Demand for low carbon food products

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Lay Summary

Scottish food consumption contributes to approximately 20 percent of the country's total greenhouse gas (GHG) emissions. Some food products such as red meats contribute to the largest portion of food based emissions. Therefore, reducing consumption of these products could help reduce GHG emissions (referred throughout lay summary as carbon emissions). This thesis investigated the likely effects of a carbon consumption tax (a tax which taxes food products based on their carbon content) on carbon emissions and the resulting impact on the consumption of different nutrients.

The data used for the analysis required the following data sources: Kantar Worldpanel data which recorded a sample of Scottish household food purchases over the years 2006-2013. The carbon emissions data (referred to as carbon footprints) were obtained from multiple sources. The nutrient data of different food products were obtained from the UK government. The methods relied mainly on demand system models which measure the responsiveness of a change in quantity of food demanded to the change in price induced through the carbon consumption tax.

The results suggest that applying carbon consumption taxes to all the major food products would likely reduce carbon emissions attributed to Scottish food consumption by approximately five percent per year. The effect on nutrient consumption suggests that households with lower socioeconomic status would likely experience some favourable changes in terms of a reduction in sugar and energy. However, these groups would also experience a likely decrease in consumption of vitamin D and an increase in consumption of salt. Despite the mainly positive effect on nutrient consumption, policy makers are likely to be cautious when considering the instrument of carbon consumption taxes because of the relatively small reduction in GHG emissions.

Declaration

I Neil George Chalmers declare that:

a) This thesis was composed by myself,
b) The work contained herein is my own except where clearly stated
c) The work has not been submitted for any other degree or professional qualification.

Signed:

Date of signature:

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Abstract

The emissions associated with food consumption make up approximately 20-30 percent of Scotland's total greenhouse gas emissions (GHG). Reducing demand for high carbon footprint food products may provide an effective instrument for reducing GHG emissions. However, there is concern that using consumption based taxes may also have negative consequences on nutrition. Therefore, this thesis investigates the likely effect of carbon consumption taxes on GHG emissions and the resulting impact on nutrient consumption.

The data used for the analysis are the Scottish part of Kantar Worldpanel data for the UK for the period 2006-2013 along with various sources of carbon footprint and nutrient data. This thesis models a carbon consumption tax which is based on the carbon footprint of the products of interest.

The impact of the taxes on demand for food products were measured through the use of demand systems. Two forms of demand systems were used: Almost Ideal Demand System (AIDS) and an Exact Affine Stone Index (EASI) which allow for the estimation of price elasticities based on time series data. These Marshallian price elasticities were then used for estimating carbon footprint and nutrient elasticities which allow for the estimated change in GHG emissions (represented as carbon emissions) and nutrients. The price elasticities were particularly important for identifying the substitutes and complements of the different food products. This is useful as some food products such as poultry have a lower carbon footprint relative to beef products.

The results suggest that applying carbon consumption taxes would likely reduce carbon emissions though the reduction is relatively small. The net effect of taxing all major food products would likely reduce emissions by 543,208.75 tCO2e/y which represents approximately five percent of the total emissions in Scotland attributed to food consumption (no land use change considered). However, taxing only meat and milk food products could reduce emissions by approximately 1.6 million tCO2e/y. While this reduction is much larger than when all food products are taxed, it is

considered that modelling all the major food products offers a more realistic understanding of how households will change their demand for the different food products. The effect on nutrient consumption with regards to taxing all food products suggests that households with lower socioeconomic status would likely experience some favourable changes in terms of a reduction in sugar and energy. Though a negative distributional effect is likely to occur when considering the decreased consumption of vitamin D and the increased consumption of salt.

Therefore, a carbon consumption tax is estimated to reduce food based GHG emissions by a relatively small amount. Despite the mainly positive effect on nutrient intake, policy makers are still likely to be cautious when considering this instrument because of the relatively small (compared to other studies) reduction in GHG emissions.

Chapter 1. Introduction

1.1 Rationale for this topic

Food consumption emissions which arise from the food chain (including imported food) represent approximately 20% of Scotland's total greenhouse gas (GHG) consumption emissions (Audsley et al., 2009, SPICe, 2012, Friends of the Earth Scotland, 2015)[1]. These emissions help contribute to the problem of climate change in the form of global warming (since the 1950s) which is likely causing increased temperatures of the earth's land and sea in addition to acidification of the oceans (Intergovernmental Panel on Climate Change, 2014). The Intergovernmental Panel on Climate Change (2014) highlights how reduced GHG emissions (measured in CO_2e) could result in global warming staying below 2^oC by 2050.

The concern regarding increased emissions resulted in the Scottish Government's legislation of the Climate Change Act (Scotland) 2009 in order to try and reduce the country's overall greenhouse gas (GHG) emissions. However, the targets for reducing emissions have been narrowly missed for both 2011 (Committee on Climate Change, 2014) and 2012 (latest year of data) (Committee on Climate Change, 2015). Food based emissions contribute towards the global issue of climate change thus focussing on domestic targets is not a complete solution to this global problem.

The supply side of the food chain has been studied with emphasis on how GHGs can be reduced through farming practices such as focussing on carbon sequestration, yet there appears to be little work considering the demand side (Garnett, 2011) i.e. understanding the substitution of food products towards increasing the demand for low carbon food products. Research suggests that 59% of food shoppers in the UK understand the link between food consumption and climate change as being "important or very important" (Gadema and Oglethorpe, 2011). Yet only 20.8% of Scottish consumers "try to buy environmentally friendly products" versus the UK figure of 21.4% (Scottish Government, 2012c). The Scottish Government's research may suggest that Scottish consumers are not aware of carbon labelling. This is despite the various consumer products (not just food) which displayed the Carbon

[1] An explanation is provided in chapter 2 on this figure of 20%

Trust label (i.e. carbon footprint label) in 2010 accounting for over £2 billion in UK sales, thus being the second most used eco label in the UK by retail sales (BBC, 2010).

Researchers from the Netherlands sent out questionnaires to 1,083 respondents asking various questions on food consumption and the respondent's view of climate change and found that 40% of respondents felt that the issue of climate change was exaggerated (de Boer et al., 2013). They also found that the idea of reducing meat dramatically from household diet would be viewed negatively by those who do not understand the link between food consumption and climate change (de Boer et al., 2013). The authors' main finding is that emphasising the other benefits of reducing meat consumption such as improved health may be a more effective way for policymakers to encourage behavioural change (de Boer et al., 2013).

This highlights the need for a policy instrument which encourages consumers to purchase low carbon food products. One possible instrument is a carbon consumption tax. This thesis will study how a carbon consumption tax reduces the emissions associated with the consumption of food products.

The carbon consumption tax proposed is not a Pigouvian tax as it does not fully internalise the cost of the externality. Tol (2014) highlights the importance of a Pigouvian tax as taxing the "activity that generates the externality". This is not therefore applicable to the carbon consumption tax as the food producer (i.e. farmer or processor) is not being directly taxed. Instead the carbon consumption tax aims to provide an incentive for households to purchase less of high carbon footprint food products (or more of low carbon food products) with the tax being based on the cost of releasing carbon emissions into the atmosphere.

The idea of using tax in order to change consumer behaviour is not a new concept given Adam Smith's statement:
"It has for some time past been the policy of Great Britain to discourage the consumption of spirituous liquors, on account of their supposed tendency to ruin the

health and to corrupt the morals of the common people…abatement of the taxes upon the distillery ought not to be so great as to reduce, in any respect, the price of those liquors. Spirituous liquors might remain as dear as ever; while, at the same time, the wholesome and invigorating liquors of beer and ale might be considerably reduced in their price" (Smith, 1776) (p711). It seems that Smith understands how substituting away from a good considered to have negative effects for a good with fewer of these effects is possible through different pricing.

1.2 Rationale for taxing consumers

The literature contained in the previous section suggests that Scottish consumers are either not aware of what low carbon food products are or are unwilling to substitute their preferences for such products. There is little disagreement regarding the potential problems which anthropogenic climate change may bring. Yet, the solution to the problem is not quite so clear and market based instruments may help with climate change mitigation. Authors such as Tol (2014) explicitly state that carbon emissions should be regarded as an externality. The demand side for food related carbon emissions is an important area to study for two reasons: Firstly there is a lack of academic work on this topic. Secondly the policy instrument of taxation could be applied to food products as is already the case for some food products sold in Scotland which have Value Added Tax applied (HMRC, 2014). Hepburn (2006) has suggested that the policy instruments which can influence consumer behaviour are economic (in form of price) or command control. Information provision also forms a potential instrument.

Command and control approaches could potentially encompass the idea of banning high carbon food products. The political effects of this instrument are beyond the scope of this thesis. Panzone et al (2011) researched the potential for bans of high carbon food products in the UK. The study used a computer which was based at a Sainbury's supermarket where respondents were given different scenarios of food shopping. One of the scenarios whereby butter is banned found that 70% of the respondents substituted towards the low carbon footprint option of margarine while a tax on butter would likely result in only 16.13% substituting into margarine (Panzone et al., 2011). This result would appear to question the effectiveness of a carbon consumption tax, yet it seems that even Panzone et al (2011) acknowledge that designing a ban would be difficult.

With regards to information provision Mazzocchi et al (2014) surveyed respondents in five different European countries (UK being one of the countries) with representative samples of approximately 600 for each country and replacement procedures used in order for samples to be representative. The results of the survey suggest that support for public information campaigns on healthy eating were low in the UK at 54.3% relative to Belgium, Italy and Poland (Mazzocchi et al., 2014). Only Denmark had a lower level of support, yet interestingly when it came to support for price policies of reflecting the healthiness of a product through VAT, 67.2% of the UK survey supported this (Mazzocchi et al., 2014). The findings did convey a high level of UK (71.5%) support for price subsidies (in the form of food vouchers for low income families and free shop deliveries for disadvantaged groups) (Mazzocchi et al., 2014).

However, Panzone et al (2011) found this to be the least successful policy instrument for changing behaviour with regards to encouraging consumers to purchase low carbon options. While the figures for Scotland could differ it seems that the idea of using a consumption tax (which VAT is) could potentially have the majority of public support.

Education may be an effective policy for changing behaviour instead of or in addition to a tax. Analysing the effects of educating the public about low carbon food products goes beyond the scope of this study.

1.2.1 Carbon emissions and taxation

Wellesley et al (2015) conclude that governments should consider the use of carbon taxes on particularly meat products in order to help reduce overall GHG gases (referred throughout this thesis as carbon emissions).

The idea of a carbon consumption tax in order to reduce GHG emissions has been favoured over a production level tax due to lower monitoring costs (Wirsenius et al., 2011). Wirsenius et al (2011) allude to the pertinent point of production taxes being expensive to apply at farm level. However, the life cycle analysis does often require the use of primary data from farm level (British Standards Institution, 2011), hence a cost is still applicable under the carbon consumption tax but the monitoring costs would likely be less. The command and control system that Wirsenius et al (2011) highlight would likely require every farm to report their carbon emissions, therefore, a taxation system based on carbon footprint data is likely to be more simplistic in terms of administration.

A further benefit of a carbon consumption tax is that it avoids "emission leakage" (Wirsenius et al., 2011). This idea is further supported by Säll and Gren (2015) who highlighted that a production tax could result in consumption of high carbon food products remaining constant and only domestic meat and dairy production reducing (while foreign imports of these products increase). A production level tax may result in home nation producers being at a competitive disadvantage relative to foreign producers who wouldn't have to pay the tax (Edjabou and Smed, 2013).

