Who's Going Green? Decomposing the Change in Household Consumption Emissions 2006 - 2012

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Abstract

We update the analysis of Allan et al. (2015) and re-examine whether New Zealand households have become greener consumers using newly available data. We combine input-output data from 2006 and 2012 with detailed data on household consumption from the 2006 and 2012 Household Economic Surveys (HES) to calculate the greenhouse gas emissions embodied in household consumption. We confirm many of our previous findings; that emissions increase less than proportionately with expenditure, and that there is significant variation in expenditure elasticities across consumption categories. We test for a change in household emissions over time and decompose this change into improvements in production efficiency and changes in households. We find that average household emissions fell by 11% between 2006 and 2012. We attribute 1.7 percentage points of this decrease to changes in households, with the remaining 9.3 percentage points from changes in emissions intensities. The majority of the change due to households is a result of changes in household behaviour rather than a change in household characteristics. Emissions from household energy fell markedly between 2006 and 2012, driven by a reduction in the emissions intensity of electricity and a decrease in household electricity consumption.

JEL codes

Q56; Q57; D12; Q54; D57

Keywords

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

Summary haiku

Power, flying, meat.
Producers' emissions are
improving. Your turn.

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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 update the analysis of Allan et al. (2015) using newly available input-output data (IO) for 2012/13.[1] We further improve our calculation of emissions intensities and calculate product emissions intensities for 2006 and 2012. We re-examine the relationship between emissions and household characteristics using our updated data. We estimate the total change in household emissions between 2006 and 2012 and decompose this change into improvements in production efficiency and changes in households. We further decompose the change in emissions from differences in households into the change due to differences in household characteristics and the change in household behaviour. Decomposing the change in emissions into improvements in production efficiency, changes in household behaviour, and changes in household characteristics is the key contribution of this paper. As far as we are aware, we are the first to provide this type of decomposition of household emissions within an IO framework.

A growing literature estimates consumption-based emissions accounts using environmental input-output (EIO) 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; Peters and Hertwich 2006; Caron et al. 2017, 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

[1] Much of the introduction and literature review is borrowed from Allan et al. (2015)

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.

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 over the period 1984-2002. 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 that, even holding production technology constant, US EECs have been shifting down over time.[2] This reflects 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 6.5 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 highly sensitive to increases in expenditure.

[2] Levinson and O'Brien (2015) did have data on changes in emissions intensity over time, but were interested in isolating the effects of changes in household behaviour.

Household size has a positive effect on emissions and we find some 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. Emissions tend to decrease with education. This is driven by differences in diet between more educated and less educated households, but this is partially offset by higher emissions from air travel for more educated households. Homeowners have lower emissions on average, but this is not driven by home owners having more energy efficient homes, as we might expect given results on the adoption of energy efficient appliances (e.g. Davis 2010). This result is driven in part by home owners having lower transport emissions.

Average household emissions fell by approximately 11% between 2006 and 2012. We can attribute 1.7 percentage points of this decrease to changes in households, with the remainder coming from improvements in product emissions intensities. Nearly 2/3 of the decrease we attribute to changes in households is the result of a change in household behaviour towards consuming less emissions-intensive goods. Emissions from household energy fell by 33% between the surveys. 10 percentage points of this decrease can be attributed to households, with the remainder due to the reduction in the emissions intensity of electricity. Offsetting this decrease is an increase in emissions from transport fuels, driven by an increase in the petrol emissions factor and an increase in driving by households.

Our finding that changes in the emissions intensity of output explains most of the decline in emissions we observe is consistent with the findings of Shapiro and Walker (2015) for the US. They found that the fall in US pollution emissions is almost entirely explained by improvements in the pollution per unit of output between 1990 and 2008. Changes in consumer preferences played only a small part in the decline of US emissions between 1990 and 2000. After 2000, US household consumption patterns actually switched to more emissions intensive goods.

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 concludes.

2 Data and methods

2.1 Calculating emissions intensities

We make modifications to the carbon intensity vector (c-vector) used in Allan et al. (2015) and Romanos et al. (2014). We update the vector of fuel emissions intensities, fuel use by industry, and refine the allocation of agricultural process emissions across industries. We use the same data sources and methods to construct c-vectors for both 2006 and 2012. Our input-output model is described by the simple equation

$$\boldsymbol{c_t} = \boldsymbol{e_t}\boldsymbol{F_t}(\boldsymbol{I} - \boldsymbol{A})_t^{\boldsymbol{-1}} \tag{1}$$

where $\boldsymbol{c_t}$ is a 1 x n vector of emissions intensities, measured as tonnes of carbon dioxide equivalent per dollar of gross output (t-CO_2e/$) for year t, $\boldsymbol{e_t}$ is a 1 x k vector of fuel emissions factors, measured as t-CO_2e per petajoule (PJ) of fuel, $\boldsymbol{F_t}$ is a k x n matrix of industry fuel requirements, measured as PJ per dollar of output, and $(\boldsymbol{I} - \boldsymbol{A})_{\boldsymbol{t}}^{-\mathbf{1}}$ is the n x n total requirements matrix from the input-output tables.[3] Entries in this matrix show how much output is required from each industry for industry j to produce another dollar of output.

2.1.1 Emissions intensities

Fuel emissions intensities are taken from Ministry of Business, Innovation and Employment (2016a). The fuels we are interested in are petrol, diesel, coal, gas, other oils, and electricity. Romanos et al. (2014) used an earlier version of this dataset to calculate the original c-vector. Minor changes were made to the historic data in the latest version of the data. To ensure the fuel emissions factors in both years come from the same data vintage, we replace the old emissions factors used by Romanos et al. (2014) with the new estimates. We take the 2006 and 2012 values of the fuel emissions factors. These are reported on a calendar year basis. Taking the 2006 and 2012 values ensures we maximise the time overlap between our emissions factor data and the input-output data.

2.1.2 Fuel use by industry

Fuel use by industry is taken from Ministry of Business, Innovation and Employment (2016b). These tables contain quarterly data on the consumption (in PJ) of coal, gas, oil (petrol, diesel, and other oil products), and electricity for broad industry categories. The data used in Romanos et al. (2014) was available only on calendar year basis. The quarterly data allows us to exactly match the period covered by the input-output tables, which are both on March years. We construct the $\boldsymbol{F_t}$ matrices in the same way as Romanos et al. (2014). We map the broad industry categories in the fuel consumption data to the industry categories in the IO tables, and allocate fuel across IO industries based on their share of (broad) industry fuel spending from the IO tables. We then divide IO industry fuel use by each industry's total gross output from the IO tables to calculate PJ of each fuel used per dollar of gross output.

2.1.3 Process emissions

Process emissions occur as a result of chemical reactions during the production process and not from the direct combustion of fossil fuels. Process emissions are very important in New Zealand, contributing 55% of New Zealand's emissions in 2014 (Ministry for the Environment 2016a). Biological emissions from agriculture contributed 49% to total emissions. Most of this is methane (CH_4) from enteric fermentation, nitrous oxide (N_2O) from agricultural soils, and CO_2 from the production of chemicals, cement, steel, and aluminium.[4]

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[3] We refer to year end March 2007 as 2006 and year end March 2013 to 2012, so t is either 2006 or 2012.
[4] We do not include PFCs from aluminium production.

We treat process emissions in the same way as Romanos et al. (2014). Process emissions are treated as a 'fuel'.[5] Total process emissions from each source are added to the $\boldsymbol{e_t}$ vectors and these are split across sectors in the $\boldsymbol{F_t}$ matrices. We have updated the numbers for total process emissions and refined the splitting of agricultural emissions across industries.

Romanos et al. (2014) used Ministry for the Environment (2010) as their source for process emissions. Methods for calculating emissions evolve over time, meaning that the process emissions calculated for 2012 in the latest Greenhouse Gas Inventory report were done using different methods. We therefore update the 2006 process emissions to those from Ministry for the Environment (2016b). These are the Common Reporting Framework tables, which recalculate emissions for each previous year using consistent methods. This ensures the process emissions in 2006 and 2012 are comparable.

Romanos et al. (2014) used 100-year global warming potentials (GWP) from IPCC (1996) to convert non-CO_2 gases to carbon-dioxide equivalent (CO_2e). We use updated global warming potentials from IPCC (2014) to convert non-CO_2 gases to CO_2e.[6] The 100-year GWP for methane increased substantially between the two reports, from 25 to 34. The GWP for nitrous oxide has hardly changed.

We make no changes to the allocation of process emissions from metals, chemicals, or minerals. These remain allocated wholly to the primary metal and metal product manufacturing (metals), basic chemical and basic polymer manufacturing (chemicals), and non-metallic mineral production manufacturing (minerals) sectors. We do change the allocation of methane and nitrous oxide across agricultural sectors. Methane was previously allocated 50/50 between the sheep, beef cattle and grain farming sector and the dairy cattle farming sector. We allocate methane across sectors using the share of methane emissions from different animals as reported in Ministry for the Environment (2016b). 35% (45%) of methane emissions are allocated to the dairy cattle farming sector in 2006 (2012), 62% (53%) to the sheep, beef, cattle and grain farming sector, and 3% (2%) to the poultry, deer, and other livestock farming sector.

