Effects of Carbon Pricing on CO2 Emissions across New Zealand industries

REPORT TO

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Executive summary

Under the Paris Agreement, to fulfill its international obligation to reduce greenhouse gas emissions, the New Zealand Government has identified carbon pricing as an important tool for achieving the targets set in the Emission Reduction Plan (Ministry for the Environment, 2021, 2022b). While various international studies have examined the effectiveness of carbon pricing, its impact in New Zealand remains unexplored. This report draws on the latest available data to investigate how carbon pricing affects emissions across New Zealand industries.

The carbon price has been increasing and is projected to increase significantly over the next decade

We adhered to OECD methodology to construct the Effective Carbon Rate (ECR) for New Zealand. The ECR quantifies the total price applied to CO2 emissions from energy use due to market-based policy tools. According to the OECD, the ECR consists of the sum of taxes, tradable emission permit prices, carbon taxes, and energy-use taxes.

We noted a significant uptick in the ECR over the past decade. The fifth biennial report under the United Nations framework Convention on Climate Change assumes that without the introduction of new policies, the carbon price will increase from $25 in 2020 to $115 in 2035 (Ministry for the Environment, 2022b, p. 47).

Our results suggest that a $10 increase in the ECR decreases emissions by 1.7 percent in short-term with significant variation across industries and 28 percent larger sectoral impacts in long-term

We used fixed effects panel regression and controlled for the impact of:[1]

- fuel-specific factors for Coal, LPG, Petrol, Diesel, Natural gas, Fuel Oil, Kerosene: past supply-side investment decisions and sunk costs affecting the long-run supply of different fuels;
- fuel and industry-specific variables: worldwide technology advancements in the use of a fuel in a specific sub-sector, unobserved country-invariant preference to tax the fuel in the sub-sector;
- common time shocks and price levels.

Our results suggest that a $10 increase in the ECR decreases emissions by 1.7 percent, which is less than a recent OECD study's estimate of 2.8 percent. In percentage terms, a one percent increase in the ECR is associated with 0.074 percent decrease in emissions, which is almost half the estimated impact by the recent OECD study.

Our sectoral estimates suggested that a 10 dollar increase in the ECR leads to a decrease in carbon emissions by 6.8 percent for Building and Construction, 26.6 percent for Food processing, 7.8 percent for Forestry and Logging, 33.2 percent for Mechanical/Electrical Equipment, 5.8 percent for Mining, 18.7 percent for Textiles, and 4.4 percent for Unallocated industrial activities. We did not identify a significant impact from carbon pricing on other sectors of the economy including Agriculture, Forestry and Fishing, Chemicals, Non-metallic Minerals, Wood, Pulp, Paper and Printing.

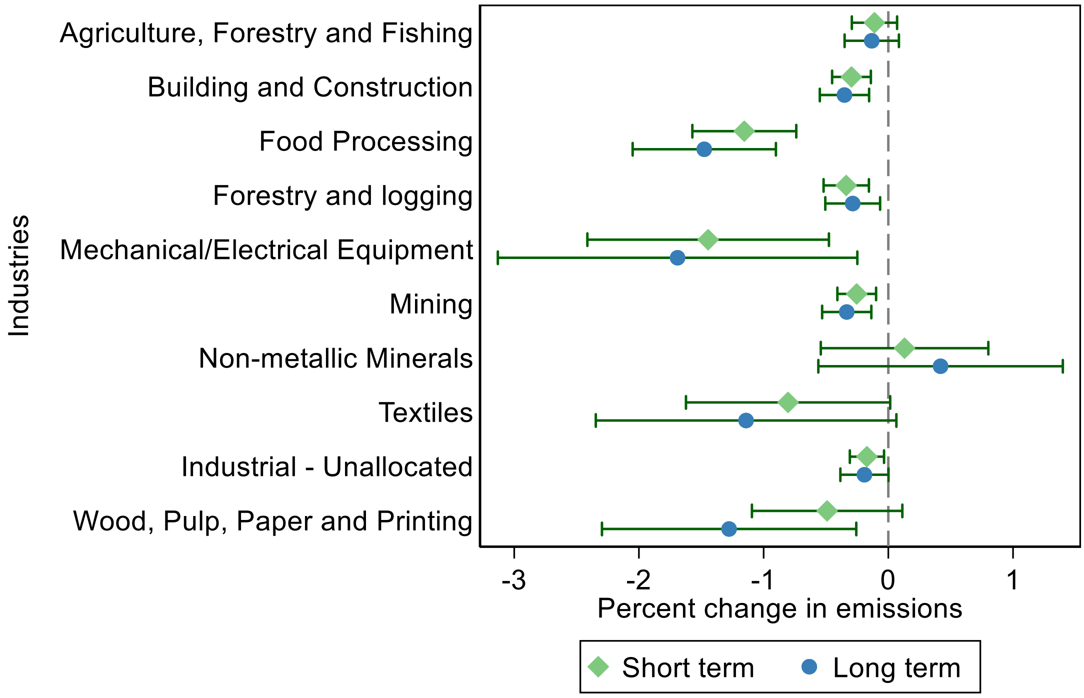
In addition to these short-term estimates, we investigated the long-term elasticities (over 2 years). The results suggested that the elasticities are on average 28 percent larger in long-term. Figure ES.1 shows the short-term and long-term sectoral elasticities, in response to a 1 percent increase in the ECR, with their 95 percent confidence intervals.[2]

1 Fixed effects method uses panel data to control for (omitted) variables that differ across industries and different fuel types but are constant over time.

2 If the confidence interval overlaps with zero values, the estimated elasticity is statistically insignificant at the 95 percent confidence level.

Figure ES.1 Percentage change in emissions of industries from one percent increase in the ECR

With 95 percent confidence interval



Source: Principal Economics

Compared to the OECD report, the elasticities of the road transport and agriculture and fisheries industries are high and statistically significant across OECD countries but not in New Zealand.

Recommendations for future study

The impact of carbon pricing depends on a range of factors, including for example:

- the availability of alternative (green) energy sources.
- elasticity of demand, which depends on a range of factors, such as availability of alternative solutions.
- the size of carbon tax relative to the sectors' size.

Investigating these factors further would help us predict sector responses to future policies, which is essential for the effective implementation of the Emission Reduction Plan's carbon pricing policy. Additionally, as public policy increasingly focuses on equitable outcomes, understanding the equity implications of carbon pricing is important. This would necessitate a more detailed breakdown of price elasticities of demand by socioeconomic characteristics. We recommend that future studies delve into these matters using more comprehensive data.

Abbreviations and acronyms

Acronyms / Abbreviations	Description
ALFS	Annual Liquid Fuels Survey
ANZSIC06	Australian and New Zealand Standard Industrial Classification 2006
CH_4	Methane
CO_2	Carbon dioxide
DPFI	Delivery of Petroleum Fuels by Industry Survey
ECR	Effective Carbon Rate
ETS	Emissions Trading Scheme
EUR	Euro
GWP	Global Warming Potentials
LPG	Liquefied petroleum gas
MBIE	Ministry of Business, Innovation and Employment
N_2O	Nitrous oxide
NZ	New Zealand
NZU	New Zealand emission unit
OECD	Organisation for Economic Co-operation and Development
RUC	Road User Charges
UK	United Kingdom

Contents

Appendices

Figures

Tables

1 Introduction

New Zealand specific evidence on the impact of emissions prices on emissions reductions is sparse. Furthermore, domestic price elasticity estimates for relevant goods and services that are most affected by emissions prices are now quite old.

Understanding the effectiveness of emissions pricing is a critical input into development of policy settings, including for the second emissions reduction plan. Carbon pricing is considered as an important tool for controlling emissions. New Zealand's fifth biennial report under the United Nations framework Convention on Climate Change assumes that without the introduction of new policies, the effective carbon price will increase from $25 in 2020 to $115 in 2035 (Ministry for the Environment, 2022b, p. 47). However, the impact of carbon price on CO_2 emissions in New Zealand has not been tested before.

A 2022 OECD working paper (D'Arcangelo et al., 2022)[3] outlines a methodology for estimating these effects based on a regression approach using fixed effects. As we present in the next chapter, elasticities vary across countries and industries. This is particularly important given the significant difference between the economies of studies of European countries and New Zealand. For some industries the differences are more important after consideration of behavioural factors for businesses and households. For example, for transport, Torshizian et al. (2023) estimated own- and cross-elasticities and identified an important role for public transport coverage. Their results suggested that while cross-price elasticities between private vehicle and public transport are currently insignificant, they would have been significant if the public transport coverage had improved. Hence, in this case, using price-elasticities derived from European studies will be misleading, given the significant difference in public transport coverage across countries. This report collects the required (more recent) New Zealand data and applies the same methodology as the OECD paper (D'Arcangelo et al., 2022), to provide New Zealand specific estimates of elasticities.

In the next chapter, we provide a review of the most relevant literature. Chapter three provides a description of effective carbon rates (ECRs) [4] and emissions in New Zealand. Chapter four describes our methodology for the estimation of elasticities. After that we present our results in Chapter 5 and conclude in the end.

3 In this report, we refer to this report as 'the OECD report'.

4 As will be presented in Section 3.1, the ECR represents the total price that applies to CO_2 emissions from energy use because of market-based policy instruments. As per the OECD definition the ECR is the sum of taxes and tradable emission permit prices, carbon tax and taxes on energy use.

2 Literature review

The concept of carbon taxation has been an increasingly important tool in combating global climate change. By assigning a cost to carbon emissions, carbon taxation aims to encourage industries and consumers to shift towards environmentally sustainable practices. In this section, we provide a brief review of the efficacy of such taxes – ie, the effect of carbon pricing on emissions.

Martinsson et al. (2022) used a unique dataset, tracking all CO_2 emissions from the Swedish manufacturing sector and estimated the impact of carbon pricing on company-level emission intensities. They employ panel regressions spanning 26 years and encompassing around 4,000 firms. Their sample dataset uses firm-level data and CO_2 emissions for Swedish manufacturing firms over the years of 1990 – 2015. Their results suggest a statistically strong and economically significant negative link between emissions and marginal carbon pricing with an emission-to-pricing elasticity of approximately 2.0, albeit with substantial heterogeneity across manufacturing subsectors.

Rafatya et al. (2020) used a dataset consisting of five sectors in a panel of 39 countries covering 1990 – 2016. The researchers make use of synthetic control methods[5] to compare observations with carbon pricing to a counterfactual where carbon pricing was not introduced. Results from found a small semi elasticity of a 0.03 percent reduction in emissions growth per average $1/metric ton of CO_2.

Leroutier (2022) finds semi-elasticity[6] of -1.65 percent of emissions per Euro of a domestic carbon tax in the UK. They use synthetic control methods, with the UK as the treated unit and European countries as control units potentially entering the synthetic UK with a dataset comprised of country-level, power plant-level panel data.

Studying the road sector in Finland, Mideksa (2021) and Lin & Li (2011) find carbon tax elasticities of carbon emissions of approximately -0.1. Mideksa (2021) similarly employs synthetic control methods with OECD countries as the donor pool for synthetic observations. Lin & Li (2011) adopt a difference in difference modelling procedure similarly comparing Finland pre and post-tax with other European countries.

