market adjustment and correction. By the end of the series in 2023, the log price stabilizes at a higher level compared to its initial values, reflecting long-term growth and resilience in the NZU market.

The return series for NZUs, depicted in Figure 3, provides insights into the daily fluctuations and volatility in the NZU market from 2009 to 2023. The return series is characterized by high volatility in the early years, particularly between 2009 and 2012, which aligns with the significant price drop observed in the log price series during the same period. This volatility is indicative of market reactions to economic and policy changes impacting the carbon market. Post-2012, the return series shows a marked decrease in volatility, suggesting a period of stabilization and recovery in the NZU market. From 2013 onwards, the returns exhibit lower amplitude fluctuations, with occasional spikes corresponding to specific market events or external shocks. Notable spikes in returns are observed around early 2020, which corresponds to the initial impact of the COVID-19 pandemic, reflecting sudden and sharp adjustments in market valuations. Throughout the series, the return data points remain centered around a mean of zero, indicating no long-term bias in price changes. However, the magnitude of returns and their frequency of occurrence provide valuable insights into the risk and volatility inherent in the NZU market. The periods of heightened volatility, particularly in the early and late stages of the series, underscore the impact of external factors and market sentiment on NZU prices. As a further description of the return series, I estimate an autoregressive model with 3 lags (AR(3)). The results, shown in Table 1, indicate that only the first lag is significantly related to the current return. This suggests a short-term autocorrelation in the return series, while longer-term lags (second and third) do not provide significant additional information. The model explains a very small portion of the return variability, indicating that other factors likely play a larger role in determining returns.

Insert Table 1 here

3.2 NZU Price Volatility Time Series

Given the significance of the first lag and the volatility clustering indicated in the return time series, I model NZU price volatility using a simple GARCH(1,1) model. I let r_t denote the return of the NZU price at time t and speficy the GARCH (1,1) model as follows:

$$r_t = \mu + \epsilon_t, \tag{1}$$

$$\epsilon_t = \sigma_t z_t, \tag{2}$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 \epsilon_{t-1}^2 + \beta_1 \sigma_{t-1}^2, \tag{3}$$

Where:

- r_t is the return of the NZU price at time t,
- μ is the mean return,
- ϵ_t is the residual return at time t,
- σ_t^2 is the conditional variance (volatility) at time t,
- $z_t \sim N(0,1)$ is a standard normal random variable,
- α_0 is the constant term in the variance equation,
- α_1 is the coefficient for the lagged squared residual (ARCH term),
- β_1 is the coefficient for the lagged conditional variance (GARCH term).

The return of the NZU price (r_t) was calculated as the logarithmic difference of the NZU price series (P_t) .

$$r_t = \ln(P_t) - \ln(P_{t-1}), \tag{4}$$

where P_t is the NZU price at time t.

The results of the AR(1)-GARCH(1,1) model presented in Table 2, confirm that there is a small but significant positive average return and that past returns have a positive influence on current returns. The ARCH term is positive and significant, showing that past shocks have a small but significant impact on current volatility. The GARCH term is very close to 1, indicating that volatility is highly persistent and tends to stay high for a while.

Insert Table 2 here

As visually depicted in Figure 4, which plots the time series of the estimated volatility from the GARCH model, volatility is highly persistent, with past shocks having a lasting impact on future volatility. The spikes in volatility between 2010 and 2012, 2018 and 2020 and 2022 and 2023 correspond with major policy events and announcements relating to the NZ ETS while the most significant spike in 2020 corresponds with the onset of the COVID-19 pandemic.

Insert Figure 4 here

To validate the impact of policy events and announcements on the return and volatility dynamics of the NZU price, I collect dates for a sample of NZ ETS related policy events and announcements and perform event studies which examine the reaction of the NZU price to these. The results reported in Table 3 indicate statistically significant cumulative abnormal returns for all the events. Figure 5 overlays a sample of these policy events and announcements on the time series of the NZU price volatility.

Insert Table 3 here

Insert Figure 5 here

The key message from the event study and policy events volatility chart is that NZU price volatility reflects policy uncertainty in a similar fashion as the return volatility of publicly traded firms during periods of political uncertainty. Using a sample of US firms, Atanassov et al. (2024) showed that the average return volatility of these firms is higher during election years when there is significant policy uncertainty. It is not unreasonable to expect that this volatility-policy uncertainty relationship should also be present in carbon markets. Carbon markets are, after all, a policy instrument controlled by policy makers and, as such, the volatility of the carbon price signal it is designed to provide to firms, should reasonably increase during periods of policy uncertainty. I, therefore, conceptualize carbon price volatility as a type of domain specific policy uncertainty. Other types of domain specific policy uncertainty which have been studied in the literature include economic policy uncertainty (EPU) and climate policy uncertainty (CPU). General policy uncertainty can, therefore, be thought of as a weighted average of these different types of domain specific uncertainties. The underlying economics of carbon markets suggest that they are sensitive to economic policy but even more so to climate policy. I, therefore, further argue that carbon price volatility is conditional on EPU and CPU. I present a conceptual model of this relationship in Appendix I. The model suggests that during periods of high policy uncertainty, particularly climate policy uncertainty, carbon price volatility should increase. Economic policy uncertainty also affects carbon price volatility, but to a lesser extent compared to climate policy uncertainty. General policy uncertainty is a composite measure but, in the context of carbon markets, is dominated by the more significant impact of climate policy uncertainty. I now test these predictions by examining the drivers of carbon price volatility in the NZ ETS.

3.3 What Drives the Price in the NZ ETS?

As an initial empirical exercise, I conduct exploratory investigations which examine the determinants of the NZU price. I begin by annualizing the lagged daily log price series for the NZU; a graph of the annualized price series is presented for the 2010-2022 period in Figure 6.

Insert Figure 6 here

I then use this annualized NZU price as the dependent variable in a series of basic OLS regressions with a collection of explanatory variables comprised of policy related variables and macro-level controls. The main explanatory variables are as follows:

Number of Minister's directives: Minister's directives for free allocations refers to free units of NZUs given to market participants at the discretion of the Minister of Climate Change. I create a variable which is a count of the number of directives issued by the Minister in a given year for 2010-2022. This serves as my main variable of climate related policy action.

Industrial Allocation: Industrial allocations are free units of NZUs allocated to eligible industry applicants on a yearly basis. I collect data on the number of units issued as industrial allocations from the New Zealand Emissions Trading Register for 2010-2022 and use it as an additional measure of climate related policy action.

Climate Attention Index (CAI): The CAI measures the extent to which climate change is discussed in the news media by analyzing the tweets of major newspapers within a country. I obtain CAI data for New Zealand for the 2010-2022 period from Arteaga-Garavito et al. (2022).

Environmental Policy Stringency (EPS) Index: I collect data from the OECD EPS index for New Zealand for the 2010-2022 period. The OECD EPS index is a country-level index constructed by assigning scores on a scale from 0-6 to 13 climate change and air pollution policy instruments from three sub-indices which are aggregated into a single index which increases scores for countries with more stringent policies (Kruse et al., 2022).

Economic Policy Uncertainty (EPU) Index: I obtain data for the New Zealand EPU index from Ali et al. (2022). The index is a newspaper based measure of policy related terms.

Climate Policy Uncertainty (CPU) Index: An intense political environment around climate issues, can create significant uncertainty for market participants in an ETS. Berestycki et al. (2022) sought to capture this uncertainty in the OECD climate policy uncertainty (CPU) index. The index is based on newspaper coverage frequency of climate issues. Data for the New Zealand CPU index is only available from 2010-2018.

I collect a range of macro-level variables which I use as control variables. I collect yearly data for the 2010-2022 period for GDP per capita growth, industrial production, percentage value added, crude oil production and crude oil import prices from the OECD statistics database. I also collect data for the producer price index (PPI), short term interest rates, the New Zealand activity index and the business confidence index from Statistics New Zealand. Technical definitions of these variables are provided in Appendix II.

The regression results are presented in Table 4. In models 1, 2 and 8, my two main variables of climate related policy actions taken by policy makers, namely, Minister's directive and industrial allocations, are associated with a decrease in the NZU price, suggesting that more policy actions may increase regulatory pressure, reducing the carbon price. The coefficient estimates for the climate attention index provide mixed results. In model 3, greater climate attention increases the carbon price, potentially due to heightened awareness and demand for carbon credits. In model 8, the effect is reversed, indicating a complex relationship that might depend on the inclusion of other variables. The economic policy uncertainty (EPU) index, environmental policy stringency (EPS) index and the climate policy uncertainty (CPU) index presented in models 4, 5 and 6 respectively are all associated with a decrease in the NZU price. These three indices capture varying degrees and types of policy and regulatory uncertainty and as such it is not surprising that that they have a negative impact on the NZU price. In model 6, where the impact of climate policy uncertainty is tested, I obtain an adjusted R-squared of 1.000 which suggest I may have an issue with over fitting. I, therefore, simplify the model by removing some predictors and checking if the fit remains reasonable. The results, presented in column 7, remain consistent with the original model and the adjusted R-squared is reduced but maintains significant explanatory power (98%) indicating that climate policy uncertainty is, perhaps, the most significant driver of NZU price dynamics in the NZ ETS. Additionally, crude oil production and crude oil import prices show significant impacts across various models, reflecting the interconnectedness between energy markets and carbon prices. Industrial production consistently shows a strong positive relationship with the NZU price, suggesting that higher industrial activity drives demand for carbon credits. GDP per capita growth, R&D as a percentage of GDP and the NZ activity index are also significant in most models, highlighting the role of economic growth and innovation in influencing carbon prices. In model 8, where all the variables are combined in the most stringent specification (except the CPU index due to lower number of observations), the results remain statistically significant and I obtain an increased adjusted R-squared of 0.995, thus confirming the significant explanatory power of the models.

Insert Table 4 here

3.4 What Drives Volatility in the NZ ETS?

I further my exploratory investigations by examining the determinants of NZU carbon price volatility using the the annualized volatility, estimated from the GARCH model, as the dependent variable and the same set of explanatory variables described in the foregoing section. A graph of the annualized volatility is presented for the 2010-2022 period in Figure 7.

Insert Figure 7 here

The results presented in Table 5 show that all the drivers of the NZU carbon price also increase its volatility. The variables which relate to policy actions (Minister's directive and industrial allocations) are likely to introduce uncertainty into the market. While these policies can drive prices up or down, they can also create uncertainty about future regulatory environments, causing higher volatility as market participants react to new information and adjust their positions. This uncertainty is, of course, captured to varying degrees in the EPU, EPS and CPU indices which are tested in models 4, 5 and 6, respectively, and as such it is not surprising that these also exhibit a positive association with NZU price volatility. Furthermore, the EPS also captures policies aimed at reducing emissions which can create volatility by making future compliance costs unpredictable. Market participants may speculate on the stringency and enforcement of these policies, leading to fluctuating prices. The Climate Attention Index, which is tested in model 3 and 8, reflects the level of attention climate issues receive in the media and public discourse. High attention can lead to increased speculation and trading activity as investors anticipate regulatory changes or shifts in market sentiment, contributing to higher volatility. Increased trading activity, driven by news and policy changes, can lead to higher price volatility as the market responds to new information. In model 7, where all the variables are combined (except the CPU index due to lower number of observations), I obtain an adjusted R-squared of 0.999/1.000 which suggest I may have an issue with over fitting. I address this issue in a similar manner as before and simplify the model by removing some predictors and checking if the fit remains reasonable. The results, presented in column 8, remain consistent with the original model and the adjusted R-squared remains the same. As was the case for the NZU price, it appears that, climate policy uncertainty is the most significant driver of NZU price volatility in the NZ ETS as it has the highest explanatory power, capturing up to 97% of variation in NZU price volatility.

Insert Table 5 here

3.5 NZU Price Volatility and Market Activity in the NZ ETS

As an empirical curiosity, I also conduct exploratory investigation which examine the impact of NZU price volatility on three measures of market activity in the NZ ETS, namely, NZUs transferred (volume), quantity of transactions and number of participants. I obtain data for these measures for the 2010-2022 period from the New Zealand Emissions Trading Register. I construct a panel around the 24 economic activities covered by the NZ ETS and obtain 312 activity-year observations. I estimate the following specification:

$$Y_{i,t} = \alpha_i + \beta ln(NZUVol_t) + \gamma X_{i,t} + \epsilon_{i,t} \tag{5}$$

Where $Y_{i,t}$ represents the various measures of NZ ETS market activity for activity i in year t, which includes NZUs transferred (volume), transaction quantity and number of participants. α_i is the activity fixed effects. $NZUVol_t$ represents the annualized NZU price volatility in year t. $X_{i,t}$ is a vector of the control variables which includes the EPS index, GDP per capita growth, the NZ activity index, industrial production, percentage value added, crude oil production, crude oil import prices and an election year dummy. I use the election year dummy to capture general policy uncertainty rather than using the domain specific policy uncertainty represented by the CPU and EPU indices. I include activity fixed effects, sector fixed effects and cluster standard errors by activity-year.

The results presented in Table 6 indicate that NZU price volatility is associated with increased liquidity in the NZ ETS but has no statistically significant impact on transaction quantity and the number of participants in the NZ ETS.

Insert Table 6 here

I proffer three possible explanations for the association between NZU price volatility and an increase in liquidity in the NZ ETS. Firstly, higher volatility often attracts speculators and arbitrageurs who seek to profit from price fluctuations. These market participants increase the trading volume as they buy and sell NZUs to capitalize on short-term price movements. Furthermore, firms and investors may engage in more frequent trading to hedge against the increased risk associated with volatile prices. This hedging activity boosts the number of NZUs transferred. Secondly, volatility can enhance the price discovery process as it reflects new information and market expectations. Higher trading volumes help to incorporate this information into prices more efficiently, prompting more trades. Finally, companies and traders might adopt more dynamic risk management strategies in response to volatility, adjusting their positions more frequently. This may result in increased trading volumes as positions are rebalanced more often.

Having examined the dynamics of NZU price volatility in the NZ ETS, I now turn attention to a general discussion of carbon price volatility. In the following section I outline the empirical implications of its potential impacts on carbon emissions and investments in a conceptual framework which guides the remainder of the paper.

