Are we turning a brighter shade of green? The relationship between household characteristics and greenhouse gas emissions from consumption in New Zealand

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Motu Working Paper 15-06
Motu Economic and Public Policy Research

25 November 2015

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Acknowledgements

We thank the Aotearoa Foundation for the financial support that enabled this work to be completed. We thank Adolf Stroombergen and Vince Smart for helpful discussions on the input-output analysis. Manfred Lenzen, Ross Cullen, and Arik Levinsson provided useful comments on earlier versions of this paper. This work has benefited from comments by attendees at the 2014 New Zealand Association of Economists Annual Conference, seminar participants from the Ministry for the Environment, attendees at the 2015 Western Economic Association International Conference, the 2015 meeting of the Australian Agricultural and Resource Economics Society, colleagues at Motu, and staff from the Energy Efficiency and Conservation Authority. The authors are solely responsible for the results presented in this paper. Any errors or omissions are our own.

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ISSN 1176-2667 (Print), ISSN 1177-9047 (Online).

Abstract

We test whether New Zealand households have become greener consumers by estimating environmental Engel curves (EECs), which describe the relationship between household income and the pollution embodied in a household's consumption bundle. Our pollutants of interest are greenhouse gases (GHGs). To our knowledge, this is the first paper that tests for a change over time in climate change-related household behaviour. We calculate the greenhouse gases embodied in household consumption bundles using standard environmental input-output (IO) analysis combined with detailed household expenditure data from the 2006/07 and 2012/13 waves of the New Zealand Household Economic Survey. Consistent with international literature, we find that emissions increase less-than-proportionately with household expenditure (a proxy for permanent income). There is significant variation in expenditure elasticities across consumption categories; emissions from household energy are unresponsive to household expenditure, while emissions from transport are highly responsive to expenditure. Household expenditure and composition explain the majority of the cross-sectional variation in household emissions. We conduct a simple test for changes over time in household consumption patterns that affect emissions, taking price changes into account. We find that, controlling for a rich set of household characteristics, household emissions were marginally lower on average in the 2012/13 survey than the 2006/07 survey. This result is largely driven by a reduction in emissions from household energy. We also find that wealthier households had a smaller reduction in emissions between surveys. Our results suggest this is due to higher levels of international air travel by wealthier households.

JEL codes

Q56; Q57; D12; Q54; D57

Keywords

Climate change; greenhouse gas emissions; household behaviour; consumption; input–output model

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1. Introduction

"Consumption is the sole end and purpose of all production"
– Adam Smith, 1776, *The Wealth of Nations*

Who is responsible for the greenhouse gas (GHG) emissions that are interrupting our climate system? This question has been at the centre of international climate change negotiations since they began. Current frameworks for measuring and reporting emissions are territorial or production based; emissions are measured where they occur. But this doesn't mean that production emissions are all we should pay attention to either as countries or as individuals. The reason these emissions occurred was to satisfy consumer demand somewhere on the planet.

In this paper, we explore the relationship between consumption emissions and household characteristics, and changes in the relationship over time. We ask whether households have changed their behaviour as they have become more aware of climate change. Ours is the first paper that we are aware of that tests for changes over time in climate change-related household behaviour. We aim to provide information on what households can do to lessen their environmental impact, through either their consumption or lifestyle choices.

We calculate the emissions embodied in the consumption bundles of a sample of households in New Zealand using standard environmental input–output (EIO) methods. We use information on energy use by industry, energy emissions and process emissions, along with the total requirements table from Statistics New Zealand's (SNZ) 2007 input–output tables to calculate emissions embodied in final products. We combine this with detailed household-level expenditure data from the 2006/07 and 2012/13 New Zealand Household Expenditure Surveys (HES) to calculate the emissions associated with each household's consumption bundle. Our work extends that of Romanos *et al.* (2014). Our detailed household data allow us to estimate environmental Engle curves (EECs), which describe the relationship between the pollution embodied in final consumption and household income and other characteristics. We explore these relationships for a household's total emissions, as well as for emissions from specific spending categories: meat, household energy, transport fuels, and domestic and international air travel. When examining changes in household emissions over time, we fix product emissions at their 2007 levels, so any change we detect over time must be due to a shift in household consumption patterns.

A growing literature estimates consumption-based emissions accounts and analyses how a household's environmental footprint varies with household characteristics (see Hertwich and Peters 2009; Lenzen 1998; Lenzen and Peters 2010; Lenzen *et al.* 2006; and Peters and Hertwich

2006, among others). Hertwich and Peters (2009) show the vast disparities in per capita consumption emissions. Values range from 0.7 tonnes of carbon dioxide equivalent (t-CO_2eq) in Malawi to 33.8 t-CO_2eq in Luxembourg. One factor stands out as the key driver of household consumption emissions: household expenditure or income. Estimated expenditure elasticities are universally less than unity for developed countries, indicating that emissions rise less than proportionately with expenditure. This result holds both across countries (e.g. Hertwich and Peters 2009) and within countries (e.g. Lenzen *et al.* 2004; Lenzen *et al.* 2006; Weber and Matthews 2008). This is due to wealthier households (countries) spending a larger fraction of their income on relatively less emissions-intensive services. In developing countries, estimated elasticities are close to, and in some cases greater than, unity (Cohen *et al.* 2005; Lenzen *et al.* 2006).

Other studies attempt to estimate the emissions associated with various consumer lifestyles and life stages. Morioka and Yoshida (1997) examine the emissions associated with various household types in Japan over the period 1960–90. Their definition of household types is simple and two-dimensional: they use the age of the household head and whether it is a single-person or family household. They find that emissions increased most for younger and elderly single-person households, and that these increases were mainly driven by increases in expenditure. Baiocchi *et al.* (2010) examine the emissions associated with various lifestyles and use detailed socioeconomic data to derive their definitions of lifestyles. They find that the lifestyle group with the highest emissions ("educated urbanites") are responsible for twice as many emissions as the lowest-emitting group ("struggling families"). They find that income is the primary driver of household emissions, and that household size also has a positive influence.

Other work in New Zealand uses EIO analysis to estimate the environmental footprint of New Zealand households. Bicknell *et al.* (1998) estimate what they call the ecological footprint, defined as the amount of land required to produce the goods we consume. Creedy and Sleeman (2006) use EIO methods to estimate the impact of a carbon tax on household welfare. The study most closely related to ours is Romanos *et al.* (2014). The authors conduct preliminary analysis of the cross-sectional drivers of household consumption emissions using publicly available household survey data.

Our work is similar to that of Levinson and O'Brien (2015), who estimate what they call environmental Engel curves (EECs) for small particulate matter in the US. They examine the relationship between the particulate matter embodied in final consumption and household income and other household characteristics. They find that the EECs are upward sloping and concave, meaning that an increase in income has a less than proportional effect on pollution.

They find evidence that US EECs have been shifting down over time, reflecting a change in consumer behaviour towards a less pollution-intensive consumption bundle. They posit this is due to a combination of environmental regulations making relatively pollution-intensive goods more expensive, and a shift in consumer preferences towards a greener consumption bundle.

We confirm the main finding in the literature, namely that expenditure explains the vast majority of variation in emissions across households, but emissions rise less than proportionately with expenditure. Our results suggest that a household's emissions increase by 7 percent when expenditure increases by 10 percent, consistent with the international literature. We find significant variation in the expenditure elasticities among the categories we consider. Emissions from household energy are unresponsive to increases in a household's expenditure, while emissions from air travel are incredibly sensitive to increases in expenditure.

Household size has a positive effect on emissions, but we find no evidence of economies of scale in household size. Emissions tend to increase with the age of the household head. This could be due to an increased demand for heating, or that older householders have more disposable income as a result of having paid off their mortgage.[1] We find a north–south effect: emissions tend to be higher in the South Island (where temperatures are lower) and our evidence suggests this is a heating effect. We find an "Auckland" effect for transport, plausibly due to Auckland's infamous traffic and the fact that the city is home to a high proportion of immigrants, who may fly to their home country more often to visit relatives. We also find that home owners tend to have higher emissions, which we hypothesise is a wealth effect. This is supported by the result that home owners have higher emissions from international air travel.

We find a small decrease in average household emissions between 2006/07 and 2012/13, after controlling for household characteristics. Our results suggest this is largely due to more efficient use of household energy in response to higher electricity prices and general improvements in energy efficiency. The decrease in emissions is smaller for wealthier households, which is partly explained by increased international air travel among wealthier households.

The rest of this paper is structured as follows. Section 2 describes the data and methods used to calculate household emissions. Section 3 presents the cross-sectional results and the tests for changes in the relationship over time. Section 4 provides an illustration of how this analysis could be used by households or policymakers to project the emissions associated with various life paths. Section 5 concludes.

[1] Older households are more likely to own a home and have paid off the mortgage.

2. Data and methods

2.1. Calculating emissions intensities

We use the same data and methods as Romanos *et al.* (2014) to calculate our vector of product emission intensities, measured as tonnes of carbon dioxide equivalent per dollar (t-CO_2eq/\$) of gross output (measured in purchaser prices). The construction of the data used in the calculation is explained in detail in Romanos *et al.* (2014), so we provide only a brief description of the process here.

The calculation is made using standard EIO analysis, as in Hertwich and Peters (2009) and Lenzen and Peters (2010), among others. The calculation is described by the equation:

$$\boldsymbol{c} = \boldsymbol{eF}(\boldsymbol{I} - \boldsymbol{A})^{-1}$$

Where $\boldsymbol{c}$ is the vector of carbon intensities measured as t-CO_2eq/\$ of gross output for each industry, $\boldsymbol{e}$ is a vector of emissions factors for both fossil fuels and process emissions,[2] $\boldsymbol{F}$ is a matrix of industry fuel requirements, and $(\boldsymbol{I} - \boldsymbol{A})^{-1}$ is the total requirements matrix from the 2007 National Accounts input–output (IO) tables produced by Statistics New Zealand.[3] Process emissions are included in the vector of emissions factors to give a more complete account of the emissions released during the production of some products. Process emissions are produced as a by-product of some production processes, such as the production of concrete and the methane released by ruminant livestock. Table 1 lists the data and data sources used in the derivation of the $\boldsymbol{c}$ vector.[4]

We have made some corrections to the original carbon intensity vector derived in Romanos *et al.* (2014). The changes relate to the allocation of fuels between industrial/commercial and household uses, and the treatment of direct energy use by households. These changes are detailed in Appendix 1.

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[2] See Romanos *et al.* (2014) for details on how process emissions are treated in the model.

[3] The 2007 IO tables are the most recent available. These are available from http://www.stats.govt.nz/browse_for_stats/economic_indicators/NationalAccounts/input-output%20tables.aspx.

[4] The input–output model and data used in this calculation is available at http://www.motu.org.nz/building-capacity/dataset/consumption_based_greenhouse_gas_emissions.