Dussaux (2020) investigate the impacts of a carbon tax to the French manufacturing sector. They find a carbon tax elasticity of -0.1 and semi-elasticity of about -0.002, ie a EUR 1 increase in the carbon tax is associated with a decline in CO2 emissions of 0.2 percent. The use annual unbalanced panel data of 8,000 French manufacturing firms, excluding the industries of tobacco, arms and ammunition. They use fixed effects regression with firm-fixed effects and year dummies to control for consumer demand and fuel price fluctuations. Further analysis is undertaken to determine the differences between impacts of different sized firms and firms of different industries.

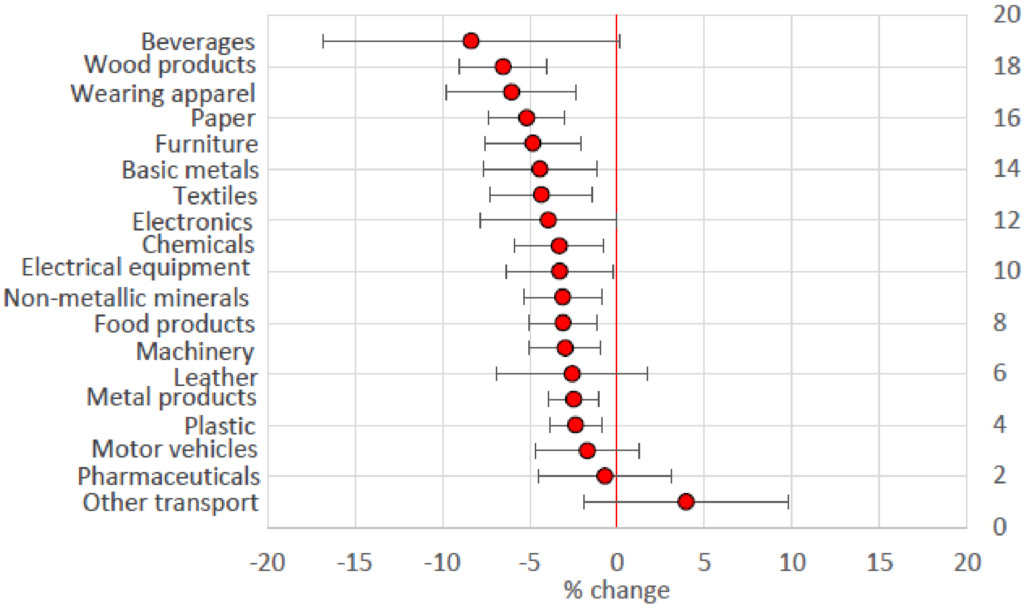
According to Dussaux (2020), a 10 percent rise in energy cost results in a 6 percent reduction in energy use for medium-sized firms and an 8.5 percent reduction for large firms. The effect on small firms is negative but not statistically significant. They further assess impacts across disaggregated manufacturing sectors. Accordingly, 79 percent of the firms experience statistically significant reduction of CO2, 26 percent reduce employment, 53 percent reduce CO2 but not employment and 0 percent reduce employment but not CO2 in response to high energy prices. The most significant decreases in CO2 emissions occur in the beverages, wood products, and wearing apparel sectors, with reductions of 8.3 percent, 6.5 percent, and 6 percent, respectively in response to a 10 percent increase in energy cost. Conversely, the largest decline in employment is seen in the basic metals, plastics, and food products sectors, at

5 Synthetic control methods operate by creating a weighted combination of other regions— that is statistically similar to the treated region before policy implementation. The impact of policy interventions, ie carbon pricing, is assessed by comparing the treated region to this synthetic region over time.

6 Semi-elasticity measures the percentage change in one variable, ie emissions, in response to the absolute change of another, ie carbon taxes. This differs from elasticity which measures the percentage change of a variable in response to a percentage change in another variable.

1.2 percent, 0.78 percent, and 0.75 percent respectively. These impacts across different manufacturing sectors are shown in Figure 2.1.

Figure 2.1 Change in CO2 emissions for a 10 percent increase in energy cost by sector



Source: Dussaux (2020)

Sen and Vollebergh (2018) find that on average a 10 percent increase in carbon price per tonne of CO2 leads to a 3.5 percent reduction in CO2 emissions, reflecting an elasticity of -0.35. The authors use the 2013 Taxing Energy Use dataset using country and fuel type, as well as their interactions between the two as control variables as well as other instrument variables to control for endogeneity (OECD, 2013).

D'Arcangelo et al. (2022) estimate a statically significant semi-elasticity of -0.369, ie a EUR 10 increase in effective carbon rates will decrease emissions by 3.7 percent.[7] They derive an elasticity at the mean of -0.152, ie a 1 percent increase in the ECR translates into a 0.15 percent decrease in emissions. We show the elasticity estimates from D'Arcangelo et al. (2022) by fuel category and industry in Figure 2.2 and Figure 2.3. [8]

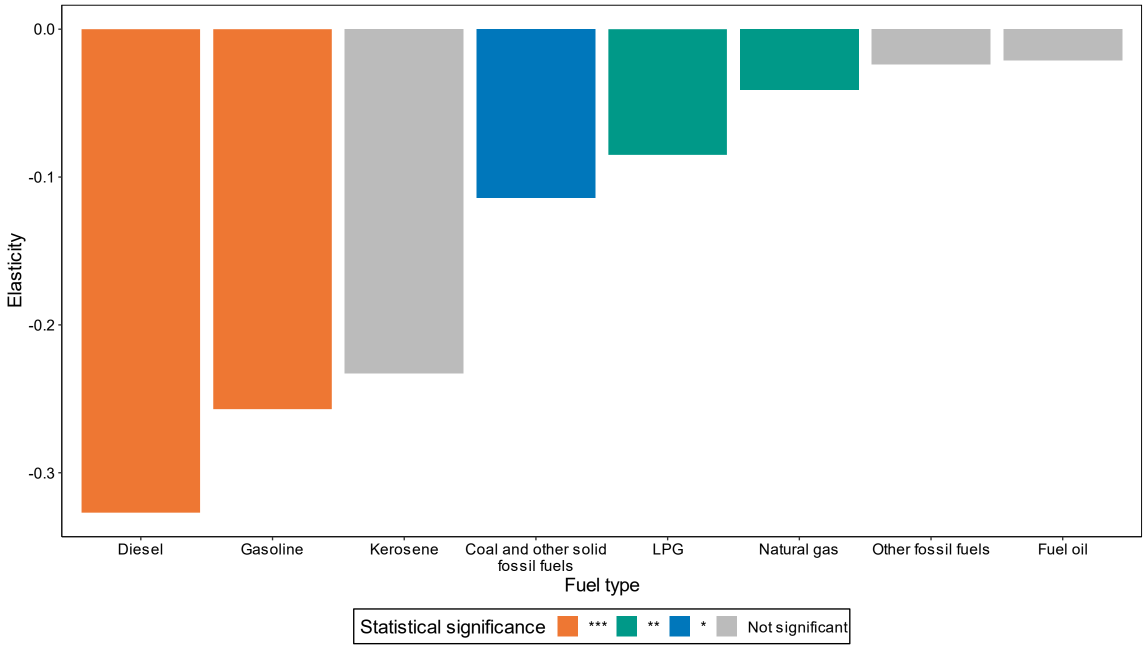
7 The authors adopt a similar approach to Sen and Vollebergh (2018) using a fixed effects econometrics method taking the form of Equation 1.

$$q_{cuft} = \beta \times ECR_{cuft} + \delta_{cut} + \delta_{uft} + \varepsilon_{cuft} \qquad \text{(Equation 1)}$$

Where $qcuft$ is the log of CO2 emissions from fossil fuel use for country c, user u and fuel category f in the year t, $ECRcuft$ is the corresponding ECR averaged at the country-user-fuel category level in year t, δcut and δuft are fixed effects, and $\varepsilon cuft$ is the error term.

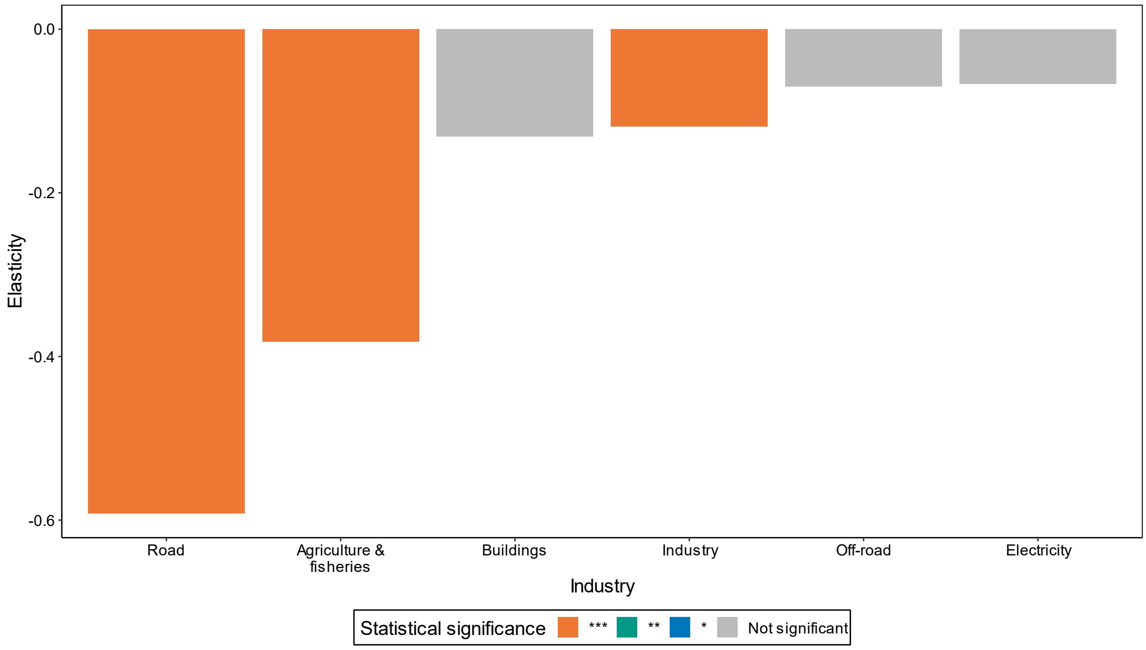
8 We present the elasticities at mean for the restricted sample only. The restricted sample excludes observations with zero effective carbon rates.

Figure 2.2 Emission responsiveness to ECR by fuel category



Source: Adapted from D'Arcangelo et al. (2022, p. 21)
Note: *p ≤ 0.1, **p ≤ 0.05, *** p ≤ 0.01.
The dependent variable is log-emissions, the independent variable is the ECR.
Estimates can be interpreted as follows: for coal and other solid fossil fuels, a 1 percent increase in the ECR decreases emissions by 0.11 percent.

Figure 2.3 Emission responsiveness to ECR by industry



Source: Adapted from D'Arcangelo et al. (2022, p. 21)
Note: *p ≤ 0.1, **p ≤ 0.05, *** p ≤ 0.01.
The dependent variable is log-emissions, the independent variable is the ECR.
Estimates can be interpreted as follows: in the Road sector at the sample mean, a 1 percent increase in the ECR decreases emissions by 0.6 percent.