Nitrous oxide emissions are separated by source in Ministry for the Environment (2016b). These are emissions from animal production (oxidisation of nitrogen expelled in urine and excreta), direct application of nitrogen (adding nitrogen-based fertilisers or manure), and indirect (oxidisation of nitrogen in soils or waterways). We assign indirect nitrous oxide emissions and emissions from animal production across sectors using the same weights that we used for methane. Emissions from direct application of nitrogen are allocated across the horticulture and fruit growing and livestock sectors based on their share of agricultural fertiliser spending in the IO tables. This gives us an allocation of total nitrous oxide emissions across

[5] The sources of process emissions we include are: enteric fermentation, agricultural soils, metals (steel/aluminium), chemicals, and mineral products (cement/lime). These are the most important sources of process emissions in New Zealand

[6] The non-CO_2 gases we include are methane from enteric fermentation and nitrous oxide from agricultural soils.

sectors of: 2% (2%) to horticulture and fruit growing in 2006 (2012), 36% (45%) to dairy cattle farming, 59% (51%) to sheep, beef cattle and grain farming, and 3% (2%) poultry, deer, and other livestock farming.

2.1.4 Direct household consumption of energy

We calculate the emissions intensity of direct household energy use separately from the IO models as we are not confident that the mapping of industry categories to consumption categories provides an accurate account of the emissions per dollar of direct energy use. We calculate emissions factors for the household consumption of petrol, diesel, coal, gas, other oils, and electricity.

We use the fuel emissions factors (in t-CO_2e/PJ from Ministry of Business, Innovation and Employment (2016a) and divide this by the retail price of the fuel (in $/PJ) from Ministry of Business, Innovation and Employment (2016b).[7] Ministry of Business, Innovation and Employment (2016a) also report an emissions factor for electricity consumption. We use this factor to calculate emissions per dollar of household electricity consumption. The result of these calculations is the emissions per dollar from the direct combustion of fossil fuels by households and the emissions per dollar from household electricity consumption.[8]

2.1.5 Comparing c-vectors over time

After doing the calculations, we obtain our two c-vectors, measuring t-CO_2e per dollar of output for each industry.[9] The gross output figures used in the calculations are in current prices, meaning that the two vectors are not comparable over time. We correct for this by inflating the output figures in the 2006 c-vector to 2013q1 prices using the industry-level output PPI.[10]

We used retail prices from Ministry of Business, Innovation and Employment (2016b) to calculate the emissions intensity of direct household energy consumption. To ensure these prices are comparable over time, we inflate the 2006 prices to 2013q1 prices using the appropriate categories of the from the CPI level 3 disaggregation from Statistics New Zealand (SNZ).[11]

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

[7] Ministry of Business, Innovation and Employment (2016b) reports prices in $/GJ for fossil fuels and c/kWh for electricity. We convert these prices into $/PJ

[8] We actually include these calculations within the IO framework so the calculations for direct household energy use are made at the same time and using the same methods as the other industries. Appendix 1 provides a detailed explanation of how we include direct household energy use into the IO model.

[9] Gross output includes both wholesale and retail margins, but exclude indirect taxes on products paid by consumers.

[10] Available from http://www.stats.govt.nz/infoshare/, table reference PPI024AA.

[11] Available from http://www.stats.govt.nz/infoshare/, table reference CPI013AA.

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 household emissions, we first map industry categories to HES consumption categories. This gives us a vector of carbon intensities per dollar spent on each consumption category. We then multiply the spending of each household in each consumption category by the emissions intensity, and sum these categories within households to calculate total emissions for each household. We have two c-vectors so we calculate two sets of emissions numbers for each household: one that assumes the goods were produced using 2006 technology and inter-industry linkages, and one that assumes goods were produced using 2012 technology and inter-industry linkages. This allows us to examine how changes in the emissions intensity of production have affected household emissions.

We calculate emissions from housing consumption separately from the input-output/HES framework, based on the physical size of the house. We estimate the total annual amount of residential investment to calculate total emissions from residential construction. We then estimate the total number of residential buildings built during a year and multiply this by the average number of rooms in a house to estimate the total number of rooms constructed in a year.[12] Dividing total construction emissions by the total number of rooms built gives us an estimate of the emissions per room. We then apportion these emissions equally over the lifetime of a house. We made a similar calculation in Allan et al. (2015) and we provide a detailed explanation of our calculation in the appendix. We exclude rental payments and mortgage principle repayments from total expenditure. We also exclude contributions to savings.

An important difference between the gross output numbers used to calculate the c-vectors and the consumption figures in the HES is the presence of indirect taxes. Gross output includes taxes on production but excludes indirect taxes that are paid by households. To correct for this, we remove the universal sales tax (GST in NZ) from each component of household spending. We do not remove other indirect taxes on specific products, such as the excise duties on alcohol and tobacco. We will slightly overstate the emissions intensity of these products, but these categories contribute a small amount to total emissions. We do not adjust household spending on petrol, diesel, gas, coal, other oils, or electricity. We used the retail price for these fuels in calculating our c-vectors. These prices include GST and other indirect taxes.

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,

[12] The number of rooms in a house is the only measure of the physical size of a house available in the HES.

but could be due to an increase in prices. To correct for this, we express all expenditure in constant 2013q1 NZ$ by applying a category specific price deflator constructed from the consumer price index (CPI) level 3 disaggregation.[13] 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. Our estimates of the marginal effect of expenditure should be considered an upper bound.

Because we use a single-region IO model, we assign imported household consumption items the same emissions intensity as if they were produced domestically.[14] 15% of final consumption expenditure was on imported goods in 2012. The four most important import categories by value were motor vehicles, clothing, air travel, and petrol.[15] Assigning domestic emissions intensity to petrol and air travel will not introduce meaningful bias into our emissions calculations. We assign motor vehicles the emissions intensity from the transport equipment manufacturing industry. The majority of output from this industry is maintenance of transport equipment, with the next largest category being boat production. Given that the majority of output in this industry is maintenance, it is likely that we will understate the emissions intensity of purchasing motor vehicles. We may overstate the emissions intensity of imported clothing, given that much of the clothing produced in NZ uses wool.

We do not claim to provide an accurate estimate of the level of emissions. We are not so much interested in the level of emissions, but in the change in the level. Both estimates of the level of emissions will be biased the same way. When looking at the difference, most of this bias will wash out.

2.3 Empirical methods

Our main empirical methods are the same as in Allan et al. (2015).[16] We estimate the following simple regression:

[13] The quarterly CPI level 3 disaggregation is available from http://www.stats.govt.nz/infoshare, table reference CPI013AA.

[14] 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.

[15] In calendar year 2015, nearly two-thirds of cars imported into New Zealand were used cars (New Zealand Transport Agency 2016).

[16] Much of this section is borrowed from Allan et al. (2015).

$$\log(Emiss_{it}) = \alpha + \beta \log(Exp_{it}) + \gamma HH\ Size_{it} + \delta X_{it} + \varepsilon_{it} \quad (2)$$

where

$$\gamma HH\ Size_{it} = \gamma_1 No.adults_{it} + \gamma_2 No.adults_{it}^2 + \gamma_3 No.children_{it} + \gamma_4 No.children_{it}^2$$

$Emiss_{it}$ is the amount of emissions embodied in household i's consumption bundle, Exp_{it} is total household expenditure (excluding housing costs and contribution to savings), $HH\ Size_{it}$ is the size and composition of the household, and X_{it} is a vector of other control variables. X_{it} includes dummy variables for the age of the 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?"[17] 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.

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. These are the sub-categories we examined in Allan et al. (2015). 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 bounded below by zero.

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 conduct a simple test for changes in average household emissions by including a dummy variable for the 2012/13 survey. We test for changes in the shape of the relationship by interacting the set of explanatory variables with the survey dummy.

We now have two c-vectors, which allows us to decompose any changes in emissions into household related changes and producer related changes. We estimate two versions of equation

[17] 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.

2, one with household emissions calculated using the c-vector corresponding to the matching survey, and one with household emissions calculated using only the 2012 c-vector. In the first specification, the coefficient on the survey dummy will capture the total change in average household emissions. In the second, the survey dummy will capture changes in average household emissions due only to differences in households and their behaviour between surveys. The difference between the two survey dummies can then be taken as an estimate of the change in average household emissions from improvements in production efficiency.

We conduct a Oaxaca decomposition (Oaxaca 1973) on the second specification, with fixed emissions intensities, to test whether any differences we detect in emissions from changes in households is due to changes in household characteristics or changes in household behaviour.