Table 1: Data sources for calculating carbon intensity vector[5]

	Data used in derivation (year of release)	Source
e	2007 fuel emissions factors from the Energy Greenhouse Gas Emissions web tables (2014)	Ministry of Business, Innovation and Employment (2014a)
	2007 oil consumption data from the Energy Data File (2012)	Ministry of Economic Development (2012) [6]
	2007 web tables from *New Zealand's Greenhouse Gas Inventory 1990–2008* provided by the Ministry for the Environment (2010)	Ministry for the Environment (2010)
F	2007 energy consumption data from the Energy Data File (2008, 2012)	Ministry of Economic Development (2012)
	2007 "Use" table and "Direct requirements" table from the National Accounts input–output tables (2012)	Statistics New Zealand (2012)
$\mathbf{(I - A)^{-1}}$	2007 "Total requirements" table from the National Accounts input–output tables (2012)	Statistics New Zealand (2012)

2.2. Calculating household emissions

To calculate household emissions, we use detailed household-level expenditure data from the 2006/07 and 2012/13 waves of the Household Economic Survey (HES) produced by SNZ. The HES provides a detailed breakdown of household spending, as well as collecting a range of household demographic characteristics. The full version of the HES, which includes detailed expenditure data, is undertaken every three years. The HES is not a panel dataset; households are not followed over time. In our analysis, we pool the two samples. The survey underwent a major revision between the 2003/04 and 2006/07 versions, meaning that we can make meaningful comparisons across time only from 2006/07.

To calculate the emissions embodied in each household's consumption bundle, we map the industry categories to household expenditure categories to get a vector of t-CO_2eq/$ of expenditure. We then multiply household spending in each category by the corresponding emissions intensity, and sum across expenditure categories within each household to calculate total emissions for that household. The exception to this is the calculation for emissions from

[5] This table is derived from table 1 in Romanos *et al.* (2014).

[6] The Ministry of Economic Development is now part of the Ministry for Business, Innovation and Employment.

housing construction, which is explained in detail in Appendix 1. The HES covers only private expenditure (not government-provided services), meaning we cannot provide a complete emissions footprint using this data.

EIO analysis assumes that an extra dollar of consumption results in a larger quantity of goods consumed and therefore more emissions. When comparing emissions over time, an increase in expenditure does not necessarily represent an increase in the quantity consumed, but could be due to an increase in prices. To correct for this, we express all expenditure in constant 2007 NZ$ by applying a category specific price deflator constructed from the consumer price index (CPI) level 3 disaggregation.[7] We use the aggregate CPI for expenditure categories that do not have a specific deflator.

Within heterogeneous expenditure categories, higher expenditure may not imply higher emissions. A kilo of beef mince has the same embodied emissions as a kilo of fillet steak, for example, but the prices of the two cuts of beef are very different. We would assign more emissions to a kilo of fillet steak than a kilo of mince. Girod and de Haan (2010) show that wealthier households consume goods of a higher quality (price per functional unit). Their analysis showed that using expenditure-based household consumption data to calculate emissions will tend to overstate both the level of emissions and the marginal effect of additional expenditure on emissions, particularly for wealthier households.

Because we use a single-region IO model, we assign imported household consumption items the same emissions intensity as if they were produced domestically.[8] The direction of bias caused by this assumption is unclear; it depends on whether the producer country is more or less emissions efficient at producing the good and on the emissions associated with international transport.

2.3. Empirical methods

We estimate a simple regression equation of the form:

$$\log(Emissions_i) = \alpha + \beta \log(Expenditure_i) + \gamma HH\ Size_i + \delta X_i + \varepsilon_i \qquad (1)$$

$$\gamma HH\ Size_i = \gamma_1 \#\ adults + \gamma_2 \#\ adults^2 + \gamma_3 \#\ children + \gamma_4 \#\ children^2$$

[7] We use 2007 as the base year as this is the year for which we have IO data. The quarterly CPI level 3 disaggregation is available from http://www.stats.govt.nz/infoshare, table reference CPI013AA.

[8] Many goods, such as cars, are not produced domestically. For these consumption categories, we assign emissions based on the closest proxy for their production for which we have information available.

where $Emissions_i$ is the amount of emissions embodied in household i's consumption bundle, $Expenditure_i$ is total expenditure for household i and is a proxy for permanent income,[9] $HH\ Size_i$ is the size and composition of household i, and X_i is a vector of other control variables. X_i contains dummy variables for age of household head, region, education, ethnicity, home ownership status and employment status.

Based on previous work, we expect $1 > \beta > 0, \gamma_1, \gamma_3 > 0$, and $\gamma_2, \gamma_4 \leq 0$ (e.g. Hertwich and Peters 2009; Levinson and O'Brien 2015, among others). We further expect $\gamma_1 > \gamma_3$, that adding a child to a household has a smaller effect on emissions than adding an adult. We also test for economies of scale in household size. In this context, economies of scale mean that, when increasing household size without affecting the material well-being of the household, emissions increase less than proportionately with household size. We ask the question: "holding household per capita expenditure constant, what effect does increasing the household size have on household emissions?"[10] Economies of scale could arise through the sharing of a common expenditure across more household members and there is evidence for economies of scale in household energy requirements. For example, heating the living room does not require more energy because a new person has entered the household. This expenditure is shared across more household members, leaving more income available for other expenditures. They key question regarding economies of scale in household size is what this income is spent on.

We also examine the relationship between household characteristics and emissions from specific consumption sub-categories. We consider five specific sub-categories: meat, household energy (electricity, gas and solid fuels), transport fuels (petrol and diesel), and domestic and international air travel. We chose these sub-categories as they are relatively emissions intensive (high t-CO_2eq/$) and they account for a significant fraction of emissions from the three largest sources of household emissions (food, household utilities and transport). This allows us to look for changes in behaviour over time in specific areas. When emissions from a specific consumption sub-category are used as the variable on the left-hand side of the equation, the equation is estimated using the Tobit estimator. Some households report no expenditure in these categories, meaning that these variables are left-censored at 0.

[9] We exclude contribution to savings and money given to others (excl. donations) from expenditure.

[10] Testing $\gamma_1 > 0, \gamma_2 < 0$ is not the appropriate test of economies of scale. Increasing household size, while keeping total household expenditure constant, effectively makes the household poorer. The γ coefficients are picking up both the scale effect and the income effect of increasing household size.

All models are estimated using the pooled 2006/07 and 2012/13 sample. This allows us to test for changes in household emissions between the surveys. We hold product emissions constant at their 2007 level, meaning that any differences in emissions between surveys that is not explained by differences in demographic characteristics must be due to a shift in household consumption patterns.[11] We conduct a simple test for changes in average household emissions, conditional on household characteristics, by including a dummy variable for the 2012/13 survey. We also interact the explanatory variables with the survey dummy. This allows us to examine which household characteristics are associated with larger (smaller) changes in emissions between the surveys.

3. Results

3.1. Descriptive statistics

Table 2 reports the carbon intensities for a selection of consumption sub-categories, measured as kg-CO_2eq/$ spent. Basic consumption items, such as food, electricity and petrol, are the most emissions intensive, with values of between 0.8kg and 2.2kg of emissions per dollar spent.

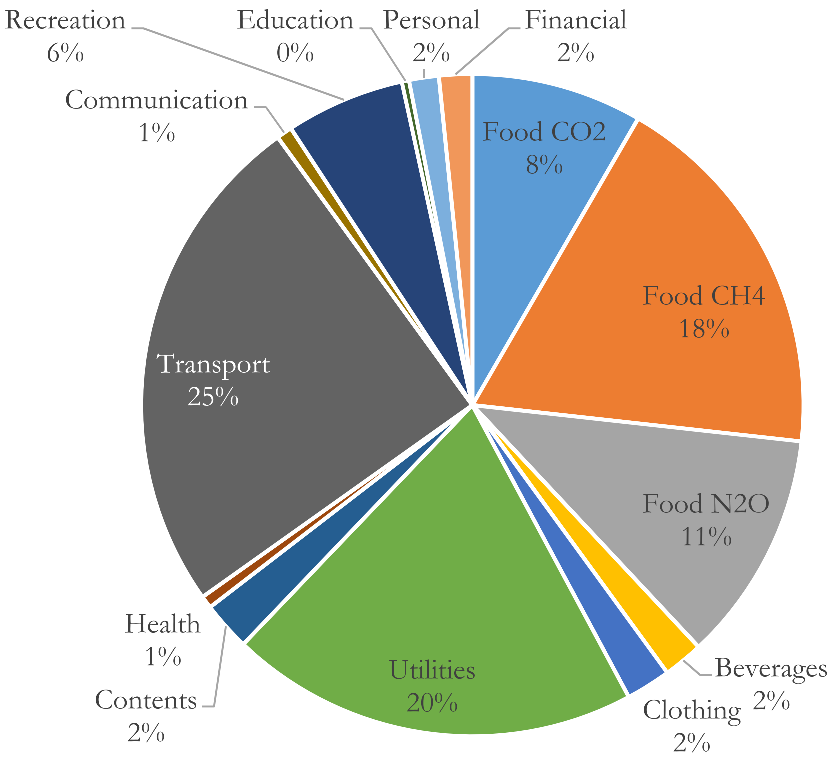
Table 2: Carbon intensities of selected HES consumption sub-categories (2007)[12]

SUB-CATEGORY	CARBON INTENSITY (kg-CO_2eq/$)
Food	
Fruit and vegetables	1.2
Meat and poultry	2.2
Milk, cheese and eggs	1.9
Other grocery food	0.40
Non-alcoholic beverages	0.26
Restaurant meals and ready-to-eat food	0.22
Transport	
Purchase of vehicles	0.12
Petrol	1.5
Other private transport services	0.11
Passenger transport services	0.56
Housing utilities	
Property maintenance materials	0.25
Property rates and related services	0.15
Electricity	0.81
Other household energy	4.6
Other housing expenses	0.023

[11] This is true even if we do not provide an accurate estimate of the level of a household's emissions.
[12] This table is an abbreviated version of table 6 in Romanos *et al.* (2014).

Figure 1 shows the composition of emissions for the average household in the 2012/13 survey. The average household footprint is 17.02 t-CO_2eq per year, or 6.5 t-CO_2eq per capita.[13]

Figure 1: Composition of average household emissions, 2012/13



Food, household utilities (operation and maintenance), and transport account for 82% percent of emissions for the average household. These three categories have been found to account for the majority of household consumption emissions across countries, although the rankings differ by country (e.g. Girod and de Haan 2010; Hertwich and Peters 2009; Kerkhof *et al.* 2009). We separate emissions from food into energy and process emissions, i.e. enteric fermentation (methane, CH_4) and nitrous oxide (N_2O). Process emissions account for 78% percent of the emissions from food, with methane contributing nearly half of total food

[13] The analysis conducted by Hertwich and Peters (2009), an updated version of which appears on Carbon Footprint of Nations – Carbon (1990–2010) (http://carbonfootprintofnations.com/) by Norwegian University of Science and Technology and Centre for International Climate and Environmental Research – Oslo (2013), gives a figure of 9.2 t-CO_2eq for New Zealand's 2010 per capita consumption emissions. Our figure is not directly comparable with theirs. The figure from Carbon Footprint of Nations is based on a multi-region IO model, which provides a better indication of the emissions associated with imported goods. The authors also account for government consumption. The fact that our per capita figure is lower does not necessarily indicate a fall in per capita consumption emissions between 2010 and 2012.

emissions.[14] This is well above the 25 percent that Kramer *et al.* (1999) found for Dutch food consumption.