3 Descriptive statistics

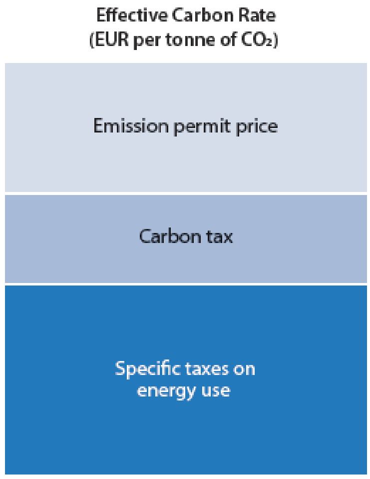
The two main variables of interest in this report are effective carbon rates (ECRs) and carbon emissions. We first provide a description of the ECR and then emissions.

3.1 Effective Carbon Rates

In our assessment we adopt effective carbon rates to represent carbon pricing in New Zealand, aligning with the methodology used by D'Arcangelo et al. (2022) and Sen & Vollebergh (2018). This captures both taxes and emission permits imposed on carbon emissions in New Zealand.

Carbon pricing have been determined for industries is based on the OECD methodology used to estimate the ECR (OECD, 2016, 2018, 2021). Effective carbon rates represent the total price that applies to CO2 emissions from energy use as a result of market-based policy instruments. As per the OECD definition they are the sum of taxes and tradable emission permit prices and are comprised of three components. We show these components in Figure 3.1.

Figure 3.1 Components of effective carbon rates



Source: OECD (2016, 2018, 2021).

We outline the specific prices we have adopted in our analysis for the context of New Zealand below.

1. **Emission permit price:** We use the average annual spot prices of the New Zealand emission unit (NZU) in the New Zealand emissions trading scheme.[9]
2. **Carbon tax:** No fuel-based carbon tax is levied in New Zealand (OECD, 2022).
3. **Specific taxes on energy use:** We include fuel excise taxes, as an implicit form of carbon pricing.[10,11]

9 In line with the OECD study, for the year of 2012 we use half the average price of the Joint Implementation Credits in 2012 to reflect that 79 percent of surrendered permits in 2012 were Joint Implementation Credits (Ministry for the Environment, 2012; OECD, 2018).

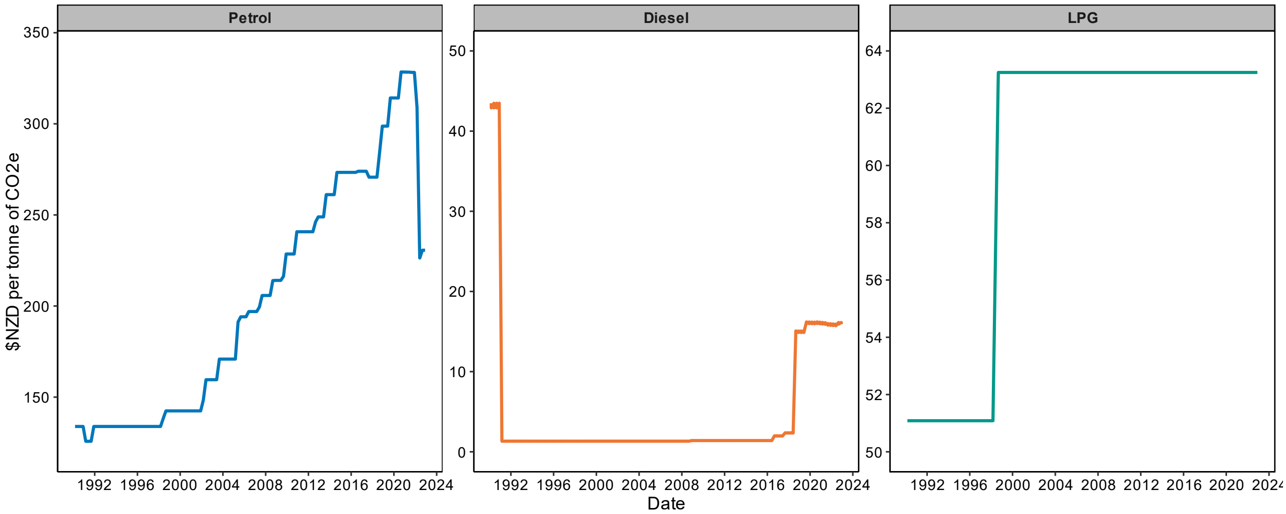
10 In line with the OECD study, we excludes road user charges which use a distance-based measures as they affect different behavioural margins compared to energy taxes (OECD, 2019).

11 We include all fuel duties, excise taxes and levies applied to energy prices reported by MBIE. This includes all excise taxes earmarked to the National Land Transport Fund (NLTF), ACC Levies, and regional taxes (applied proportionally based on regional VKT use) (Ministry of Business, Innovation & Employment, 2023b).

As fuel excise taxes are charged at a per litre basis we convert the sum of duties, taxes and levies for each fuel type we first estimate CO2e emissions per litre using conversion rates sourced from the 2022 detailed guide on measuring emissions (Ministry for the Environment, 2022a). This provides a standardised price per unit of carbon that we can compare against energy usage across sectors and fuel types, and the price of carbon derived from ETS spot prices. For example, the ECR for petrol usage will therefore be sum of price of CO2e from all fuel duties, excise taxes and levels, and the NZU spot price. For this report, we have used local currency ($NZD) for our analysis.

Figure 3.2 shows the derived price of CO2e applied to petrol and diesel from fuel duties, excise taxes and levies from the year 2012 onwards.

Figure 3.2 Quarterly price of CO2e from all fuel duties, excise taxes and levies[12,13,14,15,16]



Source: MBIE (2023b)

Figure 3.3 shows the weekly spot price for NZUs, representing one tonne of carbon dioxide-equivalent emissions within the ETS.

12 The Auckland regional fuel tax is included as a national weighted average based on population data. This weighting has been undertaken by MBIE. This tax applies to both petrol and diesel fuels.

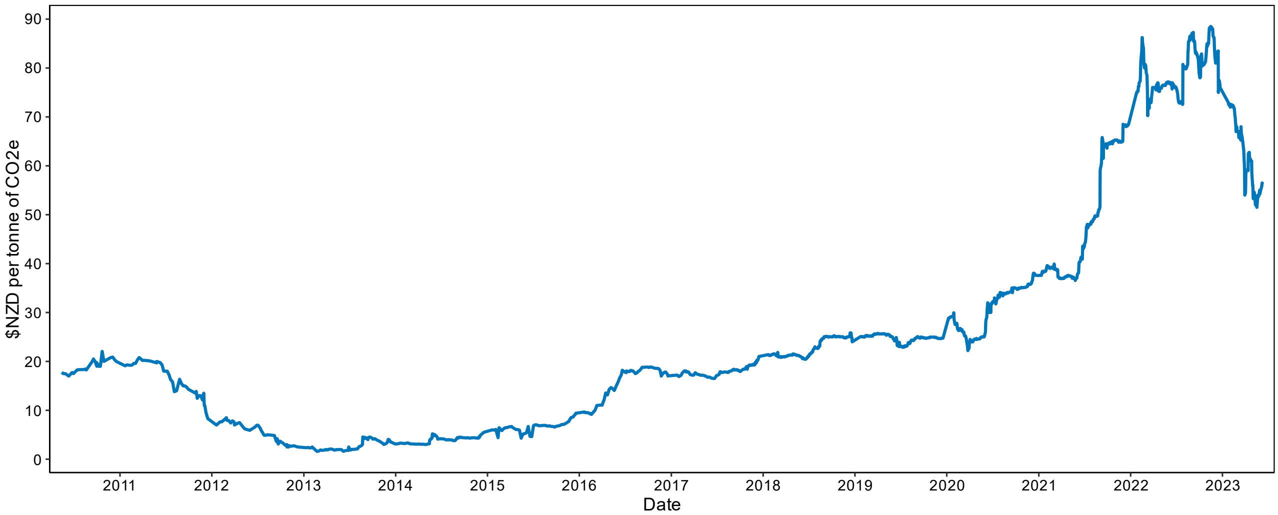
13 The significant decrease in the carbon price for petrol from fuel duties, excise taxes and levies in March 2022 is attributable to cuts in the petrol excise duty as part of the cost of living package implemented by the Government (Government Cuts 25c a Litre off Fuel Excise in Cost of Living Relief Package, 2022). Our regression analysis does not cover 2022, and hence this drop will not be captured.

14 In March 1991 the Petroleum Engine Fuels Monitoring Levy no longer applied to Automotive diesel.

15 The significant increase in the carbon price from fuel duties, excise taxes and levies for diesel in 2018 is attributable to the Auckland Regional Fuel Tax implemented on 1 July 2018 by the Land Transport Management (Regional Fuel Tax Scheme—Auckland) Amendment Act 2018.

16 Not shown on Figure 2.2 is the $0.17 levy on LPG earmarked for the National Land Transport Management Fund which has been consistent over the assessment period. LPG excise taxes have changed twice since 1990 with charges earmarked for the National Land Transport Management Fund.

Figure 3.3 Weekly NZU spot price



Source: Carbon News

Table 3.1 shows the estimated effective carbon rates by fuel type over the period of 2010 and 2021. These rates are derived from the summation of fuel taxes, levies, and the NZU spot pricing applied per metric ton of carbon. Due to the introduction of the Emissions Trading Scheme (ETS) in 2010, certain fuel types lacked carbon pricing for their emissions before this timeframe. Appendix C contains information about each component of ETS by fuel type over time.