4 Conceptual Framework

Directed technical change theory suggests that carbon pricing serves as a signal that incentivizes investment in emission mitigation technologies and low-carbon innovations (Acemoglu et al., 2012; Acemoglu et al., 2016). Fluctuations in carbon prices, may however, distort the information quality of the signal and may reflect the market's perception of regulatory and policy uncertainty. Carbon price volatility can be considered as a credible signal of regulatory and policy uncertainty within emissions trading schemes due to its correlation with market responses to policy changes, the impact of external factors influenced by policy decisions, and its influence on investor and firm behavior (Dai et al., 2022).

When there is uncertainty surrounding future regulatory frameworks, such as changes in emission caps or adjustments to compliance requirements, market participants may adjust their expectations of future carbon prices accordingly. As a result, sudden fluctuations or erratic movements in carbon prices can signal underlying uncertainty about the regulatory landscape. Carbon price volatility can also be driven by external factors such as changes in energy prices, economic conditions, or geopolitical events. However, within the context of emissions trading schemes, these external factors are often intertwined with regulatory and policy developments. For example, shifts in government policies related to renewable energy or carbon taxation can influence both carbon prices and broader market dynamics. Therefore, carbon price volatility serves as a visible indicator of the broader regulatory and policy uncertainties affecting the market. The results presented in Table 4 and Table 5 provide empirical support for this as they indicate that NZU price volatility is largely driven by climate policy actions and climate policy uncertainty.

The theory of investment under uncertainty posits that when faced with uncertainty, firms have the option to wait before making irreversible investment decisions. This waiting option carries value, known as the option value of waiting (Dixit and Pindyck, 1994) and has been used in the empirical literature to explain the negative relationship between investment and policy uncertainty. While ample empirical evidence has been provided for the negative relationship between investment and policy uncertainty, recent work by Atanassov et al. (2024) has demonstrated that the relationship is nuanced and is conditional on the type of investment being undertaken. According to Atanassov et al. (2024), the theory of investment under uncertainty provides predictions for the relationship between investment and policy uncertainty conditional on whether the investment is an irreversible investment or a growth investment. In accordance with the theory, irreversible investments such as fixed assets and capital expenditure are expected to be negatively related to policy uncertainty but growth option investments such as R&D projects should lead to a positive relationship as an initial investment is required in order for the firm to make subsequent investments and the firm has the option of abandoning the project without making further investments. The literature, to date, has, however, largely focused on irreversible investments leading to the belief that the negative relationship with policy uncertainty should hold for all types of investments. Building on work by Kim and Kung (2017) who constructed measures of asset redeployability, Atanassov et al. (2024) challenged the dominance of the irreversible investment perspective and provided evidence for the growth and abandonment option perspective of R&D investment under uncertainty. Using R&D expenses reported by a large sample of US firms, they found a positive relationship between R&D investment and policy uncertainty. An empirical question of interest for this paper is uncovering which perspective is at play within the context of carbon markets. Does the option value of irreversible investment hold during periods of carbon price volatility? Does the growth and abandonment option of R&D investment also hold under conditions of carbon price volatility?

While some studies suggest that firms postpone abatement investments during periods of uncertainty (Fuss et al., 2009; Kettunen et al., 2011), others show that firms may accelerate abatement activities to gain a competitive advantage (Wang, 2023). In the context of emissions trading schemes, where carbon prices fluctuate unpredictably due to policy changes and market factors, firms may delay investments in emission abatement technologies or low-carbon innovations to capitalize on potential future opportunities or to avoid losses if carbon prices decrease. This conjecture provides testable implications as it predicts that irreversible investments should decrease during periods of carbon price volatility. Consequently, emissions should increase as firms delay the investment required to achieve emissions reductions. On the other hand, the proactive environmental approach posits that even in the face of uncertainty firms may choose to reduce emissions not only to comply with regulations but also to gain a competitive advantage and enhance their reputation; firms can do this by investing in abatement technology, making changes to the production process and adopting sustainable practices (Aragon-Correa and Sharma, 2003) . Carbon price volatility within emissions trading schemes may incentivize firms to reduce emissions as a strategic response to potential future policy changes or carbon price fluctuations, allowing them to stay ahead of regulatory requirements and gain a competitive edge in the market. The proactive environmental approach can also serve as a risk mitigation strategy for firms facing erratic movements in the price of emissions units. By investing in emission reduction technologies, making changes to the production process or adopting sustainable practices, firms can reduce their exposure to future carbon pricing risks and regulatory uncertainties. Rather than waiting for regulatory mandates or market pressures to force compliance, firms proactively implement emission reduction measures to minimize their environmental impact and insulate themselves from potential carbon price shocks. This proactive stance may enable firms to adapt more effectively to changing market conditions and regulatory requirements, thereby reducing their overall business risks. When taken together with the growth option of R&D investment, the proactive environmental approach suggests that if emissions reductions are observed during periods of policy uncertainty they may be due to investment in R&D, changes to the production process or the adoption of sustainable practices by firms. This paper seeks to uncover whether the investment channel, changes in production channel or both are at play during periods of increased carbon price volatility.

5 Data, Sample and Empirical Strategy

5.1 Data

Measures of carbon price volatility: I use two measures of carbon price volatility. The main measure is the annualized NZU price volatility (NZU Vol) which was estimated from the GARCH model and described in earlier sections. The second measure is the NZU Volatility Index (NZU VIX) which I use as an alternative measure in robustness tests. I create the NZU VIX by collecting historical daily price data for NZUs from Bloomberg, calculating the daily returns and daily volatility (standard deviation) using a rolling window of 30 trading days; I then set an initial index value of 100 and then calculate subsequent index values by taking the ratio of daily volatility to the initial volatility. The daily index is then annualized. A graph of the annualized NZU VIX is presented for the 2010-2022 period in Figure 8.

Insert Figure 8 here

As I have conceptualized carbon price volatility as a domain specific measure of uncertainty, I also make use of the EPU and CPU indices for New Zealand as comparative measures of domain specific uncertainty which affect carbon price volatility and expect these to be moderately correlated with NZU price volatility. The EPU and CPU indices measure different types of uncertainty (economic policy and climate policy). Including both measures can, therefore, provide a comprehensive view of policy uncertainty and allows me to empirically test the conditional relationship, between carbon price volatility, EPU, and CPU, described in the conceptual model of carbon price volatility outlined in Appendix I. I present a correlation matrix of NZU Vol, NZU VIX and the EPU and CPU indices in Table 7.

Insert Table 7 here

Emissions data: Emissions data is obtained from the Environmental Protection Authority (EPA). The emissions are self-reported data from participants in the NZ ETS. NZ ETS participants are required to submit monthly emissions returns to the EPA. To protect the identity of participants, EPA aggregates the data up to the activity level and sector level. NZ ETS participants are organized around 24 activities and 7 sectors covering a majority of economic activity and sectors in New Zealand.

NZUs surrendered- The ETS operates through the trading of New Zealand Units (NZUs), with each NZU representing one tonne of CO2 equivalent emissions. May 31 is the deadline for mandatory participants to surrender their emissions units after submitting an annual emissions return. The New Zealand Emissions Trading Register provides data on the number of NZUs surrendered each year.

Measure of irreversible investment : My main measure of irreversible investment is Gross fixed capital formation (GFCF), a macro-level measure of fixed asset investments made by firms.

Measure of growth option investment : My main measure of growth option investment is GDP R&D, a macro-level measure of R&D investments made by firms, research institutions and the government.

I also make use of a range of other macro-level variables which I use as control variables. Technical definitions of these are provided in Appendix II and summary definitions of all variables are presented in Table 8 and summary statistics are presented in Table 9.

Insert Table 8 here

Insert Table 9 here

5.2 Sample

The sample period is from 2010 to 2022. As I do not observe firm-level emissions, the sample is constructed around yearly activity-level and sector-level emissions which are aggregated data of monthly emissions returns reported by participant firms in the NZ ETS. I organize the panel data around the 24 activities covered by the NZ ETS and therefore obtain 312 activity-year observations.

Figure 9 shows a general decline in reported emissions in New Zealand since 2015 while Figure 10 shows the aggregate measure of firm-level irreversible investment in New Zealand, over the sample period. Figure 11 shows the corresponding aggregate measure of growth option investment as represented by GDP R&D.

Insert Figure 9 here

Insert Figure 10 here

Insert Figure 11 here

5.3 Empirical Strategy

To determine the impact of carbon price volatility on emissions in the NZ EST, I estimate panel regressions using the following specification:

$$\begin{aligned} \mathrm{Y}_{it} = \beta_0 + \beta_1 \ln(\text{NZU Vol}_{it}) + \beta_2 \ln(\text{EPU Index}_{it}) \\ + \beta_3 \ln(\text{CPU Index}_{it}) + \mathbf{X}_{it} + \alpha_i + \epsilon_{it} \end{aligned} \tag{6}$$

Where Y_{it} represents the variable of emissions at the activity or sector level for activity or sector i in year t. α_i is the activity and sector fixed effects. $\ln(\text{NZU Vol}_{it})$ is the measure of NZU price volatility in year t. $\ln(\text{EPU Index}_{it})$ is the economic policy uncertainty index for New Zealand in year t while $\ln(\text{CPU Index}_{it})$ is the climate policy uncertainty index for New Zealand in year t. $\mathbf{X}_{it}$ is a vector of the control variables including GDP per capita growth rate, NZ activity index, industrial production, percentage value added, crude oil production and crude oil import prices.

To study the impact of carbon price volatility on aggregate level irreversible firm investment, I estimate panel regressions using the following specification:

$$\begin{aligned}\text{GFCF}_{it} = \beta_0 + \beta_1 \ln(\text{NZU Vol}_{it}) + \beta_2 \ln(\text{EPU Index}_{it}) \\ + \beta_3 \ln(\text{CPU Index}_{it}) + \mathbf{X}_{it} + \alpha_i + \epsilon_{it}\end{aligned} \tag{7}$$

Where GFCF_{it} represents the irreversible investments made by firms for activity and sector i in year t. α_i is the activity and sector fixed effects. $\ln(\text{NZU Vol}_{it})$ is the measure of NZU price volatility in year t. $\ln(\text{EPU Index}_{it})$ is the economic policy uncertainty index for New Zealand in year t while $\ln(\text{CPU Index}_{it})$ is the climate policy uncertainty index for New Zealand in year t. $\mathbf{X}_{it}$ is a vector of the control variables including GDP per capita growth rate, NZ activity index, long term interest rates, producer price index inlfation, short term interest rates and the business confidence index.

To study the impact of carbon price volatility on aggregate level growth option firm investment, I estimate panel regressions using the following specification:

$$\begin{aligned}\text{GDP R\&D}_{it} = \beta_0 + \beta_1 \ln(\text{NZU Vol}_{it}) + \beta_2 \ln(\text{EPU Index}_{it}) \\ + \beta_3 \ln(\text{CPU Index}_{it}) + \mathbf{X}_{it} + \alpha_i + \epsilon_{it}\end{aligned} \tag{8}$$

Where $\text{GDP R\&D}_{it}$ represents the growth option investments made by firms for activity and sector i in year t. α_i is the activity and sector fixed effects. $\ln(\text{NZU Vol}_{it})$ is the measure of NZU price volatility in year t. $\ln(\text{EPU Index}_{it})$ is the economic policy uncertainty index for New Zealand in year t while $\ln(\text{CPU Index}_{it})$ is the climate policy uncertainty index for New Zealand in year t. $\mathbf{X}_{it}$ is a vector of the control variables including GDP per capita growth rate, NZ activity index, long term interest rates, producer price index inlfation, short term interest rates and the business confidence index.

6 Results

6.1 Carbon Price Volatility and Emissions

I first examine the impact of carbon price volatility on emissions at the activity and sector level using various specifications of Equation 6. Table 10 presents the results for activity level emissions and Table 11 presents the results for sector level emissions.

Insert Table 10 here

Columns 1 and 2 of Table 10 displays the results on NZU price volatility, our main explanatory variable. In model 1, I include activity fixed effects but exclude the control variables. The coefficient estimate on NZU price volatility is -3.991 and is statistically significant at the 1% level. In model 2, I add the control variables and observe that statistical significance is lost but the direction of the estimate is maintained. In models 3, 4, 5 and 6, I follow a similar procedure for the EPU index and CPU index and observe a negative relationship that is statistically significant across the models. When I condition NZU price volatility on the EPU index and CPU index in model 7, its coefficient estimate increases significantly, remains negative and regains statistical significance at the 1% level. The coefficient estimates on the EPU index and CPU index also increase significantly and remains statistically significant, however, the estimates on the CPU index becomes positive. The results for sector level emissions presented in Table 11 exhibit a similar pattern of results but with lower coefficient estimates.

Insert Table 11 here

Taken together, the results suggest that the policy uncertainty captured in the volatility of the NZU carbon price, coupled with economic policy uncertainty and climate policy uncertainty affects firm polluting behavior and that firm emissions are reduced when policy uncertainty increases.

The real options perspective of investment under uncertainty predicts that firms delay irreversible investments during periods of uncertainty (Pindyck, 1993) and as such I expect emissions to actually increase as firms delay investments in abatement technology during periods of carbon price volatility. On the other hand, the growth and abandonment options perspective suggests that firms actually go ahead with R&D type investments because they can abandon the investment without any additional cost (Atanssov et al., 2024). Additionally, firms may take a proactive environmental approach by making changes to the production process (Aragon-Correa and Sharma, 2003). Before examining which of these mechanisms is responsible for the emissions reductions I observe, I investigate whether the option value of irreversible investment perspective and the growth and abandonment option perspective holds under conditions of carbon price volatility.

6.2 Carbon Price Volatility and Irreversible Investment

I examine the relationship between NZU price volatility and aggregate level irreversible investment using various specifications of Equation 7. Table 12 presents the results.

Insert Table 12 here

Column 1 shows the results without controls where the coefficient on NZU price volatility is statistically significant at the 1% level and is in the expected direction predicted by the irreversible investments perspective. The option value perspective also holds for the EPU index in models 3 and 4 which are presented without and with controls respectively. The results in models 5, 6 and 7 which make use of the CPU index suggest that when conditioned on climate policy uncertainty, NZU price volatility exhibits a positive relationship with aggregate level irreversible investment; a result which is contrary to the option value of irreversible investment perspective.

6.3 Carbon Price Volatility and Growth Option Investment

I examine the relationship between NZU price volatility and aggregate level growth option investment using various specifications of Equation 8. Table 13 presents the results.