Figure 2 shows how the proportion of total emissions from each broad expenditure category varies across expenditure deciles.[15] Emissions from food and beverages account for around 40% percent of total emissions for all deciles, although its importance does decrease for wealthier households. The share of emissions from household utilities declines with household expenditure, while the share of emissions from transport increases. This is consistent with the results of Khaled and Lattimore (2008), who found that, in New Zealand, household utilities and operation are income inelastic, while transport is income elastic.

Figure 2: Composition of emissions by expenditure decile, 2012/13

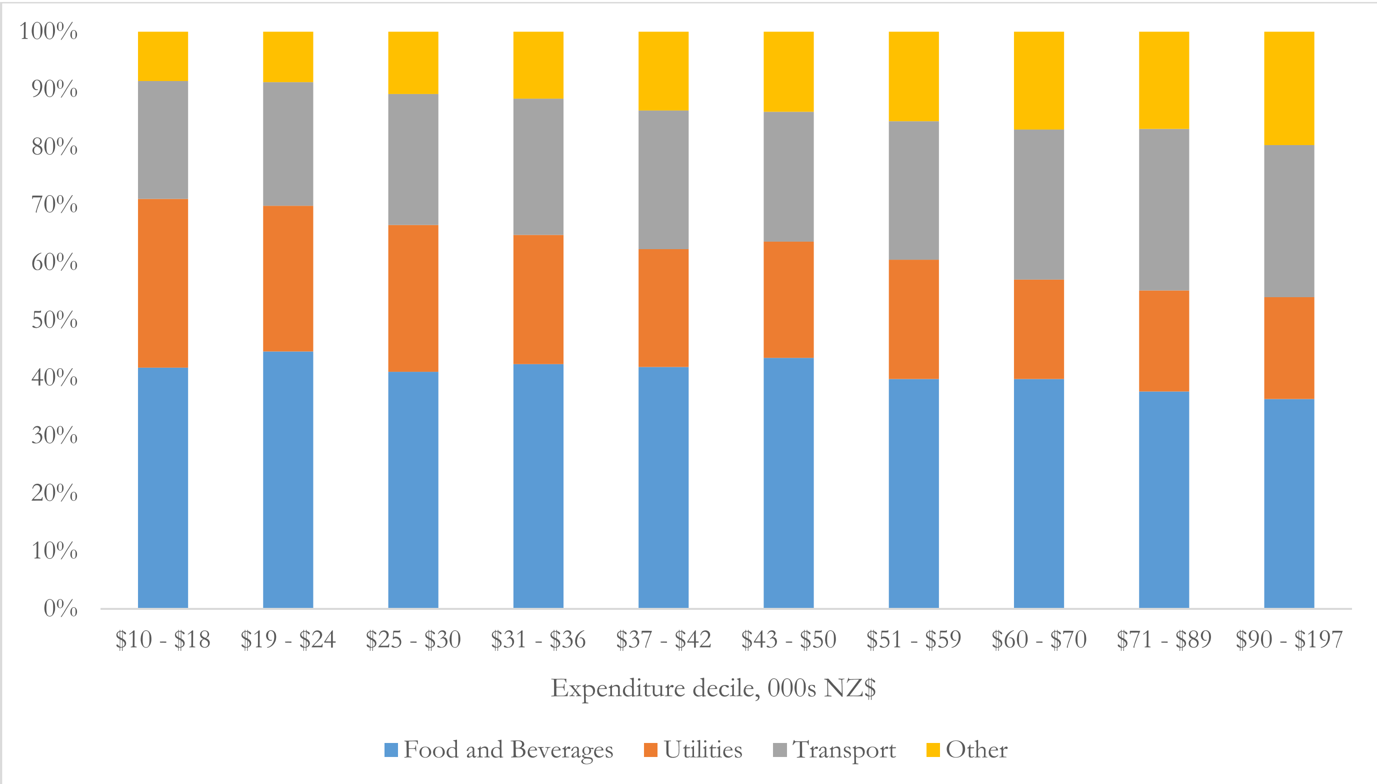


Table 3 provides summary statistics for the 2006/07 and 2012/13 survey sample, as well as the pooled sample. Summary statistics per household are presented for total emissions and emissions from the consumption of meat, household energy, transport fuels, and domestic and international air travel. We observe a small decrease in average emissions between the two surveys, a decline of 0.4 t-CO_2eq. We also observe a decline in emissions from household energy and transport fuels, while emissions from domestic and international air travel have increased.

[14] Methane, while having a higher global warming potential than CO_2, is a short-lived GHG.

[15] We have combined contents, health, communication, recreation, education, personal, financial and clothing into one category (other) for the purposes of the figure.

Household characteristics are largely unchanged between the two surveys. Total household expenditure was only NZ$500 higher in 2012/13 than in 2006/07. This is likely due to the Global Financial Crisis and local recession, which saw household incomes stagnate or fall. The recovery was well underway by 2012, by which time any fall in household incomes appears to have reversed. Household size and composition are also very similar between the two surveys. The average household size is 2.7 people.

Table 3: Summary statistics per household

	2006/07 $(N = 2{,}364)$		2012/13 $(N = 2{,}763)$		Pooled $(N = 5{,}127)$	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
$Emissions$ (t-CO_2eq)	17.4	9.8	17.0	9.5	17.2	9.6
$Meat$	2.3	2.3	2.3	2.4	2.3	2.4
$HH\ energy$	2.2	1.8	2.0	1.6	2.1	1.7
$Trans. fuels$	3.4	3.6	3.1	3.0	3.3	3.3
$Dom. air$	0.04	0.2	0.1	0.4	0.1	0.3
$Int. air$	0.3	0.9	0.4	1.1	0.4	1.0
$Expenditure$	$51,482	$32,309	$51,959	$29,992	$51,728	$31,135
$\#\ adults$	2.1	0.9	2.2	1.0	2.1	1.0
$\#\ children$	0.6	1.0	0.6	1.0	0.6	1.0
Age	48.1	16.3	49.5	16.6	48.8	16.4

Notes: The number of observations has been randomly rounded to base 3 for confidentiality reasons.

3.2. Cross-section results

Table 5 presents the cross-sectional estimates. Column 1 reports the results for total household emissions, while columns 2–6 report the results for emissions from meat, household energy, transport fuels, and domestic and international air travel, respectively.

Our estimated expenditure elasticity is 0.71 for total emissions, indicating that total emissions rise less than proportionately with household expenditure. The elasticity estimate is similar to that found by Kerkhof *et al.* (2009) for the Netherlands, Girod and de Haan (2010) for Switzerland, Weber and Matthews (2008) for the US, and Lenzen *et al.* (2006) for Australia, Denmark and Japan.[16] There is significant variation in the expenditure elasticities across consumption categories. Estimates vary from 0.32 for household energy to 6.20 for international

[16] Lenzen *et al.* (2006) estimate the expenditure elasticity for embodied energy rather than GHG emissions, although the two are closely related.

air travel. With the exception of meat, our expenditure elasticities are qualitatively consistent with the group-level expenditure demand elasticities from Khaled and Lattimore (2008) (i.e. household operations, which includes household energy, is expenditure inelastic; transport is expenditure elastic).[17]

The number of adults and the number of children both enter the regression positively, although the marginal effect is decreasing in the number of adults and the number of children. For a household with two adults and one child, adding an extra adult increases emissions by 13.2 percent, while adding an extra child increases emissions by 6.2 percent.[18] Controlling for the number of adults and children separately is important as they have different consumption bundles. For total emissions and emissions from meat, the marginal effect of adding an extra child is about half that of adding an extra adult. An extra adult and an extra child have similar effects on emissions from household energy. We find that households with more children have significantly lower emissions from air travel. We also find that children have no significant effect on emissions from transport fuels. Having an extra child does not appear to increase the amount that people drive, but will impact where they drive (e.g. school, sports practice, music lessons). Child-related driving may simply replace trips that were taken before a household had children.

We consider whether there are economies of scale in household size. We ask the question, "holding per capita expenditure constant, what effect does increasing household size have on household emissions?" Table 5 shows how emissions increase as the number of adults increases, holding per capita expenditure constant.[19] We find no evidence of economies of scale in household size. While the point estimates suggest a small reduction in emissions could be achieved by combining households, the 95 percent confidence intervals show these estimates are indistinguishable from the case where a 50 percent (100 percent) increase in household size increases household emissions by 50 percent (100 percent). We do find economies of scale for emissions from household energy, consistent with the results of Lenzen *et al.* (2006). This is offset by more than proportional increases in emissions from transport, due to the elastic response of transport emissions to the increases in household expenditure, suggesting that there is little to be gained from simply combining households.

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[17] The results from Khaled and Lattimore (2008) use the earlier version of the HES and the elasticities are estimated at the group level, i.e. food instead of meat. When we estimate these relationships at the group level, we find very similar elasticities to those reported in Khaled and Lattimore (2008).

[18] Both of these estimates are statistically significant at the 1% level.

[19] We focus on the number of adults for simplicity. While an extra child adds less to household emissions than an extra adult, this child will eventually grow up and remain in their family home, increasing the number of adults in that home, or move out and add an extra adult to another household, or establish a new household.

Household expenditure and size account for the majority of the explanatory power in the regressions; these two factors alone explain roughly 70 percent of the variation in total emissions. However, some interesting patterns emerge when looking at the other control variables. We find that emissions increase with age of the household head, all else being equal. This effect comes through most strongly in emissions from meat and household energy. We also find a north–south effect, with the colder South Island regions tending to have higher emissions than the North Island regions. Again, this effect is most apparent in emissions from household energy, leading us to hypothesise that this is a heating effect. We also find an "Auckland" effect in international air travel emissions. Auckland is home to the country's main international airport and to a large fraction of international immigrants. According to the 2013 Census, nearly 40 percent of people in Auckland were born overseas, compared to 25 percent for the country as a whole.[20] People of Asian descent have higher emissions from international air travel, plausibly because a significant fraction are first- or second-generation immigrants. These people may be more likely to travel to their home country. We also find a home-owner effect. Previous literature studying adoption of energy-efficient appliances has found that renters are less likely to own energy-efficient appliances (e.g. Davis 2010). We do not find evidence consistent with an energy-efficiency gap between home-owners and renters. We find a positive, statistically significant relationship between emissions and owning a home, and this effect comes through particularly in emissions from international air travel. We therefore hypothesise that we are picking up a wealth effect: home owners are simply wealthier.