Table 3.1 Effective carbon rates by fuel type 2010 - 2022[17]

Year	Coal - Bitum.	Coal - Sub-bitum.	Coal - Lignite	LPG	Petrol	Diesel	Natural gas	Fuel Oil	Kero.
2010	19.06	19.06	19.06	82.31	250.67	20.46	19.41	19.06	19.06
2011	16.71	16.71	16.71	79.96	257.49	18.11	17.06	16.71	16.71
2012	2.18	2.18	2.18	65.43	246.34	3.58	2.53	2.18	2.18
2013	2.72	2.72	2.72	65.97	257.74	4.12	3.07	2.72	2.72
2014	3.95	3.95	3.95	67.19	271.19	5.35	4.29	3.95	3.95
2015	6.62	6.62	6.62	69.86	279.97	8.02	6.96	6.62	6.62
2016	15.24	15.24	15.24	78.48	288.90	16.93	15.59	15.24	15.24
2017	17.93	17.93	17.93	81.18	290.28	20.09	18.28	17.93	17.93
2018	22.75	22.75	22.75	86.00	303.95	31.41	23.10	22.75	22.75
2019	24.76	24.76	24.76	88.01	331.22	40.29	25.11	24.76	24.76
2020	30.75	30.75	30.75	94.00	352.06	46.82	31.10	30.75	30.75
2021	48.96	48.96	48.96	112.20	377.25	64.90	49.31	48.96	48.96
2022	79.13	79.13	79.13	142.38	328.28	95.05	79.48	79.13	79.13

Source: Principal Economics

3.2 Emissions by sector in New Zealand

We determine energy use in New Zealand using energy balance tables sourced from MBIE (Ministry of Business, Innovation & Employment, 2023a). We use observed consumer energy balances reported in gross caloric values by

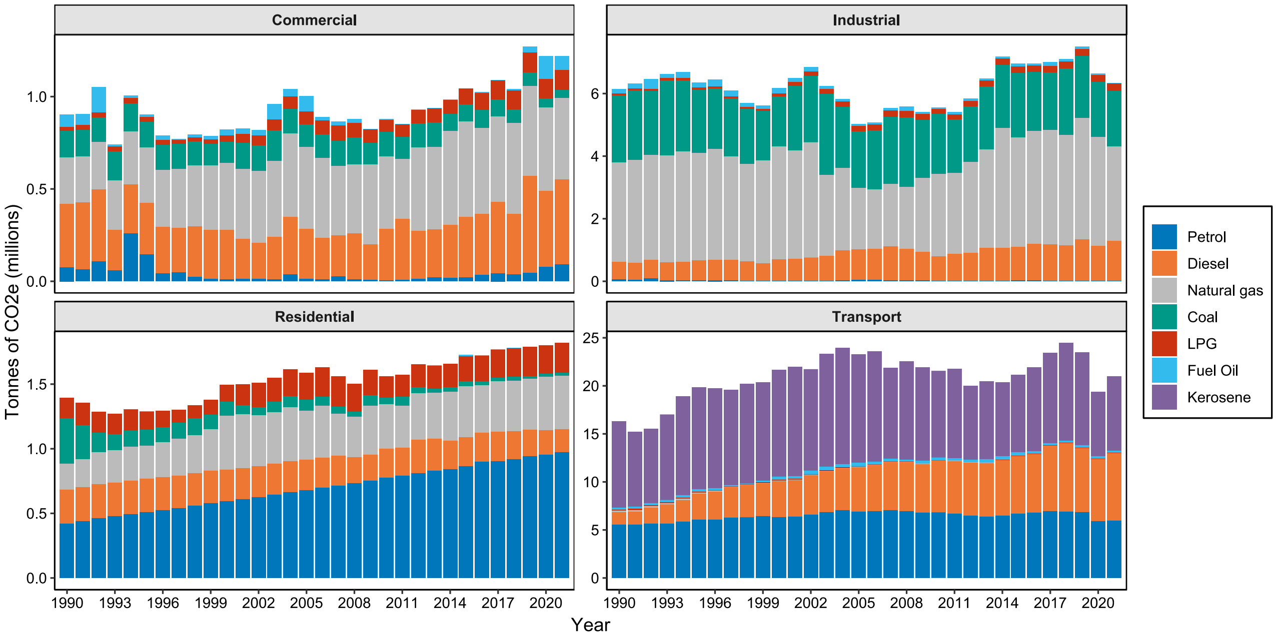
17 ECR varies between industries based on differences in fuel combustion methods. Table 3.1 shows the average across all industries relative to its respective year.

sector for the years of 2012 – 2021. Energy consumption values per annum are converted from petajoules to CO2e using conversion rates sourced from the 2022 detailed guide on measuring emissions (Ministry for the Environment, 2022a).[18]

While we acknowledge the New Zealand Greenhouse Gas Inventory as an authoritative sector-specific emissions estimate, we have opted to rely on estimated emissions derived from the MBIE energy balance tables. These tables provide a detailed breakdown of energy use by fuel-type which is required to calculate ECRs per sector and fuel-type.

Figure 3.4 shows estimated CO2e emissions by sector and fuel type for the years of 2012 to 2021 based on the methodology described.

Figure 3.4 Estimated CO2e emissions by sector and fuel type[19,20]



Source: MfE (2022a) and MBIE (2023a)

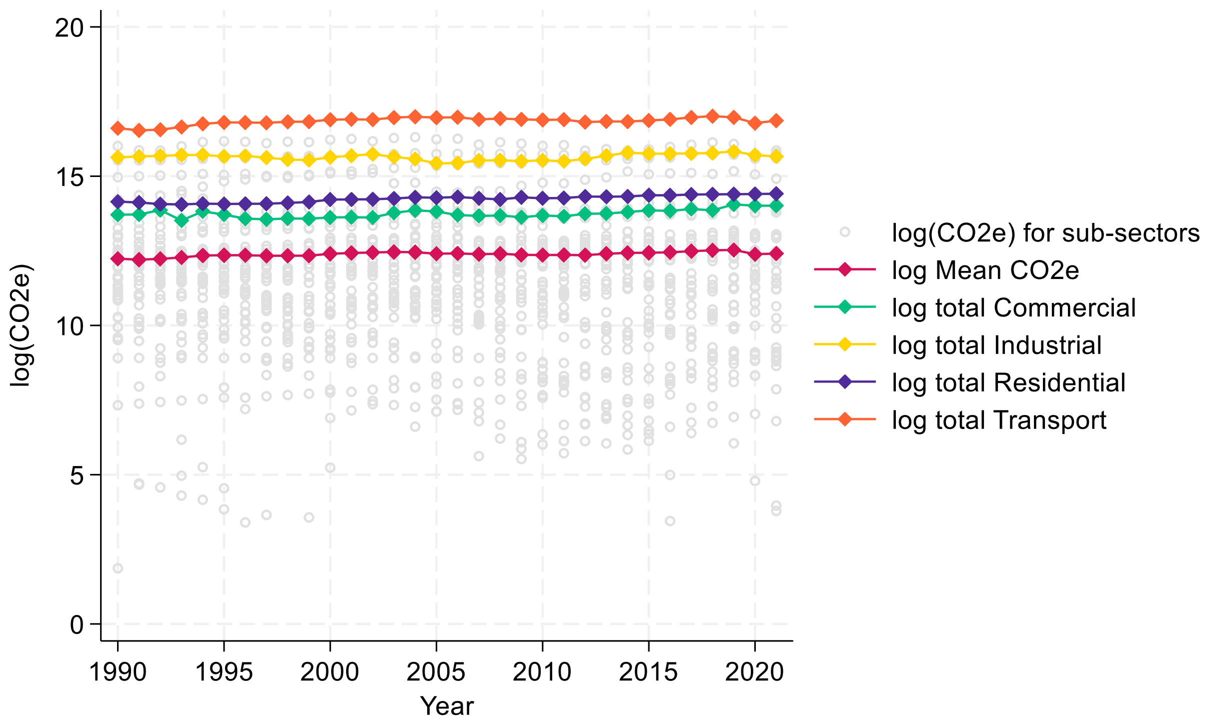
Note: The data for carbon emissions originates from the MBIE Energy Balance tables (2023a). We convert gross calorific values to CO2 equivalent emissions using conversion factors from MfE (2022a).

18 Where feasible we adopt sector specific conversion rates.

19 NB: We have aggregated the CO2e emissions for coal in Figure 3.4. In our regression analysis coal is disaggregated into bituminous & sub-bituminous and lignite.

20 NB: We have aggregated industrial sectors for the purpose of illustration. In our regression analysis industrial is disaggregated across several sectors.

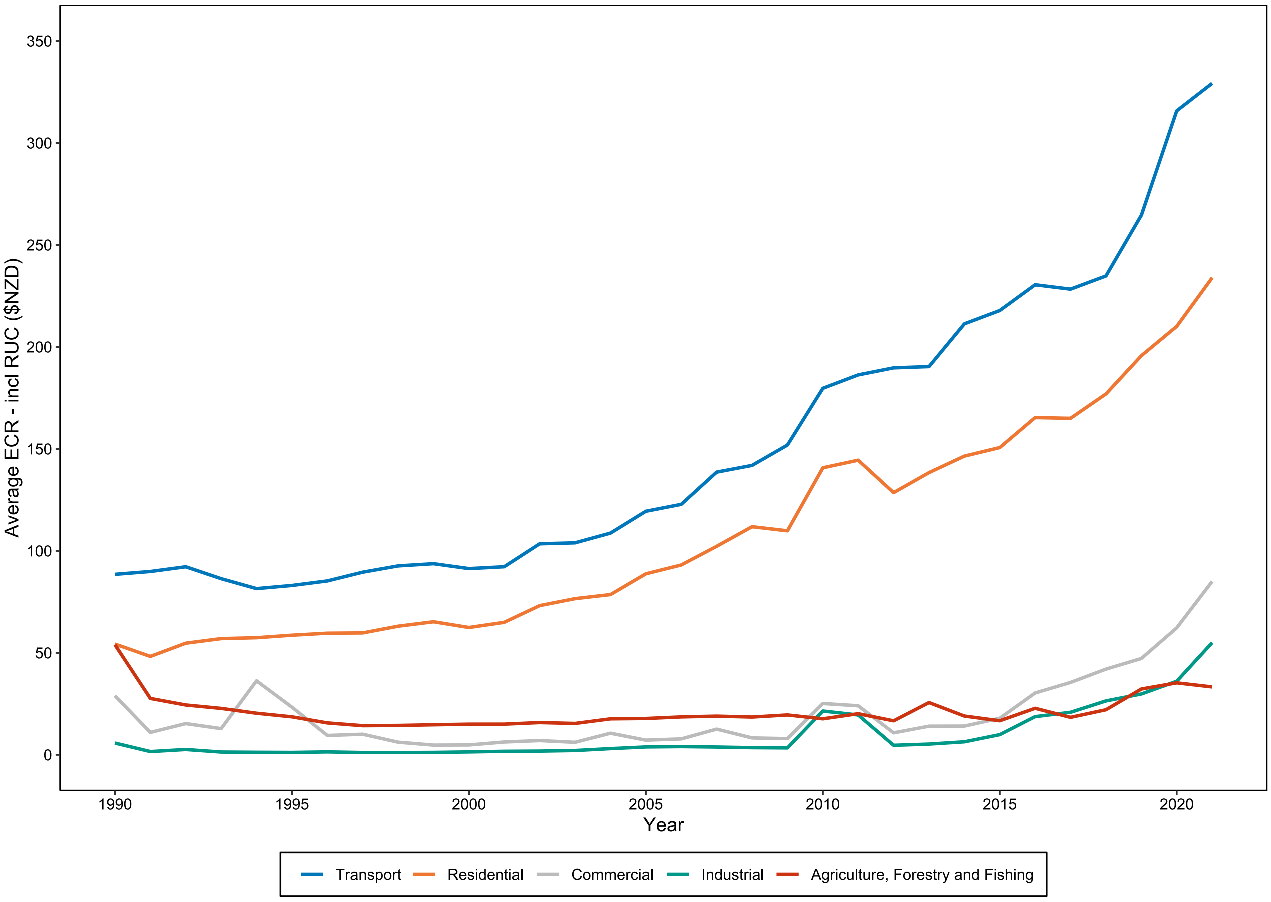
Figure 3.5 log(CO2e) for subsectors, and aggregate sectors over time (1990-2021)



Source: Principal Economics

Using the derived ECRs and considering the CO2e emissions across industries we determine the average prices paid per carbon tonne produced. The inclusion of implicit taxation via fuel taxes and levels leads to higher costs for sectors with a greater proportion of carbon emissions resulting from fuel use. As shown in Figure 3.6, residential sector pays the highest cost per tonne of carbon, followed by transport sector, commercial and industrial. While these costs are incurred implicitly as a tax on carbon, their purpose is to encompass expenses associated with other aspects such as the Accident Compensation Corporation (ACC), the National Land Transport Fund (NLTP), as well as engine fuel monitoring.