Insert Table 13 here

Column 1 shows the results without controls where the coefficient of NZU price volatility is -0.0335 and is statistically significant at the 5% level. When controls are added in Column 2, the magnitude of the coefficient remains negative and is statistically significant at the 1% level. When conditioned on the EPU and CPU indices in Column 7, the coefficient not only increases but also remains negative and statistically significant. These results do not support the growth option perspective.

Given the contrary results I obtain for both irreversible investment and growth option investment, the natural question which arises is why the theories which predict the relationship between these types of investments and policy uncertainty do not hold under conditions of carbon price volatility. I offer two possible explanations. The first is related to the marginal abatement cost curve (MACC). The MACC represents the cost of reducing an additional unit of emissions. It typically shows that the initial reductions can be achieved at a lower cost, while further reductions become increasingly expensive. Under conditions of carbon price volatility, firms might focus on investments that are lower on the MACC due to their lower cost and lower risk. These investments are often irreversible investments, such as switching to electric vehicles (EVs) or improving energy efficiency. In periods of high uncertainty, firms tend to prefer investments with lower costs and risks. Since investments lower on the MACC are usually more cost-effective and carry less financial risk, firms might prioritize these over more expensive and risky options. Firms aiming to maintain a proactive environmental strategy might still invest in abatement technologies despite volatility. However, they will choose those that offer immediate and tangible benefits with lower upfront costs, resulting in a preference for irreversible investments that are lower on the MACC. The positive relationship I observe between carbon price volatility and irreversible investments suggests that firms are indeed opting for these lower-cost, lower-risk abatement options. The negative relationship I observe between growth options investments and NZU price volatility can be explained by the fact that these types of investments are higher on the MACC and are, therefore, more expensive and risky.

The second possible explanation is that carbon related growth option investments are few and far between and as such firms face a limited investment universe. Many growth option investments in carbon reduction, such as carbon storage and capture, are in their infancy, lacking widespread commercial viability. This limits the options available to firms looking to invest in decarbonization. While R&D investments allow for abandonment without additional costs, the lack of proven technologies means firms face a higher degree of uncertainty regarding the potential success and commercial viability of these investments. The negative and statistically significant coefficients on NZU price volatility for growth option investments indicate that firms are not heavily investing in these types of projects. This supports the idea that the limited availability and high uncertainty of growth option technologies deter firms from making such investments during periods of carbon price volatility.

6.4 Which Mechanism Explains Emissions Reductions in the NZ ETS?

The mechanisms through which firms achieve emissions reductions under carbon pricing regimes are not well understood. Intuitively and as suggested by the literature, the primary mechanism should be through investments in abatement technology as emissions trading schemes are designed to increase the cost of pollution for firms and as a result incentivize abatement investment as firms seek to avoid the higher cost associated with increased emissions (Tietenberg, 2013; Best et al., 2020). Martinsson et al. (2024) suggest that firms can also achieve emissions reduction through reducing production or making changes in the production process which are less emission intensive. To uncover which of these mechanism explains the emissions reductions achieved by NZ ETS participants, I estimate panel regressions using the following specification:

$$\begin{aligned} \mathrm{Y}_{it} = \beta_0 + \beta_1 \ln(\mathrm{GDP\ R\&D}_{it}) + \beta_2 \ln(\mathrm{GFCF}_{it}) \\ + \beta_3 \ln(\mathrm{IP}_{it}) + \mathbf{X}_{it} + \alpha_i + \epsilon_{it} \end{aligned} \tag{9}$$

Where Y_{it} represents the variable of emissions at the activity level for activity i in year t. α_i is the activity and sector fixed effects. $\ln(\mathrm{GDP\ R\&D}_{it})$ is the measure of growth option investments in year t. $\ln(\text{GFCF}_{it})$ is the measure of irreversible investments in year t while $\ln(\text{IP}_{it})$ is the industrial production of firms in year t. $\mathbf{X}_{it}$ is a vector of the control variables including GDP per capita growth rate, NZ activity index, NZU price volatility, the climate policy uncertainty index for New Zealand, percentage value added and crude oil import prices. Results are presented in Table 14.

Insert Table 14 here

Columns 3 and 4 show that the coefficient estimates on the industrial production variable are not statistically significant thereby ruling out changes in production as the channel through which emission reductions are achieved. In the most restrictive model presented in Column 4, both GDP R&D and GFCF are statistically significant at the 5% level. The coefficient estimate for GFCF is, however, positive while the coefficient estimate for GDP R&D is negative. These results suggest that emissions reductions in the NZ ETS are achieved through growth option investments in R&D projects.

6.5 Robustness Tests

I conduct robustness in six ways. First, I use an instrumental variables approach (2SLS) to address possible endogeniety issues between policy uncertainty, investment and emissions. Second, I utilize the NZ VIX as an alternate measure of NZU price volatility. Thirdly, I utilize NZUs surrendered by NZ ETS participants as an alternative measure for emissions. Additionally, for activity level emissions, I restrict the sample period to account for a general decline in emissions after 2015 and the impact of COVID-19. For sector level emissions, I exclude the sector with the largest emissions in one test and also exclude the sector with the least emissions in an additional test. Finally, to address the concern that aggregate level data may mask micro-level dynamics, I hand collect data on the energy transition and decarbonisation grants provided to New Zealand firms participating in the NZ ETS by the Energy Efficiency and Conservation Authority (EECA) and use these as an alternative measure of investment.

As I have conceptualized carbon price volatility as a measure of policy uncertainty, the underlying economics of its relationship with investments and emissions suggests that my results could be driven by possible endogeneity issues which arises from the interplay and mutual influence among these factors. Policy uncertainty captured in the volatility of the carbon price can lead to reduced or postponed investments in emissions reduction technologies, as firms wait for clearer signals from policymakers. This signalling mechanism also works in the opposite direction in that the level and nature of investments being made by firms can also influence policy decisions. If policymakers observe a lack of investment in abatement technologies, they might adjust policies in unfavourable ways which make carbon prices become more volatile. Policy uncertainty can also lead to higher emissions in the short term if firms delay investments in abatement technologies. Conversely, clear and stable policies can provide the certainty needed for firms to commit to emissions reductions. As is the case with investments, current emissions levels can influence future policy directions. High emissions might lead to stricter policies, while lower emissions could result in more lenient regulations. This feedback loop creates an endogenous relationship where emissions influence policy, which in turn affects future emissions. I follow the approach suggested by Jiang (2017) in providing economic reasoning for both the ex ante and ex post estimates relating to this endogeneity.

Ex ante, I expect these endogeneity issues to result in an underestimation of the coefficient estimates of the relationship between carbon price volatility, irreversible investments and emissions and want to correct for this. Given, however, that firms are not pursuing much carbon related growth option investments because of MACC considerations and a limited investment universe for these types of investments, I expect the coefficient estimates for R&D investments to be overstated and also want to correct for this. I, therefore, expect, ex post, that whatever corrective procedure I employ should result in larger coefficient estimates for emissions and irreversible investments but smaller coefficient estimates for R&D investments.

In Table 15, I use an instrumental variable (IV) approach (two-stage-least squares (2SLS) regression) as the corrective procedure, and instrument my main measure of carbon price volatility. My instrument is a dummy variable for election years which take the value of one in years where an election is held in New Zealand and zero otherwise. I follow Julio and Yook (2012) in treating elections as a proxy for general policy uncertainty. As I have conceptualized carbon price volatility as a domain-specific measure of general policy uncertainty, it is likely to be correlated with elections. Furthermore, elections are exogenously determined and such the instrument satisfies the exogeneity requirement and should serve as a strong instrument for carbon price volatility.

I do indeed find this to be the case as the F-statistics from the first-stage regressions exceed 10 in Panel A where the dependent variable is activity level emissions, Panel B where the dependent variable is gross fixed capital formation and and Panel C where the dependent variable is R&D as a percentage of GDP. As expected, I obtain larger coefficient estimates on NZU price volatility when it is instrumented on emissions and irreversible investments and a smaller estimate when it is instrumented on growth option investments. Additionally, the coefficient estimates remain statistically significant and are in the same direction as the estimates of the baseline models.

Insert Table 15 here

Volatility can be measured and estimated in many different ways. To ensure that my results are robust to alternative volatility measures, I create one such measure in the form of a volatility index of the NZU carbon price (NZU VIX). As indicated in Panel A, Panel B and Panel C of Table 16, the results of the main model remain consistent when the NZU VIX is utilized as an alternative measure of NZU price volatility.

Insert Table 16 here

The NZ ETS operates through the trading of NZUs which each represent one tonne of CO2 equivalent emissions. At the end of each year NZ ETS participants are obligated to surrender the number of NZUs which are equivalent to the amount of emissions they have produced for the year. I obtain data on the number of NZUs surrendered annually by NZ ETS participants and use this as an alternate measure of emissions. In Table 17, I obtain results which are consistent with the activity level and sector level measures of emissions when NZUs surrendered is used as an alternative measure of emissions.

Insert Table 17 here

A possible concern is that the activity level emission results could be driven by the general reduction in emissions observed in Figure 9 after 2015. The period of the COVID-19 pandemic could also be a confounding factor. To address this issue, I restrict the sample period for activity level emissions to 2010-2017 and obtain consistent results as those of the full sample period. Table 18 presents the results for activity level emissions for the restricted sample period.

Insert Table 18 here

I also conduct robustness on the sector level emissions results by excluding the post-1989 forestry sector which reported the largest sector level emissions over the sample period. Table 19, which reports the results of this restricted sector level sample, shows that the results are consistent with those obtained when all sectors are included in the sample.

Insert Table 19 here

In a related robustness check, I exclude the agricultural sector which reported the smallest sector level emissions over the sample period. In the untabulated results the coefficient estimates maintain the expected direction but loose statistical significance because of a sharp reduction in the number of observations.

To address the concern that aggregate level data may mask micro-level dynamics, I hand collect data on the energy transition and decarbonisation investment funding support provided to New Zealand firms participating in the NZ ETS by the Energy Efficiency and Conservation Authority (EECA), a New Zealand Government agency which promotes decarbonisation and renewable energy initiatives through its business decarbonisation fund. The fund provides co-funding support to business which are making investments in the decarbonisation of hard to abate sectors. Investments in hard to abate sectors are likely to be growth option investments which require government support as they carry greater risk than irreversible investments. I calculate the intensity of the business decarbonisation fund by scaling its annual expenditure by its annual budget. Using this as an alternative measure of growth option investment, I obtain results which correspond with those obtained when aggregate level R&D was utilized. Table 20 presents the results.

Insert Table 20 here

Finally, I collect data on patents on environment technologies from the OECD indicator database. Patents on environment technologies is the number of environment-related inventions as a ratio of all domestic inventions in all technologies. Using this as an alternative measure of irreversible investment, I obtain results which correspond with those obtained when aggregate level GFCF was utilized. Table 21 presents the results.

Insert Table 21 here

7 Conclusion

This paper investigates whether carbon pricing mechanisms effectively reduce carbon emissions and spur investment in abatement technologies. Using the New Zealand Emissions Trading Scheme (NZ ETS) as the carbon pricing setting, I uncover a nuanced relationship between carbon price volatility, investment decisions, and emissions reductions. Contrary to the real options theory, which suggests that firms delay irreversible investments under uncertainty, the results I obtain show that firms continue to make these investments despite carbon price volatility. This finding is explained by factors such as the marginal abatement cost curve and proactive environmental strategies, which drive firms to focus on lower-cost, lower-risk abatement options. Additionally, the limited investment universe for growth option technologies, such as carbon capture and storage, further explains the observed investment behavior. Our analysis also highlights that while carbon pricing under the NZ ETS influences firms' emissions reduction efforts, the reductions are primarily achieved through increased R&D investments.

Furthermore, the investigations I conduct into the drivers of NZU price volatility reveal that both general policy uncertainty and climate-specific policy changes play crucial roles in influencing carbon price fluctuations. Election years, used as an instrumental variable for general policy uncertainty, confirm the impact of broader regulatory uncertainty on the NZU market.

These findings advance understanding of the uncertainty-investment relationship by showing that in carbon markets, policy uncertainty can reinforce the drive for irreversible investments in emissions reduction but may hinder growth investments. This nuanced insight adds a layer to Atanassov et al. (2024) findings, suggesting that the effect of policy uncertainty is not uniform across sectors and is highly dependent on regulatory frameworks specific to the carbon market context. This highlights the importance of considering sector-specific responses to policy uncertainty, especially in climate-sensitive industries.

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Appendix I: Conceptual Model of Carbon Price Volatility

Conceptual Framework

Carbon Price Volatility (CPV):

- Definition: CPV is the fluctuation in the price of carbon credits within carbon markets.
- It is influenced by various types of policy uncertainty.

Policy Uncertainty (PU):

- Definition: PU is the uncertainty in the policy environment that can affect economic and market outcomes.
- General PU is a weighted average of domain-specific uncertainties.

Types of Policy Uncertainty:

- **Economic Policy Uncertainty (EPU):**
  - Definition: Uncertainty in economic policies such as fiscal, monetary, and trade policies.
- **Climate Policy Uncertainty (CPU):**
  - Definition: Uncertainty in climate-related policies such as regulations on emissions, renewable energy incentives, and international climate agreements.

Mathematical Representation

Carbon Price Volatility as a Function of Policy Uncertainty:

$$\text{CPV} = f(\text{PU}) \tag{10}$$

General Policy Uncertainty as a Weighted Average:

$$\text{PU} = \alpha \times \text{EPU} + \beta \times \text{CPU} \tag{11}$$

- Where α and β are coefficients representing the weights of EPU and CPU, respectively.
- Given the sensitivity, $\beta > \alpha$.

Carbon Price Volatility (CPV) as a Function:

$$\text{CPV} = g(\text{EPU}, \text{CPU}) \tag{12}$$

- This function g captures the conditional relationship, emphasizing a stronger influence of CPU.