Bushnell et al (2008) highlight the criticism of economists regarding regulators imposing higher costs than necessary on the producer. However, the authors fail to explicitly mention the problem of potential carbon leakage through trade associated with such a policy. To elaborate, if country A imposed these restrictions then it may be cheaper to import from country B where food producers have not been borne with these additional costs.

The previous example highlighted the problems with a production level tax and Nordhaus (2007) uses the example of a country introducing a tax on coal and then subsidising the domestic coal industry as an administrative issue with regards to the effectiveness of carbon taxes. This idea does not seem so applicable to food carbon consumption taxes as agricultural subsidies are governed at European level. Also a consumption tax would be paid by the consumer and not the producer.

An example of emission (i.e. carbon) leakages being reduced using a consumption tax which is based on carbon footprints would be the current demand for meat products in Europe (and other countries) for South American meat products. The current demand has resulted in areas of South America's rainforests being converted into agricultural land in order to export to European markets (McMichael et al., 2007). A consumption tax may help to simultaneously reduce consumer demand for both international and domestic meat products. With recent changes to the Common Agricultural Policy (CAP) the number of British ruminant livestock have been decreasing yet the likelihood of domestic demand (being met by imported meat) is still likely to be present thus the GHG emission problem remains (Gill et al., 2010). This provides a further motivation to using a consumption tax in order to reduce domestic consumption of these food products.

The idea of the rebound effect is worth mentioning as this effect is essentially where the benefits of a low carbon decision such as purchasing lower carbon food products is offset by a behavioural response which involves increasing emissions in another area (Druckman et al., 2011). While this thesis only has data covering food purchases it is therefore, difficult to perform a similar study to Druckman et al (2011) looking at other food categories. However, the total government revenue obtained from the carbon consumption taxes will be calculated in chapter 5. While policymakers (i.e. government) are free to choose how they spend the subsequent revenue, it could potentially be used in the area of climate change mitigation thus minimising any possible rebound effect.

1.2.2 Consumption taxes

This thesis uses the term carbon consumption tax and does not explicitly state (until chapter 5 where the revenue calculations follow VAT format) whether this consumption tax would be a Value Added Tax (VAT) or a sales tax. The reasons for not making this distinction are: Firstly due to the slightly different nature of these two taxes whereby a sales tax is levied at a single stage of the chain such as retail (Keen and Lockwood, 2010). This differs to VAT which is where the tax is applied at each stage of a product's cycle, yet VAT is deducted from the input costs of the product hence why only the “value” of the product added at each stage is taxed (Institute for Fiscal Studies, 2014).

Secondly as this thesis makes the assumption that the carbon consumption tax rates would equate to an increase in the respective food product price by the corresponding rate then this claim could differ between the two consumption tax systems. And lastly it would be the responsibility of the policymaker to implement a carbon consumption tax through a mechanism for which they feel would work effectively. The purpose of this thesis is to model the likely effects of a carbon consumption tax on reducing demand for high carbon footprint food products, thus the avoided emissions of Scottish households; therefore accounting for these issues (related to the type of tax mechanism) are beyond the scope of this study.

1.2.3 Carbon consumption taxes

There appears to be only three peer reviewed papers which model carbon consumption taxes solely on food products and the subsequent effect on emissions avoided through either reduction in demand or substitution of food products. Briggs et al (2013) also models the potential impact on total deaths delayed or averted and some nutrients consumed through carbon consumption taxes for the UK. While Edjabou and Smed (2013) take into account consumption of three nutrients (energy, saturated fat and sugar) through modelling a carbon consumption tax for Denmark. The third paper by Säll and Gren (2015) models an environmental tax on Swedish meat and dairy products with the avoided GHG emissions being of interest to this thesis and not the other pollutants such as Phosphorous.

Briggs et al (2013) use two scenarios with 1 modelling different tax rates while 2 is a subsidy scenario. The first scenario takes the mean emissions of all the food groups which is equal to 0.41 CO_2e Kg/100g and only applies the tax (based on the MACC’s price for 2010 of £27.19 t CO_2e which is adjusted for 100g) to food products which exceed this mean emissions value (Briggs et al., 2013). The second scenario is cost neutral due to the revenue raised from scenario 1’s tax on products above the mean emissions threshold (Briggs et al., 2013). Scenario 1 is of particular interest to this

PhD as subsidising food products is not going to be considered, as the focus is on carbon consumption taxes.

Briggs et al (2013) state they are internalising "much of the cost to society of GHG emissions", yet this seems a slightly confusing statement since they exclude food products from being taxed if their mean emissions fall under a threshold. Secondly they could help internalise the costs to society of GHG emissions quite easily through applying their carbon consumption tax to all food products like Edjabou and Smed (2013)'s study for which they do make reference to. Säll and Gren (2015) model taxes which account for more pollutants than just carbon emissions of the previous two authors (they also study the pollutants of nitrogen (N), ammonia (NH_3) and phosphorus (P)).

Edjabou and Smed (2013) base their price of carbon for the purposes of the carbon consumption tax on the social cost of carbon sourced from the non-peer reviewed Stern (2006b) review figure and the peer reviewed figure from Tol (2005). Edjabou and Smed (2013) use two main scenarios with one scenario not accounting for the existing VAT of 25% on Danish food products and therefore being applied on top of VAT (this is the uncompensated scenario).

An important component of forming the carbon consumption tax is the carbon footprint data (CF). The next chapter (Chapter 2) discusses in some detail the importance of trying to use as representative figures as possible and difficulty that this poses due to the current availability of data at UK level. Briggs et al (2013) use the CF data obtained from Audsley et al (2009) which as described in chapter 2 and by Briggs et al (2013) is not full cradle to grave CFs. Briggs et al (2013) state "post-RDC emissions for individual food types are not available" which no seems longer applicable as this thesis was able to compile a large quantity of PAS 2050 accredited CF.

Briggs et al (2013) used price elasticities obtained from Tiffin et al (2010). Tiffin et al (2010) use UK Food and Expenditure section cross data for the period 2003-04 and make use of an almost ideal demand system (AIDS) and censoring. The AIDS model will be discussed in the next chapter. Briggs et al (2013) use the "Dietron" model to understand the likely change in mortality through carbon consumption taxes. As this thesis is interested in primarily the demand for low carbon food products induced by a carbon consumption tax, then mortality will not be considered.

While it is interesting to model mortality, it is not going to be adapted for this thesis as it would appear a superior grasp of natural sciences are required in addition to the "Dietron" model appearing to almost involve another PhD.

Briggs et al (2013) find that the application of taxes in scenario 1 would likely result in a decrease of demand for particularly beef products (14.22%) and also lamb products (14.14%). The authors find that the reduction in overall GHG emissions through application of all the corresponding food taxes is approximately 18 683 $ktCO_2e$ which corresponds to a 7.5% in carbon emissions with a small reduction in vitamin B_{12} (Briggs et al., 2013). Edjabou & Smed (2013) found that GHG emissions could be reduced by 4.0–7.9% in their non VAT revenue neutral scenario (based on Tol (2005) social cost).

Säll and Gren (2015) use a non-linear version of the AIDS using time series (based on per capita consumption data supplied by the Swedish government) data covering the years 1980 – 2012. The authors obtain their carbon footprint (CF) data for the meat and dairy products from Cederberg et al (2009). This CF data covers less of the life cycle than that of the data used in Briggs et al (2013) as Cederberg et al (2009) cover just the farm gate. However, their CF data does adhere to the 2007 IPCC report on global warming potential[2] adheres to a 100 year time frame (Cederberg et al., 2009), which does allow some comparison with Briggs et al (2013) findings.

The idea of the tax being optimum is questionable given the difficulties of placing a price on carbon emissions which reflects the true cost to society. However, as Baumol (1972) makes clear, even if the tax does not produce optimal reallocation

[2] Global warming potential is discussed in chapter 2

based on the "complexities" of reality then it can still be useful to have a tax which "controls" externalities. Baumol (1972) highlights the idea of "adjustment of taxes" to form an acceptable reduction in certain externalities (example given is Sulphur) without trying to implement a Pigouvian tax.

It seems that the most pertinent point regarding any type of consumption taxes is the likely distributional effects of such taxes on the lowest income groups in society. This point has been raised by Caraher and Cowburn (2005) who believe the area lacks research. These authors are not alone as the regressive effects have raised concerns from previous studies (Mytton et al., 2012). Briggs et al (2013) while modelling a carbon consumption tax at UK level makes reference to the idea that the tax may have beneficial distributional effects with regards to health due to the poorest often suffering disproportionately with chronic diseases (Briggs et al., 2013). This area will be explored in chapter 5 of this thesis.

1.3 Research question

While reducing carbon emissions through a carbon consumption tax is the focus of this thesis, the associated change in nutrient consumption will also be studied. Scotland experiences health problems associated with food purchasing decisions such as poor levels of Vitamin D and obesity which has also caused concern to policymakers (Scottish Government, 2012a).

The question is *can a carbon consumption tax on food products both reduce GHG emissions and improve nutrient consumption*?

The change in quantity demand of food products through a carbon consumption tax will be studied through the use of demand system modelling in form of Almost Ideal Demand System (AIDS) and Exact Affine Stone Index (EASI).

This thesis will model a carbon consumption tax on Scottish households. The aim is to understand how the changes in quantity demanded for different food products induced through a tax are likely to reduce carbon emissions (i.e. the emission change associated with reduced demand for food products or because of substitutions of other food products) and change intakes of nutrients. The research undertaken in this thesis contributes to the existing literature on modelling carbon consumption taxes through developing the following areas:

1. Modelling all the major food groups using the latest Scottish section of Kantar Worldpanel data
2. Using improved LCA data
3. Estimating emission changes using carbon elasticities
4. Modelling the effect of taxes on the different socio economic groups
    a. Focussing on the distributional impact of taxes on carbon consumption and nutrient intake

The focus country of this thesis is Scotland.

1.4 Aims and Objectives

The research undertaken in this thesis addresses the following areas which have been identified as areas of relevance for answering the thesis question (*can a carbon consumption tax on food products both reduce GHG emissions and improve nutrient consumption*?):

1. **Estimating demand systems for the purpose of understanding the substitutions of high carbon food products**
    a. Allows for an understanding of the substitution relationship through a price increase
2. **Developing carbon footprint elasticities in order to understand emission changes induced through carbon consumption taxes**
    a. Modelling the likely effect of a tax on Scottish households in terms of a reduction in carbon emissions
    b. Modelling the likely effect of a tax on different socio economic groups in terms of reducing carbon emissions
3. **Estimating nutrient elasticities in order to understand the likely effect on nutrient intake of taxes**
    a. Modelling the likely effect of a tax on Scottish households in terms of nutrient intake

b. Modelling the likely effect of a tax on different socio economic groups in terms of a change in nutrient intake

4. **Applying carbon consumption taxes to all major food products**

   a. Estimating the total change in carbon emissions and nutrient intake from the net application of carbon consumption taxes

1.5 Thesis structure

Chapter two to five contain empirical analysis which provides relevance to the different objectives of the thesis. Each chapter is based on a paper which has either been accepted for publication (peer reviewed journals) or submitted to a journal for publication. Each chapter takes the following structure:

Chapter 2: Carbon emissions associated with food products

This chapter explains how the carbon footprint of different food products is measured in addition to the pricing of carbon emissions. The chapter also contains an empirical section (demand system) of estimating a one percent price increase in the price of whole milk which is relevant for the purposes of objective one (Estimating demand systems for the purpose of understanding the substitutions of high carbon food products).

Chapter 3: Carbon consumption taxation and demand modelling

This is the first chapter to apply carbon consumption taxes to food products using data which is split into socio-economic groups. Only meat products are estimated in the demand systems of this chapter and the findings provide relevance to objectives one (Estimating demand systems for the purpose of understanding the substitutions of high carbon food products) and two (Developing carbon footprint elasticities in order to understand emission changes induced through carbon consumption taxes).