Figure 3.6 Average cost of carbon by industry



Source: Principal Economics analysis, MfE (2022a), MBIE (2023a, 2023b, 2023c) and Carbon News

Note: We derive the average ECR by taking the weighted average ECR for each sector ie total carbon pricing paid / total CO2e emissions. The data for carbon emissions originates from the MBIE Energy Balance tables. We convert gross calorific values to CO2 equivalent emissions using conversion factors from MfE (2022a). The ECR is summed up from fuel taxes, levies, and duties from the MBIE Fuel Pricing dataset, emissions trading scheme spot pricing, and average Road User Charges (RUC) rates harmonised to CO2e per tonne. RUC rates are determined by dividing total RUC revenues, as reported in Ministry of Transport Annual reports, by total diesel use, as estimated by in the MBIE Provisional estimates of greenhouse gas emissions from the energy sector dataset.

Table 3.2 shows estimated CO2e emissions by sector for the years of 1990 to 2021 based on the methodology described. This relates to emissions produced with fuel use only.

Table 3.2 Estimated CO2e emissions by sector, 1990 – 2021 (million tonnes)

Year	Transport	Residential	Commercial	Industrial	Agriculture, Forestry and Fishing
1990	16.32	1.40	0.90	6.15	1.24
1991	15.21	1.36	0.91	6.32	1.12
1992	15.52	1.29	1.05	6.46	1.23
1993	17.02	1.27	0.74	6.63	1.25
1994	18.91	1.30	1.01	6.68	1.32
1995	19.82	1.29	0.90	6.36	1.38
1996	19.74	1.30	0.79	6.44	1.42
1997	19.57	1.30	0.77	6.10	1.51
1998	20.21	1.34	0.79	5.70	1.57
1999	20.35	1.38	0.79	5.61	1.60
2000	21.67	1.50	0.82	6.17	1.54
2001	22.01	1.50	0.83	6.50	1.56
2002	21.74	1.51	0.82	6.84	1.70
2003	23.32	1.55	0.96	6.24	1.80
2004	23.93	1.61	1.04	5.81	1.62
2005	23.27	1.59	1.00	5.03	1.80
2006	23.58	1.63	0.89	5.07	1.82
2007	21.88	1.56	0.86	5.54	1.75
2008	22.56	1.50	0.88	5.57	1.67
2009	21.92	1.61	0.83	5.41	1.45
2010	21.57	1.56	0.88	5.56	1.32
2011	21.77	1.57	0.85	5.40	1.44
2012	20.02	1.65	0.93	5.83	1.63
2013	20.49	1.64	0.94	6.48	1.72
2014	20.37	1.66	0.98	7.19	1.58
2015	21.16	1.73	1.04	6.95	1.45
2016	21.92	1.72	1.02	6.97	1.39
2017	23.43	1.77	1.09	7.01	1.36
2018	24.45	1.78	1.04	7.09	1.36
2019	23.49	1.79	1.27	7.51	1.63
2020	19.36	1.80	1.22	6.64	1.60
2021	20.99	1.82	1.22	6.33	1.49

Source: MfE (2022a) and MBIE (2023a)

4 Methodology

Our methodology is consistent with D'Arcangelo et al.'s (2022) empirical framework. We estimate the impact of ECRs on emissions using the following equation:

$$q_{uft} = \beta \times ECR_{uft} + \gamma \times P_{ft} + \delta_{uft} + \varepsilon_{uft} \quad \text{(Equation 4.1)}$$

Where, q_{uft} is the log of CO_2 emissions from fossil fuel use for fuel category f in the year t, ECR_{uft} is the corresponding ECR in year t, P_{ft} is the price of fuel type at time t, δ_{uft} is the fixed effects, $\varepsilon_{uft}$is the error term. The parameter of interest is β which is the semi-elasticity of emissions with respect to the ECR. For example, β=-0.005 means that a $1 increase in the ECR is associated with a 0.5 percent decrease in emissions. β varies across fuel categories or sectors to accommodate fuel and sector-specific responses.

The semi-elasticity estimates translate the changes in the ECR level into percentage changes in emissions. This is helpful to benchmark these results to national and sectoral pledges as these express emission reductions in percentage and carbon price increases in absolute terms. A technical advantage of using semi-elasticities is that they permit to keep unpriced emissions (i.e. those with ECR equals to zero) in the regression analysis, which instead would drop out of the sample if working with elasticities because of the logarithmic transformation (D'Arcangelo et al., 2022).

To control for the impact of other factors, D'Arcangelo et al. (2022) considered the following fixed effects in their analysis:

- $\boldsymbol{\delta_f}$, for fuel-specific factors, for example past supply-side investment decisions and sunk costs affecting the long-run supply of different fuels;
- δ_u, for user-specific factors, for example sub-sector energy intensity;
- $\boldsymbol{\delta_t}$, for common time shocks;
- $\boldsymbol{\delta_{uf}}$ for fuel and user-specific variables, for example worldwide technology advancements in the use of a fuel in a specific sub-sector, unobserved country-invariant preference to tax the fuel in the sub-sector;
- δ_{ut} for time and user-specific variables, for example technological developments in different sub-sectors;
- δ_{uft} for user, fuel and time-specific variables, for example worldwide change in a specific use of a fuel in a subsector in a given year.

We were unable to control for all these fixed effects due to computational limits (from the large size of matrices). Hence, our fixed effects include δ_f, δ_t, δ_{uf} (bolded above). We tested for the change in results by replacing these fixed effects with other terms and did not identify significant changes (in terms of sign and magnitude). However, once we included price information in the equation in addition to the fixed effects the results changed significantly, as we will present in the next chapter.[21] Also, for the diesel fuel type, we added the road user charges per tonne of CO_2e as an additional component of ECR.[22]

21 We sourced pricing data for Diesel and Petrol from the MBIE Energy Prices dataset, excluding components that are included in the ECR, ie duties, taxes and levies, and ETS pricing. For natural gas and LPG pricing we use indices sourced from the Statistics NZ energy price statistics dataset. Australian coal prices are sourced from the World Bank Commodity Price Data (The Pink Sheet), which was converted to NZD using RBNZ Exchange rates (NZD/USD). We have used "Coal Australia" prices for all coal types. Given the lack of information on prices across different types of coal, we have used the same price for Bituminous, Lignite and Sub-Bituminous.

For conversions of carbon pricing for petrol, we used the MfE conversation rates for regular petrol (default) which is a weighted average of regular and premium petrol based on 2021 sales volume data. This is the recommended conversion factor for petrol-use data that does not distinguish between regular and premium petrol.

22 We calculate the average road user charges (RUC) per tonne of CO_2e by dividing the total RUC revenue by the total diesel CO_2e emissions from domestic transport. RUC revenue data is obtained from the MoT's financial statements, while total diesel consumption figures are sourced from the MBIE Provisional estimates for GHG emissions from the energy sector. Due to lack of emissions data, we hold the RUC per tonne of CO_2e constant for the year of 2021.

5 Results

Table 5.1 shows the results of estimation using (Equation 4.1). The first column presents the ECR semi-elasticity without including price information, the second column shows the semi-elasticity after considering price information, the third column shows the disaggregate ECR semi-elasticities for different industries and sub-sectors, and the fourth column adds price information to the sub-sector estimation.[23]

The ECR semi-elasticities at an aggregate level are presented in columns one and two. Accordingly, after considering the price effect, a $10 increase in ECR decreases emissions by 1.7 percent, which is less than D'Arcangelo's (2022) estimate of 2.8 percent.

The results presented on the third and fourth columns show impacts for total sectors (Tot-Industrial, Tot-Commercial, Tot-Residential, Tot-Residential) as well as disaggregation for each industrial sub-sector (labelled as Ind-).

As shown, the impacts at the sector aggregate levels are statistically insignificant. The identified significant impacts are all negative and suggest that a 10 dollar increase in ECR leads to a decrease in carbon emissions by 6.8 percent for Building and Construction, 26.6 percent for Food processing, 7.8 percent for Forestry and Logging, 33.2 percent for Mechanical/Electrical Equipment, 5.8 percent for Mining, 18.7 percent for Textiles, and 4.4 percent for Unallocated industrial activities.[24]

Column 5 shows the estimated impacts on columns 2 and 4 in percentage marginal impacts (at mean). For example, a ten percent increase in overall ECR decreases emissions by 0.74 percent and leads to almost 3 percent decrease in Building and Construction sector's emissions.

An important question is about the timeframe of the estimated impacts. Hence, we also estimated impacts of the current and two-year lags of ECR across different sectors.[25] The marginal impacts are shown on column 6, which we referred to as long-term (LT) estimates. The results show that the magnitude of most statistically significant short-term (ST) elasticities is on average 28 percent larger in long-term (LT). This figure excludes the Forestry and Logging industry, which has a slightly (16 per cent) lower LT elasticity estimate.

We also identified a few abnormalities, such as the positive elasticities for the fishing industry and aggregated residential category. The reason for the positive elasticities of fishing could be lack of an ETS measure for this industry.

23 D'Arcangelo et al. (2022) also considered a restricted sample for their analysis to exclude observations with zero ECR. Since, we do not have any observations with ECR equal to zero, there is no need for that exclusion in our analysis.

24 The impact on the Textile industry is insignificant after we consider price impacts.

We also tested for difference in the impact of RUC versus other taxes for Diesel vehicles (including petroleum engine fuel monitoring levy and local authorities' petroleum tax (and Auckland regional fuel tax) and the ETS). We do not identify a significant difference between the two. While both are statistically insignificant, RUC has marginally higher statistical significance.

25 We tested for the optimal number of lags and the results of goodness-of-fit measures suggest the two-year lag is the most appropriate timeframe.