3 Results

3.1 Descriptive statistics

Table 1 displays the carbon intensity for a selection of HES consumption categories in the 2006 and 2012 c-vectors, as well as the percentage difference between the two years. The carbon intensity of products decreased on average by 2.67%. Large improvements in carbon intensity were made in milk, cheese, and eggs, meat and poultry, air travel, and electricity. These improvements are generally due to an improvement in the energy efficiency of industry, measured as energy used per dollar of output. The improvement in electricity comes from the reduction in the electricity emissions factor between 2006 and 2012. The petrol emissions factor increased slightly between 2006 and 2012, which is the primary cause of the increase in the carbon intensity of petrol consumption.[18]

Table 1: Comparison of carbon intensities of selected expenditure categories over time

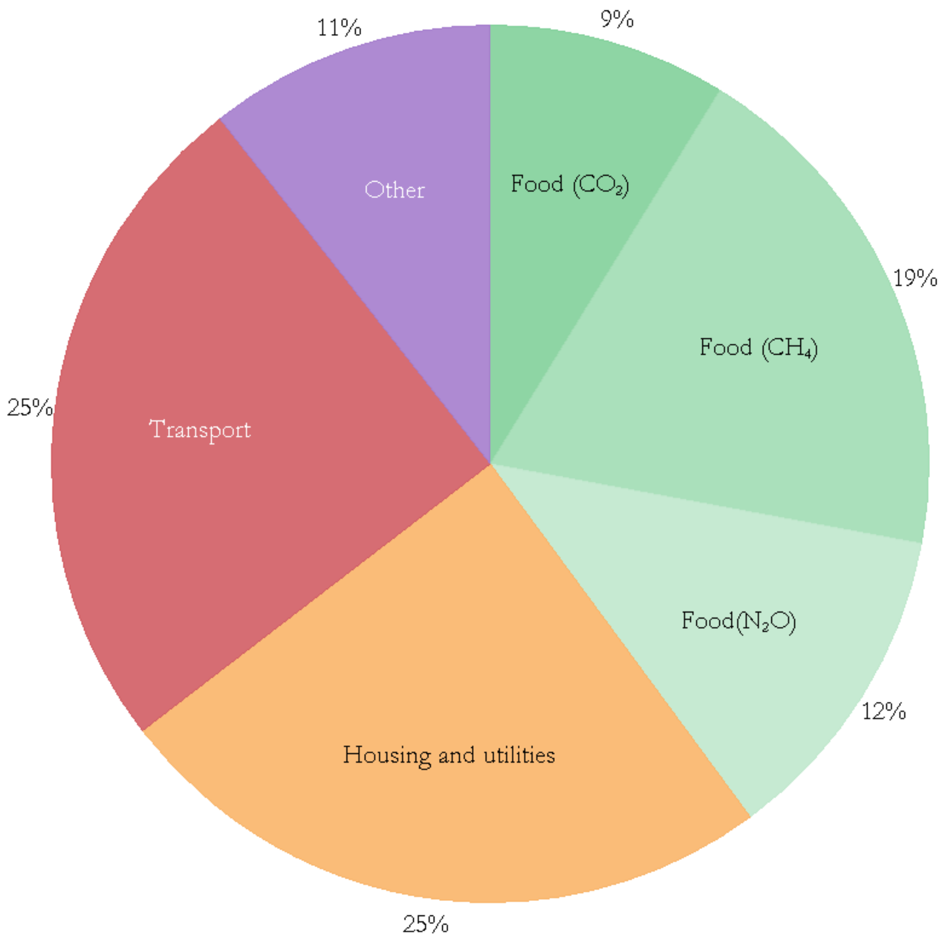
	kg-CO_2e/$ 2006	kg-CO_2e/$ 2012	Percentage change between 2006 and 2012
Milk, cheese, and eggs	1.944	1.835	-5.61%
Meat and poultry	3.149	2.843	-9.72%
Fruit	0.348	0.346	-0.57%
Petrol	1.005	1.101	9.55%
Air travel	0.509	0.229	-55.01%
Electricity	0.98	0.723	-26.22%
Average			-2.67%

[18] The petrol emissions factor increased because the calorific value of regular petrol declined between 2006 and 2012, while the carbon content of the fuel increased (Ministry for the Environment 2016c). This means that you get less energy per litre of fuel and that each litre burned generates more CO_2.

Figure 1 shows the composition of average household emissions across the 2006 and 2012 HES surveys, based on an average household total of 15.6 t-CO_2e.[19] Food, housing and utilities, and transport account for 89% of emissions for the average household.[20] This is slightly higher than the proportion we found in Allan et al. (2015) and is due to the changes we made in calculating the c-vectors. The bulk of food emissions are methane and nitrous oxide, with energy-related CO_2 emissions accounting for only 20% of food emissions.

Figure 2 shows the composition of emissions by expenditure decile, where emissions are calculated using the 2012 c-vector. Food emissions make up roughly 40% of emissions for all expenditure deciles. Utilities contribute about 30% of emissions for poorer households. This decreases to just over 20% for the wealthiest households. The importance of transport emissions increases as households become wealthier. The share rises from about 20% to about 25%. The importance of other expenditure increases from around 5% for poorer households to around 15% for the wealthiest households.

Figure 1: Composition of average household emissions, 2012



[19] Calculated using the 2012 c-vector.
[20] Other includes emissions from alcoholic beverages, clothing, education, health, house contents, communications, recreation, personal services, and financial services.

Figure 2: Composition by expenditure decile, 2012

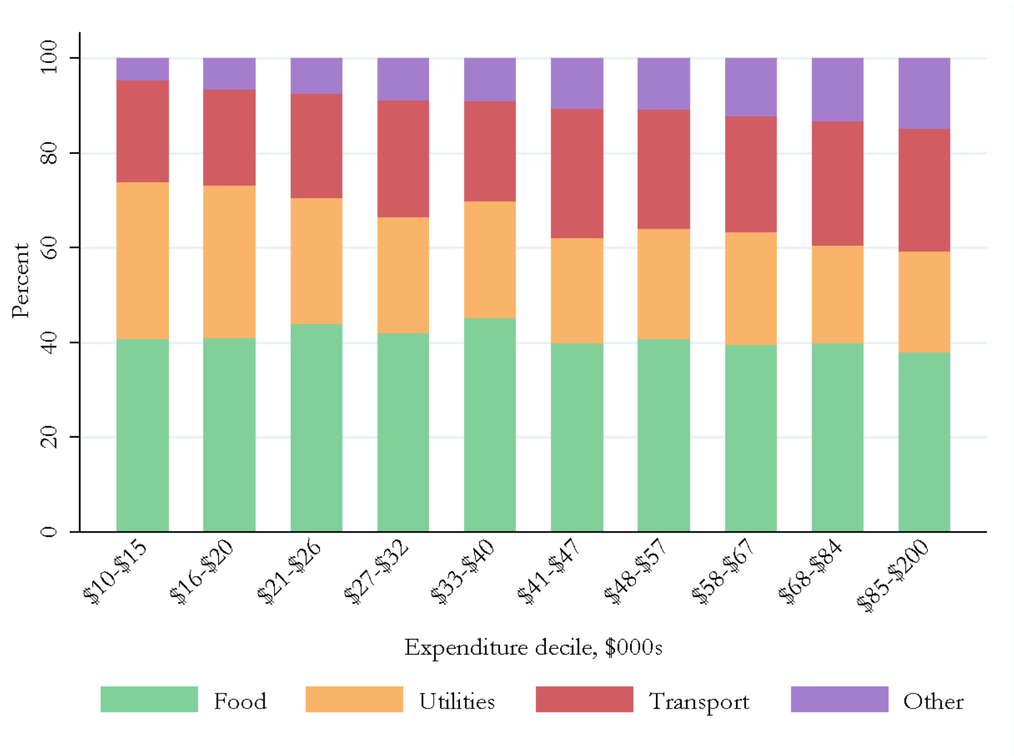


Figure 3: Comparing emissions from the top, middle, and bottom 20% of emitting households for expenditure levels