[20] http://stats.govt.nz/Census/2013-census/profile-and-summary-reports/quickstats-about-a-place.aspx?request_value=13170&tabname=Culturaldiversity

Table 4: Household characteristics and household emissions – regression results

	(1) $\log(Total\ emissions)$ OLS	(2) $\log(Meat)$ Tobit	(3) $\log(HH\ energy)$ Tobit	(4) $\log(Trans.fuels)$ Tobit	(5) $\log(Dom.air)$ Tobit	(6) $\log(Int.air)$ Tobit
$\log(Expenditure)$	0.711***	1.109***	0.317***	1.446***	4.871***	6.206***
	(0.0116)	(0.130)	(0.0575)	(0.135)	(0.466)	(0.415)
$\#\ adults$	0.206***	0.738***	0.407***	1.080***	1.223	0.575
	(0.0222)	(0.192)	(0.125)	(0.183)	(0.813)	(0.684)
$\#\ adults^2$	-0.0184***	-0.0706**	-0.0605***	-0.105***	-0.219	-0.0964
	(0.00389)	(0.0311)	(0.0229)	(0.0260)	(0.139)	(0.109)
$\#\ children$	0.0900***	0.320**	0.361***	0.168	-2.336***	-2.367***
	(0.0129)	(0.131)	(0.0883)	(0.146)	(0.505)	(0.467)
$\#\ children^2$	-0.0115***	-0.0404	-0.0858***	-0.000833	0.330**	0.415***
	(0.00336)	(0.0315)	(0.0325)	(0.0444)	(0.138)	(0.119)
$North\ NI$	0.0590***	-0.157	0.468***	-0.261	-0.00447	-0.907
	(0.0169)	(0.183)	(0.0619)	(0.181)	(0.829)	(0.625)
$Wellington$	0.0692***	0.254	0.284***	-0.114	-2.571***	-1.454**
	(0.0157)	(0.170)	(0.104)	(0.185)	(0.868)	(0.680)
$Rest\ of\ NI$	0.0183	0.0351	0.450***	-0.787***	0.608	-1.213**
	(0.0149)	(0.159)	(0.0746)	(0.170)	(0.619)	(0.539)
$Canterbury$	0.0832***	0.331**	0.506***	-0.160	1.544**	-1.225**
	(0.0150)	(0.152)	(0.0596)	(0.165)	(0.651)	(0.581)
$Rest\ of\ SI$	0.113***	0.298*	0.583***	-0.444**	0.898	-3.040***
	(0.0147)	(0.156)	(0.0617)	(0.179)	(0.658)	(0.633)
$20s$	-0.112***	-1.258***	-0.612***	0.828***	-0.643	1.185
	(0.0253)	(0.254)	(0.114)	(0.280)	(1.095)	(0.966)
$30s$	-0.110***	-1.282***	-0.352***	0.619**	-2.088**	0.618
	(0.0246)	(0.244)	(0.1000)	(0.269)	(1.048)	(0.914)
$40s$	-0.0908***	-0.985***	-0.317***	0.613**	-2.437**	0.189
	(0.0217)	(0.234)	(0.0985)	(0.258)	(0.987)	(0.898)
$50s$	-0.00625	-0.563***	-0.0858	0.729***	-2.137**	0.664
	(0.0207)	(0.199)	(0.0852)	(0.247)	(0.949)	(0.849)
$60s$	0.0391**	-0.222	-0.0692	0.730***	-0.624	2.771***
	(0.0188)	(0.178)	(0.0744)	(0.246)	(0.906)	(0.785)
$High\ school$	0.00519	0.0858	0.0806	-0.221	1.320	1.448**
	(0.0158)	(0.172)	(0.0682)	(0.179)	(0.803)	(0.656)
$Post-school$	0.0149	-0.0235	0.0880	0.130	1.268	1.429**
	(0.0161)	(0.169)	(0.0619)	(0.176)	(0.805)	(0.653)

Bachelor degree	0.0302	-0.0843	-0.0274	0.0950	3.588***	3.067***
	(0.0207)	(0.218)	(0.0924)	(0.209)	(0.898)	(0.764)
Post − graduate	0.0132	-0.225	-0.130	-0.137	4.106***	2.272***
	(0.0214)	(0.231)	(0.0951)	(0.229)	(0.890)	(0.795)
Maori/Pacific	0.00344	-0.186	0.0262	0.533***	0.153	0.938
	(0.0202)	(0.214)	(0.101)	(0.189)	(1.003)	(0.765)
Asian	-0.0637***	-1.043***	-0.112	0.0412	-2.082**	2.951***
	(0.0228)	(0.272)	(0.101)	(0.206)	(0.921)	(0.680)
Other	-0.0398*	-0.138	-0.109	-0.363	1.853*	0.244
	(0.0234)	(0.278)	(0.114)	(0.333)	(1.020)	(1.015)
Social housing	0.127***	0.653***	-0.0192	-0.214	1.854	-1.471
	(0.0249)	(0.229)	(0.144)	(0.356)	(1.743)	(1.197)
Home owner	0.114***	-0.0274	0.0997	0.0901	0.0845	0.951*
	(0.0141)	(0.152)	(0.0657)	(0.145)	(0.574)	(0.516)
# of rooms	0.0127***	0.0390	0.0313*	-0.0628	-0.188	-0.0916
	(0.00350)	(0.0410)	(0.0167)	(0.0414)	(0.155)	(0.132)
Employed	0.0100	-0.219	0.0690	0.0274	0.836	1.152**
	(0.0131)	(0.138)	(0.0603)	(0.144)	(0.606)	(0.523)
Unemployed	-0.0265	0.00344	-0.296	0.189	2.408	-0.922
	(0.0364)	(0.337)	(0.217)	(0.379)	(1.647)	(1.652)
Constant	-5.453***	-6.159***	2.747***	-10.91***	-61.03***	-74.48***
	(0.110)	(1.228)	(0.549)	(1.281)	(4.469)	(4.027)
N	5,127	5,127	5,127	5,127	5,127	5,127
$\bar{R}^2$	0.763	-	-	-	-	-
Psuedo R^2	-	0.0188	0.0188	0.0247	0.0247	0.0291
Uncensored obs.	-	4461	4461	4992	4992	4221
Censored obs.	-	663	663	138	138	906

Notes: Robust standard errors are in parentheses. *, ** and *** denote statistical significance at the 1%, 5% and 10% level, respectively. The number of observations, uncensored observations, and censored observations have been randomly rounded to base 3 for confidentiality reasons. The number of censored and uncensored observations may not sum to total observations due to rounding. The omitted categories are: Auckland for region, 70-plus for age, no qualifications for education, New Zealand European for ethnicity, private rental for housing status, and not in the labour force for labour force status.

Table 5: Testing for economies of scale in household size

	Household 1	Household 2	Household 3
Expenditure (NZ$)	60,000	90,000	120,000
# adults	2	3	4
Emissions (t-CO_2eq)	15.2	22.7	30.1
		(20.6-24.8)	(28.0-32.2)
% difference in emissions from household 1		49.5%	98.0%
		(35.9%-63.0%)	(84.4%-111.5%)

Notes: 95% confidence intervals in parentheses. Values calculated by setting all other variables to 0.

3.3. Is consumer behaviour changing?

We now look for changes in consumer behaviour between the 2006/07 and 2012/13 waves of the HES. To test for such a change, we include a dummy variable for the 2012/13 survey wave in the regressions reported in Table 4. Table 6 presents the estimated coefficients on the survey dummy. We find that, after controlling for household expenditure, size and composition, and other characteristics, emissions are 4.6 percent lower in the 2012/13 survey than the 2006/07 survey. This represents a fall of approximately 1 t-CO_2eq for a two-adult household with NZ$80,000 of total expenditure.

While the point estimates on the survey dummies are negative for four of the five consumption sub-categories, it is statistically significant only in the regression for emissions from household energy. Controlling for household characteristics, emissions from household energy are estimated to be 10 percent lower in the 2012/13 survey. This result is consistent with the observed decline in total electricity consumed by residential customers since 2006 (Ministry of Business, Innovation and Employment 2014). Part of this decrease could be a price response: electricity prices increased by 38 percent between the surveys.[21] Using an estimate of the price elasticity of demand for electricity in New Zealand of -0.12 from Halliburton and Lermit (2011), 4.5 of the 10.4 percentage point reduction in emissions from household energy is consistent with a response to rising electricity prices. The remainder is consistent with gradual improvements in energy efficiency. A subsidy for home insulation was offered by the New Zealand government

[21] This estimate of the price increase represents an upper bound of the increase experienced by a household in the survey. This figure is calculated using the price change between the first quarter of the 2006/07 survey and the last quarter of the 2012/13 survey.

between the two surveys. The results of Grimes *et al.* (2012) suggest that the effects of the insulation scheme on electricity and metered energy use in general were negative though small.[22]

Table 6: Coefficient estimates for survey dummy in equation 1

Dependent variable	Survey dummy
$\log(Total\ emissions)$	-0.0459***
	(0.00969)
$\log(Meat)$	-0.0796
	(0.103)
$\log(HH\ energy)$	-0.104**
	(0.0444)
$\log(Trans.fuels)$	0.0274
	(0.110)
$\log(Dom.air)$	-0.348
	(0.431)
$\log(Int.air)$	-0.403
	(0.380)

Notes: Table A2 in Appendix 2 contains the full regression results. *** and ** denote statistical significance at the 1% and 5% levels, respectively.

While we find evidence consistent with a price response for household energy emissions, we find no such effect in emissions from transport fuels, despite a significant price increase between the surveys and similar estimates for the price elasticity of petrol demand (Kennedy and Wallis 2007).[23] This result is consistent with two effects: an increased preference for driving offset by a response to higher fuel prices. While we cannot rule out a price effect, our results are not consistent with a response to rising petrol prices, all else being equal.

Table 7 reports the estimated coefficients for the expenditure–survey dummy interactions.[24] Only the interaction effects are presented; the full regression results are reported in Table A2 in Appendix 2. This allows us to examine which household characteristics are associated with larger (smaller) reductions in emissions between surveys.

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[22] Part of the household energy reduction could also be due to differences in seasonal weather between the survey waves. A warmer winter would lead households to spend less on heating, for example.

[23] Petrol prices increased by 23 percent between the 2006/07 and 2012/13 surveys.

[24] We report only the results for the expenditure–survey dummy interactions in Table 7 as it is the main significant result. A small number of other interaction effects are statistically significant but, given the large number of estimated coefficients, this is to be expected.