Table 5.1 Estimation results

Column:	(1)	(2)	(3)	(4)	(5)	(6)
Regression components:	**ECR**	**ECR + price**	**Sub-sectors**	**Sub-sectors + price**	**Sub-sectors + price**	**Sub-sectors + price**
Marginal impact:	Level	Level	Level	Level	Percent	Level
Timeframe:	ST	ST	ST	ST	ST	LT
ECR	-0.0023**	-0.0017*			-0.0738**	-0.0433
	(0.0007)	(0.0007)			(0.0313)	(0.0361)
Tot-Commercial ECR			0.0012	-0.0003	-0.0142	0.1321
			(0.0019)	(0.0018)	(0.0768)	(.0960)
Tot-Industrial ECR			-0.0023	-0.0031	-0.1333	-0.1401
			(0.0019)	(0.0018)	(0.0768)	(0.0960)
Tot-Residential ECR			0.0020	0.0020	0.0756	0.2010*
			(0.0019)	(0.0018)	(0.0687)	(0.0960)
Tot-Transport ECR			-0.0001	0.0005	0.0228	0.0242
			(0.0016)	(0.0015)	(0.0651)	(0.0785)
Ind-Agriculture, Forestry and Fishing ECR			-0.0023	-0.0026	-0.1114	-0.1331
			(0.0022)	(0.0021)	(0.0917)	(0.1100)
Ind-Basic Metals ECR			0.0139	0.0183	0.7891	0.6967
			(0.0105)	(0.0104)	(0.4525)	(0.8169)
Ind-Building and Construction ECR			-0.0063**	-0.0068**	-0.2956***	-0.3519***
			(0.0020)	(0.0018)	(0.0784)	(0.0999)
Ind-Chemicals ECR			0.0161	0.0224	0.9730	2.0447**
			(0.0106)	(0.0116)	(0.5032)	(0.7736)
Ind-Fishing ECR			0.0036	0.0080**	0.3493**	0.4245**
			(0.0023)	(0.0025)	(0.1076)	(0.1225)
Ind-Food Processing ECR			-0.0160**	-0.0266***	-1.155***	-1.4760***
			(0.0050)	(0.0049)	(0.2104)	(0.2901)
Ind-Forestry and logging ECR			-0.0085***	-0.0078***	-0.3377**	-0.2857**
			(0.0023)	(0.0021)	(0.0918)	(0.111)
Ind-Mechanical/Electrical Equipment ECR			-0.0368**	-0.0332**	-1.445**	-1.692*
			(0.0111)	(0.0113)	(0.4892)	(0.7280)
Ind-Mining ECR			-0.0067***	-0.0058**	-0.2536**	-0.3336**
			(0.0019)	(0.0018)	(0.0784)	(0.0997)
Ind-Non-metallic Minerals ECR			0.0037	0.0030	0.1300	0.4190
			(0.0076)	(0.0078)	(0.3392)	(0.4951)
Ind-Textiles ECR			-0.0258**	-0.0187*	-0.8041*	-1.1408
			(0.0088)	(0.0095)	(0.4135)	(0.6086)
Ind-Unallocated ECR			-0.0035	-0.0044*	-0.1718*	-0.1917**
			(0.0019)	(0.0018)	(0.0692)	(0.0975)
Ind-Wood, Pulp, Paper and Printing ECR			-0.0080	-0.0125	-0.4908	-1.2769*

			(0.0074)	(0.0078)	(0.3046)	(0.5150)
Constant	11.1205***	11.0392***	11.1261***	11.1635***		
	(0.0982)	(0.0979)	(0.0976)	(0.0945)		
Observations	2,462	2,462	2,462	2,462	2,462	2,310
Fixed effects (δ_f, δ_t, δ_{uf})	Yes	Yes	Yes	Yes	Yes	Yes
Price control	No	Yes	No	Yes	Yes	Yes

Source: Principal Economics

Note: Standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

We tested for multiple structural breaks based on Bai and Perron (1998) and identified no structural breaks. For unit root test, the null hypothesis of unit root (including trend) is rejected for all fuel types but Kerosene and LPG. If we used differenced log(CO2e) as the dependent variable, then the interpretation of outcomes will be complex.[26] The null hypothesis of no cointegration (in panel-data using Kao (1999) test) is not rejected for the LPG fuel type.

26 That is because the estimates will show change in elasticities rather than elasticities.

6 Conclusion and recommendation for future studies

This report investigated the impact of carbon pricing on emissions both at an aggregate economy level and at sectoral levels. Carbon pricing is an important policy for achieving the targets of Emission Reduction Plan (Ministry for the Environment, 2021, 2022b). While there are limited international evidence available on the effectiveness of carbon pricing, there are no information available in New Zealand. We discussed in this report that there are various reasons for variation in the effectiveness of carbon pricing, including for example the availability of alternative energy sources.

For the analysis, we followed a similar approach to the recent 2022 OECD report (D'Arcangelo et al., 2022). Compared to the OECD study, we collected more information about various taxes, such as road user charges (RUC) for the construction of the Effective Carbon Rates measure. We also controlled for pricing information, which the OECD report did not directly include in their analysis.

After considering the price effects, our results suggested that a $10 increase in ECR decreases emissions by 1.7 percent, which is less than D'Arcangelo et al.'s (2022) estimate of 2.8 percent. In percentage terms, a one percent increase in ECR is associated with 0.074 percent decrease in emissions, which is almost half the estimated impact by the OECD study (D'Arcangelo et al., 2022).

Our sectoral estimates suggested that a 10 dollar increase in ECR leads to a decrease in carbon emissions by 6.8 percent for Building and Construction, 26.6 percent for Food processing, 7.8 percent for Forestry and Logging, 33.2 percent for Mechanical/Electrical Equipment, 5.8 percent for Mining, 18.7 percent for Textiles, and 4.4 percent for Unallocated industrial activities. We did not identify a significant impact from carbon pricing on other sectors of the economy. In addition to these short-term estimates, we investigated the long-term elasticities (over 2 years). The results suggested that the elasticities are on average 28 percent larger in long-term.

One reason for the small magnitude of the estimated impacts across various sectors could be inelasticity of demand. Another reason might be the (relatively) small size of carbon tax relative to the sectors' size. By further investigating these factors, we could infer (extrapolate) the response of sectors to future policies, which as discussed is crucial for effectiveness of carbon pricing policy of the Emission Reduction Plan. About price elasticities of demand, some recent analyses exist for aggregate industry levels.[27] However, the available information covers limited sectors (mostly transport and food). Also, with the increased focus of public policy on equity outcomes, we suggest it will be important to understand the equity implications of carbon pricing. This will require further disaggregation of price elasticities of demand by socioeconomic features. Hence, we suggest that a future study further investigates these issues using household economic survey and business revenue information available from Stats NZ IDI.

The scope of this report was to follow the methodology of the recent OECD study (D'Arcangelo et al., 2022). The literature of elasticities shows a level of variation in the magnitude of elasticities with changes in the methodology. This variation usually does not lead to significant changes in elasticities (in terms of statistical significance and sign), but we suggest a future study to consider the impact of changes in methodology on the estimated elasticities.

27 For example, the price elasticity of demand for private vehicle and food is inelastic (Torshizian & Meade, 2020).

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Appendix A: Energy consumption

Emissions

Emissions have been based on energy balance tables provided by MBIE. They estimate emissions based on use of the gross caloric value of fuels used by different sectors of the economy. We provide extract of relevant data collection notes from the Ministry of Business, Innovation & Employment in this Appendix.

Use statistics cover energy transformation activities, non-energy use, and consumption by sector.

Energy transformation includes electricity generation, cogeneration, fuel production, other transformation activities, and losses and own use.

Sectors for consumption statistics are based on Australian and New Zealand Standard Industrial Classification (ANZSIC06) codes with the following mappings used for industrial and commercial sectors:

Table A.1 Sector and corresponding ANZSIC06 classifications

Sector	ANZSIC codes (Division or subdivision)
Agriculture, Forestry, and Fishing	A
Mineral and Petroleum Extraction	B
Food Processing	C11, C12
Textiles and Leather	C13
Wood, Pulp, Paper and Printing	C14, C15, C16
Chemicals	C17, C18, C19
Non-metallic minerals	C20
Basic Metals	C21, C22
Mechanical/Electrical Equipment	C23, C24
Industry unallocated	C25, D26, D27, D28, D29
Building and Construction	E
Commercial	F-G, H, I, J, K-N, O, P, Q, R-S

Source: Ministry of Business, Innovation & Employment

Oil consumption

Oil consumption is estimated using data from the Ministry's Delivery of Petroleum Fuels by Industry (DPFI) survey and Annual Liquid Fuels Survey (ALFS). The Ministry also receives data directly from companies that use oil for non-energy purposes[28].

The DPFI surveys each major petrol company quarterly for data on sales broken down by sector and fuel type. For the ALFS, independent liquid fuel distributors are asked annually to report their fuel purchases and sales broken down by sector and fuel type:

28 Oil can be transformed into products that are not used for energy, such as bitumen used in road construction

- Data from the DPFI is used to calculate the quantity of petroleum fuels consumed by each sector for energy based on reported sales.
- The ALFS data is then used to supplement the DPFI data as some fuels are sold to independent distributors, which the DPFI cannot allocate to a sector.
- The data obtained directly from companies can be added to these calculations based on the companies' sector.

As part of the data collection for electricity generation, the Ministry also calculates the amount of oil used to produce electricity based on information provided by plant operators. This is reported under energy transformation in the energy balance table. Where autoproducers use oil for electricity generation, this is subtracted from industrial consumption figures and reported under energy transformation.

Liquefied Petroleum Gas (LPG)

The LPG Association directly supplies data on imports, exports, and sales. LPG distribution figures by bottle size are collected monthly from major LPG distributing companies, through the Liquefied Petroleum Gas Supply survey. The Ministry does not collect data on LPG resales, so LPG end-use is estimated by assuming the uses of different bottle sizes.

Gas consumption

Gas consumption is calculated from data collected under the Quarterly Retail Sales Survey (QRSS) and data collected directly from companies that use gas for non-energy purposes[16]. In the QRSS, gas retailers report their sales classified by ANZSIC code[17].

As part of the data collection for electricity generation, the Ministry also calculates the amount of gas used to produce electricity based on information provided by plant operators. This is reported under energy transformation in the energy balance table. Where autoproducers use gas for electricity generation, this is subtracted from industrial consumption figures and reported under energy transformation.

Coal consumption

The sales reported by coal mine operators are classified by ANZSIC code, which enables the disaggregation of coal use by industry.

Coal mine owners and operators report on total coal resales. Coal resales is coal sold to other companies or parties, who then onsell it to end-users. MBIE does not collect data on coal resales, so consumption of coal that has been onsold has to be estimated. As the quantity of coal used is known from sales data, use of onsold coal by sector is estimated by allocating fixed proportions of this quantity to various sectors. This is done by assuming the end-uses of the different types of coal, and also accounting for sales between producers.

As part of the data collection for electricity generation, the Ministry also calculates the amount of coal used to produce electricity based on information provided by plant operators. This is reported under energy transformation in the energy balance table. Where autoproducers use coal for electricity generation, this is subtracted from industrial consumption figures and reported under energy transformation.