Chapter 4: Carbon consumption taxation and nutrient consumption

This chapter introduces modelling nutrient intake induced through carbon consumption taxes and extends the food products to milk, meat, fish and ready-meals. The findings of this chapter provide relevance to objectives one (Estimating demand systems for the purpose of understanding the substitutions of high carbon food products), two (Developing carbon footprint elasticities in order to understand emission changes induced through carbon consumption taxes) and three (Estimating nutrient elasticities in order to understand the likely effect on nutrient intake of taxes).

Chapter 5: The distributional effects of carbon consumption taxes on carbon emissions and nutrient intake

This is the final empirical chapter and estimates a demand system containing all the major food groups. The chapter accounts for the effects of the carbon consumption taxes on the carbon emissions and nutrient intake of the different socioeconomic groups. The findings provide relevance to objectives two, three and objective four ("Applying carbon consumption taxes to all major food products") which only applies to this chapter.

Chapter 6: Conclusions

This chapter brings together all the main findings and addresses the aims and objectives in order to answer the thesis question.

Chapter 2. Carbon emissions associated with food products[3]

This chapter introduces the issue of climate change and also reviews the literature on measuring the carbon footprint of different food products. This forms the basis for the succeeding chapters mainly as the carbon footprint values are based on the reviewed literature. While the data availability of carbon footprints for different food products was somewhat limited, this chapter provides a source of Publicly Available Specification (PAS) 2050 compliant data. Also the issue regarding the validity of milk carbon footprints is clarified despite a lack of peer reviewed literature.

This chapter also provides some empirical analysis which is relevant to the first objective of the introduction chapter: "Estimating demand systems for the purpose of understanding the substitutions of high carbon food products". This is done through estimating the effect of a one percent price increase on the demand for whole milk and its substitute low fat milk (lower carbon footprint).

2.1 Introduction to Climate change

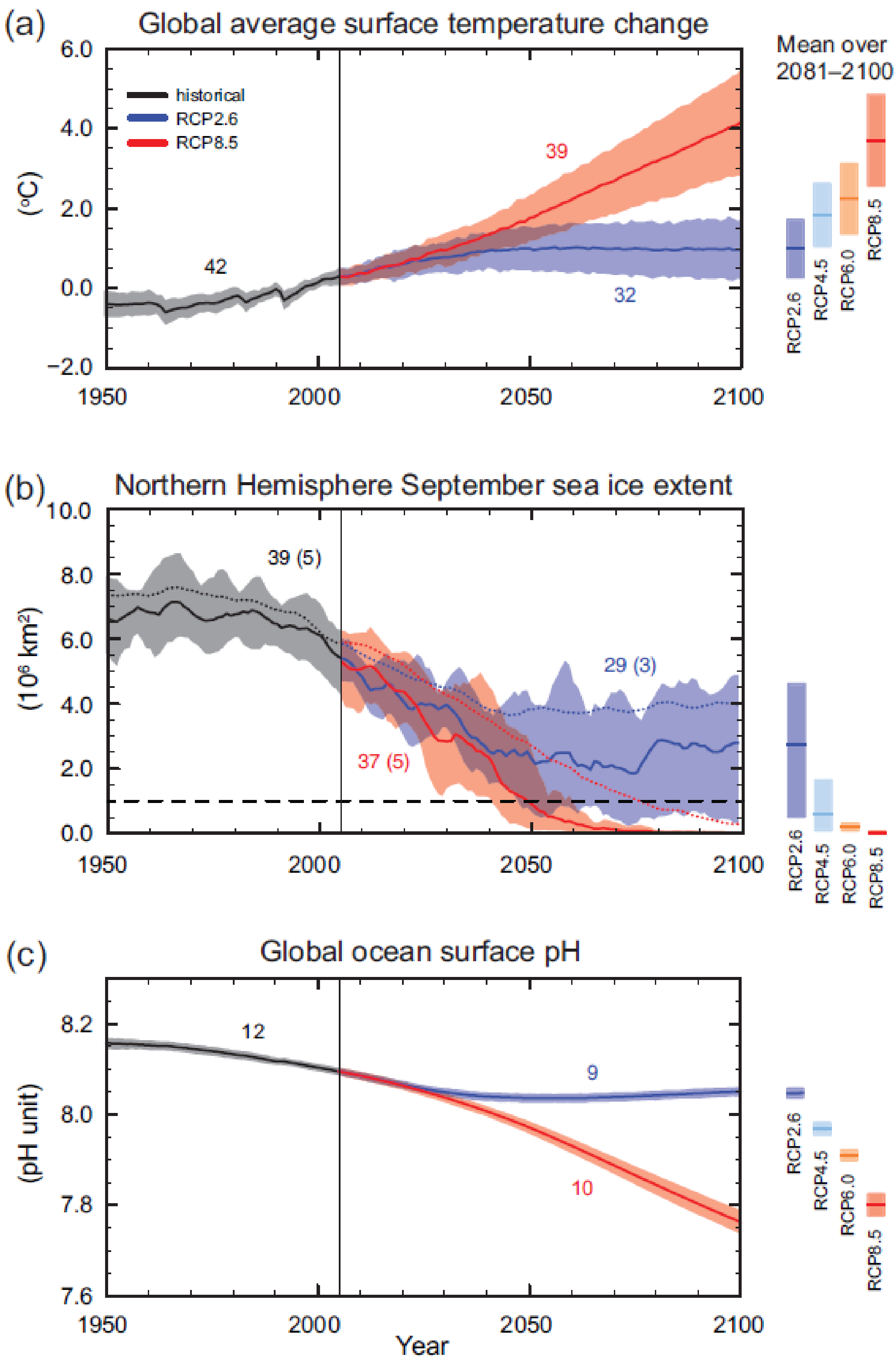
Aside from the Intergovernmental Panel on Climate Change literature, it seems that 97% of peer reviewed climate science papers agree that anthropogenic climate change is very likely to be occurring (Cook et al., 2013). Therefore, human behaviour is very likely to be responsible for climate change which highlights the need for state intervention. One form of government policy intervention is a carbon consumption tax. Figure 1 shows that Climate change in the form of global warming (since the 1950s) has seen the earth's land and sea temperatures increasing and acidification of the oceans (Intergovernmental Panel on Climate Change, 2014). The potential impact of climate change on North Western Europe (i.e. relevant for Scotland) could see increased flooding due to increased precipitation despite the short term potential gain of improved crop yields (European Environment Agency, 2012).

[3] Some of this chapter is based on the paper "The Implications of Empirical and 1:1 Substitution Ratios for Consequential LCA: Using a 1% Tax on Whole Milk as an Illustrative Example", and accepted to the "The International Journal of Life Cycle Assessment" journal. The paper can be found in the final appendix

The Intergovernmental Panel on Climate Change (2014) reported that total anthropogenic greenhouse gas (GHG) emissions have continued to increase from 2000 to 2010, despite various climate change mitigation policies. The climate models suggest that representative concentration pathway (RPC) 2.6 (shown in Figure 1) is most likely to result in global warming staying below $2^{o}C$ for 2050, provided GHG emissions (measured in CO_2e) are reduced by approximately 72% relative to 2010 levels (Intergovernmental Panel on Climate Change, 2014). Figure 1 shows the potential for RPC 2.6 to help reduce global average surface temperature, reduce rate of ice sheet melting and reduce acidification of the oceans. The atmospheric concentrations for this RPC 2.6 would need to be approximately 450 parts per million (ppm) CO_2e for the year 2100 (Intergovernmental Panel on Climate Change, 2014).

However, Figure 1 also shows the problem of adopting RPC 8.5, which is essentially whereby there are no additional efforts to “constrain emissions” (Intergovernmental Panel on Climate Change, 2014). This demonstrates the importance of trying to mitigate against climate change.

Figure 1 Climate change



Notes: Figure sourced from IPCC et al (2013)

With regards to Scotland there has been a decrease in GHG emissions of approximately 30% since the 1990s (Committee on Climate Change, 2015). However, the Climate Change (Scotland) Act 2009 has set ambitious absolute annual targets of reducing GHG emissions coupled with the relative overall decline target of 42 percent for the year 2020 (Scottish Government, 2009). The absolute targets for 2011 were narrowly missed with the Committee on Climate Change suggesting the need to find "additional opportunities to reduce emissions" (Committee on Climate Change, 2014). The most recent absolute target for 2012 was missed by approximately 4% (Committee on Climate Change, 2015) which does question how the Scottish Government is going to meet future absolute targets without some form of policy intervention. Though for the reasons highlighted by the IPCC, carbon emissions cross borders and therefore even if Scotland meets the 42% target, the reducing emissions further can only be a benefit with regards to controlling climate change.

The Scottish Parliament's information centre SPICe (2012) recently highlighted research from Friends of the Earth Scotland (2015) that emissions associated with food products accounted for 25% of Scotland's GHG emissions. At UK level, it is estimated that emissions arising from the food chain (includes imported food) are approximately 20% of (attributed to food consumption) and 30% when also considering land use change (LUC) (Audsley et al., 2009). For Denmark, food consumption emissions account for 27% of the country's GHG consumption emissions (Olesen, 2010). While neither of these sources are peer reviewed it does seem likely that the GHG emissions associated with food consumption make up a large share of a country's overall emissions. The absolute value of emissions will be addressed in "2.2.2.8 Total Scottish food based emissions" of this chapter. This provides further reasoning for government intervention in the food market.

2.2. Forms of LCA

Carbon footprints are obtained from either attributional (ALCA) or consequential life cycle assessments (CLCA). ALCA studies are where the majority of carbon footprints for different food products are obtained and will be the data of choice throughout this thesis for determining the carbon content of food. There has been a recent focus on which form of LCA to use for policy decisions with Plevin et al (2014) highlighting the simple assumption of areas such as "perfect substitution" being assumed when using ALCA. However, Plevin et al (2014) do highlight how ACLA provide an average idea of the emissions associated with a static process without the implications of policy or economics. This is important since this thesis is modelling a carbon consumption tax and therefore it seems correct to use the ACLA instead of the CLCA which would have incorporated a particular policy scenario.

However, Plevin et al (2014) have faced some criticism in the form that CLCA use scenarios which have potential to be uncertain (Brandão et al., 2014). Also the idea that CLCA require use of ALCA which represent "more than 99.9% of ALCA" (Dale and Kim, 2014) does highlight the importance of ALCA. Anex and Lifset (2014) appear to see the benefits and problems of both LCAs and question whether the use of CLCA could pose problems for policy makers in terms of their subsequent understanding of the results.

A recent paper comparing ALCA and CLCA of Dutch milk production found that both methods had the same major hotspots (areas in the chain where the majority of emissions occur) of "keeping animals" and "feed production" (Thomassen et al., 2008). The system expansion component of Thomassen et al (2008) CLCA highlights the importance of studying the effects of an increase in the feed of soybean meal on the production of palm oil. However, the different milk products such as whole and skimmed were not mentioned in Thomassen et al (2008) as potential competing products i.e. scenarios (though they are functionally equivalent products). Therefore it seems that the "scenario dependent" issue discussed in Plevin et al (2014) is important to note.

Dalgaard et al (2014) studied the consequential and attributional LCA of milk production with the focus being on 1 kg of raw milk at the farm gate level, which found that Swedish and Danish values were broadly similar. Their study has only focussed on the farm gate level which for Scottish milk production would represent

83% of emissions for a Scottish LCA on liquid milks (Sheane et al., 2011) and therefore it seems that a more representative LCA study would have incorporated the processing, distribution and consumption stages. An interesting feature of Dalgaard et al (2014) paper is how the CLCA includes the negative emissions associated with beef substitution. However, the paper makes no reference to the different types of milk products or the potential effect of consumer demand on displacement of milk fat through substitution.