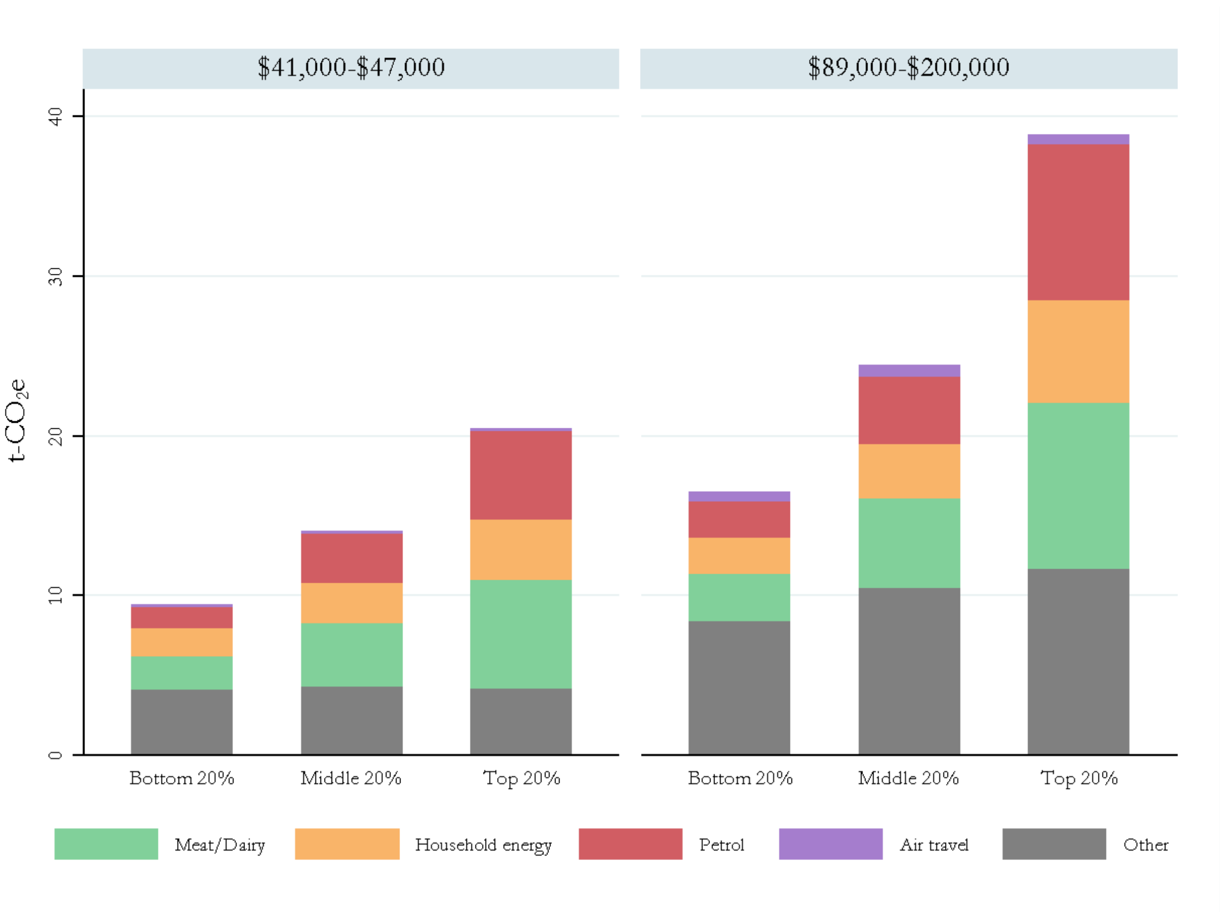


Figure 3 shows the variation in emissions for 2-adult households within the sixth ($41,000-$47,000) and tenth ($89,000-$200,000) expenditure deciles. The bars show average emissions for the bottom 20%, middle 20%, and top 20% of emitting households within each decile. Total expenditure within each decile is set at the within decile average; $43,000 for the sixth decile and $110,000 for the tenth decile. The variation within decile comes from differences in expenditure shares. Within both deciles, total emissions from the most emitting households are more than twice that of the lowest emitting households. Emissions from the highest emitters in the sixth decile are less than the emissions from the lowest emitting households in the tenth decile, despite the latter households having more than twice the level of expenditure. Important sources of the difference between households within each decile are diet and transport behaviour. Emissions from meat and dairy are 228% (251%) higher in the most emitting households than the least emitting households in the sixth (tenth) expenditure decile, while emissions from petrol are 314% (377%) higher. This shows that it is not just the level of expenditure that is important in determining emissions; the choices households make about what goods to consume also have large impacts on their environmental impact.

Table 2: Summary statistics per household

	2006/2007 N=2364		2012/2013 N=2763		Total N=5127	
	Mean	Std. dev	Mean	Std. dev	Mean	Std. dev
Emissions	17.04	9.35	15.19	8.27	16.04	8.83
Meat	3.38	3.3	3.07	3.05	3.21	3.17
Household fuels	3.18	2.55	2.41	2.1	2.76	2.35
Transport fuels	2.98	3.05	3.11	3.02	3.05	3.03
Air travel	0.31	0.81	0.18	0.46	0.24	0.65
Expenditure	$47,561	$32,338	$45,861	$29,699	$46,645	$30,952
No. adults	1.97	0.83	2.02	0.9	2	0.87
No. kids	0.58	0.96	0.53	0.95	0.55	0.96
Age	48.83	16.65	51.72	16.66	50.38	16.71

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

Table 2 provides summary statistics for both the 2006/07 and 2012/13 surveys, as well as the overall sample. Emissions were calculated using the appropriate c-vector for each year. Average household emissions were 17 t-CO_2e in 2006 and 15.2 t-CO_2e in 2012. Transport fuels is the only consumption category where we see an increase in emissions across surveys. Total household expenditure (excluding housing and savings) is slightly higher in 2006, at $47,500 compared to $45,800 in 2012. The average household size is very consistent across surveys, at just over 2.5 people. The household head was slightly older in the 2012 survey.

Table 3: Breakdown of change in average emissions into production changes and consumption changes

		C-vector		
Emissions Category	HES Survey	2006/07	2012/13	Difference (%)
Total	2006/07	17.04	15.61	-1.43 (-8.4%)
	2012/13	16.66	15.19	-1.47 (-8.8%)
	Difference (%)	-0.38 (-2.2%)	-0.42 (-2.7%)	**-1.85 (-10.9%)**
		2006/07	2012/13	Difference
Meat	2006/07	3.38	3.05	-0.33 (-9.8%)
	2012/13	3.4	3.07	-0.33 (-9.7%)
	Difference	0.02 (0.6%)	0.02 (0.7%)	**-0.31 (-9.1%)**
		2006/07	2012/13	Difference
Household energy	2006/07	3.18	2.64	-0.54 (-17%)
	2012/13	2.92	2.41	-0.51 (-17.4%)
	Difference	-0.26 (-8.2%)	-0.23 (-8.7%)	**-0.78 (-24.2%)**
		2006/07	2012/13	Difference
Transport fuels	2006/07	2.98	3.29	0.3 (10.4%)
	2012/13	2.82	3.11	0.29 (10.3%)
	Difference	-0.16 (-5.4%)	-0.18 (-5.5%)	**0.13 (1.4%)**
		2006/07	2012/13	Difference
Air travel	2006/07	0.31	0.14	-0.17 (-54.8%)
	2012/13	0.41	0.18	-0.23 (-56.1%)
	Difference	0.1 (32.3%)	0.04 (28.6%)	**-0.13 (-41.9%)**

Table 3 shows a summary breakdown of the change in average emissions over time into changes from households and changes from producers. Looking down a column, emissions have been calculated using fixed emissions factors for both sets of households. The difference is due to differences in household characteristics and household behaviour. Looking across a row, emissions have been calculated using both c-vectors for a consistent set of households. The difference here is due to changes in the emissions intensity of products. The bolded entries are the total change in emissions, which is the difference between the diagonal elements. We are not conditioning on any household characteristics in these calculations.

For total emissions, the contribution of households to the overall decrease is modest. Average emissions fell by between 2.2% and 2.7%, depending on which c-vector is used. This represents 20-23% of the total fall in emissions. The remaining 80% of the overall reduction comes from improvements in emissions intensities. Emissions fell by between 8.4% and 8.8%, depending on which set of households are used. The fall in emissions from improvements in emissions intensities is between 1.43 and 1.47 t-CO_2e for the average household.

The fall in emissions from meat is entirely due to improvements in the emissions intensities. Emissions fell by 1/3 t-CO_2e, or nearly 10%. Households appear to be consuming slightly more meat and this offsets the fall in meat emissions from improvements in the emissions intensity. The increase in emissions from households is very small, only 0.6%-0.7%.

Emissions from household energy shows a similar pattern to total emissions. The emissions intensity of electricity fell between 2006 and 2012, mainly due to the increased share of renewables in total generation.[21] Households are also consuming less electricity; Ministry of Business, Innovation and Employment (2016b) shows that total residential electricity consumption fell from 12,665 GWh to 12,493 GWh between 2006 and 2012.

Emissions from transport fuels increased between the 2006 and 2012. This is due to the increase in the emissions factor for petrol. This caused a 10.3%-10.4% increase in emissions from transport fuels when calculating emissions for a consistent set of households. This is partially offset by a reduction in fuel consumption by households of around 5.5% between surveys. This reduction in consumption does not fully offset the increase in emissions from the increase in the emissions factor.

Emissions from air travel show the opposite pattern to emissions from transport fuels. The emissions intensity of air travel fell considerably between surveys (see Table 1), driven by improvements and fuel efficiency and a reduction in the fuel emissions factor. This is partially offset by households consuming more air travel. The increase in consumption between surveys results in a 28%-32% increase in emissions. Overall, emissions from air travel fell by nearly 42% between the two surveys.

Figures 4 and 5 show the relationship between (log) emissions and (log) expenditure for the 2006/07 and 2012/13 HES households. In Figure 4, emissions are calculated using the appropriate c-vector for each set of households. In Figure 5, emissions are calculated using the 2012 c-vector. The lines on each figure show the bivariate relationship between emissions and expenditure in each survey. These figures reinforce the result from Table 3; most of the overall difference in emissions between surveys is due to improvements in carbon intensities. In Figure 4, we see a small but significant decrease in the level of the relationship between emissions and expenditure across surveys. The decrease in the level of the relationship in Figure 5 is barely discernible.