Table 7: Coefficient estimates for expenditure, survey dummy interactions

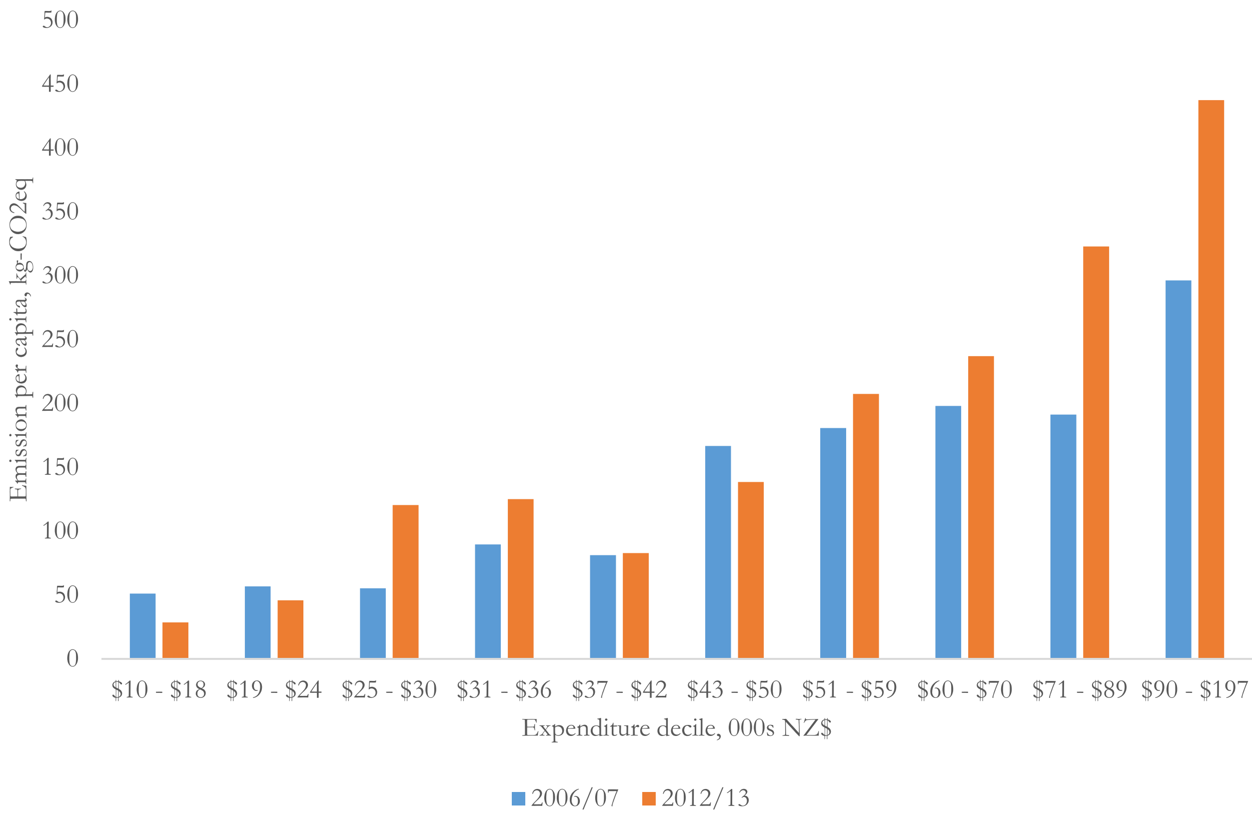
	$\log(Expenditure) \times Survey\ 12/13$
$\log(Total\ emissions)$	0.0463**
	(0.0232)
$\log(Meat)$	-0.124
	(0.201)
$\log(HH\ energy)$	0.0268
	(0.0946)
$\log(Trans.fuels)$	0.204
	(0.237)
$\log(Dom.air)$	0.964
	(0.789)
$\log(Int.air)$	1.517**
	(0.729)

Notes: Table A3 in Appendix 2 reports the full regression results. *** denotes statistical significance at the 1% level.

Table 8 shows a positive and significant interaction with expenditure. The result indicates that wealthier households had a smaller reduction in emissions between the 2006/07 and 2012/13 surveys.[25] This change is significant only for emissions from international air travel. The point estimate on the survey dummy in the regression explaining international air travel emissions is significant and negative; the interaction effect is significant and positive. The relative magnitude of the survey dummy and the interaction effect indicate that emissions from international air travel have increased for wealthier households. This is shown in Figure 4, which plots international air travel emissions by expenditure decile across the two surveys. International air travel emissions have increased for the top four expenditure deciles, with the largest increases occurring in the top two deciles.

[25] Emissions may have increased for the very wealthiest households.

Figure 3: Emissions from international air travel by expenditure decile ($000s)



4. Illustration of life-choice and consumption choice impacts

We now provide an illustration of how our model can be used to show the effects of different lifestyle choices on household emissions. Our simple illustration traces an individual through different life paths to examine how different choices affect emissions. Our starting point is a person, who we shall call Alex. Alex is in his early 20s, has a total expenditure (permanent income) of $25,000, has just completed a bachelor degree and lives alone.[26] Alex's consumption emissions are 6.6 t-CO_2eq. The first choice Alex faces is what career to enter and consequently how much to earn. We model two highly stylised life paths: one we call the "artist" track, and the other we call the "IT engineer" track. The track that Alex chooses in his 20s will define his lifetime income and also his lifetime emissions. If Alex decides to become an artist, we assume that there will be no change in his total household expenditure, meaning his household emissions have not changed since his student days. If Alex instead chooses to become an IT engineer, then

[26] Alex's emissions would be the same even if we assumed he didn't live alone. We found no evidence of economies of scale in household size. If Alex was sharing a house with people like him, emissions per adult would be approximately equal to household emissions if Alex lived alone.

his expenditure will be $85,000, 3.4 times more than in the base case. Emissions in the first step of the IT engineer track are 15.7 t-CO_2eq, or 2.4 times that in the artist track.

We then assume Alex gets married and faces the decision of whether or not to have kids. We assume that Alex marries someone with the same level of expenditure (permanent income), so we double household expenditure in Alex's household when the couple are in their 30s.[27] If they decide to have two children, this adds 1.8 t-CO_2eq of emissions to the household in the artist track and 4.3 t-CO_2eq in the IT engineer track.[28]

In the next life stage, Alex is in his 60s. We assume Alex's household is wealthier if the couple chose not to have children, meaning Alex and his partner were able to afford a house on the 'no kids' track.[29] If Alex and his partner have chosen to have children, they will now be grown up and will have left home; the children will be at the beginning of the choice tree at the "student" level. We assign the emissions of the children to Alex's household; the choice to have children in his 30s has created two new households as the children move out.

If Alex decides not to have children, the couple's household emissions increase slightly on both tracks between the time when they are in their 30s and in their 60s. The main driver of this is the wealth effect of owning a house. The largest difference is in the two tracks where Alex decides to have children. In these tracks, we assign the emissions for the two new households created when the children move out of Alex's household. We assume the children are at the beginning of the tree, so the amount we add is two times the "student" emissions. The decision to have children, or how many to have, is important as it creates new households in the future.

Figure 4 shows how emissions per adult evolve over time for the four different life paths that we model. Emissions per adult diverge slightly when Alex and his partner decide whether to have children. As the children grow up and leave home, the gap between the "2 kids" and "no kids" scenarios increases markedly. As a result of the significantly larger household expenditure, emissions per adult on the IT engineer track are always greater than emissions on the artist track.

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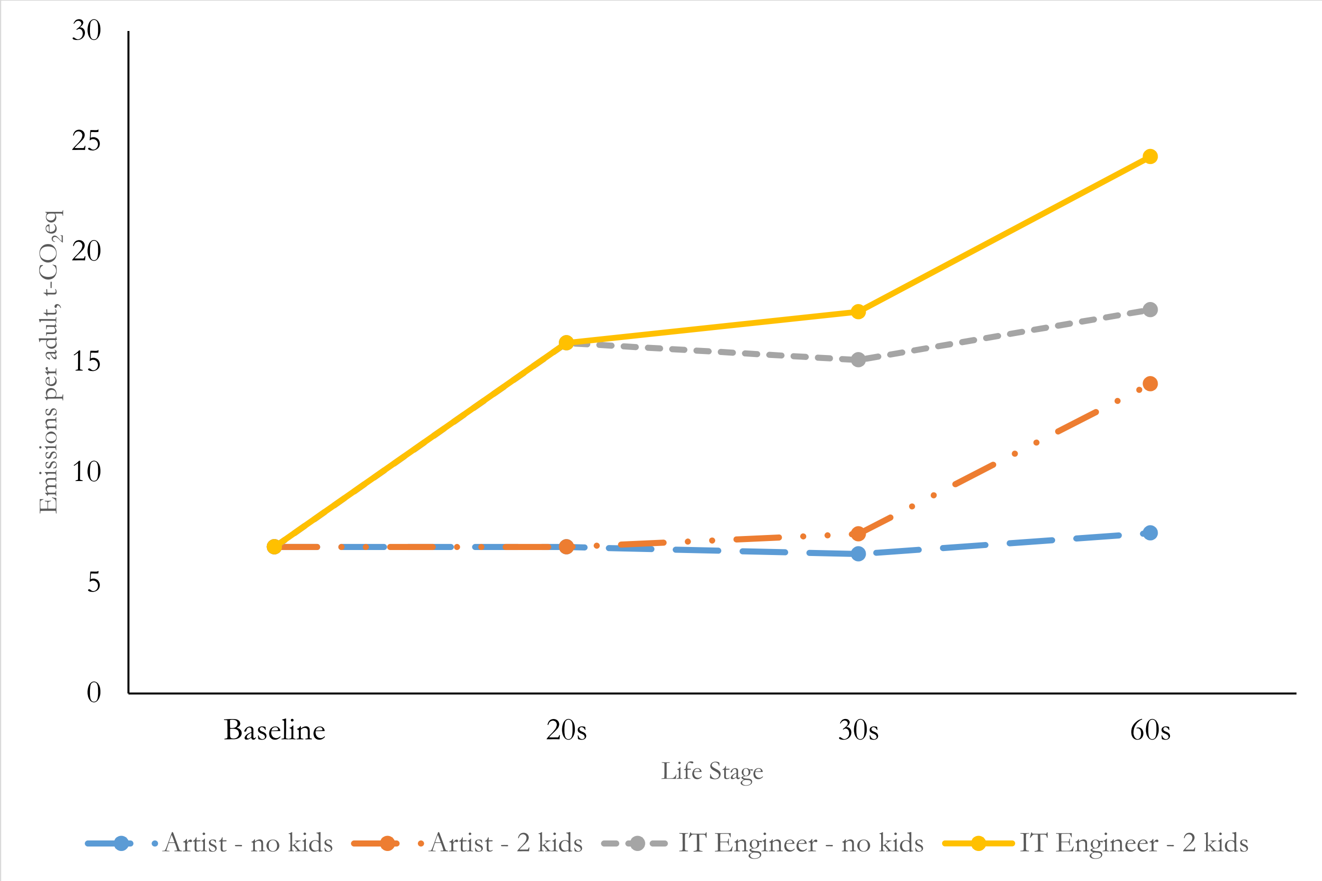
27 We are not necessarily assuming that Alex's partner always works. It could be the case that Alex, or his partner, experiences an increase in permanent income in their 30s, meaning the other does not have to work while maintaining total household expenditure.