The use of carbon footprints in this thesis is primarily for ranking different food products amongst one another in order to understand which products contain the most carbon emissions. This is why it's important to use a similar measurement so the comparison is done on a like for like basis. The proceeding chapter will introduce the idea of ranking the products by carbon footprint in order to obtain a carbon share which is then used in formulating the carbon elasticity (this term will be explained in the next chapter). This carbon elasticity estimates how a change in price will change carbon emissions associated with the change in demand. This elasticity can then be applied to food based consumption emissions for Scotland in order to estimate the change in carbon emissions arising from a carbon consumption tax (this will be described in more detail in the next chapter).

2.2.1 PAS 2050

The concept of a "carbon footprint" is derived from a life cycle assessment (LCA) and expresses the carbon dioxide equivalent (CO_2e) of a particular product (British Standards Institution, 2011). Most of the carbon footprint data used in this thesis adheres to the British Standards Institution (2011) Publically Accessible Specification (PAS) 2050, cradle to grave which is formed from attributional LCAs. Attributional life cycle assessments (ALCA) which will be explained in this section with the first group to be discussed being Meat and Fish since it is on the whole categorised as having a "very high" carbon content (British Standards Institution, 2011).

Based on the British Standards Institute (BSI) PAS 2050, a carbon footprint is made up of 63 different Green House Gases (GHGs) such as carbon dioxide (CO_2) and methane (CH_4) (British Standards Institution, 2011). This thesis will use the term “carbon emissions” which refers to carbon dioxide equivalent (CO_2e).

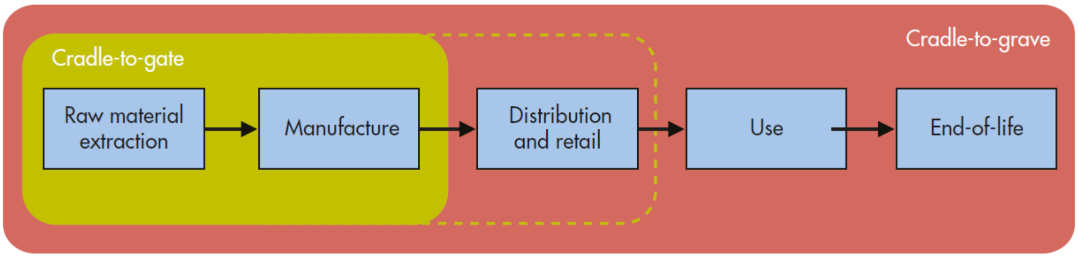
A limitation of carbon footprint data is how extensive ruminant livestock farming will often have a higher carbon footprint relative to intensive livestock farming due largely to more inefficient feed conversion of the former (grassland is also less productive) (Nijdam et al., 2012). Nijdam et al (2012) also highlight how animals in intensive livestock farming exert less energy finding their food hence the increase food efficiency ratio. This does raise the issue of trade-offs between animal welfare and reducing carbon emissions which Nijdam et al (2012) highlight and it seems this will remain an issue. It should also be noted that Lesschen et al (2011) make reference to animal feed being a major contributor of carbon emissions and that cattle grazed on grass (i.e. extensively farmed) require “concentrates” thus highlighting how heavy grazing usually has reduced carbon emissions. This is despite the potential for carbon to be lost from the soil due to heavy grazing (Creamer et al., 2010).

There is some evidence to suggest that soil organic carbon (SOC) released from the soil is reduced under extensive grazing. Smith et al (2014) find that low sheep grazing of temperate grasslands of Scotland provides for optimal conditions of SOC storage. Soil Organic Matter (SOM) contains approximately 58% of SOC and consists of matter such as plant roots (Stockmann et al., 2013). A reported limitation of many food related LCA is the failure to account for Soil Organic Matter (SOM) (Bosco et al., 2013). Bosco et al (2013) highlight that PAS 2050 would consider SOM only in situations concerning land use change.

Despite these limitations of the carbon footprint’s (i.e. PAS 2050) inability to measure possible carbon loss from the soil it does measure methane emissions for which ruminant animals are a major contributor (González et al., 2011). A further limitation of carbon footprints calculated through PAS 2050 is the inability to measure indirect emissions from land use change such as changes in the way crops are farmed (Sinden, 2009). Land use change occurring within a certain type of farming such as arable could have benefits to the soil which is currently not captured through the PAS 2050 methodology (Sinden, 2009). Therefore, extensively farmed cattle may have a lower carbon footprint relative to intensive, yet it fails to recognise biodiversity damage.

The scope of an ALCA can either be cradle to gate or cradle to grave. Figure 2 shows that cradle to gate (i.e. farm gate) encompasses fewer stages of an LCA and therefore, takes into account less of the GHG emissions of a particular product. For this reason this thesis will be using cradle to grave data where possible. The British Standards Institution (2011) when describing the PAS 2050 make reference to stakeholders needing to account for energy required to cook or store a product in the "use" stage. Throughout this thesis the term emissions associated with food consumption will appear. This highlights how a change in the price of a food product will affect the demand for it, hence if demand reduces for a high emission product then it is concluded that emissions associated with the food consumption decrease[4]. The demand system model shows the substitution and complement goods induced through a 1% price increase which is useful for this thesis as an understanding of the relationship between high carbon and low carbon food products can be inferred.

Figure 2 Cradle to Grave



Note: cradle-to-gate boundaries can vary according to the position of the 'gate'

Source: Figure sourced from British Standards Institution (2011)

[4] The issue of carbon leakage with regards to carbon consumption taxes is discussed in chapter 3 in more detail

Returning to the issue surrounding land use change (LUC). It appears that there is uncertainty over the measurement. As highlighted in Bosco et al (2013) it seems that LCA studies have desirable parameters such as SOM which are difficult to account for in the present LCA methods when not considering LUC. However, it seems that LUC poses problems as Briggs et al (2013) highlight the difficulty of some LCA studies for food products varying both within countries and between countries due to differing LUC. Audsley et al (2009) state that "perhaps the highest uncertainty of any emissions source" is attributed to LUC which appears to be because of all the assumptions made of average land use.

Audsley et al (2009) highlight Ramankutty et al (2007) where concerns are raised over the importance of land use history in determining LUC. While Audsley et al (2009) raise concerns that agricultural land will have different emission factors due to the differing carbon stocks they still use a single emission factor. This idea of carbon stocks differing would be important for food producing countries such as Scotland which contain the majority of the UK's carbon soil stock (Bradley et al., 2005). Therefore, the variability makes using a single emissions factor seem a poor representation. This thesis will present the final results of a tax on all food products using primarily non LUC emission data as Audsley et al (2009) concede that more work needs to be done on the land emission factors of LUC. There will be some results presented with emissions including LUC though these are provided for a comparison to be made with the Briggs et al (2013) study in chapter 5.

2.2.2.1 Meat and fish

With regards to meat consumption, poultry is the least damaging to the environment in terms of having a lower carbon footprint relative to the other meats (beef having one of the highest footprints for the meat category) (Williams et al., 2006). Poultry meat carbon footprints[5] (does not conform to PAS 2050 and is cradle to gate-raw material extraction) were: non organic (4,570 kg CO_2e/t), organic (6,680 CO_2e/t) and free range non organic (5,480 CO_2e/t) (Williams et al., 2006). Williams et al (2006) attribute this to organic poultry production having a "longer growing period" (page

[5] GWP_{100} kg 100 year

74) which requires more energy relative to non-organic poultry. The idea of high feed efficiency being applicable to poultry and pig farming was supported by Garnett (2010) with the succinct explanation that less animal feed produces more human edible output relative to ruminant animals. Therefore it seems that for farming systems non organic poultry has the lower carbon footprint.

Organic beef has a higher kg CO_2 equivalent compared to non-organic beef which is attributed to non-organic beef production using fertiliser which limits the growth of clover in fields (Williams et al., 2006). The emissions per tonne of organic beef 18,200 Kg CO_2e[6] are higher when compared to a tonne of non-organic beef having 15,800 Kg CO_2e (Williams et al., 2006). However, organic pig meat and sheep meat both have lower carbon footprints relative to their respective non-organic meats (Williams et al., 2006). Organic ruminant products such as beef tend to have a higher carbon footprint since they are produced more extensively (Garnett 2010).

A further benefit in reduced demand for livestock products is for the potential of increased levels of “natural vegetation” covering the land and helping to create a carbon sinks (Stehfest et al., 2009). While this study acknowledges that meat products purchased in Scotland comprise of both domestic and non-domestic products, it is worth making reference to how a reduction in Scottish livestock could help partially reduce GHG emissions. The idea of a carbon sink in Scotland is important since Gill, Smith and Wilkinson (2010) report results from another study that Scotland contains at least 50% of the UK’s carbon soil stock (Bradley et al., 2005). It is worth emphasising that moderate grazing can have a positive effect upon “carbon sequestration” it is however heavy grazing which can increase Carbon dioxide and Methane loss from soil (Creamer et al., 2010). It seems that despite some limitations, the carbon footprints obtained from an ALCA of meat products do highlight the main “hotspots” within the product’s life cycle. Extensively produced ruminants will often have a lower “per” area footprint yet a higher kg per product footprint relative to intensively produced ruminants (Garnett, 2010).

[6] GWP_{100} kg 100 year

Table 1 shows the different meat and fish PAS 2050 conforming values which will be used in Chapters 4 and 5. Finding a carbon footprint for lamb was challenging and while Houses of Parliament (2013a) provide a figure which was ranked lower than beef. This contrasts with Audsley et al (2009) which found domestic beef to have a lower carbon footprint relative to domestic sheep/lamb. Webb et al (2013) found that NZ lamb has a lower carbon footprint relative to British lamb. This study will use NZ lamb carbon footprint as a representative value. This may underestimate the true damage in terms of GHG emissions associated with consumption of lamb and sheep products. Chapter 3 introduces the method of carbon elasticity which in effect ranks the carbon footprints, therefore, this issue of selecting either a NZ or UK carbon footprint is not so important as long as all the carbon footprints share a common underlying LCA method.

With regards to salmon it can be seen from Table 1, that the carbon footprint is greater relative to chicken. This is despite the carbon footprint for salmon being based on farmed fish and not line caught salmon. The main hotspot identified with farmed salmon is the production of feed (The Co-operative Group, 2012). For line caught Norwegian salmon, the marine based feed is what causes a higher carbon footprint relative to chicken (Ellingsen and Aanondsen, 2006). If salmon were fed on a “vegetarian diet” then there is the possibility that the carbon footprint could be lower as salmon has a greater feed conversions ratio relative to chicken (Ellingsen and Aanondsen, 2006).

Table 1 Carbon footprints of meat and fish products

Products	Carbon Footprint (Kg CO_2e Kg)	Source
Salmon	8.33	The Co-operative Group (2012)
Haddock	5.60	The Co-operative Group (2012)
Tuna	3.29	Poovarodom et al (2012)
Beef	12.65	Houses of Parliament (2013b)
Chicken	2.90	Defra (2010)
Pork	3.58	Aarhus university (2014)
NZ Lamb	19.00	Ledgard et al (2011)

In the next chapter (chapter 3) the meat carbon footprints have been obtained from Audsley et al (2009) which are only cradle to regional distribution centre. Audsley et al (2009) provide data on the overall per capita emissions of different food products for Scotland (this figure was scaled up to represent the whole population) which is useful for understanding overall emission changes of a carbon consumption tax and will be discussed in chapter 3.