Graphical Representation

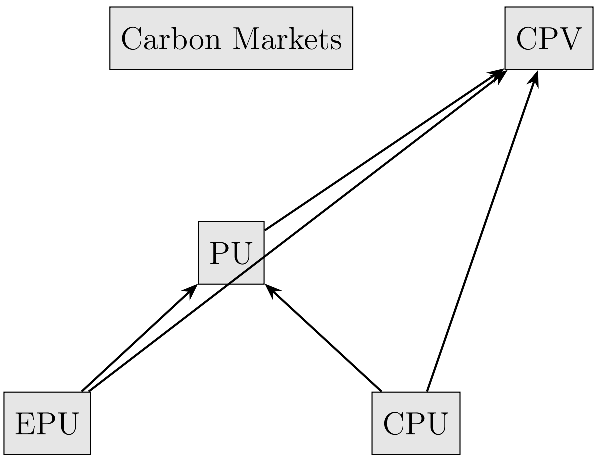

Figure 1: Conceptual Framework of Carbon Price Volatility and Policy Uncertainty

Appendix II: Technical Description of Macro-Level Variables

GDP Per capita growth rate- Growth rate (annual change) of total value of goods and services produced in New Zealand divided by population size. This data is provided by Statistics New Zealand.

New Zealand Activity Index (NZAC)- NZAC summarises several monthly indicators, including spending, unemployment, job vacancies, traffic volumes, electricity generation, business outlook, and manufacturing activity. NZAC is a broad measure of economic activity. This data is provided by Statistics New Zealand.

GDP spending on R&D- Gross domestic spending on R&D is defined as the total expenditure (current and capital) on R&D carried out by all resident companies, research institutes, university and government laboratories, etc., in new Zealand as a percentage of GDP. This data is provided by the OECD indicator database and serves as the main measure of growth option investment.

Industrial Production- Industrial production refers to the output of industrial establishments in New Zealand and covers sectors such as mining, manufacturing, electricity, gas and steam and air-conditioning. This indicator is measured in an index based on a reference period that expresses change in the volume of production output. This data is provided by the OECD indicator database.

Gross Fixed Capital Formation- Gross fixed capital formation (GFCF), also called "investment", is defined as the acquisition of produced assets (including purchases of second-hand assets) by New Zealand firms. The relevant assets relate to assets that are intended for use in the production of other goods and services for a period of more than a year. This data is provided by the OECD indicator database and serves as the main measure of irreversible investment.

Percentage value added by activity- Value added reflects the value generated by producing goods and services in New Zealand and is measured as the value of output minus the value of intermediate consumption. Value added also represents the income available for the contributions of labour and capital to the production process. Value added by activity shows the value added created by the various industries (such as agriculture, industry, utilities, and other service activities). The indicator presents value added for an activity, as a percentage of total value added. This data is provided by the OECD indicator database.

Crude oil production- Crude oil production is defined as the quantities of oil extracted from the ground after the removal of inert matter or impurities. It includes crude oil, natural gas liquids (NGLs) and additives. This indicator is measured in thousand tonne of oil equivalent. This data is provided by the OECD indicator database.

Crude oil import prices- Crude oil import prices come from the IEA's Crude Oil Import Register and are influenced not only by traditional movements of supply and demand, but also by other factors such as geopolitics. Information is collected from national agencies according to the type of crude oil, by geographic origin and by quality of crude. Average prices are obtained by dividing value by volume as recorded by customs administrations for each tariff position. Values are recorded at the time of import and include cost, insurance, and freight, but exclude import duties. This data is provided by the OECD indicator database.

Primary Energy Supply- Primary energy supply for New Zealand is defined as energy production plus energy imports, minus energy exports, minus international bunkers, then plus or minus stock changes. This data is provided by the OECD indicator database.

Electricity Generation-Electricity generation for New Zealand is defined as electricity generated from fossil fuels, nuclear power plants, hydro power plants (excluding pumped storage), geothermal systems, solar panels, biofuels, wind, etc. It includes electricity produced in electricity-only plants and in combined heat and power plants. This data is provided by the OECD indicator database.

Short Term Interest Rates-Short-term interest rates are the rates at which short-term borrowings are effected between financial institutions or the rate at which short-term government paper is issued or traded in the market. Short-term interest rates are generally averages of daily rates, measured as a percentage and are based on three-month money market rates.This data is provided by the OECD indicator database.

Long Term Interest Rates-Long-term interest rates refer to government bonds maturing in ten years. These interest rates are implied by the prices at which the government bonds are traded on financial markets. This data is provided by the OECD indicator database.

Inflation CPI-Inflation measured by consumer price index is defined as the change in the prices of a basket of goods and services that are typically purchased by specific groups of households. Inflation is measured in terms of the annual growth rate and in index, 2015 base year with a breakdown for food, energy and total excluding food and energy. This data is provided by the OECD indicator database.

Inflation PPI-Inflation measured by producer price index measures the rate of change in prices of products sold as they leave the producer. They exclude any taxes, transport and trade margins that the purchaser may have to pay. PPIs provide measures of average movements of prices received by the producers of various commodities.This data is provided by the OECD indicator database.

Business Confidence Index-The business confidence indicator provides information on future developments, based upon opinion surveys on developments in production, orders and stocks of finished goods in the industry sector of New Zealand. It is used to monitor output growth and to anticipate turning points in economic activity. This data is provided by the OECD indicator database.