Appendix B: Emission factors

Table B.1 Underlying data used to calculate fuel emission factors

Emission source	User	Unit	Calorific value (MJ/unit)	t CO_2 / TJ	t CH_4 / TJ	t N_2O / TJ
Stationary combustion						
Coal – bituminous	Residential	kg	29.59	89.13	0.285	0.001425
Coal – sub-bituminous	Residential	kg	21.64	91.99	0.285	0.001425
Coal – lignite	Residential	kg	15.26	93.11	0.285	0.001425
Distributed natural gas	Commercial	kWh	n/a	0.19	0.00002	0.00000
		GJ	n/a	53.96	0.005	0.000
Coal – bituminous	Commercial	kg	29.59	89.13	0.0095	0.0014
Coal – sub-bituminous	Commercial	kg	21.64	91.99	0.0095	0.0014
Coal – lignite	Commercial	kg	15.26	93.11	0.0095	0.0014
Diesel	Commercial	litre	38.21	69.31	0.0095	0.0006
LPG	Commercial	g	50.00	60.43	0.005	0.0001
Heavy fuel oil	Commercial	litre	40.90	73.59	0.010	0.0006
Light fuel oil	Commercial	litre	40.32	72.30	0.010	0.0006
Distributed natural gas	Industry	kWh	n/a	0.19	0.000003	0.0000003
		GJ	n/a	53.96	0.001	0.00009
Coal – bituminous	Industry	kg	29.59	89.13	0.0095	0.001
Coal – sub-bituminous	Industry	g	21.64	91.99	0.0095	0.001
Coal – lignite	Industry	kg	15.26	93.11	0.0095	0.001
Diesel	Industry	litre	38.21	69.31	0.0029	0.0006
LPG	Industry	kg	50.00	60.43	0.001	0.0001
Heavy fuel oil	Industry	litre	40.90	73.59	0.003	0.0006
Light fuel oil	Industry	litre	40.32	72.30	0.003	0.0006
Transport fuels						
Regular petrol	Mobile use	litre	35.17	66.70	0.03	0.008
Premium petrol	Mobile use	litre	35.38	66.12	0.03	0.008
Diesel	Mobile use	litre	38.21	69.31	0.004	0.004
LPG	Mobile use	litre	26.54	60.43	0.06	0.0002
Heavy fuel oil	Mobile use	litre	40.90	73.59	0.007	0.002
Light fuel oil	Mobile use	litre	40.32	72.30	0.007	0.002
Jet kerosene / Jet A1	Mobile use	litre	46.29	68.22	0.48	1.9
Jet aviation gasoline	Mobile use	litre	47.3	65.89	0.48	1.9

Source: Ministry for the Environment (2022a)

Table B.2 Transport fuel emission factors

Fuel type	Unit	kg CO_2-e/unit	kg CO_2/unit	kg CH_4/unit (kg CO_2-e)	kg N_2O/unit (kg CO_2-e)	Uncertainties kg CO_2-e/unit
Regular petrol (default)	litre	2.46	2.35	0.0276	0.0797	1.8%
Premium petrol	litre	2.48	2.37	0.0277	0.0801	1.8%
Diesel	litre	2.69	2.65	0.00354	0.0422	0.9%
LPG	litre	1.64	1.60	0.0391	0.00150	1.3%
Heavy fuel oil	litre	3.04	3.01	0.00680	0.0232	0.6%
Light fuel oil	litre	2.94	2.92	0.00670	0.0228	0.6%
Aviation fuel (kerosene) / Jet A1	GJ	70.6	68.2	0.480	1.90	0.1%
	litre	2.63	2.54	0.0179	0.0707	0.1%
Aviation gasoline	GJ	68.3	65.9	0.480	1.90	0.1%
	litre	2.31	2.23	0.0163	0.0643	0.1%

Notes: These numbers are rounded to three significant figures.
No estimates are available for marine diesel as the refinery has stopped making the marine diesel blend. If an organisation was using marine diesel, it is now likely to be using light fuel oil; so the corresponding emission factor for light fuel oil should be used instead.
These petrol emission factors are higher than the ones in ETS regulations so could be updated in future when the ETS emission factors are updated. The refinery closure will also affect them.[29]

Source: Ministry for the Environment (2022a)

As GHGs can trap differing amounts of heat in the atmosphere, they have different relative impacts on climate change, known as global warming potentials (GWPs).[30] We convert each of these gases emissions to their commonly expressed form of carbon dioxide equivalent or CO_2-e used to provide meaningful comparison between different gas types.

Table B.3 Global warming potential (GWP) of GHGs based on 100-year period

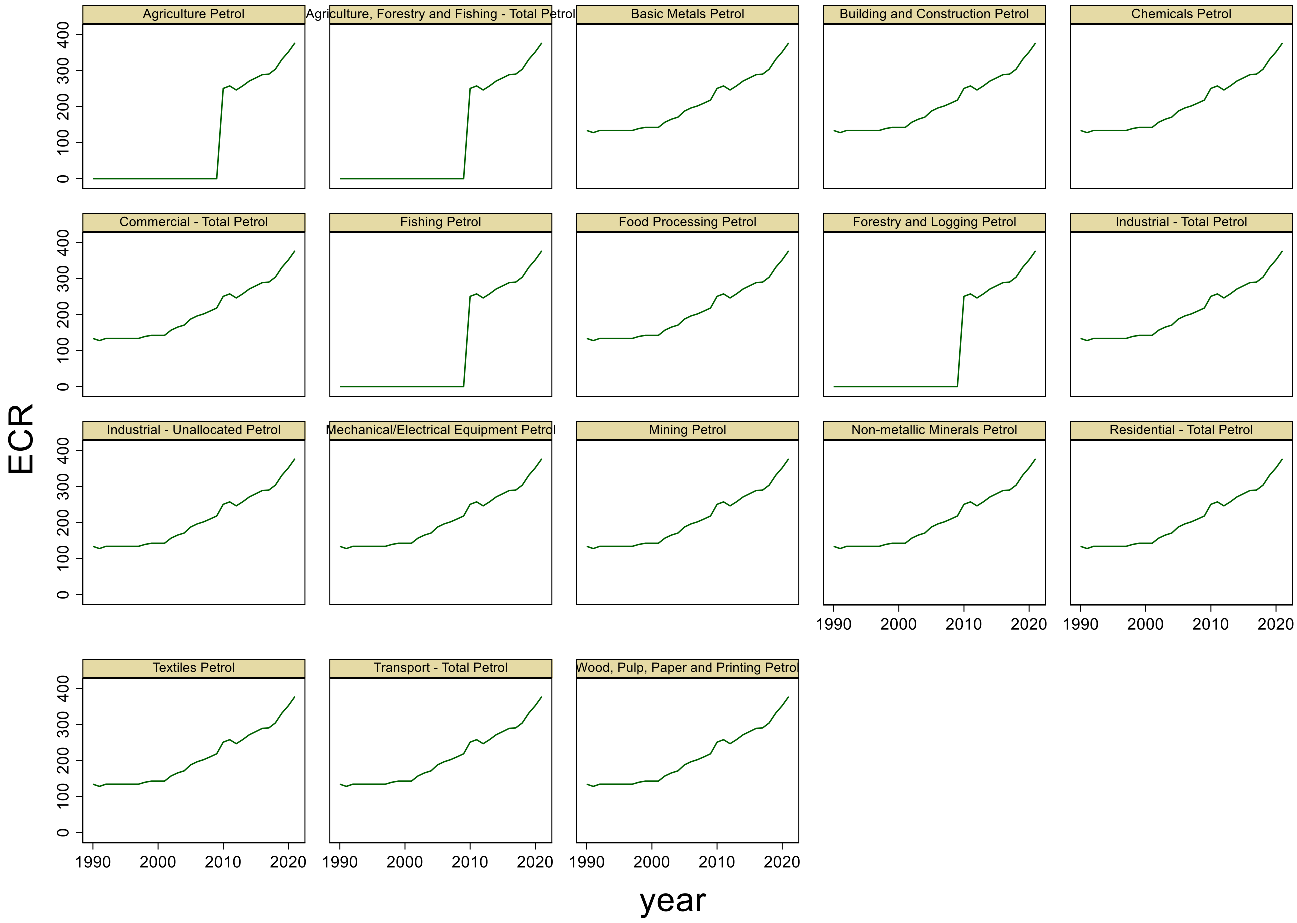
GHGs	Scientific Formula	GWP (AR4)
Nitrous Oxide	N_2O	298
Methane	CH_4	25
Carbon Dioxide	CO_2	1

Source: Ministry for the Environment (2022a)

29 Climate Change (Liquid Fossil Fuels) Regulations 2008 (SR 2008/356) (as at 1 October 2018) Schedule Emissions factors for tonnes of carbon dioxide equivalent greenhouse gases per kilolitre – New Zealand Legislation.

30 We use the 2007 IPCC GWPs to ensure consistency with New Zealand's Greenhouse Gas Inventory 1990–2020.

Figure A.1 ECR by subsector for petrol fuel type, 1990-2021



Appendix C: ECR components by fuel type

Table C.1 ECR components for coal – bituminous ($/ t CO2)

Year	Taxes/duties/levies	ETS	RUC	ECR
1990	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00
1994	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00
1997	0.00	0.00	0.00	0.00
1998	0.00	0.00	0.00	0.00
1999	0.00	0.00	0.00	0.00
2000	0.00	0.00	0.00	0.00
2001	0.00	0.00	0.00	0.00
2002	0.00	0.00	0.00	0.00
2003	0.00	0.00	0.00	0.00
2004	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00
2006	0.00	0.00	0.00	0.00
2007	0.00	0.00	0.00	0.00
2008	0.00	0.00	0.00	0.00
2009	0.00	0.00	0.00	0.00
2010	0.00	19.06	0.00	19.06
2011	0.00	16.71	0.00	16.71
2012	0.00	2.18	0.00	2.18
2013	0.00	2.72	0.00	2.72
2014	0.00	3.95	0.00	3.95
2015	0.00	6.62	0.00	6.62
2016	0.00	15.24	0.00	15.24
2017	0.00	17.93	0.00	17.93
2018	0.00	22.75	0.00	22.75
2019	0.00	24.76	0.00	24.76
2020	0.00	30.75	0.00	30.75
2021	0.00	48.96	0.00	48.96

Table C.23 ECR components for coal - lignite ($/ t CO2)

Year	Taxes/duties/levies	ETS	RUC	ECR
1990	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00
1994	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00
1997	0.00	0.00	0.00	0.00
1998	0.00	0.00	0.00	0.00
1999	0.00	0.00	0.00	0.00
2000	0.00	0.00	0.00	0.00
2001	0.00	0.00	0.00	0.00
2002	0.00	0.00	0.00	0.00
2003	0.00	0.00	0.00	0.00
2004	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00
2006	0.00	0.00	0.00	0.00
2007	0.00	0.00	0.00	0.00
2008	0.00	0.00	0.00	0.00
2009	0.00	0.00	0.00	0.00
2010	0.00	19.06	0.00	19.06
2011	0.00	16.71	0.00	16.71
2012	0.00	2.18	0.00	2.18
2013	0.00	2.72	0.00	2.72
2014	0.00	3.95	0.00	3.95
2015	0.00	6.62	0.00	6.62
2016	0.00	15.24	0.00	15.24
2017	0.00	17.93	0.00	17.93
2018	0.00	22.75	0.00	22.75
2019	0.00	24.76	0.00	24.76
2020	0.00	30.75	0.00	30.75
2021	0.00	48.96	0.00	48.96

Table C.45 ECR components for coal - sub-bitum ($/ t CO2)

Year	Taxes/duties/levies	ETS	RUC	ECR
1990	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00
1994	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00
1997	0.00	0.00	0.00	0.00
1998	0.00	0.00	0.00	0.00
1999	0.00	0.00	0.00	0.00
2000	0.00	0.00	0.00	0.00
2001	0.00	0.00	0.00	0.00
2002	0.00	0.00	0.00	0.00
2003	0.00	0.00	0.00	0.00
2004	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00
2006	0.00	0.00	0.00	0.00
2007	0.00	0.00	0.00	0.00
2008	0.00	0.00	0.00	0.00
2009	0.00	0.00	0.00	0.00
2010	0.00	19.06	0.00	19.06
2011	0.00	16.71	0.00	16.71
2012	0.00	2.18	0.00	2.18
2013	0.00	2.72	0.00	2.72
2014	0.00	3.95	0.00	3.95
2015	0.00	6.62	0.00	6.62
2016	0.00	15.24	0.00	15.24
2017	0.00	17.93	0.00	17.93
2018	0.00	22.75	0.00	22.75
2019	0.00	24.76	0.00	24.76
2020	0.00	30.75	0.00	30.75
2021	0.00	48.96	0.00	48.96