[21] The share of renewables in total generation increased from 65.9% to 72.8% between 2006 and 2012 (Ministry of Business, Innovation and Employment 2016b).

Figure 4: Emissions and expenditure by survey, both c-vectors

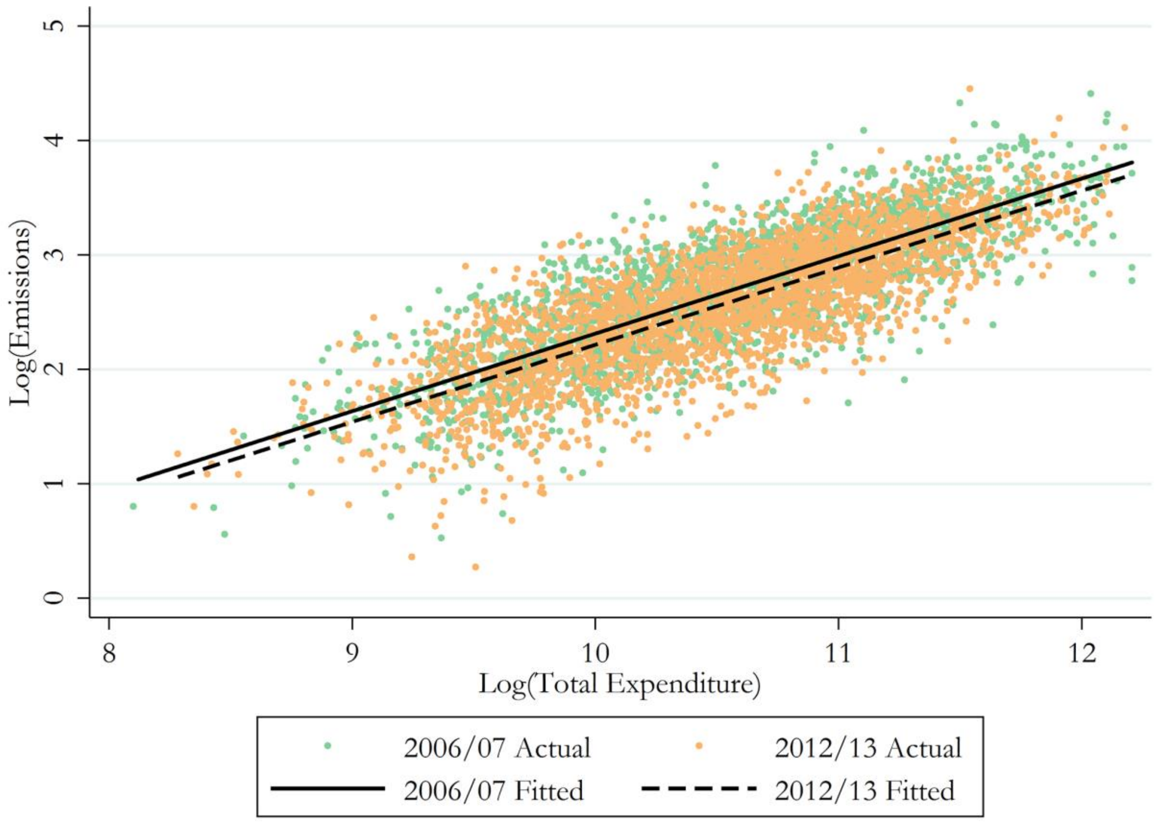
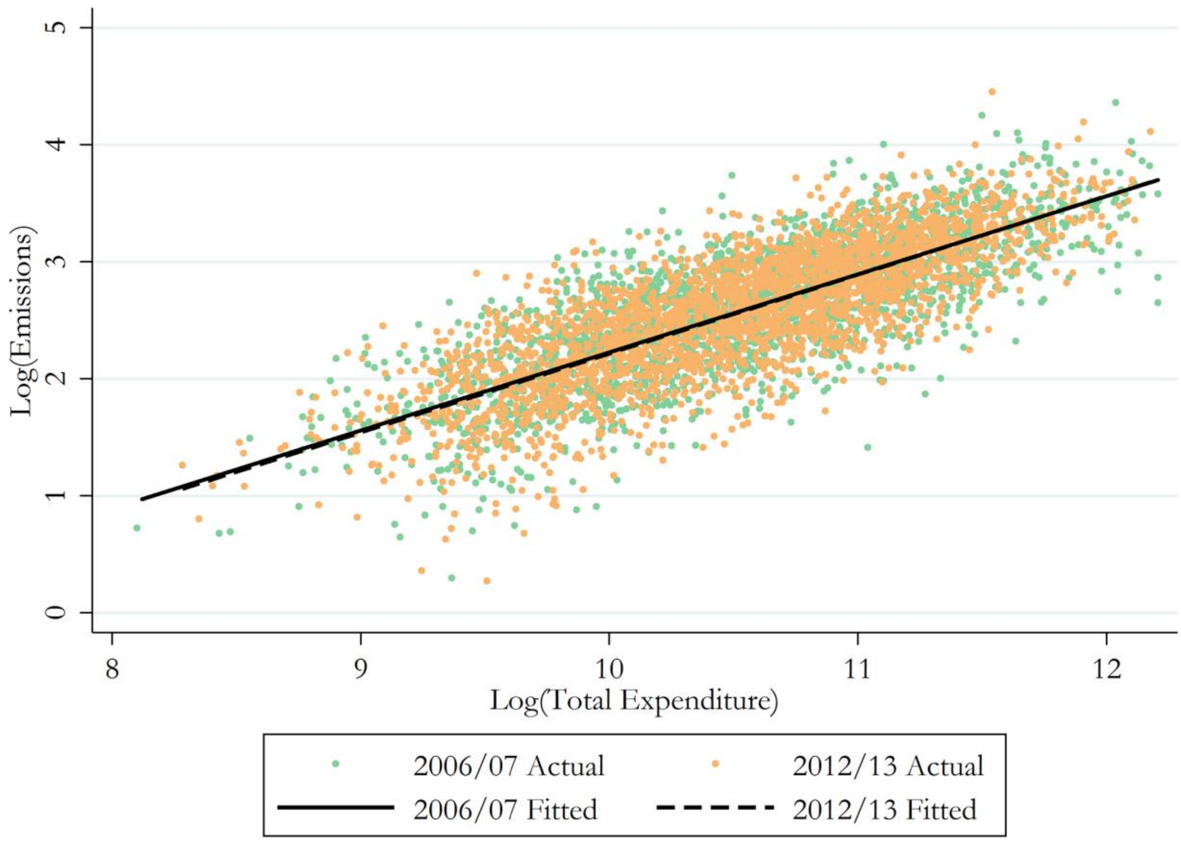


Figure 5: Emissions and expenditure by survey, 2012 c-vector



3.2 Cross-section results

Table 4 reports the results from estimating equation 2. We report the results for total emissions and for emissions from five sub-categories: meat, household energy (electricity, gas, solid fuels), transport fuels (petrol and diesel), and domestic and international air travel.

Column 1 reports the results for total emissions. We find a strong, positive relationship between emissions and expenditure. This estimate is less than unity, indicating that emissions increase less than proportionately with expenditure. Our estimate of 0.65 is slightly below our previous estimate but is consistent with findings from the international literature (Allan et al. 2015; Hertwich and Peters 2009; Levinson and O'Brien 2015; Lenzen et al. 2006, among others). There is considerable variation in the estimated expenditure elasticities across expenditure categories shown in columns 2-6. Emissions from household energy are unresponsive to increases in expenditure, while emissions from transport, and air travel in particular, are very responsive to changes in expenditure. Emissions from meat increase slightly more than proportionately with expenditure.

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 14%, while adding an extra child increases emissions by 7.8%. The turning points of the quadratics for total emissions occur at 5 adults and 4 children. These numbers are in the upper range of values for the number of adults and children in our sample. Adding an extra child increases emissions by roughly half the amount of adding an extra adult. Household size and composition affect emissions from meat and household energy in the same way they affect total emissions. The number of adults shows the inverted-U shaped relationship with emissions from transport fuels, but the number of children affects transport emissions linearly. The number of adults has no effect on emissions from air travel, while the number of children have a negative effect. Families with children fly less.