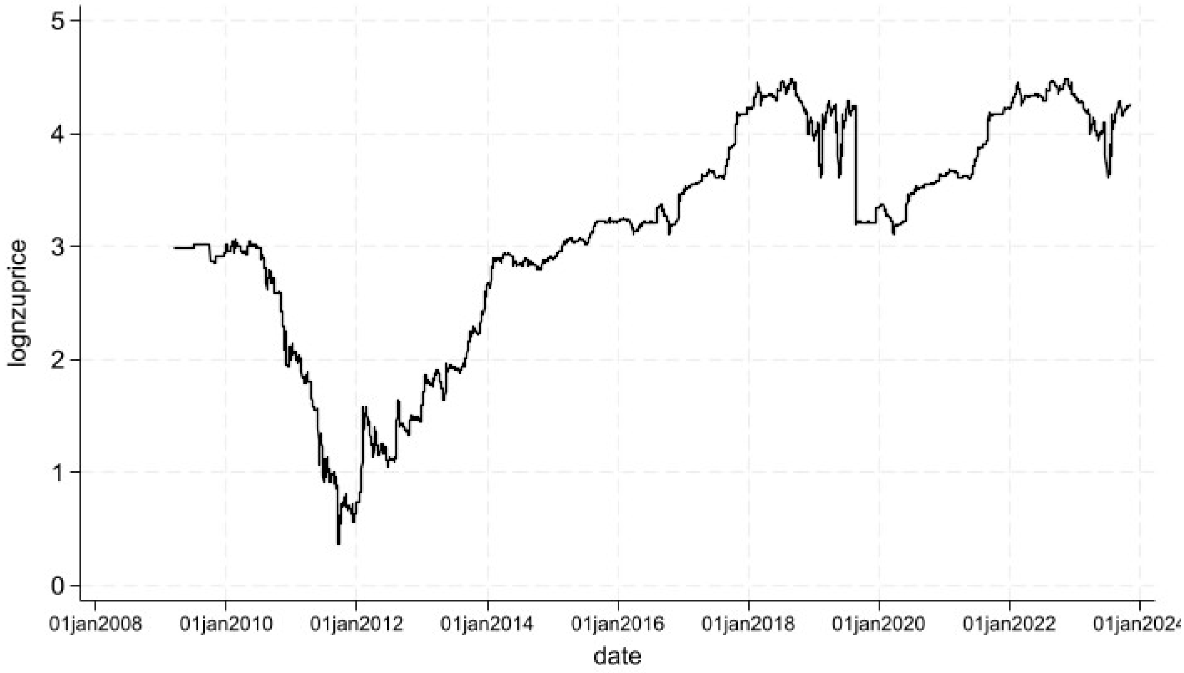

Figure 2: Time series of log price of daily NZU price for 2009-2023

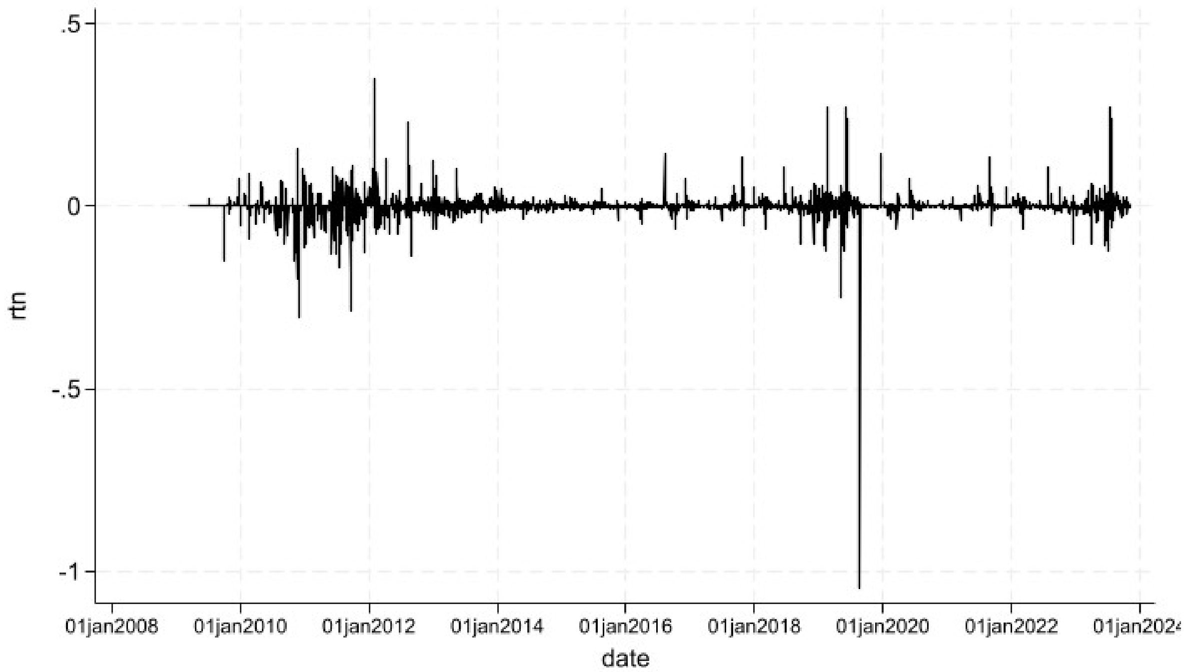

Figure 3: Time series of daily returns of NZU price for 2009-2023

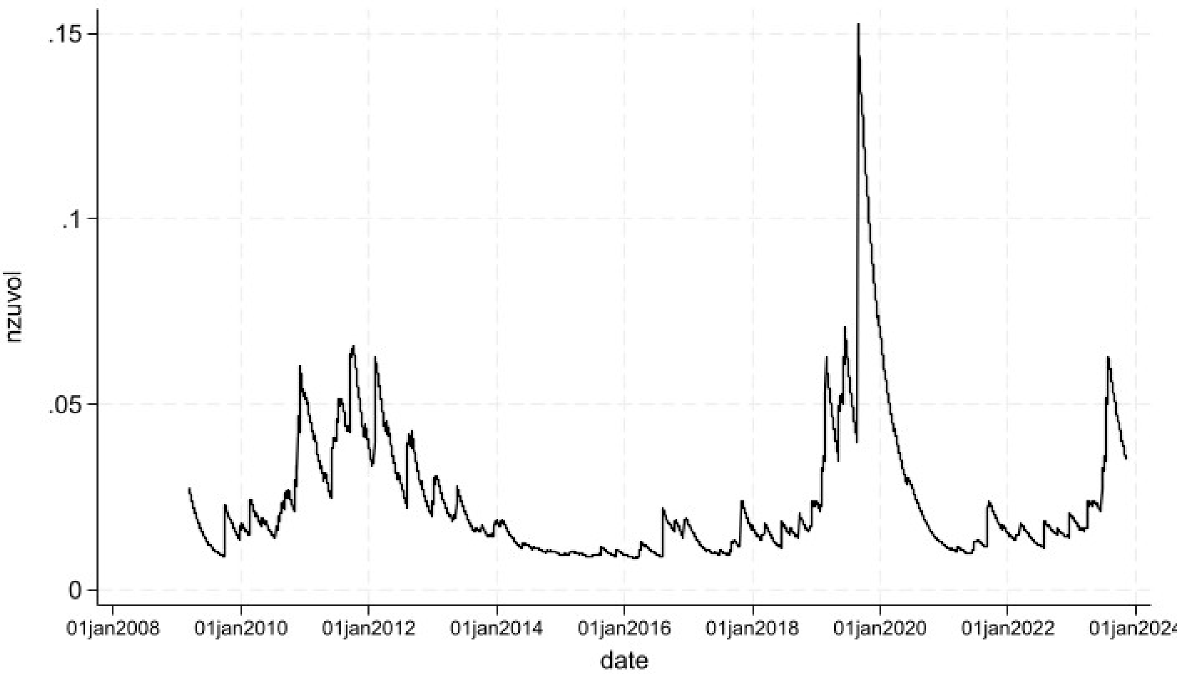

Figure 4: Time series of daily realized volatility of NZU price for 2009-2023

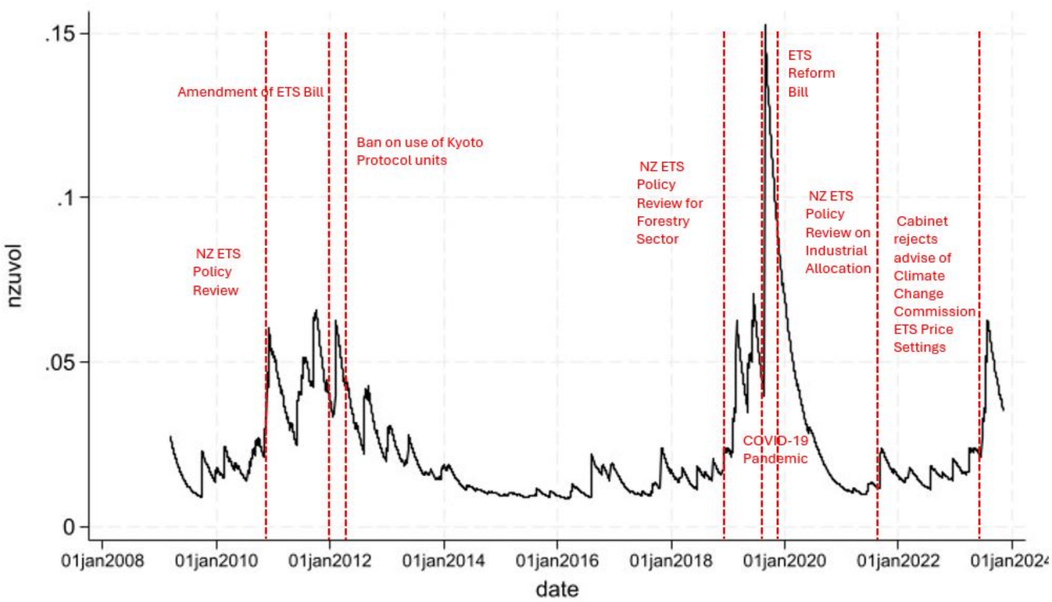

Figure 5: Policy event timeline of NZU price volatility for 2009-2023

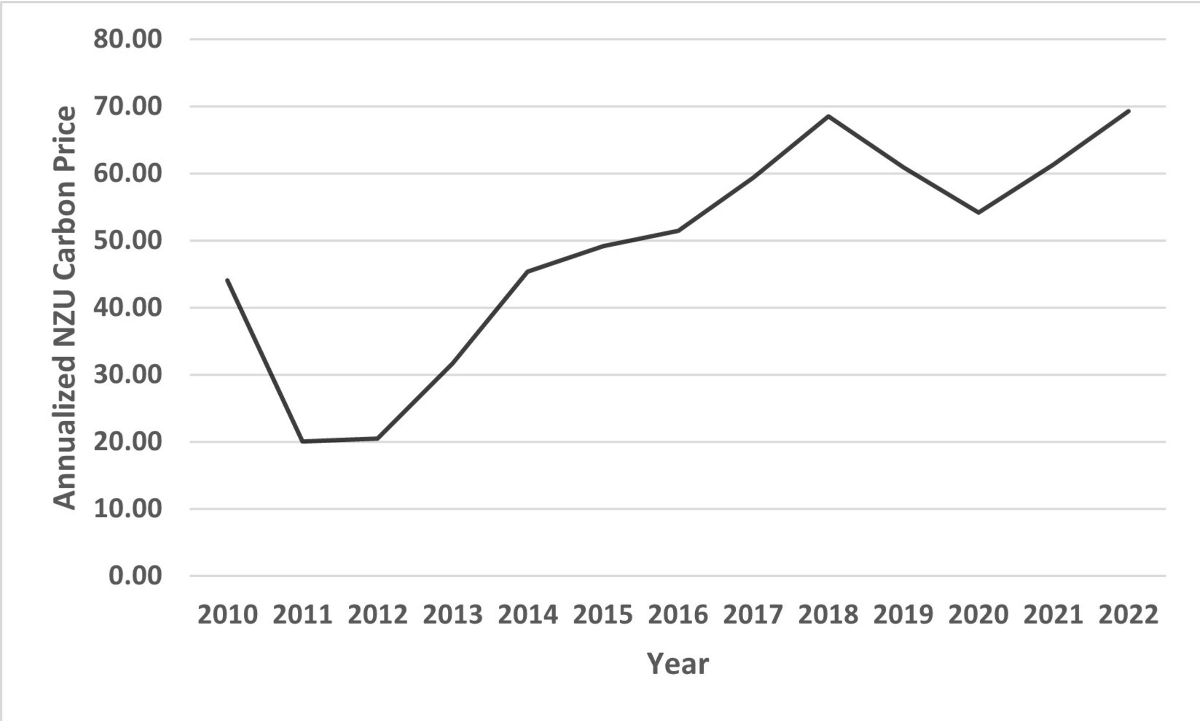

Figure 6: Annualized NZU carbon price over sample period

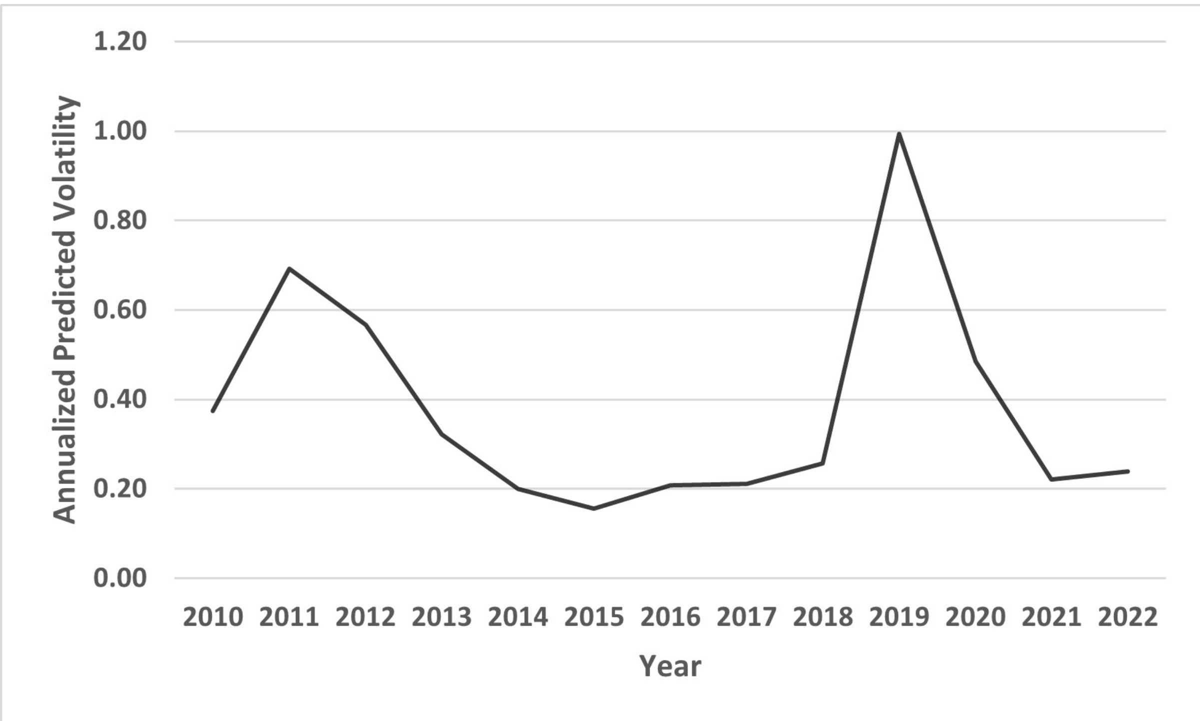

Figure 7: Annualized volatility of NZU carbon price over sample period

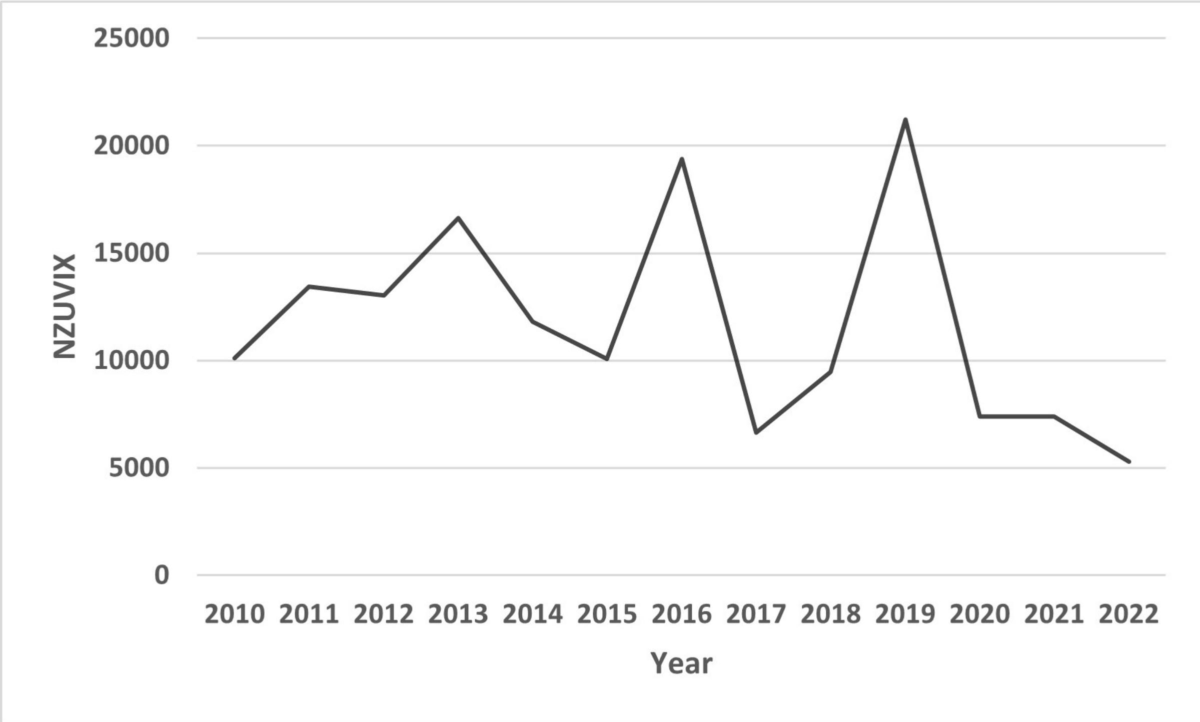

Figure 8: Volatility Index of NZU carbon price over sample period

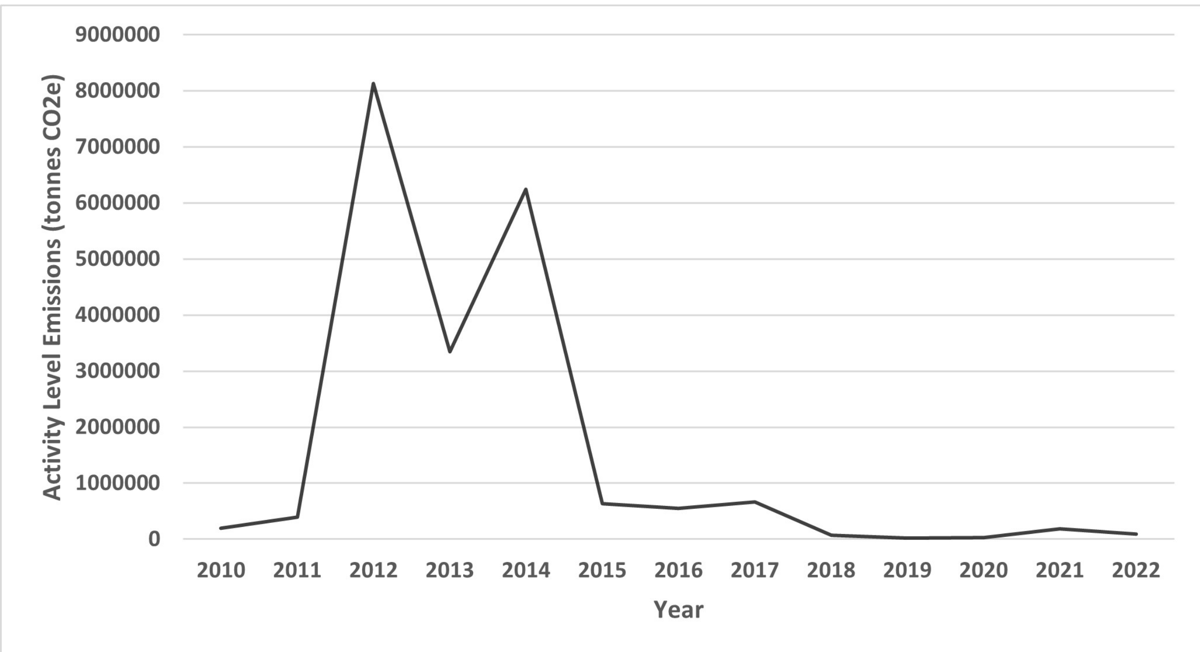

Figure 9: Activity-level emissions over sample period

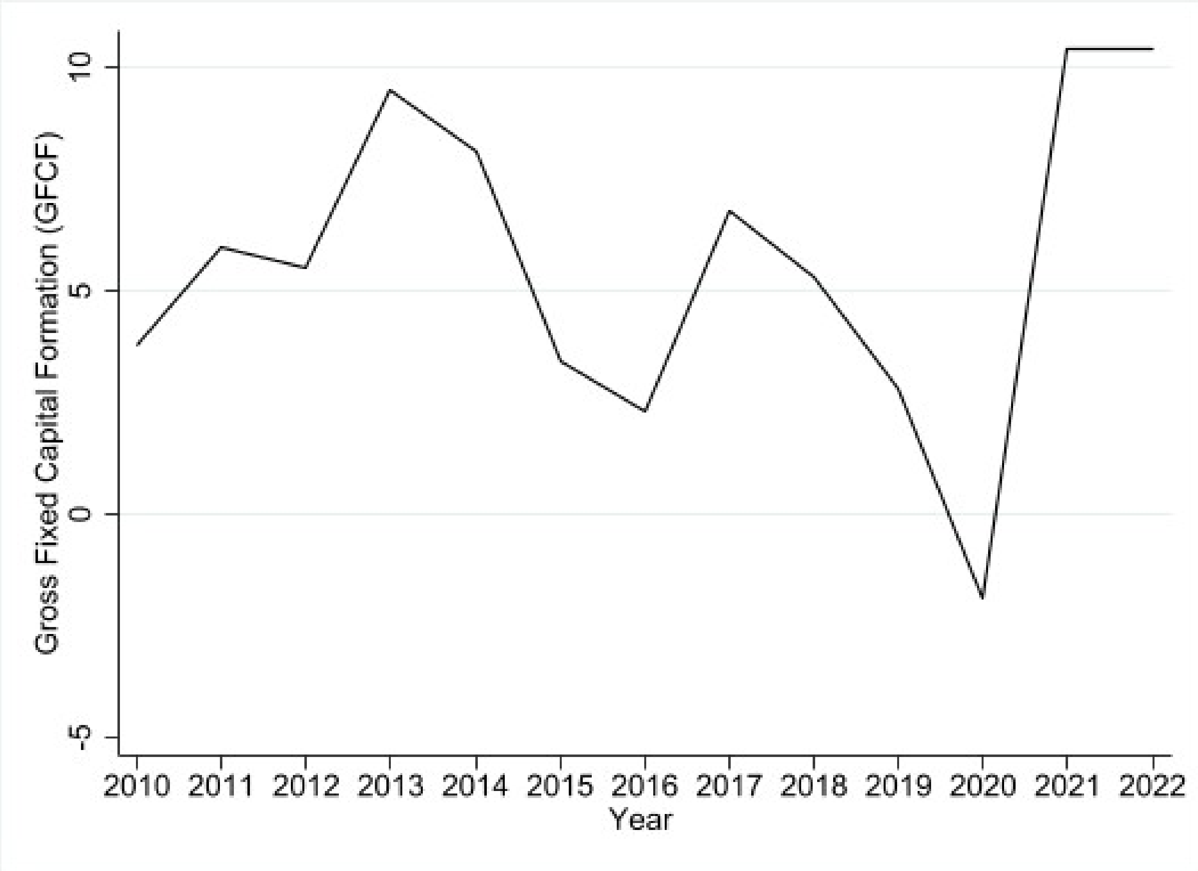

Figure 10: Variability of GFCF, aggregate measure of firm-level investment, over sample period