2.2.2.2 Dairy

The main dairy products which will be covered in this thesis are milk products as they are the most commonly purchased dairy products by volume (Defra, 2014a). Much attention has been focussed on milk products as milk appears to have a high carbon footprint relative to other foods (Macdiarmid et al., 2011, Berners-Lee et al., 2012). At the beginning of this PhD various academics at conferences questioned if there would be a difference in carbon footprints between the different milk products as they are essentially similar products in terms of the manufacturing stages required. Table 2 shows cow based milk products having differing carbon footprints with whole milk having the higher footprint, whilst skimmed milk has the lower carbon footprint. The Carbon Trust confirmed that all raw milk is skimmed which produces skimmed milk and cream (referred to as milk fat) and to produce semi skimmed or whole milk, requires the addition of some of this cream (Stephens, 2014). As the wet mass (usually a dry mass measure is used) of a unit of semi skimmed and whole is higher than skimmed milk (due to the higher fat content) then they are allocated a greater share of emissions relative to the total milk production emissions (DairyCo, 2010). It should be noted that in LCA studies the functional unit which is the volume or mass of the carbon footprint can be of any units (DairyCo, 2010). As shown in Table 2, litres have been chosen.

Table 2 Carbon footprints of milk products

Products	Carbon Footprint ($kg\ CO_2e$ Litre)
Skimmed milk	1.23
Semi Skimmed milk	1.41
Whole milk	1.58
UHT Skimmed milk	1.23
UHT Semi-Skimmed milk	1.41
UHT Whole milk	1.58
Unsweetened Soy milk	0.70
Organic Unsweetened Soy milk	1.40

Notes:

All sourced from Tesco (2012)

The LCA covering cradle to farm gate for milk farming takes into account the following emissions: of enteric fermentation, fertiliser use, feed, farm energy and finally farm electricity (DairyCo, 2010). The transport stage is considered and interestingly DairyCo (2010) emphasise that during the "use" stage, the refrigeration and freezing of products is where the majority of emissions at this stage occurs. This helps to explain why long storage UHT milk does not have a higher carbon footprint despite different production methods (DairyCo, 2010). The carbon footprint between fresh semi skimmed and UHT semi skimmed are both 800g[7] (per pint) CO_2e (Tesco, 2012). Therefore there is no difference in carbon footprint between the two milk products. A possible substitute for dairy sourced milk is soy milk which also has a lower carbon footprint relative to skimmed, semi skimmed or whole milk[8] (Tesco, 2012).

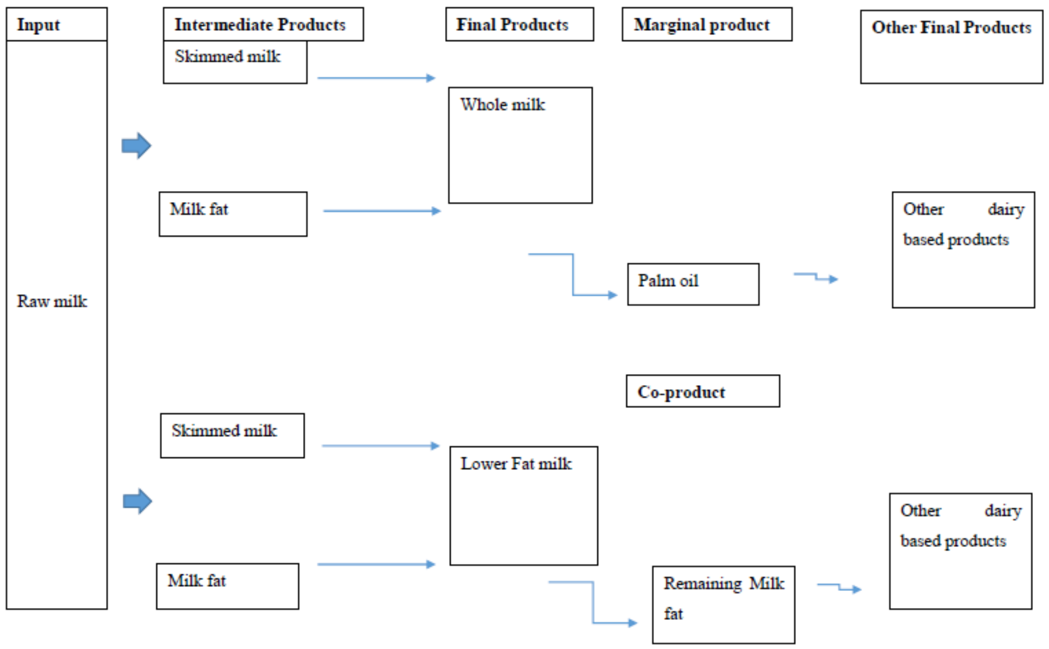
Despite ALCA studies suggesting that the values were different a Scottish based CLCA supported these ALCA results. Chalmers et al (2015) conducted a CLCA through setting a scenario of a 1 percent tax on whole milk and found this would

[7] For Tesco based milk products

[8] Soya and cow's milk listed in different units however when converted to same units this result occurs

likely increase demand for low fat milk. Figure 3 below illustrates how the CLCA works. The input of raw milk can be used to produce both skimmed milk and milk fat which serve as the intermediate products[9]. If more whole milk is produced then the availability of milk fat for other products decreases thus palm oil is used.

Figure 3 Milk production process



Notes: Designed by author of this thesis

This is important as the 1:1 substitution ratios are often assumed in CLCAs (without any empirical analysis) and can be checked from the demand system by estimation of the actual substitution ratios. The demand system modelling part of the paper found that the actual substitution ratio equates to 1:0.52 ratio could underestimate the emissions reduced by 400 percent (Chalmers et al., 2015). This means consumers do not substitute one unit of whole milk for one unit of low fat milk.

With regards to butter and margarine, the two products' carbon footprints differ quite substantially. Butter produced in the UK has 4.8 Kg CO_2e relative to margarine produced in the UK which has 0.55 Kg CO_2e (Nilsson et al., 2010). The carbon

[9] The final products are restricted to whole milk low fat milk as the Marshallian price elasticity reported that these are the only statistically significant cross price elasticities within the milk group.

footprint value for British produced butter is similar to the Tesco (2012) LCA result despite Nilsson et al (2010) appearing not to use PAS 2050 applicable data and restricting the LCA to cradle to distribution centre. Nilsson et al (2010) could also have explained their allocation stage in more detail as it seems that butter has quite a few co-products.

A recent LCA study for Scottish dairy products does not quite adhere to PAS:2050 due to its primary data yet it is a cradle to grave LCA (Sheane et al., 2011). This study allows for a comparison with other LCA studies, indicating that Scottish milk has the same carbon footprint of 1.4 Kg CO_2e (per Kg) of both the UK and Western Europe (Sheane et al. 2011). Sheane et al (2011) provides a useful account of the share of emissions at each stage of the LCA, with the farm stage accounting for 83% of emissions which is in contrast to the use stage accounting for only 1%, however, the waste stage accounts for 0%. This non-existent waste stage is disputed in Reay et al (2012) which state that 3% of all milk at the UK consumption stage is wasted. It seems unlikely that Scottish households would waste 0%. Reay et al (2012) also highlight the need for a form of “demand side mitigation” as this milk waste contributes to the avoidable emissions of 0.25 Gg N_2O-N yr^{-1}.

2.2.2.3 Readymade meals

The ready-made meal group will be discussed in chapter 4 with regards to nutrition and Table 3 highlights the differing carbon footprints of different ready-made meals. Of particular concern is the high carbon footprints of the beef based category.

Table 3 Carbon footprints of readymade meals

Processed category	**Processed Foods**	Carbon Footprint (Kg CO_2e Kg)
Pizza	Cheese and Tomato Pizza	4.4
	Thin & Crispy Pepperoni	5.3
Chicken based	Chicken & Broccoli Pie	4
	Chicken Korma & Pilau Rice	5.3
	Chicken Enchiladas	4.6
Beef based	Cottage Pie	10.4
	Steak & Ale with Cheddar Mash	11.3
	Chilli con carne and rice	10.7
Vegetable based	Baked Potatoes & Cheese	2.2
	Vegetarian three bean enchiladas	2.6
Fish based	Fish pie	4

Source: Tesco (2012)

2.2.2.4 Grains

With regards to one tonne of bread wheat, non-organic product requires nearly "50% more energy" relative to organic and has a footprint (measured in GWP_{100} kg CO_2e) of 804[10] compared to organic bread wheat of 786 (Williams et al., 2006). Most households are unlikely to make their own bread from wheat hence the carbon footprint values of bread being more relevant.

[10] measured in GWP_{100} kg 100 year CO_2e when citing any of (Williams, Audsley, & Sandars 2006)

An LCA looking into the carbon footprint of bagged: sliced white and wholemeal bread in the UK was conducted using PAS:2050 methodology (Espinoza-Orias et al., 2011). The paper used mainly primary data in order to comply with PAS 2050's methodology ,however, secondary data were used specifically for transport and raw material (Espinoza-Orias et al., 2011). The paper provided an interesting result that wholemeal (both medium and thick sliced[11]) had a lower carbon footprint relative to white bread[12] which is attributed to "more efficient utilisation of the wheat grain" (Espinoza-Orias et al., 2011). Espinoza-Orias et al (2011) highlight differing results of carbon footprints depend on if British wheat (high productivity) is mixed with imported wheat which can result in the carbon footprint of all bread products increasing. Unfortunately a literature search did not return any values for British organic breads in order to understand the difference between the two products.

Oil seed rape also has a lower carbon footprint when produced organically where 1 tonne of organic is 1,620 versus 1 tonne of non-organic which is 1,710 (Williams et al., 2006).

2.2.2.5 Fruit

With regards to the fruit carbon footprints, various different sources were used. Audsley et al (2009) carbon footprint data are not cradle to grave (extends only to regional distribution centres), therefore only fresh products which require little packaging have been selected such as fresh fruits as shown in Table 4 (Audsley et al., 2009). All the studies selected as footprint sources cover a period of 100 years therefore this complies with an aspect of the PAS 2050 (British Standards Institution, 2011).

[11]Wholemeal: Medium sliced 1156.39 g and thick sliced 1110.76g CO_2e per 800g (Espinoza-Orias, Stichnothe, and Azapagic 2011)

[12] White bread: Medium sliced 1244.27g and thick sliced 1198.70g CO_2e per 800g (Espinoza-Orias, Stichnothe, and Azapagic 2011)

Table 4 Carbon footprints of fruit, nuts and sugar

Fruit, Nuts & Sweeteners	Carbon Footprint (g CO_2e 100g)	Source
Fresh oranges	51	Audsley et al (2009)
Fresh apples	32	Audsley et al (2009)
Fresh pears	32	Audsley et al (2009)
Fresh grapes	42	Audsley et al (2009)
Fresh bananas	133	Audsley et al (2009)
Fresh melons	133	Audsley et al (2009)
Fresh Spanish strawberries	150	The Co-operative Group (2012)
Fresh Scottish strawberries	170	The Co-operative Group (2012)
Canned plum peeled tomatoes	120	Tesco (2012)
Canned cherry tomatoes	120	Tesco (2012)
Fresh tomatoes	379	Audsley et al (2009)
Groundnuts	65	Audsley et al (2009)
Sesame seeds	105	Audsley et al (2009)
Beet sugar	60	British Sugar (2010)

The example of baby plum tomatoes highlights how domestic produced food does not necessarily have a lower carbon footprint relative to imported food. The reason that the authors highlight baby plum tomatoes for comparison is due to the product being grown in a similar method as British plum tomatoes (Defra, 2008). The LCA analysis undertaken for Defra does not conform to PAS 2050 and the authors make reference to how PAS 2050 was still being developed during the time of preparing the study thus the carbon footprint findings are higher than the equivalent for PAS 2050 (Defra, 2008). Defra (2008) find that the emissions per tonne of tomatoes produced in the UK is 5.86 Kg CO_2e compared to 3.11 Kg CO_2e for Spain. Therefore, British produced baby plum tomatoes have a higher carbon footprint relative to Spanish tomatoes. This highlights why carbon footprints are a more effective measure of potential harm to the natural environment rather than food miles.