28 This causes household emissions to double, but leaves emissions per adult unchanged.

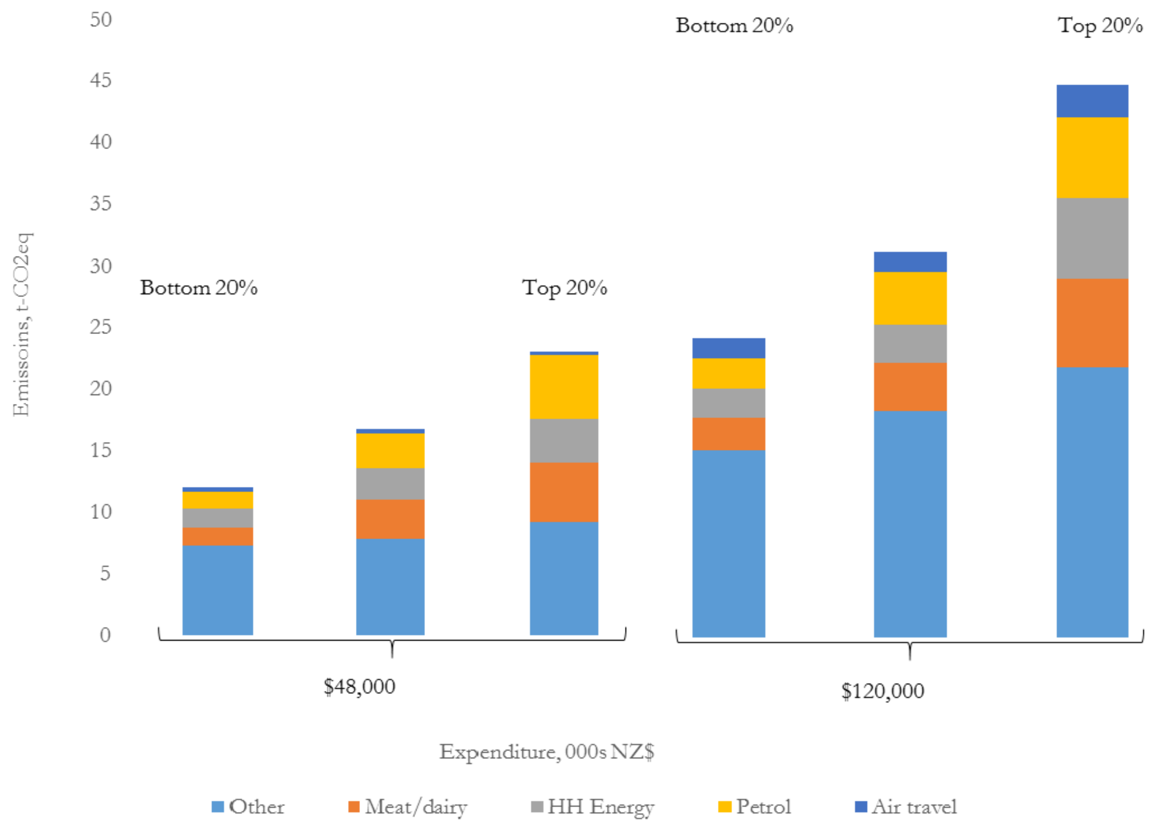
29 The money that would have been spent on children was instead spent on the mortgage.

Figure 4: Time paths of emissions per adult for each simulated life path



Consumption choices also have a large impact on household emissions. Figure 3 provides an illustration of the heterogeneity in emissions for two-adult households with different levels of expenditure. The figure shows average household emissions for two-adult households in the bottom 20%, middle 20%, and top 20% of emitting households within the 6th and 10th expenditure deciles. Household expenditure is set at the within-decile average: $48,000 for the 6th decile and $120,000 for the 10th decile. The variation in emissions comes from variation in expenditure shares and is not the result of an income effect within the deciles. The differences between the highest and lowest emitting households in each decile are 11.0 t-CO_2eq (23.0 vs. 12.0) and 20.1 t-CO_2eq (44.1 vs. 24.0), or almost double in both deciles.

Figure 5: Comparing emissions from the top, middle, and bottom 20% of emitting households for fixed income levels



A key driver of the within-decile differences are transport and diet choices. Table 4 shows the absolute and percentage differences in emissions for a subset of categories. Petrol is the largest contributor to the heterogeneity in the 6th income decile, with a 283% difference between the highest and lowest emitting households. In the 10th decile, this difference is 170%. Differences in diet are also important, with a 223% difference in meat/dairy emissions between the highest and lowest emitting households in the 6th decile and a 168% difference in the 10th.

Table 8: Absolute and percent differences between top and bottom 20% of emitting households by decile

	Meat/dairy	HH Energy	Petrol	Air Travel	Other
Difference between top and bottom 20%, 6th decile	3.31	1.96	3.84	-0.04	1.92
	223%	122%	283%	-12%	26%
Difference between top and bottom 20%, 10th decile	4.40	4.03	4.08	0.96	6.68
	168%	172%	170%	58%	45%

5. Conclusions

The purpose of all economic activity is the production of goods and services for final consumption. Economic activity requires energy, and energy use causes emissions. Production processes often involve chemical reactions, which are another important source of emissions. Consumers are not necessarily aware of the amount of energy or emissions that goes into the production of the goods and services they consume. Input–output analysis allows us to quantify the amount of energy and emissions embedded in products. Combined with information on household expenditure patterns, we are able to provide an estimate of emissions associated with a household's consumption bundle. This information is useful to households looking to reduce their environmental footprint, either through changing the types of goods they consume or by making different choices about jobs, family size and where to live. This information is also useful for policymakers who want to encourage changes in household behaviour that reduce emissions as part of general efforts to combat climate change.

We find that basic goods, such as food, transport and household energy, are relatively emissions intensive in terms of emissions per dollar spent. A dollar less expenditure in these categories will therefore have a relatively large effect on a household's total emissions. Our cross-section results show that the major factors explaining the emissions embodied in a household's consumption bundle are permanent household income (proxied by expenditure) and household composition. Consistent with other studies, we find that emissions increase less than proportionately with increases in expenditure. This is driven by increased demand for relatively less emissions-intensive services by higher-income households. We find large variation in expenditure elasticities between consumption sub-categories. Household energy is unresponsive to increases in expenditure, while transport, particularly air travel, is highly responsive.

We do not find evidence of economies of scale in household size while keeping per capita household expenditure constant, suggesting that combining households will not be an effective mitigation strategy in New Zealand. We find evidence of economies of scale for household energy, but this is offset by more than proportional increases in emissions from transport.

We find evidence of a small reduction in average household emissions between surveys, controlling for a rich set of household characteristics. This reduction is not due to a reduction in expenditure, nor is it due to improved production techniques. This overall reduction is partly explained by the reduction in emissions from household energy. About half of the observed reduction in household energy is consistent with a price response, while the rest could be due to general improvements in energy efficiency. Despite a significant price increase in transport fuels between surveys, there is no reduction in emissions from transport fuels. This reduction in average household emissions occurred during a period where we see very little growth in household incomes. It is likely that consumption emissions would have risen significantly if household incomes had grown or electricity and petrol prices had not increased. An extremely high carbon price would be required to generate the price increases we observed for electricity and petrol. Complementary policies may be needed to generate mitigation action by households.

We also find that the reduction in emissions over time is smaller for wealthier households. This result is driven in part by the increased use of international air travel by wealthier households.

We have demonstrated that households do have some control over their emissions. Households can reduce their current and future emissions by making different lifestyle and consumption choices e.g. taking the job that makes you happiest instead of richest, flying and driving less, eating less meat etc.

To our knowledge, this is the first study to look at whether households have made a systematic shift in their climate change-related consumption behaviour. We find no evidence that household preferences have systematically shifted towards greener products, although this does not preclude changes in behaviour that our methodology cannot capture. A combination of low income growth and higher prices for emissions-intensive goods are the likely drivers behind the small decline in emissions we observe.

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Appendix 1 – Calculating emissions from direct energy use and use of housing

Direct energy use

The carbon intensity vector from Romanos *et al.* (2014) does not properly separate fuel use by industry and households. Too much fuel was allocated to industry, resulting in the carbon intensities being too large. Also, it is not clear that the mapping from industry categories to consumption categories provides an accurate account of the emissions per dollar of spending of direct energy use. For these reasons, we have re-run the input-output model to correct these flaws.

We also made an adjustment to the emissions factor for the household use of electricity.[30] Electricity is represented by two sectors in the total requirements matrix of the IO tables: electricity generation and transmission and distribution. The previous emissions intensity for electricity was calculated using only the electricity generation sector, meaning that distribution and transmission costs (which accounted for nearly 40% of the residential electricity price in 2007) are not accounted for. This led us to overstate the emissions per dollar spent on electricity consumption.

In order to calculate the emissions intensity (t-CO2eq/$ spent) for direct household use of petrol, diesel, coal, gas, other oils, and electricity we added six new 'sectors' to the fuel requirements (F) and total requirements ($(I - A)^{-1}$) matrices to account for direct household use of petrol, diesel, coal, gas, other oils, and electricity. We set electricity use by industry to zero in the fuel requirements matrix for all but direct household use of electricity. Industrial use of electricity is captured in the total requirements matrix. Including electricity in the F-matrix means that we need to add an electricity emissions factor to the fuel emissions factors (e) matrix. We also need to know, for each fuel: the amount of each fuel (in PJs) consumed directly by households, and the retail price of the fuels.

For the electricity emissions factor, we used the 2007 average emissions factor for purchased electricity from Ministry for the Environment (2008). This is measured as kg-CO2eq/kilowatt hour (kwh). We converted this factor to t-CO2eq/PJ to be consistent with our other figures.

[30] Conversations with the Energy Efficiency and Conservation Authority (EECA) led us to conclude that the emissions factor for electricity was too high.

For the amount of each fuel consumed directly by households we used the following approach. For petrol and diesel, we first assigned the PJs used in the 'residential' sector in the Energy Data File to the appropriate 'direct use by households' sector'. This figure does not include the fuel used by households for personal travel. 53% of the petrol and 7% of the diesel consumed in New Zealand are consumed directly by households, according to the 2007 IO tables. We assume that these fuels are used exclusively for transport purposes. We reallocate petrol/diesel used in the 'national transport sector' in the Energy Data File to the 'direct use by households' and transport sectors based on their relative spending shares. The amount of coal, gas, and other oils consumed by households is provided by the Energy Data File - fuel use by the 'residential' sector. Residential electricity consumption in PJs for 2007 come from Ministry of Business, Innovation and Employment (2014b).

We obtained data on retail price per PJ for petrol diesel, gas, other oils, and electricity, from the Energy Data File. We could not find a retail price for coal. In order to construct the PJ/$ spent for coal, we used the final household consumption spending from the use table within the 2007 IO tables. Final household consumption spending is measured in basic prices (rather than purchaser or retail prices) so the figure is a lower bound for household spending on coal. This means our emissions factor for direct household use of coal will be too high. However, household consumption of coal is very minor (see Table A1), so this will have only a minor effect on our results. Table A1 contains the extra information collected and included in the $F, (I - A)^{-1}$, and e matrices, along with the calculated emissions intensity.