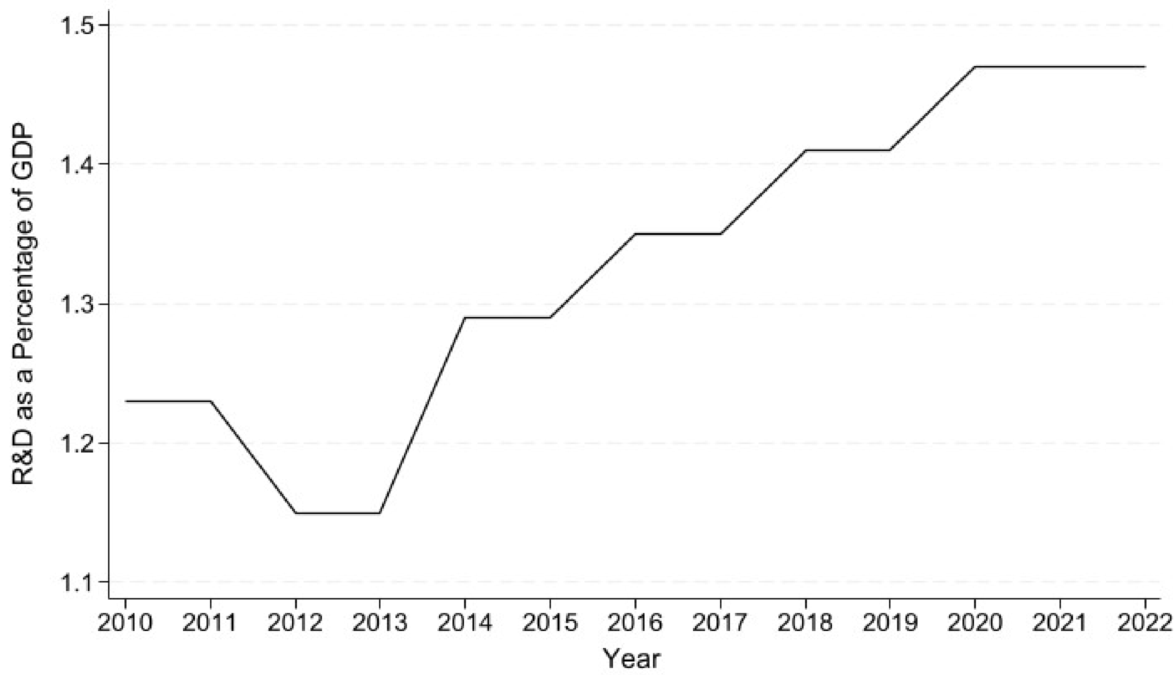

Figure 11: Variability of GDP R&D, aggregate measure of firm-level investment over sample period

Table 1: **NZU Daily Returns**. Results of autoregressive model of NZU daily returns with 3 lags. Returns are calculated as the logarithmic difference of the NZU price series. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

	NZU Daily Return
	(1) **NZU Return**
AR (1)	0.0675***
	(4.72)
AR (2)	-0.000388
	(-0.03)
AR (3)	-0.000168
	(-0.01)
Constant	0.000240
	(0.62)
Adjusted R-squared	0.0039
N	4905

Table 2: **NZU Price Volatility**. Results of AR(1)-GARCH(1,1) model of estimated volatility for the NZU daily returns.*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

	NZU Price Return
	(1) **NZU Return**
AR (1)	0.0945***
	(6.96)
ARCH (1)	0.0198***
	(74.91)
GARCH (1)	0.982***
	(6537.12)
Constant	0.00000108***
	(62.95)
Wald chi2	48.5
Prob > chi2	0.0000
Log Likelihood	12412.38
N	4908

Table 3: **Event Study of Policy Announcements and Events**. This table presents event studies which estimates cumulative abnormal returns for the reaction of the NZU price to a sample of NZ ETS related policy announcement and events that occurred between 2018 and 2023.

Policy Announcement and Event Dates	Event Window	CAAR
Press Release by Climate Change Minister: ETS forestry improvements to create more benefits for New Zealand		
December 12,2018	[-10,+10]	-2.84%
	[-30,+30]	-23.83%
	[-30,+60]	-58.24%***
Press Release by Climate Change Minister: Latest Emissions Trading Scheme reforms target transparency and compliance		
May 16,2019	[-10,+10]	-59.53%***
	[-30,+30]	-2.67%
	[-30,+60]	18.92%
Press Release by Climate Change Minister: ETS fixes drive climate action		
July 31,2019	[-10,+10]	3.93%
	[-30,+30]	-60.56%***
	[-30,+60]	-63.41%***
The Climate Change Response (Emissions Trading Reform) Amendment Act 2020		
June 16, 2020	[-10,+10]	24.25%**
	[-30,+30]	27.60%
	[-30,+60]	28.69%
Climate Change Commission 2nd Advice on ETS Settings		
April 13,2023	[-10,+10]	-2.94%
	[-30,+30]	-24.12%
	[-30,+60]	-58.66%**
Lawyers for Climate Action Judicial Review of 2022 Cabinet Decision Court Ruling		
July 13,2023	[-10,+10]	48.69%***
	[-30,+30]	27.71%
	[-30,+60]	24.70%
Industrial Allocation Reform Amendment Act		
August 16,2023	[-10,+10]	16.58%
	[-30,+30]	61.17%***
	[-30,+40]	65.31%***
	[-30,+50]	67.69%***

Table 4: **Determinants of NZU Price**. Results from various specifications of OLS regressions where the dependent variable is the annualized NZU carbon price. Standard errors are robust. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

	Annualized NZU Carbon Price							
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
ln(Number of Minister's Directive)	-1.592*							-11.97***
	(-2.54)							(-49.38)
ln(Industrial Allocation)		-22.75***						-48.09***
		(-8.55)						(-58.67)
Climate Attention Index			313.5***					-626.4***
			(4.55)					(-36.82)
EPU index				-0.0148***				-0.0146***
				(-21.73)				(-65.39)
EPS index					-72.57**			179.8***
					(-3.10)			(29.95)
CPU Index						-0.0394***	-0.0140*	
						(-172.79)	(-2.35)	
ln(Inflation PPI)	0.203	1.286	-0.471	-3.271	0.433	0.0572		0.190
	(0.02)	(0.11)	(-0.04)	(-0.40)	(0.03)	(0.25)		(0.09)
ln(Business Confidence Index)	-22.82	-6.247	-11.46	-0.317	-20.00	-0.478		-2.034
	(-0.36)	(-0.11)	(-0.18)	(-0.01)	(-0.31)	(-0.42)		(-0.18)
ln(Short Term Interest Rates)	0.0129	0.223	-0.0356	0.0731	0.117	-0.00170		0.0800
	(0.01)	(0.20)	(-0.03)	(0.10)	(0.10)	(-0.08)		(0.38)
ln(Primary Energy Supply)	2.493	-1.244	1.079	-1.564	1.741	0.135		-0.0461
	(0.19)	(-0.10)	(0.08)	(-0.19)	(0.13)	(0.58)		(-0.02)
ln(Electricity Generation)	-24.96	-12.96	-17.34	-5.959	-26.08	-0.0508		4.260
	(-0.45)	(-0.26)	(-0.32)	(-0.17)	(-0.47)	(-0.05)		(0.45)
Crude Oil Production	0.00244	-0.0168***	0.00249	0.00848***	0.00397*	0.0125***		0.706***
	(1.54)	(-6.58)	(1.64)	(8.31)	(2.31)	(392.81)		(48.17)
Crude Oil Import Prices	0.0801*	-0.0103	-0.107**	0.0497**	0.0324	0.391***	0.244***	-0.0313***
	(2.09)	(-0.42)	(-2.89)	(2.89)	(1.16)	(493.92)	(12.87)	(-43.62)
Industrial Production	2.528***	2.639***	1.830***	2.926***	2.308***	8.036***	5.074***	7.084***
	(8.23)	(10.61)	(6.78)	(17.02)	(8.51)	(828.33)	(30.59)	(78.20)
GDP PC Growth	-0.239	0.804**	1.312**	-1.162***	-0.544	-3.251***	-3.234***	-1.535***
	(-0.91)	(3.05)	(3.14)	(-6.82)	(-1.92)	(-392.17)	(-14.34)	(-16.95)
GDP R&D	79.58***	47.58***	30.61*	79.74***	91.73***	8.468***	47.51***	108.1***
	(10.21)	(6.37)	(2.54)	(16.87)	(9.78)	(30.72)	(6.80)	(40.08)
NZ Activity Index	0.0276	0.0309	0.169***	-0.181***	0.0317	0.360***	0.511***	-0.625***
	(0.81)	(1.05)	(4.27)	(-7.85)	(0.96)	(280.14)	(15.34)	(-53.03)
Constant	59.58	253.6	-7.657	-261.8	119.3	-812.6***	-544.9***	-41.84
	(0.07)	(0.34)	(-0.01)	(-0.50)	(0.15)	(-56.22)	(-37.52)	(-0.30)
Adjusted R-squared	0.848	0.875	0.855	0.941	0.850	1.000	0.976	0.995
N	312	312	312	312	312	216	216	312

Table 5: **Determinants of NZU Volatility**. Results from various specifications of OLS regressions where the dependent variable is the annualized NZU volatility. Standard errors are robust. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

	Annualized NZU Price Volatility							
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
ln(Number of Minister's Directives)	0.132***						0.564***	0.564***
	(4.35)						(164.21)	(212.85)
ln(Industrial Allocation)		0.862***					2.394***	2.395***
		(6.22)					(206.24)	(217.00)
Climate Attention Index			-4.014				44.75***	44.77***
			(-1.14)				(185.75)	(197.96)
EPU index				0.000674***			0.000616***	0.000616***
				(17.9)			(195.29)	(205.24)
EPS index					9.751***		0.0151	
					(9.41)		(0.18)	
CPU Index						0.00623***		
						(29.46)		
ln(Inflation PPI)	0.0865	0.0485	0.0999	0.247	0.0521	0.0530	0.00268	
	(0.14)	(0.08)	(0.15)	(0.55)	(0.09)	(0.25)	(0.09)	
ln(Business Confidence Index)	0.672	-0.0147	0.435	-0.403	0.359	-0.443	-0.0288	
	(0.22)	(-0.00)	(0.14)	(-0.18)	(0.13)	(-0.42)	(-0.18)	
ln(Short Term Interest Rates)	0.0179	0.00752	0.0148	0.0132	0.00672	-0.00158	0.00113	
	(0.30)	(0.13)	(0.24)	(0.31)	(0.13)	(-0.08)	(0.38)	
ln(Primary Energy Supply)	-0.111	0.0714	-0.0293	0.108	-0.0567	0.125	-0.000653	
	(-0.17)	(0.11)	(-0.04)	(0.23)	(-0.10)	(0.58)	(-0.02)	
ln(Electricity Generation)	0.897	0.421	0.766	0.0136	1.073	-0.0470	0.0603	
	(0.33)	(0.16)	(0.28)	(0.01)	(0.44)	(-0.05)	(0.45)	
Crude Oil Production	0.000719***	0.00149***	0.000785***	0.000480***	0.000464***	-0.0000104	0.00224***	0.00224***
	(1.54)	(11.22)	(10.09)	(8.49)	(6.07)	(-0.35)	(220.13)	(242.72)
Crude Oil Import Prices	0.0177***	0.0242***	0.0249***	0.0216***	0.0206***	-0.00430***	-0.0173***	-0.0173***
	(9.35)	(18.81)	(13.09)	(22.77)	(16.68)	(-5.86)	(-83.15)	(-94.95)
Industrial Production	0.176***	0.189***	0.212***	0.172***	0.186***	-0.192***	-0.0586***	-0.0587***
	(11.76)	(14.59)	(15.34)	(18.09)	(15.47)	(-21.33)	(-45.68)	(-50.55)
GDP PC Growth	-0.142***	-0.184***	-0.166***	-0.102***	-0.0988***	0.0418***	0.0212***	0.0212***
	(-11.18)	(-13.40)	(-7.76)	(-10.82)	(-7.87)	(5.44)	(16.50)	(16.68)
GDP R&D	-1.847***	-0.386	-0.834	-1.648***	-3.760***	2.170***	-6.992***	-6.991***
	(-4.87)	(-0.99)	(-1.35)	(-6.30)	(-9.06)	(8.51)	(-183.06)	(-187.22)
NZ Activity Index	-0.0352***	-0.0368***	-0.0393***	-0.0269***	-0.0342***	-0.0357***	0.00197***	0.00198***
	(-21.08)	(-24.13)	(-19.34)	(-21.12)	(-23.30)	(-29.96)	(11.77)	(12.69)
Constant	-30.90	-39.85	-32.52	-17.58	-37.12	18.44	-37.83***	-37.30***
	(-0.77)	(-1.02)	(-0.79)	(-0.61)	(-1.02)	(1.38)	(-18.88)	(-256.34)
Adjusted R-squared	0.691	0.709	0.673	0.841	0.746	0.969	0.999	0.999
N	312	312	312	312	312	216	312	312

Table 6: **NZU Price Volatility and NZ ETS Market Activity**. This table reports results from various specifications of equation 5 where the dependent variables are various measures of NZ ETS market activity and the main independent variable is the annualized volatility of the NZU price. Standard errors are robust and clustered by activity-year.*** p < 0.01, ** p < 0.05, * p < 0.1.