2.2.2.6 Vegetables

Canals et al (2008) calculated the British and foreign carbon footprints of broccoli, lettuce and runner beans (exact carbon footprint figures do not appear). With regards to broccoli the LCA was cradle to grave which incorporated human waste (i.e. faeces) due to eutrophication and toilet paper usage (Canals et al., 2008). Due to the seasonality issue regarding broccoli production in the UK, the study also calculated the footprint of frozen British broccoli which is available to consumers at the same time as Spanish imported Broccoli during November to April (Canals et al., 2008). The results were as follows (all denoted in kg CO_2e / Kg of broccoli on plate): Fresh Spanish is 2.22, fresh British is 1.94 and frozen British is 2.64 (Canals et al., 2008). Therefore when available the fresh British broccoli has the lowest carbon footprint.

With regards to runner beans (type of legume) the LCA is also cradle to grave (Canals et al., 2008). As British runner bean varieties are seasonal they can't be fully compared to foreign imports which can be produced in their respective countries all year round (Canals et al. 2008). Two British varieties of runner bean were analysed (early and late) in addition to runner beans from both Kenya and Uganda. Canals et al (2008) results were as follows (all denoted in kg CO_2e / Kg of beans on plate): UK early is 1.55, UK late is 1.42, UK late frozen is 1.72, Kenya is 10.7 and Uganda is 10.9. The reason both Kenya and Uganda have such high footprints is due to the use of aircrafts and fertilisers (Canals et al., 2008). British runner beans both fresh and frozen have the lowest carbon footprint (Canals et al. 2008). While Canals et al study appears to be a detailed LCA as it cradle to grave, there is no mention as to what footprint methods have been used such as PAS 2050. Tesco (2012) provide a variety of carbon footprints as shown in Table 5 which will be used in chapter 5.

Table 5 Carbon footprints of vegetable

Vegetables	Carbon Footprint ($g\ CO_2e$ 100g)
Loose Carrots Class 1	80
Scottish Carrots 500g	84
Yorkshire Carrots Class 1 Pack	79
Canned Baby Carrots in Water	150
Canned Whole Carrots in water	160
Garden Peas in Water	250
Petits Pois in Water	170
Marrowfat Peas	150
Mushy Peas	110
Cucumber Portion	136.7
Tesco Berkshire Whole Cucumber	133.3
Loose Large Open Mushrooms	480
Baking Potatoes	116
Eastern Counties Baking Potatoes Tray	124
New Potatoes	80
Jersey Royal New Loose Potatoes	96
White Potatoes Tray	88
Eastern Counties White Potatoes	92
Red Kidney Beans	300
Chick peas	200
Baked Beans in Tomato Sauce	150

Source: Tesco (2012)

2.2.2.7 Alcohol

With regards to alcohol the carbon footprint has mainly been obtained from Tesco (2012). A recent PhD thesis on what appears to be similar methodology to PAS 2050 (though not exact) highlights how the container for which the alcohol is sold in can make a large difference in terms of the carbon footprint (Amienyo, 2012). Amienyo

(2012) describes how a steel can relative to a beer can results in a carbon footprint value of 487 gCO_2e/l while glass can almost double emissions for a similar product to 819 gCO_2e/l. This finding broadly supports the Tesco (2012) published data.

2.2.2.8 Total Scottish food based emissions

The 2013 Scottish domestic total emissions are 53.0 million tonnes of carbon dioxide equivalent (MtCO2e) and comprise of seven GHG which are Carbon dioxide, Methane, Nitrous oxide, and four fluorinated gases (Scottish Government, 2015a). Understanding the total Scottish food based consumption emissions[13] is useful for understanding the effects of the carbon consumption tax on CO_2e. In the "Introduction to Climate change" section of this chapter the percentages of food based consumption emissions were provided and there is a quite a range involved. From that section it was found that emissions vary between 20 – 30% of emissions.

The Scottish Government (2015b) have estimated Scotland's total consumption emissions for the most recent year of 2012 (78 MtCO2e) though they caution that the results are not as robust as those estimated for domestic GHG emissions (being 53.0 MtCO2e) due measurement issues regarding carbon footprints of imports. However, they do make reference to the domestic GHG emissions including international shipping and aviation (Scottish Government, 2015b).

This thesis selected Scottish domestic GHG emissions as the base to calculate food emissions (which is used in chapter 5) for the following reasons: The domestic GHG inventory already includes the more reliable estimates of international shipping and aviation emissions which are also included in consumption emissions. The Scottish Government (2015b) report showed since the year 2000, the domestic and consumption emissions have moved in differing directions. The consumption emissions appear to be more dependent on the state of the economy relative to domestic emissions. While Baiocchi and Minx (2010) show that as the UK became a more service sector dominated economy (years of study: 1992 – 2004), more goods

[13] These emissions are "associated with the spending of Scottish residents on goods and services, wherever in the world these emissions arise together with emissions directly generated by Scottish households, through private heating and motoring" (Scottish Government, 2015b)

were produced overseas and did not appear as domestic emissions which subsequently reduced. However, the study's input-output model used three aggregated regions of trade (Europe OECD, non-Europe (OECD) and non OECD) which the authors highlight as a source of uncertainty (Baiocchi and Minx, 2010).

The most important reason for domestic emissions being selected as an emissions value is that Audsley et al (2009) figures for Scotland do not differ too much relative to using the Scottish domestic emissions as a base for calculating the 20 percent food consumption share. Table 6 shows the actual tCO_2e of these range values and the Audsley et al (2009) row shows how emissions vary from 12,189,000 tCO_2e (representing 20 percent) to 20,298,000 (representing 30 percent) tCO_2e per year based.

With regards to Audsley et al (2009), the values were based on their regional food based emission data which was presented in per capita format. Audsley et al (2009) provides the 2005 Scottish per capita emissions associated with food consumption (with and without LUC) and these were multiplied by the Scottish population (provided by Audsley et al (2009)). This is not a very recent measure of emissions for Scotland since Audsley et al (2009) use 2005 consumption data and they do not appear to explain in detail the uncertainties surrounding their per capita emission calculations.

After estimating the total Scottish based emissions it seems that including LUC which is estimated to make up 30% of UK based consumption emissions provides a larger value than this study's (i.e. this thesis) inferred value. This study calculated the 2013 Scottish total GHG inventory and applied both the 20% and 30% values which correspond to 10,600,000 tCO_2e and 15,900,000 tCO_2e per year respectively. The 20% value of 10,600,000 tCO_2e differed slightly from that of Audsley et al (2009) though as Audsley et al (2009) use 2005 data then it is not surprising that the values differ. However, the 30 percent value differed between the two estimated food based emissions by a relatively higher value.

Table 6 Scottish food based consumption emissions (tCO_2e)

	food based emissions	
	20%	30% (inclusive of LUC)
Audsley et al (2009)	12,189,000	20,298,000
Study inferred	10,600,000	15,900,000

Sources: Various sources and some calculation based on own elaborations

This thesis focusses mainly on not using LUC for the reasons of uncertainty which have been described in the "PAS 2050" section. However, in chapter 5 in order to allow a comparison with the UK based Briggs et al (2013) carbon consumption tax study, the study inferred LUC value of 15,900,000 tCO_2e per year has been included. It should be noted that the focus of chapter 5 is on using non LUC emissions.

When modelling the demand for the different high carbon emitting groups such as meat the Audsley et al (2009) value is chosen as it provided a breakdown in emissions for these groups. However, when considering the emissions of all food products (for chapter 5), then the study estimated 20 percent of the latest Scottish emission totals which is 10.6 million tonnes CO_2e. This approach is more representative given that emissions have been reducing since the year 2005 when Audsley et al (2009) study was mainly based, thus the smaller emission value attributed to 2013. There is a lack of research on the recent shares of food based consumption emissions (relative to a country's domestic inventory) and the previous section on "Forms of LCA" highlighted how some domestic food products have a lower carbon footprint to foreign foods (and vice versa) and the same argument being applied to organic and non-organic.

As chapters three and four study individual food groups, the emissions apportioned to these groups required use of Audsley et al (2009) data which was pre regional distribution centre which gives a conservative estimate of the total emissions for reasons discussed earlier in this section.

2.3 Demand for milk products[14]

2.3.1 Introduction

The first objective of this thesis “Estimating demand systems for the purpose of understanding the substitutions of high carbon food products” will be addressed in this section by estimating a linear approximate almost ideal demand system using kantar Worldpanel data consisting of five milk products. The dairy section of section 2.2 highlighted how milk products had a relatively large carbon footprint when compared to other foods such as grain though within the milk groups the carbon footprint does vary. Therefore it is important to understand consumers underlying preferences when the price of high carbon footprint whole milk is increased by 1% and the effect on the demand for other milk products. Whilst the aim of this section is to understand the substitutions between high and low carbon food products it also serves as a means of introducing demand system modelling.

2.3.2 Data

The effect of a 1% tax on whole milk was modelled using Scottish household purchasing data obtained from the Kantar Worldpanel dataset for the years 2006 – 2011. Each year comprises 13 periods of four weeks and aggregates individual household purchases. The total Kantar sample population was 2,098 households. Only the milk products matching Table 7 were extracted from the Kantar Worldpanel dataset. The number of purchased observations from the sample are shown in Table 7.

[14] This section (2.3) is based on the paper: “The Implications of Empirical and 1:1 Substitution Ratios for Consequential LCA: Using a 1% Tax on Whole Milk as an Illustrative Example”, and accepted to the “The International Journal of Life Cycle Assessment” journal. The paper can be found in the final appendix

Table 7 Milk Data

Products	Purchased observations	Share of milk expenditure
Low fat	6,928.00	0.04
Semi-Skimmed	73,657.00	0.59
Skimmed	13,918.00	0.10
Soy Milk	1,596.00	0.01
Whole milk	32,925.00	0.26

Source: Own elaborations based on Kantar Worldpanel data

The summary statistics of the data used in the demand system for this chapter are provided in Table 8. From both tables it can be seen that mean milk budget share of low fat milk (0.04) is very small relative to whole milk (0.26).

Table 8 Descriptive statistics

	Share					Price					Expenditure
	Low fat	Semi-Skimmed	Skimmed	Soy Milk	Whole milk	Low fat	Semi-Skimmed	Skimmed	Soy Milk	Whole milk	
min	0.03	0.54	0.08	0	0.21	-0.69	-0.69	-0.78	-0.32	-0.64	-1.62
max	0.07	0.63	0.14	0.02	0.30	-0.58	-0.57	-0.65	0.05	-0.51	-1.30
range	0.04	0.09	0.06	0.02	0.10	0.11	0.12	0.13	0.37	0.13	0.32
sum	3.18	45.34	7.88	0.68	19.92	-48.97	-46.94	-54.18	-8.44	-42.93	-117.82
median	0.04	0.59	0.10	0.01	0.26	-0.64	-0.60	-0.70	-0.08	-0.56	-1.55
mean	0.04	0.59	0.10	0.01	0.26	-0.64	-0.61	-0.70	-0.11	-0.56	-1.53
St.d	0.01	0.02	0.01	0	0.02	0.02	0.04	0.03	0.10	0.03	0.08

Source: Own elaboration based on Kantar Worldpanel data. Price is in natural logarithm form

The data on total purchases of milk were obtained from DairyCo (2014) (though created by Kantar Worldpanel) for a 52 week period ending on the 12th of October 2014 and shown in Table 9. Since the dataset covered the whole of the UK it required being adjusted to account for Scottish purchasing. The was done through the use of Defra's 2013 household consumption dataset (Defra, 2014), which at the time of the study was the most recent consumer purchasing data available. A limitation of adjusting this data is that Defra aggregated both liquid milk and cream into one group. The Kantar dataset used in estimating the demand system has not been used in the volume calculations due to DairyCo being more recent data. Therefore, this allows for an idea of the potential impact of a 1 percent tax on quantity demanded of the differing milk products.