Table 4: Cross-section regression results

	(1) OLS $\log(\boldsymbol{Emiss})$	(2) Tobit $\log(\boldsymbol{Meat})$	(3) Tobit $\log(\boldsymbol{HH\ energy})$	(4) Tobit $\log(\boldsymbol{Trans.fuels})$	(5) Tobit $\log(\boldsymbol{Dom.air})$	(6) Tobit $\log(\boldsymbol{Int.air})$
$\log(Exp)$	0.647***	1.151***	0.408***	1.667***	4.089***	5.237***
	(0.00964)	(0.102)	(0.0511)	(0.112)	(0.337)	(0.306)
$No.adults$	0.225***	0.782***	0.417***	0.863***	-0.304	-0.593
	(0.0218)	(0.170)	(0.118)	(0.165)	(0.605)	(0.501)
$No.adults^2$	-0.0215***	-0.0804***	-0.0656***	-0.0868***	-0.0528	0.0457
	(0.00412)	(0.0291)	(0.0227)	(0.0236)	(0.105)	(0.0781)
$No.children$	0.108***	0.372***	0.271***	0.217*	-1.930***	-2.073***
	(0.0109)	(0.106)	(0.0637)	(0.121)	(0.384)	(0.341)
$No.children^2$	-0.0149***	-0.0464*	-0.0633***	-0.0161	0.288***	0.398***
	(0.00310)	(0.0259)	(0.0209)	(0.0341)	(0.102)	(0.0844)
$20s$	-0.0753***	-1.309***	-0.421***	0.493**	-0.556	0.314
	(0.0205)	(0.211)	(0.108)	(0.246)	(0.755)	(0.754)
$30s$	-0.0487**	-1.207***	-0.211**	0.304	-1.994***	0.113
	(0.0195)	(0.201)	(0.0890)	(0.239)	(0.733)	(0.710)
$40s$	-0.0167	-0.776***	-0.222**	0.407*	-1.759***	0.114
	(0.0181)	(0.183)	(0.0865)	(0.225)	(0.676)	(0.687)
$50s$	0.0379**	-0.530***	-0.0221	0.480**	-1.789***	0.510
	(0.0178)	(0.169)	(0.0774)	(0.214)	(0.651)	(0.645)
$60s$	0.0413**	-0.252*	-0.0604	0.542**	-0.236	2.190***
	(0.0165)	(0.148)	(0.0647)	(0.211)	(0.595)	(0.597)
$North\ NI$	0.0194	-0.0906	0.428***	-0.256	-0.619	-1.431***
	(0.0142)	(0.154)	(0.0678)	(0.164)	(0.611)	(0.513)
$Wellington$	0.0501***	0.213	0.323***	-0.0475	-1.047	-0.917
	(0.0149)	(0.158)	(0.0918)	(0.179)	(0.703)	(0.573)
$Rest\ NI$	0.0114	0.0465	0.460***	-0.647***	2.949***	0.350
	(0.0138)	(0.145)	(0.0673)	(0.163)	(0.494)	(0.449)
$Canterbury$	0.0612***	0.364***	0.488***	-0.120	2.806***	-0.0785
	(0.0133)	(0.138)	(0.0652)	(0.156)	(0.508)	(0.462)
$Rest\ SI$	0.0966***	0.322**	0.558***	-0.271	3.417***	-0.890*
	(0.0139)	(0.139)	(0.0687)	(0.166)	(0.500)	(0.488)
$High\ school$	-0.00216	-0.0314	0.0266	-0.184	1.583***	1.059**

	(0.0138)	(0.130)	(0.0632)	(0.164)	(0.548)	(0.515)
Post school	-0.000177	-0.0714	0.00662	0.0889	1.664***	1.158**
	(0.0136)	(0.128)	(0.0600)	(0.161)	(0.542)	(0.510)
Bachelor's	-0.0424**	-0.311*	-0.199**	0.00193	3.639***	2.588***
	(0.0170)	(0.175)	(0.0849)	(0.192)	(0.623)	(0.592)
Postgrad	-0.0384**	-0.520***	-0.0945	-0.0812	3.767***	2.329***
	(0.0178)	(0.190)	(0.0889)	(0.207)	(0.642)	(0.623)
Maori	0.0443***	0.0910	0.0182	0.441**	0.143	-0.685
	(0.0163)	(0.174)	(0.0887)	(0.176)	(0.643)	(0.608)
Pacific	-0.0304	-0.349	0.0169	0.691***	-1.055	1.927**
	(0.0236)	(0.264)	(0.127)	(0.230)	(1.162)	(0.877)
Asian	-0.0582***	-0.869***	0.0161	0.260	-1.170	2.744***
	(0.0182)	(0.221)	(0.0975)	(0.180)	(0.720)	(0.538)
Other	-0.0163	-0.149	-0.0110	-0.319	1.115	0.895
	(0.0213)	(0.232)	(0.102)	(0.284)	(0.756)	(0.775)
Home owner	-0.192***	-0.451***	0.0358	-0.782***	-1.201**	-1.012**
	(0.0126)	(0.131)	(0.0609)	(0.143)	(0.468)	(0.431)
Social housing	0.0446**	0.132	0.133	-0.178	-0.401	-1.767*
	(0.0204)	(0.234)	(0.119)	(0.260)	(1.002)	(0.963)
Employed	-0.0157	-0.246**	-0.0353	0.0611	0.420	1.044**
	(0.0116)	(0.114)	(0.0564)	(0.129)	(0.432)	(0.408)
Unemployed	-0.0320	-0.272	-0.408*	0.466	1.385	-1.235
	(0.0289)	(0.346)	(0.213)	(0.325)	(1.310)	(1.262)
No.rooms	0.0135***	-0.0259	0.0422***	-0.0748**	-0.0254	-0.152
	(0.00319)	(0.0328)	(0.0155)	(0.0373)	(0.107)	(0.103)
Constant	-4.545***	-5.419***	2.118***	-11.94***	-50.86***	-59.73***
	(0.0863)	(0.924)	(0.463)	(1.031)	(3.091)	(2.860)
N	5,127	5,127	5,127	5,127	5,127	5,127
R^2	0.720					
Pseudo R^2		0.0186	0.0272	0.0284	0.0608	0.0572
Uncensored N		4461	4989	4221	762	1221
Censored N		663	135	903	4365	3906

Notes: Robust standard errors in parentheses. ***, **, and * denote statistical significance and the 1%, 5%, and 10% levels, respectively. Columns 2-6 report the marginal effects of the Tobit estimates. These are evaluated at the mean of the continuous variables and at 1 for the binary variables. 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.

Household expenditure, size, and composition explain nearly 70% of the variation in emissions across households. However, some interesting patterns do emerge when looking at our other control variables. Emissions tend to increase with age until the household head is in their 60s. Emissions from meat increase monotonically with age. Emissions from household energy increase with age until the household head greater than 50 years of age. There is no clear pattern between age and transport fuel emissions, with all households (except those with a household head in their 30s) having significantly more emissions from transport fuels than those in their 70s. Households with a household head in their 60s have significantly higher emissions from air travel, while the others are not significantly different from households in their 70s.

Households in Wellington, Canterbury, and the rest of the South Island have significantly higher emissions than households in Auckland.[22] The South Island regions (Canterbury and the rest of the South Island) have significantly higher emissions from meat, while all regions have higher emissions from household energy than Auckland. Emissions tend to decrease with education. This shows up as a reduction in emissions from meat, but is partly offset by increases in emissions from air travel among more educated households. Maori tend to have higher emissions on average, while Asians tend to have lower emissions. Maori and Pacifica have higher emissions from transport fuels, Asians have lower emissions from meat, and both Asians and Pacifica have higher emissions from international air travel.

Homeowners have significantly lower emissions than renters. There is evidence that home owners are more likely to adopt energy-efficient appliances than renters (e.g. Davis 2010). If this were the case, we would expect to see a negative coefficient on emissions from household energy. We see that homeowners have significantly lower emissions from meat and transport, but not for household energy. Households with larger houses have higher emissions. These households also have significantly higher emissions from household energy.

Table 5 tests for 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 compares emissions from three households, each with per-capita expenditure of $30,000. Household 1 is our baseline; a two-adult household with $60,000 in total expenditure. When we add another adult to household 1 (and increase expenditure to keep per-capita expenditure constant), emissions increase from 19.6 t-CO2e to 28.6 t-CO_2e, an increase of 46%. When we add yet another adult, doubling the household size relative to household 1, emissions increase to 37.1 t-CO_2e, an increase of 90%. The 95% confidence

[22] Results for the regions variables could be the result of households in the different regions having different consumption bundles and/or due to regional price differences. There is no official regional price deflator in New Zealand, so we are unable to say what combination of the two possible causes is driving the results.

intervals exclude behaviour consistent with a proportionate increase in emissions in response to an increase in household size. An increase in household size of 50% (100%) increases household emissions by less than 50% (100%), showing there is some economies of scale in household size and that there may be some benefit, in terms of lower overall consumption emissions, from combining households. This is in contrast to our finding from Allan et al. (2015), where we did not find evidence of economies of scale. This result is holds when we fix emissions factors at their 2006 or 2012 levels (see Tables 11 and 12 in Appendix 2). Our sample is exactly the same as in Allan et al. (2015), so the difference in findings must be due to the changes we made in calculating our c-vectors.

Table 5: Economies of scale in household size

	Household 1	Household 2	Household 3
Expenditure	\$60,000	\$90,000	\$120,000
No. adults	2	3	4
Emissions (t-CO_2e)	19.56	28.61	37.14
	(18.4-20.8)	(26.76-30.58)	(34.52-39.94)
% difference from household 1		46.2%	89.8%
		(45.4%-47%)	(87.6%-92.1%)

Note: 95% confidence interval in parentheses. Values are calculated by setting all other variables to zero.