	NZ ETS Market Activity		
	(1) **Volume**	**(2)** **Transaction Quantity**	**(3)** **Number of Participants**
ln(NZU Vol)	0.414***	0.0843	-0.0241
	(7.87)	(1.91)	(-0.78)
EPS index	-25.43***	-4.325***	-2.266***
	(-34.86)	(-6.74)	(-3.94)
GDP PC Growth	0.115***	0.171***	0.0776***
	(5.79)	(11.29)	(8.88)
NZ Activity Index	0.0235***	0.0252***	0.00852***
	(9.43)	(11.98)	(6.68)
Industrial Production	-0.172***	-0.182***	-0.0761***
	(-9.27)	(-13.59)	(-10.73)
Percentage Value Added	0.0246	0.0285	-0.0176
	(1.27)	(1.52)	(-1.46)
Crude Oil Production	-0.00221***	-0.00179***	-0.000973***
	(-23.42)	(-23.84)	(-22.28)
Crude Oil Import Prices	-0.0182***	-0.0151***	-0.00542***
	(-10.91)	(-11.94)	(-6.77)
Election Year	-0.0529	0.00546	-0.0931***
	(-1.12)	(0.14)	(-5.43)
Constant	60.29***	32.09***	18.84***
	(28.78)	(20.29)	(21.25)
Adjusted R-squared	0.909	0.838	0.852
Activity FE	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes
N	312	312	312

Table 7: **Correlation Matrix**. This table presents a correltion matrix of annualized NZU price volatility, the NZU VIX, the EPU Index and the CPU Index.

	ln(NZU Vol)	**NZUVIX**	**EPU Index**	**CPU Index**
ln(NZU Vol)	1.000			
NZU VIX	0.4452*	1.000		
EPU Index	0.6441*	-0.024	1.000	
CPU Index	0.2185*	-0.6505*	0.4952*	1.000

Table 8: **Variable Definitions**. This table presents definition of the variables utilized in the empirical analysis. Variables are categorized by themes.

Variables	**Definitions**
Carbon Price Volatility Variables	
ln(NZU Vol)	Natural log of annualized NZU price volatility
NZU VIX	Annualized index of NZU price volatility
Policy Uncertainty Variables	
EPU Index	Newspaper based index of economic policy uncertainty
CPU Index	Newspaper based index of climate policy uncertainty
Election Year Dummy	Dummy variable which takes the value of 1 in an election year and 0 otherwise
Emissions Variables	
ln(Activity level emissons)	Natural log of annual emissions returns aggregated to the activity level
ln(Sector level emissons)	Natural log of annual emissions returns aggregated to the sector level
Investment Variables	
R&D as a Percentage of GDP	Macro-level measure of R&D expenditure made by firms and the NZ government
Gross Fixed Capital Formation	Macro-level measure of aggregate investments made by NZ firms
NZ ETS Market Activity Variables	
ln(NZUs Surrendered)	Natural log of annual number of NZUs surrendered by NZ ETS participants
Energy Variables	
ln(Primary Energy Supply)	Natural log of measure of energy production and imports in New Zealand
ln(Electricity Generation)	Natural log of electricity produced in New Zealand
Business Environment Variables	
ln(Short Term Interest Rates)	Natural log of three-month money market rates in New Zealand
ln(Long Term Interest Rates)	Natural log of New Zealand ten-year government bonds
ln(Inflation CPI)	Natural log of consumer price index
ln(Inflation PPI)	Natural log of producer price index
ln(Business Confidence Index)	Natural log of survey measures of business confidence
Macro-level Variables	
GDP Per Capita Growth Rate	Growth rate (annual change) of total value of goods and services scaled by population
NZ Activity Index	Index of broad measures of economic activity in New Zealand
Industrial Production	Index measure of output of industrial establishments in New Zealand
Percentage Value Added (By Activity)	Measure of value generated by the production of good and services in New Zealand
Crude Oil Production	Quantity of oil extracted from the ground in New Zealand
Crude Oil Import Prices	Annual prices of crude oil imported by New Zealand

Table 9: **Summary Statistics**. This table provides summary statistics which describe the distribution of the main variables of interest.Variables are categorized by themes.

Variables	N	Mean	SD	P25	Median	P75
Carbon Price Volatility Variables						
NZU Vol	312	0.38	0.24	0.21	0.26	0.29
NZU VIX	312	11688.06	4751.86	7405.93	10099.02	13442.31
Policy Uncertainty Variables						
EPU Index	312	1297.83	383.50	1047.96	1317.32	1531.21
CPU Index	216	96.68	35.72	59.51	95.22	107.58
Election Year Dummy	312	0.31	0.46	0	0	1
Emissions Variables						
Activity level emissons (CO2 equivalent tonnes)	312	3M	5.25M	46,771	669,599	2.31M
Sector level emissons (CO2 equivalent tonnes)	312	1.30B	1.06B	2.15M	1.55B	1.77B
NZUs Surrendered	312	2.97B	1.03B	2.25B	3.25B	3.85B
Investment Variables						
R&D as a Percentage of GDP	312	1.32	0.11	1.23	1.35	1.41
Gross Fixed Capital Formation	312	100.08	3.64	97.20	100.10	102.90
EECA Decarbonization Fund Intensity	312	0.85	0.19	0.81	0.93	0.93
Energy Variables						
Primary Energy Supply	312	0.11	0.01	0.10	0.11	0.12
Primary Electricity Generation	312	43080.62	388.33	43030	43182.00	43270
Business Environment Variables						
Short Term Interest Rates	312	2.06	0.99	1.52	2.33	2.80
Long Term Interest Rates	312	3.13	1.34	1.81	2.99	4.09
Inflation CPI	312	2.19	1.79	1.10	1.60	2.30
Inflation PPI	312	105.84	6.38	100.40	104.10	110.90
Business Confidence Index	312	100.36	1.38	99.37	100.88	101.11
Macro-level Variables						
GDP Per Capita Growth Rate	312	3.01	1.74	1.50	3.50	3.90
NZ Activity Index	312	32.40	15.82	26.86	34.82	37.47
Industrial Production	312	100.08	3.64	97.2	100.1	102.9
Percentage Value Added	312	12.77	4.64	6.86	14.63	16.62
Crude Oil Production	312	1553.38	520.45	1119.57	1640.31	1925.32
Crude Oil Import Prices	312	81.55	24.52	58.00	77.70	106.00

Table 10: **NZU Price Volatility and Activity Level Emissions**. This table shows results for the specification of equation 6 where the annualized NZU price volatility is the main independent variable and activity level emissions of NZ ETS participants is the dependent variable. Activity and sector fixed effects are included. Standard errors are robust and clustered by activity-year.*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

	Activity Level Emissions						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
ln(NZU Vol)	-3.991***	-1.360					-18.26***
	(-4.49)	(-0.87)					(-3.39)
ln(EPU Index)			-5.228***	-3.048*			-100.0*
			(-4.60)	(-2.50)			(-2.26)
ln(CPU Index)					-5.176***	-3.045*	64.09*
					(-3.72)	(-2.53)	(2.36)
GDP PC Growth		0.772*		0.788*		1.051	10.87**
		(2.06)		(2.33)		(1.63)	(2.81)
NZ Activity Index		0.137*		0.149***		0.309**	-2.983*
		(2.14)		(3.72)		(3.08)	(-2.29)
Industrial Production		-1.569**		-1.654***		-1.734*	-13.27**
		(-3.05)		(-4.03)		(-2.06)	(-2.96)
Percentage Value Added		1.455**		1.477**		1.960*	2.091**
		(2.66)		(2.74)		(2.48)	(2.73)
Crude Oil Production		-0.0122***		-0.0122***		-0.0133***	0.00785
		(-4.37)		(-6.07)		(-4.16)	(0.78)
Crude Oil Import Prices		-0.161***		-0.189***		-0.182*	-1.520**
		(-3.42)		(-5.66)		(-2.36)	(-2.72)
Constant	6.042***	172.8**	47.76***	206.0***	33.36***	194.2*	1875.2**
	(4.69)	(3.01)	(6.11)	(4.88)	(5.66)	(2.26)	(2.74)
Adjusted R-squared	0.196	0.272	0.17	0.281	0.161	0.264	0.298
Activity FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector FE	No	Yes	No	Yes	No	Yes	Yes
N	312	312	312	312	216	216	216

Table 11: **NZU Price Volatility and Sector Level Emissions**. This table shows results for the specification of equation 6 where the annualized NZU price volatility is the main independent variable and sector level emissions of NZ ETS participants is the dependent variable. Activity and sector fixed effects are included. Standard errors are robust and clustered by activity-year.*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

	Sector Level Emissions						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
ln(NZU Vol)	-1.687**	-0.926					-14.32**
	(-2.99)	(-0.87)					(-3.17)
ln(EPU Index)			-3.122***	-2.118*			-77.15*
			(-3.61)	(-2.14)			(-2.04)
ln(CPU Index)					-1.938**	-2.855**	49.05*
					(-2.72)	(-2.85)	(2.14)
GDP PC Growth		0.505		0.514*		0.186	7.775*
		(1.55)		(2.05)		(0.41)	(2.48)
NZ Activity Index		0.0398		0.0479*		0.0801	-2.467*
		(0.83)		(2.01)		(1.65)	(-2.23)
Industrial Production		-0.363		-0.418*		-0.353	-9.281**
		(-1.09)		(-2.06)		(-0.64)	(-2.61)
Percentage Value Added		1.799**		1.815**		1.360	1.460*
		(3.18)		(3.22)		(1.94)	(2.15)
Crude Oil Production		-0.00775**		-0.00774***		-0.00918**	0.00713
		(-3.17)		(-3.75)		(-3.31)	(0.81)
Crude Oil Import Prices		-0.0503		-0.0691***		-0.0366	-1.070*
		(-1.70)		(-4.02)		(-0.77)	(-2.34)
Constant	12.98***	40.48	37.11***	63.15**	23.21***	60.45	1359.7*
	(14.99)	(1.08)	(6.26)	(3.31)	(7.73)	(1.02)	(2.43)
Adjusted R-squared	0.080	0.272	0.137	0.235	0.149	0.225	0.268
Activity FE	No	Yes	No	Yes	No	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	312	312	312	312	216	216	216

Table 12: **NZU Price Volatility and Gross Fixed Capital Formation (GFCF)**. This table shows results for the specification of equation 7 where the annualized NZU price volatility is the main independent variable and the measure of irreversible investment represented by the dependent variable is the aggregate level of GFCF. Activity and sector fixed effects are included. Standard errors are robust and clustered by activity-year.*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

	Gross Fixed Capital Formation (GFCF)						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
ln(NZU Vol)	-2.216***	0.107					4.880***
	(-7.71)	(0.35)					(26.86)
ln(EPU Index)			-6.284***	-4.489***			-10.77***
			(-13.88)	(-11.10)			(-34.42)
ln(CPU Index)					1.324***	1.730***	4.230***
					(3.58)	(5.68)	(25.21)
GDP PC Growth		-0.152		-0.246***		0.277*	0.0749*
		(-1.69)		(-5.05)		(2.31)	(2.31)
NZ Activity Index		0.146***		0.110***		0.133***	0.139***
		(12.73)		(19.96)		(9.03)	(11.85)
ln(Long Term Interest Rates)		0.142		0.391		0.513	0.148
		(0.21)		(0.69)		(0.73)	(0.57)
ln(Inflation PPI)		0.11		-0.507		0.603	0.411
		(3.18)		(-0.13)		(0.13)	(0.23)
ln(Short Term Interest Rates)		-0.143		-0.241		-0.286	-0.0819
		(-0.29)		(-0.60)		(-0.57)	(-0.46)
ln(Business Confidence Index)		0.636		-2.737		-6.750	-0.716
		(0.03)		(-0.14)		(-0.30)	(-0.08)
Constant	3.074***	-4.025	50.32***	49.39	-0.326	20.14	65.19
	(8.74)	(-0.04)	(15.94)	(0.52)	(-0.19)	(0.18)	(1.55)
Adjusted R-squared	0.046	0.436	0.289	0.608	-0.066	0.066	0.871
Activity FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	312	312	312	312	216	216	216

Table 13: **NZU Price Volatility and GDP R&D**. This table shows results for the specification of equation 8 where the annualized NZU price volatility is the main independent variable and the measure of growth option investment represented by the dependent variable is the aggregate level of R&D as a percentage of GDP. Activity and sector fixed effects are included. Standard errors are robust and clustered by activity-year.*** p < 0.01, ** p < 0.05, * p < 0.1.