Table 9 Total purchases of milk

Products	52 week period (ending 12 Oct 14)
	Quantity (million litres)
Low fat	57.15
Semi-Skimmed	713.16
Skimmed	158.94
Soy Milk	31.98
Whole milk	255.44
Total	1,216.67

Source: Own elaborations based on DairyCo (2014)

2.3.3 Method

2.3.3.1 Linear Approximated Almost Ideal Demand System

The purpose of using the Linear Approximated Almost Ideal Demand System (LA-AIDS) was to obtain the Marshallian price elasticities. The own price elasticity of demand measures the responsiveness of a change in quantity demanded of product with respect to a change in the price of the product (Snyder and Nicholson, 2008). Cross price elasticity measures how the quantity demanded of product B responds to a change in the price of product A, and the income elasticities measure the responsiveness of a change in quantity demanded to a change in income. Marshallian price elasticities account for both income and substitution effects. Hicksian price elasticities do not account for the income effect and are not used throughout this thesis for modelling carbon consumption taxes. The Hicksian and income elasticities will not be used for any part of the modelling in this thesis as the Marshallian price elasticities are required as they account for both income and substitution effects.

The LA-AIDS system was first developed by Deaton and Muellbauer (1980a) and is superior to the previously common demand systems of either the Rotterdam or Translog as the AIDS can impose linear demand theory restrictions in addition to being able to calculate arbitrary first order approximations for a given demand system (i.e. set of equations). Utility is derived by the consumer from quantities of goods or services (in this case goods) and when faced with a linear budget constraint the utility function is dependent upon expenditure and prices i.e. the indirect utility function (Deaton and Muellbauer, 1980b).

This section provides an overview of demand system modelling and provides justification for the use of an Almost Ideal Demand System (AIDS) introduced by (Deaton and Muellbauer (1980a).

The relationship between the cost function (c) and expenditure (x) is whereby the highest level of utility (u) (subject to prices (p)) is equal to the expenditure as shown in equation 1 (Deaton, 1986).

$$c(u, p) = x \tag{1}$$

The direct utility function (v(q)) cannot be recovered but instead it is assumed that the underlying preference can be recovered in the form of the cost function through Shephard’s lemma whereby the Hicksian and Marshallian demands are recovered in addition to convex preferences being assumed through the Shephard-Uzawa duality theorem (Deaton, 1986). However, there is a more straightforward method for recovering consumer preferences and that involves using the indirect utility function (Deaton, 1986). Before proceeding to explain the necessary properties of the cost function it should be highlighted that duality allows for retrieving preferences from the cost function (Deaton and Muellbauer, 1980b).

Duality is an important concept in demand modelling as it is focussed on change of variables since the consumer derives utility from quantities of goods/services, yet when faced with a linear budget constraint the utility function is dependent on expenditure and prices i.e. indirect utility function (Deaton and Muellbauer, 1980b). This idea is further developed since maximising utility will allow for minimizing costs and when this integration of the utility function occurs then cost function should be concave and linearly homogenous (Deaton and Muellbauer, 1980b).

Deaton and Muellbauer (1980b) highlight the integrability conditions, whereby to go from the original preferences of a demand function to a cost function requires "maximisation of utility to be treated as minimization of costs" hence the relationship between the two functions.

In order for preferences to be obtained from the cost function, five properties are required for the cost function (Deaton and Muellbauer, 1980b):

1. Homogenous of degree of one in prices $c(u, \theta p) = \theta c(u, p)$
2. Non decreasing in p but increasing in u
3. Concave in prices
4. Continuous in p
5. Shephard's lemma whereby partial derivatives of cost functions equate to Hicksian demand functions

There are two forms of the AIDS model which are used in this thesis; the first being the linear approximated almost ideal demand system (LA-AIDS shown in equation 2) which is used in this chapter. The second model is the dynamic error correction version of the almost ideal demand system which is used in in chapter 3.

For this chapter, the conditional LA-AIDS model only considers expenditure on milk products. The proceeding chapters expand demand system modelling through the incorporation of more food groups.

Equation 2 shows the LA-AIDS which incorporates the Stone price index of equation 3 and the parameters represent: w_i= budget shares of the i th good, m = expenditure, P_t = price index, γ = relative prices, p_j= price of the j th good, D = seasonal dummy variables with subscript k representing 12 dummy variables as there are 13 periods within each year (this avoids the problem of the dummy variable trap) and a time trend is also included (T). Subscripts: t = time. The i indexes the products of the shares (i = 1, 2, …,N) while j indexes the products in the price variables (j = 1, 2, …,N) (Sun, 2015). Subscript k indexes the dummy variables (k = 1, 2,…,N) (Sun, 2015).

The expenditure allocated to milk products by households is assumed to be fixed as this is a conditional demand system model.

$$w_{it} = \alpha_i + \beta_i \ln\left(\frac{\mathrm{m}_t}{P_t^*}\right) + \sum_{j=1}^{N} \gamma_{ij} \ln(p_{jt}) + \sum_{k=1}^{K} \beta_{ik} D_{kt} + T + \mathrm{u}_{it} \qquad (2)$$

$$\ln(P_t^*) = \sum_{j=1}^{N} \mathrm{w}_{jt} \ln(p_{jt}) \qquad (3)$$

The LA-AIDS model must meet the four restrictions of demand in order to produce plausible results[15] (Deaton and Muellbauer, 1980b). These four restrictions are imposed through the demand systems of the proceeding chapters:

Adding up $\sum_k a_k = 1, \sum_k \beta_k = 0, \sum_k \gamma_{kj} = 0$

Homogeneity $\sum_k \gamma_{jk} = 0$

Symmetry $\gamma_{ij} = \gamma_{ji}$

Negativity[16] $c_{ij} = \gamma_{ij} + \beta_i \beta_j \log\left(\frac{x}{P}\right) - w_i \delta_{ij} + w_i w_j$

[15] These restrictions are imposed in the estimation.

The LA-AIDS model used in this section is calculated in R, using package "Erer" (Sun, 2014) which is based on a paper by Wan et al (2010).

2.4.3.2 Computation of Price elasticities

The Marshallian price elasticities were modelled from the LA-AIDS and allowed inference on how a 1% increase in the price of whole milk would likely affect the demand for whole milk (i.e. own price elasticity), as well demand for substitute/complement goods (i.e. cross-price elasticity).

The price elasticities were then applied to the quantities of

Table 7 in order to calculate the absolute change in quantity demanded. This allowed the substitution ratios[17] to be obtained which were relevant to challenging the CLCA assumption of 1:1 substitution ratios. For this thesis the substitution ratios are not of such importance but the estimation of the absolute changes in quantities demand (QC) induced through a price change is important. This was estimated by the use of equation 4 whereby the matrix of price elasticities (D) of the food group is multiplied by the initial quantities of food group of interest as shown in Table 9.

$$\mathrm{QC} = D.\mathrm{Q0} \qquad (4)$$

This method was adapted by Huang (1996) and more detail will be provided in the proceeding chapters on how changes of the following variables were calculated: carbon emissions, nutrients and revenue.

2.3.4 Results and Discussion

2.3.4.1 Diagnostic results

Table 10 shows the results of the various diagnostic tests used for the demand equations within the demand system. The Breusch-Godfrey (BG) tests for serial

[16] This matrix C must be negative semidefinite for the restriction of negativity to be satisfied (Deaton & Muellbauer, 1980b).

[17] Estimated through division of a change in volume of low fat milk consumption by the change in whole milk volume consumption

correlation within the error term (i.e. consecutive error terms with an observation are correlated) and is useful particularly for equations with lagged variables (which is not an issue for the equations in this chapter) (Verbeek, 2008). With regards to the BG results, it would appear that only the Soy milk equation is likely to have an issue with serial correlation. The equation of interest is whole milk and it seems unlikely that serial correlation is present. The Breusch-Pagan (BP) tests for heteroscedasticity which is whereby the variance of the error term varies with the observations (Verbeek, 2008). Judging from the results, it seems that heteroscedasticity is not present in the whole milk equation. The next test being the Ramsey's Regression Specification Error test is useful for understanding functional form. Shukur (2002) make reference to using the RESET for testing against misspecification.

It should be highlighted that the whole milk equation appears, despite being dropped the initial estimation of the demand system. The reason for dropping the equation upon estimation of the demand system is to fulfil adding up constraint. The system was re-run with the Soy equation dropped in order to get an “idea” of the potential statistical issues facing the whole milk equation.

The final diagnostic (Jarque-Bera (JB)) test is used to understand if there is excess kurtosis (i.e. skewness) of the error terms and therefore it is useful for understanding if the error terms are normally distributed (Wan et al., 2010). It can be concluded that the error term within the whole milk equation is likely to be normally distributed. Compared to the dynamic AIDS (more information on this model will be given in the next chapter) results of Wan et al (2010) static model, this study's diagnostic results would appear to be superior considering the relatively few equations which likely experience statistical problems.

Table 10 Diagnostic tests

Equation	Breusch-Godfrey (BG) test		Breusch-Pagan (BP) test		Ramsey's Regression Specification Error test (RESET)		Jarque-Bera (JB) test	
		p-Value		p-Value		p-Value		p-Value
Lower fat	1.731	0.19	15.875	0.67	3.137	0.05	2.432	0.3
Semi-Skimmed	0.464	0.5	20.323	0.38	0.589	0.56	5.972	0.05
Skimmed	0.234	0.63	29.108	0.06	0.165	0.85	2.871	0.24
Soy	4.873	0.03	12.751	0.85	0.617	0.54	3.17	0.2
Whole	0.946	0.33	27.18	0.1	0.022	0.98	0.712	0.7

Source: Own elaborations based on Kantar Worldpanel data

2.4.4.2 Marshallian price elasticities

Table 11 shows the results for the Marshallian price elasticities of demand. The whole milk equation is of particular interest. It would appear that the condition of negativity has been met as all the statistically significant own price elasticities are negative. The only result of particular concern is that of Soy milk which may be explained by the findings of the diagnostic tests which indicate possible bias. However, as stated only the whole milk equation is of interest and the other results for the other milk products are not being used. A 1% price increase of whole milk is likely to result in the demand for whole milk decreasing by 1.48% while the demand for low fat milk increases by 3.45%, thus being a substitute good.

Whilst, this chapter is only concerned with the effect of a 1% price increase in whole milk it also worthwhile discussing the statistically significant cross price elasticity results for the other milk products. It should be highlighted that no other study could be sourced which contains modelling of similar milk products at Scottish or UK level which makes providing a comparison difficult. With regards to low fat milk, a 1% price increase suggests that semi-skimmed milk is a complement and substitutes would consist of soy and whole milk. This result appears to be consistent with consumer choices as it is unlikely that whole milk which has a greater fat content would be a complement to lower fat milk and vice versa.

The cross price elasticity of skimmed milk being a substitute of low fat milk is broadly consistent with the idea that the two products are similar by fat content and therefore would serve as a substitute.