3.3 Changes in emissions over time

We now examine how household emissions have changed between the two surveys. We do this by adding a dummy variable to the regressions reported in Table 4. We also test for changes in the shape of the relationship between emissions and household characteristics by interacting the survey dummy with our explanatory variables.

Table 6 shows the coefficient estimates on the survey dummy. Column 1 displays the estimate when using the c-vectors that match the survey year, column 2 reports the results when using the 2012 c-vector, and column 3 reports the difference between the coefficient estimates.[23] Conditional on household characteristics, average household emissions fell by 11% between 2006 and 2012. This is the total change; the sum of improvements in production efficiency and changes in households. Emissions from household energy fell by 33% between the two surveys, while emissions from transport fuels increased by 28%. We see no change in the level of average emissions from meat or air travel between the two surveys.

1.7 percentage points of the 11% reduction between surveys can be attributed to changes in households and their behaviour. The remaining 9.3 percentage points is due to improvements

[23] Table 13 in Appendix 2 shows the results from using the 2006 c-vector to calculate household emissions.

in emissions intensities. 10.6 percentage points of the overall 33% reduction in emissions from household energy can be attributed to a reduction in household energy consumption. The remaining 22 percentage points is due to the reduction in the energy intensity of household energy consumption. Most of the increase in emissions from transport fuels is due to increases in consumption by households, controlling for household characteristics. The calorific value of regular petrol decreased between 2006 and 2012, meaning more petrol is required to drive a fixed distance. This could partly explain the increase in the number of litres of petrol consumed by households. Only 7.8 percentage points of the 28% increase can be attributed to the increase in the emissions intensity of petrol.

Table 6: Change in the average level of emissions

Dependent variable	Survey dummy 2006 and 2012 c-vectors	Survey dummy 2012 c-vector	Difference
$\log(Total\ emissions)$	-0.110*** (0.00828)	-0.0172** (0.00859)	-0.928
$\log(Meat)$	-0.0972 (0.0858)	-0.00667 (0.0852)	-0.0875
$\log(HH\ energy)$	-0.332*** (0.0399)	-0.106*** (0.0397)	-0.226
$\log(Trans.fuels)$	0.283*** (0.100)	0.205** (0.101)	0.078
$\log(Dom.air)$	0.180 (0.318)	0.428 (0.295)	-0.248
$\log(Int.air)$	-0.315 (0.299)	0.0302 (0.281)	-0.3452

Notes: See notes to Table 4.

Table 7: Changes in the relationship between household emissions and household characteristics over time, c-vectors matched to survey year

	$\log(Exp) \cdot Survey\ dummy$	$No.adults \cdot Survey\ dummy$	$No.kids \cdot Survey\ dummy$
$\log(Total\ emissions)$	0.0215	-0.00208	-0.00776
	(0.0220)	(0.0422)	(0.0271)
$\log(Meat)$	-0.203	-0.0174	0.167
	(0.203)	(0.373)	(0.226)
$\log(HH\ energy)$	0.0686	0.205	-0.334**
	(0.101)	(0.213)	(0.137)
$\log(Trans.fuels)$	0.167	-0.263	-0.0234
	(0.223)	(0.395)	(0.244)
$\log(Dom.air)$	0.608	2.009	-1.295
	(0.693)	(1.395)	(0.994)
$\log(Int.air)$	1.208*	-1.219	-0.299
	(0.639)	(1.180)	(0.755)

Notes: See notes to Table 4.

Table 8: Changes in the relationship between household emissions and household characteristics over time, 2012 c-vector

	$\log(Exp) \cdot Survey\ dummy$	$No.adults \cdot Survey\ dummy$	$No.kids \cdot Survey\ dummy$
$\log(Total\ emissions)$	0.0305 (0.0196)	-0.0103 (0.0403)	-0.00241 (0.0233)
$\log(Meat)$	-0.194 (0.202)	-0.0129 (0.370)	0.169 (0.224)
$\log(HH\ energy)$	0.0668 (0.0997)	0.209 (0.211)	-0.338** (0.134)
$\log(Trans.fuels)$	0.157 (0.224)	-0.274 (0.398)	-0.0249 (0.246)
$\log(Dom.air)$	0.662 (0.642)	1.834 (1.290)	-1.253 (0.915)
$\log(Int.air)$	1.283** (0.600)	-1.163 (1.101)	-0.350 (0.707)

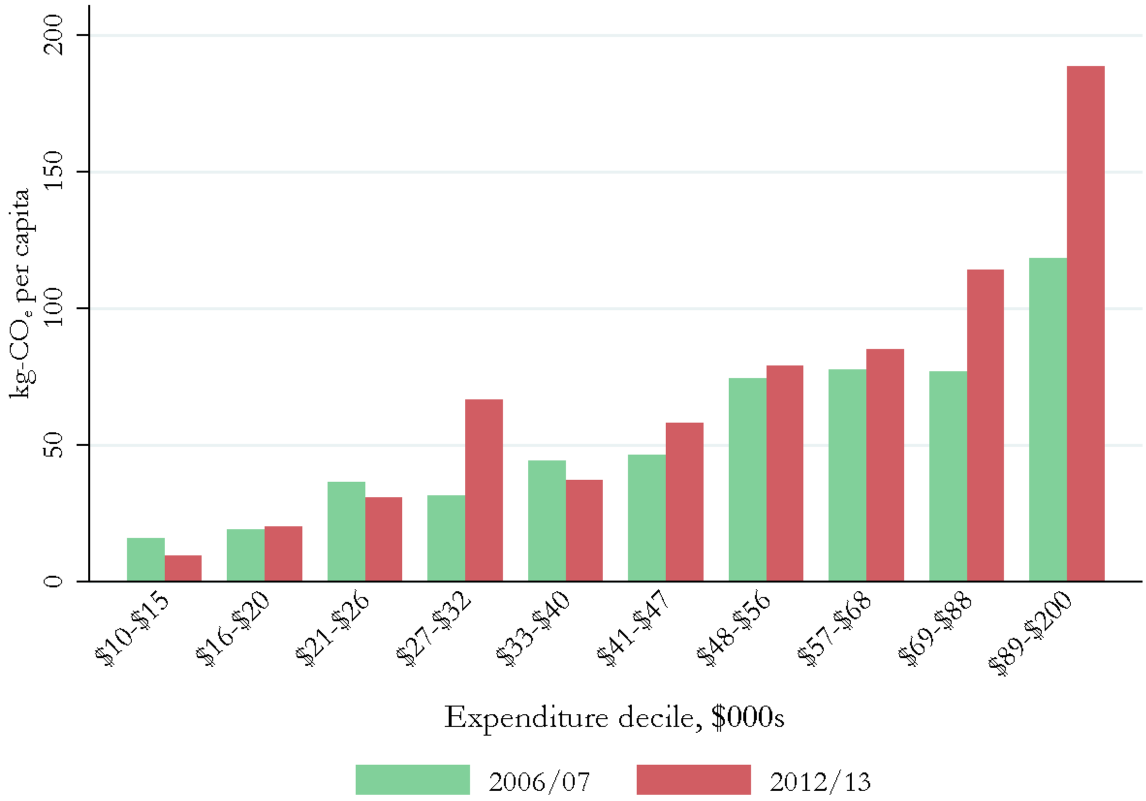
Notes: See notes to Table 4.

Tables 7 and 8 shows the coefficients on the interactions between the survey dummy and expenditure, the number of adults, and the number of children. Table 7 shows the results when both c-vectors were used in calculating emissions, while Table 8 shows the results from using the 2012 c-vector.[24] Overall, the relationships between emissions from different consumption categories and household characteristics are very stable across the two surveys. In both tables, we see only two significant results. Adding an extra child had a smaller effect on emissions from household energy in 2012 than 2006, while increases in expenditure had a much larger effect on emissions from international air travel in 2012 than in 2006. The coefficients in Table 7 are very similar to those in Table 8, suggesting that much of this difference is due to changes in households.

The finding for international air travel is consistent with our findings in Allan et al. (2015). We found a significant increase in international air travel emissions among wealthier households. Figure 6 shows international air travel by expenditure decile for each survey year, calculated using the 2012 c-vector. Air travel emissions increased significantly in the top two expenditure deciles, those with expenditure above $69,000. This is the likely cause of the increase in the expenditure elasticity of international air travel emissions across surveys.

[24] Table 14 in Appendix 2 shows the results from suing the 2006 c-vector.

Figure 6: International air travel emissions per capita by year and expenditure decile, 2012 c-vector



We now examine how much of the difference that we observe in total emissions that is due to changes in households can be attributed to changes in household behaviour. We conduct a Oaxaca decomposition on emissions, where emissions are calculated using either the 2006 c-vector or the 2012 c-vector (Oaxaca 1973). Table 9 shows that about two thirds of the total difference is due to changes in the coefficients between surveys, showing that much of the difference attributed to changes in households is due to changes in household behaviour. Two thirds of the remaining difference is explained by differences in household characteristics between the two surveys, while the remainder is due to the interaction between changes in coefficients and changes in household characteristics.