Table C.67 ECR components for diesel - transportation ($/ t CO2)

Year	Taxes/duties/levies	ETS	RUC	ECR
1990	25.35	0.00	27.49	52.84
1991	20.05	0.00	26.06	46.11
1992	20.73	0.00	21.90	42.62
1993	20.73	0.00	19.64	40.37
1994	20.73	0.00	18.11	38.83
1995	20.73	0.00	16.73	37.46
1996	20.73	0.00	16.36	37.08
1997	20.73	0.00	15.92	36.65
1998	22.17	0.00	16.66	38.84
1999	23.03	0.00	15.93	38.96
2000	23.03	0.00	15.66	38.69
2001	23.04	0.00	16.05	39.09
2002	24.63	0.00	16.19	40.82
2003	25.57	0.00	16.63	42.20
2004	26.20	0.00	17.68	43.88
2005	28.05	0.00	17.62	45.68
2006	29.02	0.00	17.64	46.66
2007	29.66	0.00	17.83	47.49
2008	30.54	0.00	18.97	49.51
2009	31.47	0.00	20.15	51.62
2010	32.96	19.06	19.34	71.36
2011	33.97	16.71	20.96	71.64
2012	34.35	2.18	21.74	58.27
2013	35.56	2.72	21.97	60.24
2014	36.91	3.95	23.70	64.56
2015	37.59	6.62	24.30	68.51
2016	37.66	15.24	25.82	78.72
2017	37.57	17.93	24.60	80.09
2018	39.27	22.75	24.75	86.77
2019	42.83	24.76	28.50	96.10
2020	44.54	30.75	29.97	105.27
2021	45.30	48.96	29.97	124.24

Table C.8 ECR components for diesel – Other sectors ($/ t CO2)

Year	Taxes/duties/levies	ETS	RUC	ECR
1990	43.25	0.00	0.00	43.25
1991	1.33	0.00	0.00	1.33
1992	1.33	0.00	0.00	1.33
1993	1.33	0.00	0.00	1.33
1994	1.33	0.00	0.00	1.33
1995	1.33	0.00	0.00	1.33
1996	1.33	0.00	0.00	1.33
1997	1.33	0.00	0.00	1.33
1998	1.33	0.00	0.00	1.33
1999	1.33	0.00	0.00	1.33
2000	1.33	0.00	0.00	1.33
2001	1.33	0.00	0.00	1.33
2002	1.33	0.00	0.00	1.33
2003	1.33	0.00	0.00	1.33
2004	1.33	0.00	0.00	1.33
2005	1.33	0.00	0.00	1.33
2006	1.33	0.00	0.00	1.33
2007	1.33	0.00	0.00	1.33
2008	1.35	0.00	0.00	1.35
2009	1.40	0.00	0.00	1.40
2010	1.40	19.06	0.00	20.46
2011	1.40	16.71	0.00	18.12
2012	1.40	2.18	0.00	3.58
2013	1.40	2.72	0.00	4.12
2014	1.40	3.95	0.00	5.35
2015	1.40	6.62	0.00	8.02
2016	1.69	15.24	0.00	16.93
2017	2.17	17.93	0.00	20.10
2018	8.68	22.75	0.00	31.43
2019	15.56	24.76	0.00	40.32
2020	16.10	30.75	0.00	46.85
2021	15.98	48.96	0.00	64.93

Table C.910 ECR components for fuel oil ($/ t CO2)

Year	Taxes/duties/levies	ETS	RUC	ECR
1990	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00
1994	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00
1997	0.00	0.00	0.00	0.00
1998	0.00	0.00	0.00	0.00
1999	0.00	0.00	0.00	0.00
2000	0.00	0.00	0.00	0.00
2001	0.00	0.00	0.00	0.00
2002	0.00	0.00	0.00	0.00
2003	0.00	0.00	0.00	0.00
2004	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00
2006	0.00	0.00	0.00	0.00
2007	0.00	0.00	0.00	0.00
2008	0.00	0.00	0.00	0.00
2009	0.00	0.00	0.00	0.00
2010	0.00	19.06	0.00	19.06
2011	0.00	16.71	0.00	16.71
2012	0.00	2.18	0.00	2.18
2013	0.00	2.72	0.00	2.72
2014	0.00	3.95	0.00	3.95
2015	0.00	6.62	0.00	6.62
2016	0.00	15.24	0.00	15.24
2017	0.00	17.93	0.00	17.93
2018	0.00	22.75	0.00	22.75
2019	0.00	24.76	0.00	24.76
2020	0.00	30.75	0.00	30.75
2021	0.00	48.96	0.00	48.96

Table C.11 ECR components for kerosene ($/ t CO2)

Year	Taxes/duties/levies	ETS	RUC	ECR
1990	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00
1994	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00
1997	0.00	0.00	0.00	0.00
1998	0.00	0.00	0.00	0.00
1999	0.00	0.00	0.00	0.00
2000	0.00	0.00	0.00	0.00
2001	0.00	0.00	0.00	0.00
2002	0.00	0.00	0.00	0.00
2003	0.00	0.00	0.00	0.00
2004	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00
2006	0.00	0.00	0.00	0.00
2007	0.00	0.00	0.00	0.00
2008	0.00	0.00	0.00	0.00
2009	0.00	0.00	0.00	0.00
2010	0.00	19.06	0.00	19.06
2011	0.00	16.71	0.00	16.71
2012	0.00	2.18	0.00	2.18
2013	0.00	2.72	0.00	2.72
2014	0.00	3.95	0.00	3.95
2015	0.00	6.62	0.00	6.62
2016	0.00	15.24	0.00	15.24
2017	0.00	17.93	0.00	17.93
2018	0.00	22.75	0.00	22.75
2019	0.00	24.76	0.00	24.76
2020	0.00	30.75	0.00	30.75
2021	0.00	48.96	0.00	48.96

Table C.12 ECR components for LPG ($/ t CO2)

Year	Taxes/duties/levies	ETS	RUC	ECR
1990	51.09	0.00	0.00	51.09
1991	51.09	0.00	0.00	51.09
1992	51.09	0.00	0.00	51.09
1993	51.09	0.00	0.00	51.09
1994	51.09	0.00	0.00	51.09
1995	51.09	0.00	0.00	51.09
1996	51.09	0.00	0.00	51.09
1997	51.09	0.00	0.00	51.09
1998	58.70	0.00	0.00	58.70
1999	63.25	0.00	0.00	63.25
2000	63.25	0.00	0.00	63.25
2001	63.25	0.00	0.00	63.25
2002	63.25	0.00	0.00	63.25
2003	63.25	0.00	0.00	63.25
2004	63.25	0.00	0.00	63.25
2005	63.25	0.00	0.00	63.25
2006	63.25	0.00	0.00	63.25
2007	63.25	0.00	0.00	63.25
2008	63.25	0.00	0.00	63.25
2009	63.25	0.00	0.00	63.25
2010	63.25	19.06	0.00	82.31
2011	63.25	16.71	0.00	79.96
2012	63.25	2.18	0.00	65.43
2013	63.25	2.72	0.00	65.97
2014	63.25	3.95	0.00	67.19
2015	63.25	6.62	0.00	69.86
2016	63.25	15.24	0.00	78.48
2017	63.25	17.93	0.00	81.18
2018	63.25	22.75	0.00	86.00
2019	63.25	24.76	0.00	88.01
2020	63.25	30.75	0.00	94.00
2021	63.25	48.96	0.00	112.20

Table C.13 ECR components for natural gas ($/ t CO2)

Year	Taxes/duties/levies	ETS	RUC	ECR
1990	0.23	0.00	0.00	0.23
1991	0.23	0.00	0.00	0.23
1992	0.23	0.00	0.00	0.23
1993	0.23	0.00	0.00	0.23
1994	0.23	0.00	0.00	0.23
1995	0.23	0.00	0.00	0.23
1996	0.23	0.00	0.00	0.23
1997	0.23	0.00	0.00	0.23
1998	0.23	0.00	0.00	0.23
1999	0.23	0.00	0.00	0.23
2000	0.26	0.00	0.00	0.26
2001	0.35	0.00	0.00	0.35
2002	0.35	0.00	0.00	0.35
2003	0.35	0.00	0.00	0.35
2004	0.35	0.00	0.00	0.35
2005	0.35	0.00	0.00	0.35
2006	0.35	0.00	0.00	0.35
2007	0.35	0.00	0.00	0.35
2008	0.35	0.00	0.00	0.35
2009	0.35	0.00	0.00	0.35
2010	0.35	19.06	0.00	19.41
2011	0.35	16.71	0.00	17.06
2012	0.35	2.18	0.00	2.53
2013	0.35	2.72	0.00	3.07
2014	0.35	3.95	0.00	4.29
2015	0.35	6.62	0.00	6.96
2016	0.35	15.24	0.00	15.59
2017	0.35	17.93	0.00	18.28
2018	0.35	22.75	0.00	23.10
2019	0.35	24.76	0.00	25.11
2020	0.35	30.75	0.00	31.10
2021	0.35	48.96	0.00	49.31

Table C.14 ECR components for petrol ($/ t CO2)

Year	Taxes/duties/levies	ETS	RUC	ECR
1990	133.91	0.00	0.00	133.91
1991	127.80	0.00	0.00	127.80
1992	133.91	0.00	0.00	133.91
1993	133.91	0.00	0.00	133.91
1994	133.91	0.00	0.00	133.91
1995	133.91	0.00	0.00	133.91
1996	133.91	0.00	0.00	133.91
1997	133.91	0.00	0.00	133.91
1998	139.29	0.00	0.00	139.29
1999	142.46	0.00	0.00	142.46
2000	142.46	0.00	0.00	142.46
2001	142.46	0.00	0.00	142.46
2002	156.76	0.00	0.00	156.76
2003	165.22	0.00	0.00	165.22
2004	170.88	0.00	0.00	170.88
2005	187.58	0.00	0.00	187.58
2006	196.26	0.00	0.00	196.26
2007	202.01	0.00	0.00	202.01
2008	209.91	0.00	0.00	209.91
2009	218.26	0.00	0.00	218.26
2010	231.61	19.06	0.00	250.67
2011	240.78	16.71	0.00	257.49
2012	244.16	2.18	0.00	246.34
2013	255.03	2.72	0.00	257.74
2014	267.24	3.95	0.00	271.19
2015	273.35	6.62	0.00	279.97
2016	273.67	15.24	0.00	288.90
2017	272.35	17.93	0.00	290.28
2018	281.20	22.75	0.00	303.95
2019	306.46	24.76	0.00	331.22
2020	321.31	30.75	0.00	352.06
2021	328.30	48.96	0.00	377.25