Table A1: Information collected for calculation of emissions intensity of direct household energy use

Fuel	PJ used by households	Emissions factor (t-CO_2e/PJ)	$/PJ (retail)	Total household spending	kg-CO_2eq/$
Petrol	92.6	65,900	$44,865,609		1.47
Diesel	21.0	68,694	$27,745,513		2.48
Gas	5.7	53,214	$34,922,622		1.52
Coal	0.6	88,200	-	$6,000,000	8.08
Other oils	3.9	66,118	$14,681,230		4.50
Electricity	44.8	49,778	$61,387,533		0.81

Use of housing

The ideal measure of emissions from housing would be an estimate of emissions from the use of housing, rather than housing construction. Most studies looking at embodied emissions in a household's consumption bundle do not consider emissions from the use of housing separately; these emissions are calculated using an expenditure approach (e.g. Hertwich and Peters 2009; Kerkhof *et al.* 2009; Lenzen *et al.* 2006). The expenditure approach uses current construction to calculate emissions and spreads these across households based on rent and mortgage repayments. The bulk of a mortgage payment is interest during the early stages of repayment, so using the mortgage principal repayment underestimates the emissions associated with the use of housing for households in the early stages of repayment. We adopt an approach similar to that of Monahan and Powell (2011) and Ochoa *et al.* (2002), which was used in the analysis of Jones and Kammen (2011, 2014). This methodology also uses input–output analysis to calculate the emissions embodied in construction materials and energy used, but expresses the emissions in terms of a physical characteristic of the building, e.g. t-CO_2eq/m^2. We approximate this approach as closely as possible given our data.

We first calculate the emissions associated with housing construction nationally each year. From our c-vector, we have the emissions associated with a dollar of output in the residential construction sector. As an estimate for the dollar amount of residential construction, we use the long-run average of gross fixed capital formation of residential buildings from the System of National Accounts.[31, 32] Using the long-run average means we dampen the effects of construction booms on our measure of national construction emissions.[33] Multiplying our value of emissions per dollar of output in residential construction by the gross fixed capital formation of residential buildings gives us a figure for the emissions associated with construction nationally each year.

We next approximate the total number of new residential dwellings constructed per year. For this, we take the long-run average change in the number of private dwellings.[34] We distribute national annual construction emissions across households based on the number of rooms in the house; this is the only measure of the physical size of the house available to us in the HES data. To convert the total number of houses constructed each year into the total number of rooms, we multiply the number of houses constructed by the average number of rooms per household in

[31] www.stats.govt.nz/infoshare, table reference SND160AA.
[32] This includes expenditure on altering and maintaining residential buildings.
[33] We do this for all variables that provide a measure of construction activity.
[34] www.stats.govt.nz/infoshare, table reference DDE005AA.

the HES, which is equal to six. Dividing total construction emissions by the total number of rooms constructed gives us an estimate of the emissions associated with the construction of a room. We allocate these emissions evenly across the lifetime of a house, which we take from the Inland Revenue Department's depreciation schedules as 50 years (Inland Revenue Department 2011).

Finally, we multiply our estimate of emissions per room per year by the number of rooms in each household to calculate the annual emissions from housing construction. Our approach is summarised in the equation:

$$GHG_{i,h} = \frac{c_h \cdot Residential\ investment}{\#\ of\ new\ dwellings \cdot avg.rooms \cdot 50} \cdot \#\ rooms_i$$

Where i denotes household and h denotes emissions from housing construction. This measure gives a better indication of the emissions associated with the use of housing than the simple expenditure approach based on mortgage principal and rent payments. Use of housing accounts for a relatively small fraction of total emissions and emissions from household utilities. Changes in the assumptions used in this calculation will have a relatively minor effect on our estimate of total household emissions.

Appendix 2 – Full regression tables

Table A2: Full regression results for tests of level shift

	(1)	(2)	(3)	(4)	(5)	(6)
	$\log(Total\ emissions)$	$\log(Meat)$	$\log(HH\ energy)$	$\log(Trans.fuels)$	$\log(Dom.air)$	$\log(Int.air)$
	OLS	Tobit	Tobit	Tobit	Tobit	Tobit
$Survey\ 12/13$	-0.0459***	-0.0796	-0.104**	0.0274	-0.348	-0.403
	(0.00969)	(0.103)	(0.0444)	(0.110)	(0.431)	(0.380)
$\log(Expenditure)$	0.713***	1.111***	0.320***	1.445***	4.876***	6.215***
	(0.0117)	(0.130)	(0.0574)	(0.135)	(0.464)	(0.415)
$\#\ adults$	0.204***	0.736***	0.404***	1.080***	1.216	0.554
	(0.0223)	(0.192)	(0.125)	(0.183)	(0.813)	(0.684)
$\#\ adults^2$	-0.0182***	-0.0702**	-0.0599***	-0.105***	-0.217	-0.0978
	(0.00390)	(0.0311)	(0.0229)	(0.0259)	(0.139)	(0.117)
$\#\ children$	0.0901***	0.320**	0.361***	0.168	-2.335***	-2.360***
	(0.0129)	(0.131)	(0.0889)	(0.146)	(0.504)	(0.467)
$\#\ children^2$	-0.0114***	-0.0403	-0.0856***	-0.000862	0.332**	0.415***
	(0.00336)	(0.0315)	(0.0328)	(0.0444)	(0.138)	(0.119)
$North\ NI$	0.0585***	-0.158	0.467***	-0.260	-0.00198	-0.904
	(0.0168)	(0.183)	(0.0619)	(0.181)	(0.827)	(0.626)
$Wellington$	0.0684***	0.253	0.282***	-0.114	-2.570***	-1.464**
	(0.0157)	(0.170)	(0.103)	(0.185)	(0.867)	(0.680)
$Rest\ of\ NI$	0.0175	0.0336	0.448***	-0.786***	0.611	-1.222**
	(0.0147)	(0.159)	(0.0746)	(0.170)	(0.618)	(0.539)
$Canterbury$	0.0832***	0.331**	0.506***	-0.160	1.553**	-1.230**

	(0.0149)	(0.152)	(0.0593)	(0.165)	(0.651)	(0.581)
$Rest\ of\ SI$	0.113***	0.298*	0.583***	-0.444**	0.903	-3.048***
	(0.0147)	(0.156)	(0.0616)	(0.179)	(0.657)	(0.632)
$20s$	-0.118***	-1.268***	-0.625***	0.832***	-0.708	1.126
	(0.0255)	(0.254)	(0.115)	(0.282)	(1.104)	(0.971)
$30s$	-0.118***	-1.296***	-0.369***	0.623**	-2.156**	0.548
	(0.0246)	(0.244)	(0.0995)	(0.271)	(1.057)	(0.919)
$40s$	-0.0965***	-0.994***	-0.330***	0.617**	-2.485**	0.140
	(0.0217)	(0.234)	(0.0983)	(0.260)	(0.992)	(0.901)
$50s$	-0.00962	-0.569***	-0.0934	0.731***	-2.185**	0.628
	(0.0207)	(0.199)	(0.0852)	(0.248)	(0.954)	(0.849)
$60s$	0.0392**	-0.222	-0.0690	0.730***	-0.624	2.777***
	(0.0188)	(0.178)	(0.0744)	(0.246)	(0.903)	(0.784)
$High\ school$	0.00534	0.0860	0.0809	-0.221	1.334*	1.457**
	(0.0157)	(0.172)	(0.0685)	(0.179)	(0.801)	(0.656)
$Post-school$	0.0158	-0.0218	0.0902	0.129	1.276	1.442**
	(0.0161)	(0.169)	(0.0624)	(0.176)	(0.802)	(0.652)
$Bachelor\ degree$	0.0336	-0.0784	-0.0197	0.0928	3.621***	3.101***
	(0.0206)	(0.217)	(0.0925)	(0.210)	(0.898)	(0.765)
$Post-graduate$	0.0152	-0.222	-0.126	-0.139	4.122***	2.297***
	(0.0213)	(0.231)	(0.0969)	(0.229)	(0.888)	(0.796)
$Maori/Pacific$	0.00280	-0.187	0.0247	0.534***	0.147	0.928
	(0.0200)	(0.214)	(0.101)	(0.189)	(0.997)	(0.766)
$Asian$	-0.0614***	-1.039***	-0.107	0.0399	-2.055**	2.973***
	(0.0229)	(0.272)	(0.101)	(0.206)	(0.920)	(0.683)
$Other$	-0.0458**	-0.148	-0.122	-0.360	1.809*	0.176

	(0.0232)	(0.278)	(0.116)	(0.334)	(1.023)	(1.017)
Social housing	0.125***	0.649***	-0.0247	-0.213	1.821	-1.483
	(0.0250)	(0.229)	(0.145)	(0.355)	(1.725)	(1.196)
Home owner	0.109***	-0.0355	0.0891	0.0929	0.0496	0.913*
	(0.0141)	(0.151)	(0.0666)	(0.145)	(0.573)	(0.516)
# of rooms	0.0133***	0.0400	0.0326*	-0.0631	-0.183	-0.0879
	(0.00348)	(0.0409)	(0.0167)	(0.0413)	(0.154)	(0.132)
Employed	0.0111	-0.217	0.0715	0.0267	0.851	1.161**
	(0.0131)	(0.138)	(0.0603)	(0.144)	(0.606)	(0.524)
Unemployed	-0.0170	0.0201	-0.274	0.183	2.471	-0.869
	(0.0360)	(0.337)	(0.217)	(0.379)	(1.647)	(1.650)
Constant	-5.442***	-6.139***	2.772***	-10.91***	-60.89***	-74.32***
	(0.110)	(1.230)	(0.550)	(1.282)	(4.479)	(4.033)
N	5,127	5,127	5,127	5,127	5,127	5,127
$\bar{R}^2$	0.763	-	-	-	-	-
Psuedo R^2	-	0.0189	0.0250	0.0291	0.0539	0.0666
Uncensored obs.	-	4,461	4,992	4,221	762	1,218
Censored obs.	-	663	138	906	4,362	3,906

Notes: See notes to Table 4.