Table 9: Oaxaca decomposition of changes in emissions from changes in households

C-vector	Total difference 2006-2012	Difference due to household endowments	Difference due to changes in coefficients	Interaction
2006	-0.020	-0.004	-0.013	-0.002
2012	-0.024	-0.006	-0.016	-0.003

4 Conclusions

We re-examine the results reported in Allan et al. (2015) using newly available data. We combine information on industry fuel use, fuel emissions factors, inter-industry transactions, and household spending for 2006 and 2012 to examine the relationship between household consumption emissions and look at how household consumption emissions have changed between 2006 and 2012. We are able to separate changes into changes in product emissions intensity, changes in household characteristics, and changes in household behaviour.

Food, utilities, and transport make up 89% of average household emissions, meaning these areas should receive the most attention for households looking to reduce their environmental impact. The importance of food emissions is relatively constant over the expenditure distribution. Utilities emissions are more important for households with lower levels of expenditure, while transport emissions increase in importance with expenditure.

We show there is considerable variation in emissions among households with the same level of expenditure and the same size and composition.

Our main results about the relationship between household emissions and household characteristics are largely unchanged. Household emissions increase less than proportionately with non-housing expenditure, and household size has a positive but diminishing effect on emissions. We find some evidence for economies of scale in household size, contrary to our results in Allan et al. (2015). This result is robust to using different c-vectors in to calculate household emissions. There appears to be a small emissions benefit in NZ from people living in larger groups.

While total emissions increase less than proportionately with expenditure, there is considerable variation in the expenditure elasticities for specific emissions categories. Emissions from household energy are unresponsive to increases in expenditure, while emissions from transport, in particular air travel, are very sensitive to increases in expenditure. Emissions from meat increase approximately proportionately with expenditure.

Household emissions decreased by 11% between the two surveys, conditional on household characteristics. About 1.7 percentage points of this reduction can be attributed to changes in households, with the remainder due to improvements in production efficiency. We find a 33% decrease in emissions from household energy. About one third of this decrease is due to reductions in household electricity consumption, with the remainder due to a decrease in the electricity emissions factor from an increase in renewables generation. Emissions from transport fuels increased by 28%, with 20 percentage points of the increase due to an increase in fuel consumption, conditional on household characteristics.

We find that the relationship between emissions and household characteristics is very stable between survey years. We find that adding an additional child had a smaller effect on household emissions in 2012 than in 2006, and that emissions from international air travel became more sensitive to increases in expenditure in 2012. This increase in the sensitivity of air travel emissions is due to an increase in air travel among wealthier households.

Our main conclusions remains the same as in Allan et al. (2015). We find that households have not made a large systematic shift in their climate-change related consumption behaviour. Our methodology does not preclude such a change, we are simply unable to detect one using our data and methods. The majority of the change in emissions we observe is due to reductions in the emissions intensity of products.

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Appendix 1 – calculating emissions direct household energy consumption and use of housing[25]

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. This section describes how we added household consumption of these fuels into the model.

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 ($\boldsymbol{F}_t$) and total requirements ($(\boldsymbol{I}-\boldsymbol{A})_{\boldsymbol{t}}^{-\mathbf{1}}$) 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 ($\boldsymbol{e}_{\boldsymbol{t}}$) matrices. 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 factors, we 2006 and 2012 electricity consumption emissions factors from Ministry of Business, Innovation and Employment (2016a). This is measured as kilotons (kt) of CO2e/Gigawatt hour (GWh). We converted this factor to t-CO2e/PJ to be consistent with our other figures.

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 Ministry of Business, Innovation and Employment (2016b) to the appropriate 'direct use by households' sector'. This figure does not include the fuel used by households for personal travel. We assume that households use these fuels exclusively for transport purposes. We reallocate petrol/diesel used in the 'national transport sector' in Ministry of Business, Innovation and Employment (2016b) to the 'direct use by households' and transport sectors based on their relative spending shares. The amount of coal, gas, other oils, and electricity consumed by households is provided in Ministry of Business, Innovation and Employment - fuel use by the 'residential' sector.

[25] The bulk of this text is taken from Allan et al. (2015)

We obtained data on retail price per PJ for petrol diesel, gas, other oils, and electricity, from Ministry of Business, Innovation and Employment (2016b). 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 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 not have a large effect on our results. Table A1 contains the extra information collected and included in the $\boldsymbol{F}_t$, $(\boldsymbol{I}-\boldsymbol{A})_{\boldsymbol{t}}^{-\boldsymbol{1}}$, and $\boldsymbol{e}_t$ matrices, along with the calculated emissions intensity.

Table 10: Information collected for the calculation of the emissions intensity of household energy consumption

2006	Fuel	PJ used by households	Emissions factor (t-CO_2e/PJ)	$/PJ (retail, 2013 $NZ)	Total household spending (2013 $NZ)	kg-CO_2eq/$
	Petrol	91.46	66,580	$66,271,656		1.00
	Diesel	20.39	69,322	$45,118,351		1.54
	Gas	6.84	52,740	$35,382,672		1.49
	Coal	0.67	91,437	-	$6,965,853	8.82
	Other oils	3.78	67,362	$21,835,138		3.09
	Electricity	45.6	67,663	$69,074,692		0.98
2012	Fuel	PJ used by households	Emissions factor (t-CO_2e/PJ)	$/PJ (retail, 2013 $NZ)	Total household spending (2013 $NZ)	kg-CO_2eq/$
	Petrol	97.36	66,653	$60,518,761		1.10
	Diesel	20.91	69,732	$39,743,029		1.75
	Gas	6.18	53,470	$36,947,307		1.45
	Coal	0.36	91,400	-	$10,000,000	9.14
	Other oils	2.83	66,705	$20,894,818		1.45
	Electricity	44.98	52,339	$72,376,099		0.72

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. Housing construction occurs in the first year of the house's life. 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. Also, the fraction of the property price that is driven by land values varies significantly across NZ. A large fraction of mortgage principal repayments or rent payments will therefore be payments for land, which has no emissions.

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 calculate two measures of the emissions intensity of the use of housing, one for 2006 and one for 2012. The measures are interpreted as the emissions intensity of the use of housing, assuming the house was constructed in 2006 (2012).

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.[26, 27] Using the long-run average means we dampen the effects of construction booms on our measure of national construction emissions.[28] 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.[29] 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 the HES, which is 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).

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

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 the use of housing. Our approach is summarised in the equation:

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

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 – Appendix tables

Table 11: Economies of scale in household size, 2012 c-vector

	Household 1	Household 2	Household 3
Expenditure	$60,000	$90,000	$120,000
No. adults	2	3	4
Emissions (t-CO_2e)	18.68 (17.55-19.87)	27.36 (25.48-29.28)	35.59 (32.94-38.32)
% difference from household 1		46.5% (45.1%-47.3%)	90.6% (87.6%-92.9%)

Table 12: Economies of scale in household size, 2006 c-vector

	Household 1	Household 2	Household 3
Expenditure	$60,000	$90,000	$120,000
No. adults	2	3	4
Emissions (t-CO_2e)	20.46 (19.31-21.67)	29.85 (28.04-31.78)	38.76 (36.19-41.51)
% difference from household 1		45.9% (45.2%-46.7%)	89.5% (87.4%-91.6%)

Table 13: Changes in average emissions, 2006 c-vector

Dependent variable	Survey dummy 2006 and 2012 c-vectors	Survey dummy 2012 c-vector	Difference
$\log(Total\ emissions)$	-0.110*** (0.00828)	-0.0145* (0.00797)	-0.955
$\log(Meat)$	-0.0972 (0.0858)	-0.00689 (0.0863)	-0.0903
$\log(HH\ energy)$	-0.332*** (0.0399)	-0.101** (0.0402)	-0.231
$\log(Trans.fuels)$	0.283*** (0.100)	0.201** (0.0998)	0.082
$\log(Dom.air)$	0.180 (0.318)	0.498 (0.346)	-0.318
$\log(Int.air)$	-0.315 (0.299)	0.0238 (0.318)	-0.339

Notes: See notes to Table 4.

Table 14: Changes in the relationship between household emissions and household characteristics, 2006 c-vector

	$\log(Exp) \cdot Survey\ dummy$	$No.adults \cdot Survey\ dummy$	$No.kids \cdot Survey\ dummy$
$\log(Total\ emissions)$	0.0313* (0.0183)	-0.00627 (0.0382)	-0.00210 (0.0217)
$\log(Meat)$	-0.196 (0.205)	-0.0119 (0.374)	0.170 (0.227)
$\log(HH\ energy)$	0.0624 (0.102)	0.204 (0.216)	-0.336** (0.137)
$\log(Trans.fuels)$	0.154 (0.222)	-0.268 (0.394)	-0.0246 (0.243)
$\log(Dom.air)$	0.765 (0.751)	2.172 (1.510)	-1.449 (1.071)
$\log(Int.air)$	1.441** (0.680)	-1.309 (1.249)	-0.385 (0.801)

Notes: See notes to Table 4.

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