	GDP R&D						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
ln(NZU Vol)	-0.0335**	-0.0729***					-0.208***
	(-2.93)	(-5.49)					(-22.41)
ln(EPU Index)			-0.00159	-0.0284			0.171***
			(-0.07)	(-1.33)			(15.81)
ln(CPU Index)					0.0342*	0.0387**	0.0298**
					(2.21)	(2.63)	(3.26)
GDP PC Growth		-0.0172***		-0.0160***		0.0251***	0.0230***
		(-4.84)		(-4.07)		(7.52)	(2.31)
NZ Activity Index		-0.00313***		-0.00197***		0.00389***	-0.00328***
		(-8.11)		(-4.44)		(3.82)	(-5.92)
ln(Long Term Interest Rates)		0.00285		-0.00219		-0.0144	-0.00125
		(0.11)		(-0.07)		(-0.53)	(-0.09)
ln(Inflation PPI)		-0.023		-0.0259		0.0226	0.0170
		(-0.12)		(-0.13)		(0.13)	(0.19)
ln(Short Term Interest Rates)		-0.00171		-0.000286		0.00567	0.00208
		(-0.08)		(-0.01)		(0.31)	(0.21)
ln(Business Confidence Index)		-0.232		-0.168		0.434	0.105
		(-0.25)		(-0.17)		(0.52)	(0.23)
Constant	1.291***	2.576	1.340***	2.540	1.118***	-1.218	-0.859
	(79.05)	(0.56)	(8.18)	(0.52)	(16.13)	(-0.30)	(-0.39)
Adjusted R-squared	-0.055	0.068	-0.083	-0.022	-0.100	0.145	0.764
Activity FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	312	312	312	312	216	216	216

Table 14: **Investments, Production and Emissions**.This table shows results for regressions which confirm aggregate level R&D as the main channel for emissions reduction.*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

	Activity Level Emissions			
	(1)	**(2)**	**(3)**	**(4)**
GDP R&D	8.493*			-94.87**
	(2.26)			(-3.26)
GFCF		0.178*		2.400**
		(2.03)		(2.95)
Industrial Production			(0.166)	0.565
			(1.07)	(0.43)
ln(NZU Vol)				-1.355
				(-0.34)
ln(CPU Index)				-6.232*
				(-2.59)
GDP PC Growth				3.247***
				(3.73)
NZ Activity Index				-0.486
				(-1.57)
Percentage Value Added				2.091**
				(2.73)
Crude Oil Import Prices				-0.407**
				(-3.20)
Constant	-0.745	9.545***	-6.035	100.4
	(-0.15)	(12.57)	(-0.39)	(0.92)
Adjusted R-squared	0.142	0.134	0.134	0.298
Activity FE	Yes	Yes	Yes	Yes
Sector FE	No	No	No	Yes
N	312	312	312	216

Table 15: **Election Year Dummy as IV for NZU Price Volatility**. This table shows the results from an instrumental variable regression (2SLS) where NZU price volatility is instrumented with a dummy variable for years when elections are held in New Zealand. Panel A shows the results for regressions where activity level emissions is the main dependent variable. Panel B shows the results for regressions where gross fixed capital formation is the main dependent variable and Panel C shows results for regressions where R&D as a percentage of GDP is the dependent variable.*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

	NZU Vol Instrumented with Election Year Dummy
Panel A	**Activity Level Emisions**
ln(NZU Vol)	-43.37**
	(-2.64)
Constant	733.7***
	(3.44)
First-stage F-statistics	36.24
Adjusted R-squared	0.964
Controls	Yes
Activity FE	Yes
Sector FE	Yes
N	216
Panel B	**GFCF**
ln(NZU Vol)	7.301***
	(3.92)
Constant	-38.5
	(-0.33)
First-stage F-statistics	13.64
Adjusted R-squared	0.488
Controls	Yes
Activity FE	Yes
Sector FE	Yes
N	216
Panel C	**GDP R&D**
ln(NZU Vol)	-0.150***
	(-10.13)
Constant	-0.871
	(-0.41)
First-stage F-statistics	145.22
Adjusted R-squared	0.752
Controls	Yes
Activity FE	Yes
Sector FE	Yes
N	216

Table 16: **NZU VIX, Emissions and Investment**.This table shows results for regressions which use a volatility index of NZU price volatility (NZU VIX) as an alternate measure of carbon price volatility. Panel A shows results for regressions which use the NZU VIX as the main independent variable and activity level emissions as the main dependent variable, Panel B shows the results when GFCF is the dependent variable and Panel C shows the results when the dependent variable is R&D GDP.*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

	Activity Level Emissions		
Panel A	**(1)**	**(2)**	**(3)**
ln(NZU VIX)	-2.796**	0.264	-12.76***
	(-3.05)	(0.24)	(-3.39)
ln(EPU Index)			-104.6*
			(-2.30)
ln(CPU Index)			48.28*
			(2.06)
Constant	36.50***	203.2***	1922.7**
	(4.37)	(4.78)	(2.76)
Adjusted R-squared	0.147	0.269	0.298
		GFCF	
Panel B	**(1)**	**(2)**	**(3)**
ln(NZU VIX)	-2.117***	-1.934***	4.873***
	(-4.30)	(-4.74)	(7.93)
ln(EPU Index)			-4.404***
			(-5.99)
ln(CPU Index)			6.220***
			(17.55)
Constant	25.23***	7.128	-11.33
	(5.42)	(0.07)	(-0.13)
Adjusted R-squared	-0.015	0.491	0.479
		GDP R&D	
Panel C	**(1)**	**(2)**	**(3)**
ln(NZU VIX)	-0.135***	-0.129***	-0.124***
	(-8.53)	(-8.36)	(-4.99)
ln(EPU Index)			-0.0635*
			(-2.23)
ln(CPU Index)			-0.0161
			(-1.03)
Constant	2.580***	2.914	0.977
	(17.93)	(0.68)	0.24)
Adjusted R-squared	0.178	0.203	0.196
Controls	No	Yes	Yes
Activity FE	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes
N	312	312	216

Table 17: **NZU Price Volatility and NZUs Surrendered**. This table shows results for the specification of equation 6 where the annualized NZU price volatility is the main independent variable and NZUs surrendered by NZ ETS participants is the dependent variable. Activity and sector fixed effects are included. Standard errors are robust and clustered by activity-year.*** p < 0.01, ** p < 0.05, * p < 0.1.

	NZUs Surrendered									
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
ln(NZU Vol)	0.0507	-0.119*								-1.253***
	(1.34)	(-2.51)								(-54.19)
ln(NZU VIX)			0.0709	0.228***					-0.884***	
			(1.67)	(5.03)					(-28.39)	
ln(EPU Index)					-0.175*	-0.0766			-8.676***	-7.233***
					(-2.54)	(-1.05)			(-73.27)	(-131.04)
ln(CPU Index)							-0.0133	-0.472***	4.167***	4.623***
							(-0.25)	(-6.02)	(78.29)	(115.49)
GDP PC Growth		0.0238		0.0279*		0.0314*		-0.0856***	0.672***	0.715***
		(1.52)		(2.03)		(2.11)		(-3.42)	(63.23)	(96.26
NZ Activity Index		-0.00731***		-0.00367**		-0.00462**		0.00343	-0.231***	-0.220***
		(-3.46)		(-2.71)		(-3.14)		(0.75)	(-61.46)	(-100.27)
Industrial Production		0.0846***		0.0711***		0.0753***		0.167***	-0.871***	-0.911***
		(9.61)		(9.81)		(11.68)		(9.16)	(-64.50)	(-98.29)
Percentage Value Added		-0.0980***		-0.151***		-0.112***		-0.224***	-0.00748	-0.0045
		(-3.81)		(-5.75)		(-4.48)		(-5.80)	(-1.57)	(-1.51)
Crude Oil Import Prices		0.0134***		0.0116***		0.0115***		0.0275***	-0.0999***	-0.0927***
		(9.01)		(12.96)		(13.86)		(12.57)	(-62.84)	(-101.04)
Constant	17.18***	8.845***	16.47***	8.908***	18.37***	10.68***	17.07***	3.429	168.6***	149.3***
	(291.07)	(7.99)	(41.92)	(9.52)	(38.46)	(11.71)	(74.64)	(1.75)	(71.12)	(123.63)
Adjusted R-squared	-0.079	0.370	-0.079	0.399	-0.066	0.362	-0.125	0.526	0.987	0.995
Activity FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	312	312	312	312	312	312	216	216	216	216

Table 18: **NZU Price Volatility and Activity Level Emissions 2010-2017**. This table shows results for the specification of equation 6 where the sample period is restricted to 2010-2017. The annualized NZU price volatility is the main independent variable and activity level emissions of NZ ETS participants is the dependent variable. Activity and sector fixed effects are included. Standard errors are robust and clustered by activity-year.*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

	Activity Level Emissions 2010-2017						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
ln(NZU Vol)	-5.488***	-8.223***					-11.20**
	(-4.96)	(-4.32)					(-3.07)
ln(EPU Index)			-9.549***	-8.550***			-16.19
			(-4.83)	(-3.69)			(-1.18)
ln(CPU Index)					-4.647***	-3.709***	9.849
					(-3.41)	(-3.66)	(1.37)
GDP PC Growth		0.682		0.423		0.255	1.189**
		(1.94)		(1.24)		(0.74)	(2.65)
NZ Activity Index		-0.382**		-0.375**		-0.00522	-1.215
		(-2.74)		(-2.69)		(-0.05)	(-1.89)
Industrial Production		-0.245		0.780**		0.351	0.352
		(-0.87)		(2.63)		(1.35)	(0.47)
Percentage Value Added		1.077		1.092		1.069	1.014
		(1.51)		(1.45)		(1.42)	(1.43)
Crude Oil Production		-0.00770***		-0.00544*		-0.00919***	0.0195
		(-3.56)		(-2.43)		(-4.02)	(0.01)
Constant	3.892*	36.31	78.23***	2.325	31.12***	-4.957	59.80
	(2.32)	(1.08)	(5.68)	(0.07)	(5.41)	(-0.15)	(1.64)
Adjusted R-squared	0.315	0.405	0.310	0.392	0.239	0.384	0.409
Activity FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector FE	No	Yes	No	Yes	No	Yes	Yes
N	192	192	192	192	192	192	192

Table 19: **NZU Price Volatility and Sector Level Emissions (Post-1989 Forestry Sector Excluded)**. This table shows results for the specification of equation 6 where the post-1989 forestry sector is excluded. The annualized NZU price volatility is the main independent variable and sector level emissions of NZ ETS participants is the dependent variable. Activity and sector fixed effects are included. Standard errors are robust and clustered by activity-year.*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

	Sector Level Emissions Post-1989 Forestry Sector Excluded						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
ln(NZU Vol)	-1.744**	-0.965					-14.51**
	(-3.05)	(-0.88)					(-3.09)
ln(EPU Index)			-3.144***	-2.158*			-79.80*
			(-3.50)	(-2.12)			(-2.02)
ln(CPU Index)					-1.969**	-2.868**	50.66*
					(-2.66)	(-2.78)	(2.13)
GDP PC Growth		0.472		0.484		0.165	7.986*
		(1.39)		(1.85)		(0.34)	(2.45)
NZ Activity Index		0.0368		0.0458		0.0792	-2.544*
		(0.74)		(1.86)		(1.57)	(-2.21)
Industrial Production		-0.345		-0.405		-0.332	-9.522*
		(-1.01)		(-1.95)		(-0.58)	(-2.58)
Percentage Value Added		2.029**		2.044**		1.576	1.636*
		(3.06)		(3.11)		(1.93)	(2.06)
Crude Oil Production		-0.00817**		-0.00818***		-0.00953**	0.00737
		(-3.11)		(-3.65)		(-3.20)	(0.81)
Crude Oil Import Prices		-0.0531		-0.0728***		-0.0395	-1.105*
		(-1.72)		(-4.00)		(-0.80)	(-2.33)
Constant	12.93***	36.23	37.28***	59.79**	23.38***	56.07	1359.7*
	(14.76)	(0.93)	(6.04)	(3.04)	(7.48)	(0.91)	(2.41)
Adjusted R-squared	0.135	0.232	0.139	0.241	0.153	0.226	0.269
Activity FE	No	Yes	No	Yes	No	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	299	299	299	299	207	207	207

Table 20: **NZU Price Volatility and Growth Option Investment Alternative**. This table shows results for the specification of equation 8 where the annualized NZU price volatility is the main independent variable and the measure of growth option investment represented by the dependent variable is the investment support provided to businesses in hard to abate sectors through the EECA decarbonisation fund. Activity and sector fixed effects are included. Standard errors are robust and clustered by activity-year.*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

	EECA Business Decarbonisation Fund Intensity						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
ln(NZU Vol)	0.00257	0.0244					-0.0938***
	(0.18)	(1.22)					(-23.14)
ln(EPU Index)			0.191***	0.253***			-0.00724
			(4.01)	(6.76)			(-1.18)
ln(CPU Index)					-0.0151	-0.0313***	-0.00663
					(-1.42)	(-4.65)	(-1.34)
GDP PC Growth		0.0650***		0.0696***		0.00408**	-0.0000283
		(9.52)		(13.09)		(2.73)	(-0.04)
NZ Activity Index		0.00360***		0.00501***		-0.00368***	-0.00896***
		(4.64)		(8.29)		(-6.90)	(-21.14)
ln(Long Term Interest Rates)		0.00415		-0.00714		-0.00451	0.000751
		(0.11)		(-0.19)		(-0.33)	(0.11)
ln(Inflation PPI)		-0.0106		0.0459		-0.00649	-0.0131
		(-0.04)		(0.17)		(-0.07)	(-0.28)
ln(Short Term Interest Rates)		-0.00324		0.00144		-0.00176	-0.00187
		(-0.11)		(0.05)		(-0.19)	(-0.36)
ln(Business Confidence Index)		0.328		0.482		0.183	0.0133
		(0.24)		(0.39)		(0.44)	(0.06)
Constant	0.855***	-0.896	-0.508	-3.747	1.017***	0.399	1.231
	(76.33)	(-0.13)	(-1.47)	(-0.60)	(22.18)	(0.19)	(1.08)
Adjusted R-squared	-0.084	0.224	0.032	0.404	-0.106	0.115	0.742
Activity FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	312	312	312	312	216	216	216

Table 21: **NZU Price Volatility and Irreversible Investment Alternative**. This table shows results for the specification of equation 7 where the annualized NZU price volatility is the main independent variable and the measure of irreversible investment represented by the dependent variable is patents on environmental technology. Activity and sector fixed effects are included. Standard errors are robust and clustered by activity-year.*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

	Patents on Environmental Technologies						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
ln(NZU Vol)	1.230***	1.810***					5.148***
	(5.89)	(8.79)					(20.03)
ln(EPU Index)			-0.267	-0.0338			4.005***
			(-0.69)	(-0.11)			(12.89)
ln(CPU Index)					-0.309	0.0318	-2.546***
					(-0.57)	(0.07)	(-9.77)
GDP PC Growth		0.638***		0.593***		0.299**	0.659***
		(7.52)		(7.13)		(3.27)	(28.61)
NZ Activity Index		0.0588***		0.0244***		0.121***	0.498***
		(9.15)		(4.01)		(4.03)	(43.39)
ln(Long Term Interest Rates)		-0.0486		0.116		0.354	0.0945
		(-0.09)		(0.19)		(0.42)	(0.27)
ln(Inflation PPI)		0.324		0.227		-0.926	-0.391
		(0.09)		(0.06)		(-0.18)	(-0.17)
ln(Short Term Interest Rates)		0.156		0.105		-0.04540	-0.103
		(0.42)		(0.26)		(-0.08)	(-0.42)
ln(Business Confidence Index)		-4.764		-6.899		-12.44	-2.239
		(-0.28)		(-0.37)		(-0.49)	(-0.20)
Constant	11.84***	29.08	12.35***	38.68	12.34***	66.81	-7.41
	(53.67)	(0.34)	(4.49)	(0.41)	(5.01)	(0.54)	(-0.14)
Adjusted R-squared	0.007	0.224	-0.0821	0.0801	-0.123	-0.035	0.8264
Activity FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	312	312	312	312	216	216	216