Table A3: Full regression results for tests of changes in slope coefficients

	(1) $\log(Total\ emissions)$ OLS	(2) $\log(Meat)$ Tobit	(3) $\log(HH\ energy)$ Tobit	(4) $\log(Trans.fuels)$ Tobit	(5) $\log(Dom.air)$ Tobit	(6) $\log(Int.air)$ Tobit
$\log(Expenditure)$	0.691***	1.101***	0.337***	1.347***	4.160***	5.366***
	(0.0170)	(0.137)	(0.0659)	(0.174)	(0.574)	(0.509)
$Survey$ 12/13	-0.439**	2.115	-0.360	-0.923	-11.41	-14.10**
	(0.220)	(1.880)	(0.884)	(2.253)	(7.506)	(7.125)
$\log(Expenditure) \times Survey$ 12/13	0.0463**	-0.124	0.0268	0.204	0.964	1.517**
	(0.0232)	(0.201)	(0.0946)	(0.237)	(0.789)	(0.729)
$\#\ adults$	0.214***	0.896***	0.264*	1.215***	-1.826	0.409
	(0.0305)	(0.303)	(0.141)	(0.343)	(1.219)	(1.091)
$\#\ adults \times Survey$ 12/13	-0.0102	-0.0249	0.232	-0.322	2.093	-1.414
	(0.0416)	(0.362)	(0.208)	(0.398)	(1.537)	(1.262)
$\#\ adults^2$	-0.0210***	-0.116**	-0.0318	-0.130**	0.276	-0.155
	(0.00530)	(0.0572)	(0.0263)	(0.0595)	(0.229)	(0.200)
$\#\ adults^2 \times Survey$ 12/13	0.00346	0.0374	-0.0429	0.0412	-0.467*	0.258
	(0.00711)	(0.0655)	(0.0389)	(0.0652)	(0.283)	(0.218)
$\#\ children$	0.0930***	0.244	0.483***	0.193	-1.016	-2.255***
	(0.0196)	(0.167)	(0.114)	(0.183)	(0.950)	(0.654)
$\#\ children \times Survey$ 12/13	-0.0113	0.152	-0.327**	-0.0343	-1.425	-0.422
	(0.0263)	(0.217)	(0.130)	(0.245)	(1.085)	(0.814)
$\#\ children^2$	-0.00929*	0.00479	-0.136***	0.0364	-0.210	0.497**
	(0.00560)	(0.0469)	(0.0438)	(0.0481)	(0.373)	(0.198)

$\# \, children^2 \times Survey\ 12/13$	-0.00257	-0.0655	0.113**	-0.0617	0.647*	0.000585
	(0.00713)	(0.0564)	(0.0460)	(0.0670)	(0.390)	(0.225)
$North\ NI$	0.0402	0.124	0.453***	-0.274	-1.465	-1.054
	(0.0245)	(0.220)	(0.0962)	(0.259)	(1.041)	(0.825)
$North\ NI \times Survey\ 12/13$	0.0367	-0.310	-0.0130	0.0694	1.750	-0.809
	(0.0333)	(0.295)	(0.130)	(0.332)	(1.371)	(1.115)
$Wellington$	0.0520**	0.225	0.453***	0.139	-1.988*	-0.535
	(0.0223)	(0.232)	(0.119)	(0.273)	(1.153)	(0.900)
$Wellington \times Survey\ 12/13$	0.0300	0.000507	-0.204	-0.311	1.797	-0.627
	(0.0315)	(0.304)	(0.174)	(0.361)	(1.566)	(1.241)
$Rest\ of\ NI$	0.0358*	0.303	0.484***	-0.540**	2.362***	0.951
	(0.0207)	(0.209)	(0.0995)	(0.260)	(0.825)	(0.738)
$Rest\ of\ NI \times Survey\ 12/13$	-0.0348	-0.432	0.00137	-0.130	1.683	-1.002
	(0.0291)	(0.280)	(0.132)	(0.333)	(1.117)	(0.988)
$Canterbury$	0.0693***	0.743***	0.586***	-0.0587	2.358***	0.789
	(0.0217)	(0.190)	(0.0914)	(0.239)	(0.829)	(0.732)
$Canterbury \times Survey\ 12/13$	0.0278	-0.718***	-0.187	-0.0484	1.595	-1.485
	(0.0299)	(0.267)	(0.126)	(0.314)	(1.139)	(1.008)
$Rest\ of\ SI$	0.0964***	0.632***	0.641***	-0.198	3.394***	-0.399
	(0.0211)	(0.189)	(0.0938)	(0.255)	(0.819)	(0.774)
$Rest\ of\ SI \times Survey\ 12/13$	0.0310	-0.576**	-0.132	-0.119	0.938	-0.735
	(0.0293)	(0.264)	(0.132)	(0.337)	(1.125)	(1.066)
$20s$	-0.101***	-1.546***	-0.473***	0.848**	-0.505	-0.604
	(0.0376)	(0.299)	(0.152)	(0.399)	(1.285)	(1.213)
$20s \times Survey\ 12/13$	-0.0338	0.501	-0.0117	-0.463	-0.444	0.898
	(0.0500)	(0.403)	(0.212)	(0.507)	(1.697)	(1.649)

$30s$	-0.0826**	-1.417***	-0.291**	0.593	-2.682**	-1.474
	(0.0380)	(0.268)	(0.129)	(0.383)	(1.247)	(1.122)
$30s \times Survey\ 12/13$	-0.0682	0.387	0.0417	-0.371	0.635	2.191
	(0.0494)	(0.384)	(0.175)	(0.491)	(1.645)	(1.555)
$40s$	-0.0647*	-1.059***	-0.370***	0.813**	-2.804**	-1.539
	(0.0340)	(0.253)	(0.129)	(0.363)	(1.187)	(1.101)
$40s \times Survey\ 12/13$	-0.0540	0.525	0.191	-0.664	1.189	2.482
	(0.0438)	(0.350)	(0.169)	(0.466)	(1.546)	(1.512)
$50s$	0.0276	-0.617***	-0.00185	0.724**	-1.875*	-0.862
	(0.0331)	(0.225)	(0.114)	(0.353)	(1.130)	(1.047)
$50s \times Survey\ 12/13$	-0.0695*	0.104	-0.110	-0.387	-0.471	1.943
	(0.0421)	(0.321)	(0.153)	(0.445)	(1.481)	(1.418)
$60s$	0.0923***	-0.175	0.0501	0.873**	-0.184	1.458
	(0.0291)	(0.211)	(0.0963)	(0.348)	(1.069)	(1.006)
$60s \times Survey\ 12/13$	-0.101***	-0.0844	-0.178	-0.568	-0.210	1.337
	(0.0377)	(0.285)	(0.127)	(0.437)	(1.359)	(1.328)
$High\ school$	0.0177	0.0786	-0.243	-0.226	2.025**	1.076
	(0.0227)	(0.0907)	(0.242)	(0.246)	(0.906)	(0.808)
$High\ school \times Survey\ 12/13$	-0.0252	-0.417*	-0.0871	0.152	-0.529	0.0619
	(0.0311)	(0.250)	(0.123)	(0.330)	(1.221)	(1.123)
$Post-school$	0.0314	0.0955	0.0942	-0.115	2.203**	1.483*
	(0.0240)	(0.181)	(0.0868)	(0.242)	(0.896)	(0.795)
$Post-school \times Survey\ 12/13$	-0.0335	-0.296	-0.131	0.455	-0.688	-0.607
	(0.0319)	(0.245)	(0.117)	(0.325)	(1.209)	(1.111)
$Bachelor\ degree$	0.0548*	-0.106	-0.0245	-0.219	3.965***	3.558***
	(0.0323)	(0.254)	(0.123)	(0.305)	(1.104)	(0.969)

$Bachelor\ degree \times Survey\ 12/13$	-0.0426	-0.291	-0.208	0.478	-0.0391	-1.592
	(0.0414)	(0.338)	(0.164)	(0.394)	(1.433)	(1.305)
$Postgrad$	0.0316	-0.233	0.109	-0.413	4.641***	2.570**
	(0.0298)	(0.271)	(0.125)	(0.327)	(1.063)	(1.014)
$Post-graduate \times Survey\ 12/13$	-0.0390	-0.464	-0.279	0.691	-0.979	-0.393
	(0.0415)	(0.367)	(0.172)	(0.423)	(1.445)	(1.370)
$Maori/Pacific$	0.0122	-0.109	0.00110	0.239	-0.967	0.651
	(0.0295)	(0.261)	(0.147)	(0.287)	(1.254)	(0.957)
$Maori/Pacific \times Survey\ 12/13$	-0.0236	-0.112	0.0407	0.347	0.753	0.0210
	(0.0396)	(0.358)	(0.183)	(0.366)	(1.654)	(1.346)
$Asian$	-0.108***	-1.021***	0.183	0.348	-3.922***	1.984**
	(0.0321)	(0.330)	(0.119)	(0.277)	(1.491)	(0.975)
$Asian \times Survey\ 12/13$	0.0844*	0.239	-0.292	-0.400	3.779**	1.849
	(0.0448)	(0.435)	(0.181)	(0.367)	(1.787)	(1.230)
$Other$	-0.0120	-0.208	-0.185	-0.378	0.349	1.498
	(0.0448)	(0.311)	(0.154)	(0.384)	(1.169)	(1.061)
$Other \times Survey\ 12/13$	-0.0367	0.0400	0.316*	0.0467	1.961	-1.701
	(0.0437)	(0.458)	(0.180)	(0.586)	(1.669)	(1.798)
$Social\ housing$	0.0989***	0.277	0.0732	-0.363	1.450	-0.236
	(0.0339)	(0.329)	(0.171)	(0.397)	(1.504)	(1.445)
$Social\ housing \times Survey\ 12/13$	0.0514	0.0340	0.173	0.803	-3.030	-1.725
	(0.0481)	(0.453)	(0.230)	(0.526)	(2.243)	(2.082)
$Home\ owner$	0.0884***	-0.203	0.240***	-0.167	0.595	1.125*
	(0.0206)	(0.181)	(0.0870)	(0.205)	(0.751)	(0.663)
$Home\ owner \times Survey\ 12/13$	0.0362	0.421*	-0.102	0.165	-0.458	-0.204
	(0.0279)	(0.239)	(0.115)	(0.267)	(0.996)	(0.893)

$\# rooms$	0.0177***	0.0613	0.0513**	-0.00709	0.00321	-0.146
	(0.00538)	(0.0454)	(0.0249)	(0.0575)	(0.178)	(0.169)
$\# rooms \times Survey\ 12/13$	-0.00811	-0.141**	0.00329	-0.101	-0.0718	-0.0417
	(0.00693)	(0.0631)	(0.0310)	(0.0758)	(0.239)	(0.228)
$Employed$	0.00883	-0.151	0.0204	0.0436	1.127	1.703***
	(0.0185)	(0.153)	(0.0804)	(0.195)	(0.751)	(0.653)
$Employed \times Survey\ 12/13$	0.00298	-0.0374	-0.0291	0.163	-1.244	-0.980
	(0.0259)	(0.218)	(0.109)	(0.260)	(0.974)	(0.893)
$Unemployed$	0.0157	-0.689	-0.389	0.194	3.480	0.569
	(0.0463)	(0.655)	(0.395)	(0.572)	(2.138)	(2.258)
$Unemployed \times Survey\ 12/13$	-0.0338	0.686	0.0596	0.317	-3.335	-2.778
	(0.0666)	(0.758)	(0.462)	(0.696)	(2.867)	(2.839)
$Constant$	-5.262***	-6.322***	2.404***	-10.36***	-52.92***	-64.54***
	(0.158)	(1.280)	(0.620)	(1.659)	(5.398)	(4.899)
N	5,127	5,127	5,127	5,127	5,127	5,127
$\bar{R}^2$	0.764	-	-	-	-	-
$Psuedo\ R^2$	-	0.0192	0.0303	0.0266	0.0626	0.0591
$Uncensored\ obs.$	-	4,461	4,992	4,221	762	1,218
$Censored\ obs.$	-	663	138	906	4,362	3,906

Notes: See notes to Table 4.

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