Table 11 Marshallian price elasticities for milk products

	Lower fat		Semi-Skimmed		Skimmed		Soy		Whole	
Low fat	-2.859	***	-3.614	***	1.424	*	1.391	***	3.445	***
Semi-Skimmed	-0.279	***	-0.88	***	0.213		-0.043		0.159	
Skimmed	0.51		0.661		-1.823	*	-0.106		-1.035	
Soy	6.496	***	-2.622		-1.077		-2.594	***	-0.581	
Whole	0.509	***	0.133		-0.351		-0.027		-1.483	**

Notes: Statistical significance: '*'=10%, '**'=5% or '***'=1%.

Table 12 shows the expenditure elasticities which were not of any use for the study. It is however, interesting to see that semi skimmed milk is the only statistically significant elasticity which can be defined as a normal good. Whole milk would be classified as a luxury good owing to the elasticity value being slightly greater than one.

Table 12 Expenditure elasticities

Lower fat	0.212	
Semi-Skimmed	0.831	***
Skimmed	1.793	***
Soy	0.378	
Whole	1.219	***

Notes: Statistical significance: '*'=10%, '**'=5% or '***'=1%.

The results suggest the importance of modelling actual substitution ratios between competing milk products in order to understand the consequences of a 1% price increase in whole milk. Under a 1% tax on whole milk the substitution relationship between whole milk and low fat milk is not 1:1. The substitution ratio was calculated in two steps: the change in consumption (induced through a 1% price increase of whole milk) of the two milk products was estimated by applying the price elasticities to the volume of milk purchased in Scotland, with the results shown in Table 13

Table 13 Change in consumption (million litres)

Products	Change (million litres)
Low fat milk	1.97
Whole milk	- 3.79
Total	- 1.82

Source: Own elaborations

The second step involves the change in low fat milk purchasing being divided by the change in whole milk purchases which gave rise to the substitution ratio equating 1:0.52. This would suggest that consumers do not see one unit of low fat milk being equivalent to one unit of whole milk in terms of their underlying preferences.

It should be emphasised that this is obviously under the scenario of a 1% tax on whole milk and the tax rate would very much determine this relationship. The assumption which is supported by the demand system modelling results of Table 13 is that if a tax is placed on whole milk then there will be less demand for whole milk and increased demand for low fat milk which results in more milk fat being available for other products and less use of relatively higher carbon footprint palm oil, thus an overall decrease in emissions. It should also be inferred that the overall quantity of milk declines.

2.3.5 Chapter 2 Empirical summary

The findings suggest that applying a 1% tax to whole milk could potentially reduce demand for whole milk while increasing the demand for the substitute good of low fat milk. This potentially results in less palm oil being used for other food products as there is greater availability of milk fat which has lower emissions relative to palm oil. Thus a tax of 1% is likely to reduce GHG emissions which demonstrates that milk fat content is important for determining how harmful (in terms of GHG emissions) a milk product is.

This section has shown the importance of using demand systems to understand potential substitution effects. The use of demand systems and of the ALCA data will be developed in the next chapters.

2.4 Summary

The purpose of this chapter was threefold: introduce how food consumption contributes towards the problem of climate change, explain how food emissions are measured and demonstrate how price is an effective means to reduce demand for high carbon whole milk using a conditional demand system and the importance of understanding substitutes.

Food emissions are measured through carbon footprints which provide an estimation of the carbon dioxide equivalent of different food products. This helps to categorise the high carbon food products of meat and dairy and the lower carbon footprint products of grain. Within the food groups there is a degree of variability in terms of carbon footprint as poultry had a lower carbon footprint relative to red meats such as beef.

The demand system modelling results suggest that price increases can encourage substitution into lower carbon food products. The empirical work of this chapter highlighted how a 1% price increase of whole milk would likely result in substitution into low fat milk (demand for low fat milk would increase by 3.45%).

The next chapter takes the modelling further by understanding the change in emissions induced for different meat products. In addition to this chapter three forms a carbon consumption tax.

Chapter 3. Carbon consumption taxation and demand modelling[18]

3.1 Introduction

This chapter expands the demand system modelling of chapter 2 and calculates the carbon consumption tax for meat products. This chapter provides support for answering objective one (Estimating demand systems for the purpose of understanding the substitutions of high carbon food products**)** and two (Developing carbon footprint elasticities in order to understand emission changes induced through carbon consumption taxes).

As highlighted in chapter 2, meat products are the largest carbon emitting food products and are responsible for 34.5% (cradle to distribution centre) of Scottish food chain emissions (CO_2e) (Audsley et al., 2009). The ability for households to substitute into chicken and away from beef or sheep could result in a decrease in household carbon footprints (i.e. reduced emissions consumed by households)

Demand system modelling is described in more detail with emphasis on the dynamic version of the AIDS which is used for the purposes of estimating the Marshallian price elasticities. Through the application of the carbon footprint elasticity, the potential reduction in emissions of a tax for meat products can be estimated for the different socio-economic groups in Scotland.

3.2 Data

This section describes the main food purchasing database used in the study (i.e. Kantar Worldpanel). This dataset contains a wealth of information and only some of this information is used in the study for which an explanation will be provided. The other relevant dataset used is that containing carbon footprints, which is described in the previous chapter. The data used in this chapter covered Scottish purchases from the year 2006-2011 with each year comprising of 13 periods of four weeks and individual household purchases are thus aggregated. The descriptive statistics of the data used for this chapter are provided in Table 14 to Table 16.

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[18] This chapter is based on the paper "Socioeconomic effects of reducing household carbon footprints through meat consumption taxes", which was accepted to the "Journal of Food Products Marketing" journal. The paper can be found in the final appendix.

Table 14 Descriptive statistics: Social grade A, B & C1

	Share					Price					Expenditure
	Beef	Chicken	Pork	Sheep	Turkey	Beef	Chicken	Pork	Sheep	Turkey	
min	0.19	0.31	0.28	0.03	0.01	1.71	1.72	1.52	1.91	1.54	-0.39
max	0.30	0.43	0.36	0.08	0.08	2.10	2.02	1.76	2.34	2.10	0.43
range	0.10	0.12	0.08	0.05	0.07	0.39	0.30	0.25	0.43	0.57	0.82
sum	17.73	29.47	24.40	3.96	1.44	147.28	142.88	128.57	163.02	139.01	0.49
median	0.23	0.39	0.32	0.05	0.02	1.94	1.86	1.70	2.09	1.81	0.03
mean	0.23	0.38	0.32	0.05	0.02	1.91	1.86	1.67	2.12	1.81	0.01
std.dev	0.02	0.02	0.02	0.01	0.01	0.09	0.07	0.07	0.09	0.13	0.15

Source: Own elaboration based on Kantar Worldpanel data. Price is in natural logarithm form.

Table 15 Descriptive statistics: Social grade C2 & D

	Share					Price					Expenditure
	Beef	Chicken	Pork	Sheep	Turkey	Beef	Chicken	Pork	Sheep	Turkey	
min	0.20	0.29	0.31	0.02	0	1.61	1.60	1.41	1.84	1.42	-0.84
max	0.28	0.42	0.40	0.06	0.07	2.02	1.95	1.73	2.29	2.16	0.14
range	0.08	0.13	0.08	0.04	0.07	0.41	0.35	0.32	0.45	0.74	0.98
sum	18.34	27.68	26.65	3.14	1.19	141.47	137.96	122.58	158.43	136.07	-26.64
median	0.24	0.36	0.34	0.04	0.01	1.90	1.80	1.63	2.04	1.76	-0.35
mean	0.24	0.36	0.35	0.04	0.02	1.84	1.79	1.59	2.06	1.77	-0.35
std.dev	0.02	0.03	0.02	0.01	0.01	0.12	0.08	0.08	0.10	0.15	0.20

Source: Own elaboration based on Kantar Worldpanel data. Price is in natural logarithm form.

Table 16 Descriptive statistics: Social grade E

	Share					Price					Expenditure
	Beef	Chicken	Pork	Sheep	Turkey	Beef	Chicken	Pork	Sheep	Turkey	
min	0.08	0.27	0.15	0.01	0	1.58	1.51	1.46	1.67	1.28	-1.54
max	0.32	0.74	0.43	0.07	0.06	1.99	2.02	1.68	2.43	2.15	-0.21
range	0.24	0.47	0.28	0.06	0.06	0.41	0.51	0.22	0.76	0.86	1.33
sum	16.50	30.86	25.81	2.72	1.10	141.33	135.95	121.10	156.06	131.05	-80.08
median	0.24	0.34	0.36	0.04	0.01	1.86	1.76	1.57	2.03	1.66	-1.09
mean	0.21	0.40	0.34	0.04	0.01	1.84	1.77	1.57	2.03	1.70	-1.04
std.dev	0.06	0.14	0.08	0.01	0.01	0.10	0.12	0.05	0.15	0.19	0.30

Source: Own elaboration based on Kantar Worldpanel data.

Only purchases observed on households buying meat products were used as the interest on focussing on meat products (this is not the case for chapter 4 where other food products are used.) alone arose due to their particularly high carbon footprints and the potential for substitution within the meat group. The different cuts of meat were selected such as pork loin and bacon (which originates from many different cuts) were extracted from the Kantar dataset. These cuts were aggregated together which is important as the carbon footprint data is for the whole animal and not the individual cuts. A description of the meat carbon footprint data can be found in chapter 2. The point of aggregating all the meat products is important considering if different cuts were selected then the resulting carbon emission change would be difficult to estimate due to data availability.

Purchase data which exists in the public domain in the UK is the Expenditure and Food survey (Leicester and Oldfield, 2009). The EFS was replaced in with the "Living Costs and Food Survey" 2008 with the same requirement for the respondent (over age of seven) to keep a record of their expenditure and quantity bought of food and drinks over a two week period (Defra, 2011).

However a private sector data source is Kantar Worldpanel data which (formerly known as TNS data). The differences between the two data sources is mainly the EFS's respondents are surveyed on their expenditure and quantity of food bought for two weeks (Leicester and Oldfield, 2009). Data from the period 2001 – 2006 found that the mean length of time that respondents remain in the TNS data survey is 48 weeks (Leicester and Oldfield, 2009). Overall the two dataset spending levels approximately match one another with the TNS data showing that the response rate for respondents was not significantly affected by "fatigue" (Leicester and Oldfield, 2009). There is, however, evidence to suggest that households who record no spending in certain weeks is higher for the TNS data (14%) compared to the EFS (4%) (Leicester and Oldfield, 2009).

Leicester et al (2009) conclude by favouring TNS data over the government provided EFS due to more precise information being gathered such as price paid for product, store of purchase and product information. A problem mentioned in Macdiarmid et al's report was the issue regarding recording of food i.e. cooked rice is actually consumed and not uncooked rice (Macdiarmid et al., 2011). However the Kantar Worldpanel data is recorded on what the households have purchased which can be different to consumption due to wastage.

The UK government's Department for Environment, Food and Rural Affairs (Defra) publishes a consumer survey dataset called "Family Food Module of the Living Costs and Food Survey (LCFS)". The participants are asked to record their purchases and prices of food bought for a two week period (Defra, 2014a). This means the dataset records restaurant meals which the Kantar data does not. However, as the purpose of this study is on modelling a carbon consumption tax then restaurant meals are not of interest as only food and drink purchased from retailers would have the hypothetical tax applied. There is also the need to form specific groups of products as to differentiate between different food products for which the LCFS does not allow due to its level of aggregation.

3.2.1 Time series data

The Kantar data is collected as panel data and this thesis uses it in the form of time series data. The succinct explanation is that since the primary aim is to understand the total change in carbon emissions in Scotland associated with a carbon consumption tax, then aggregated time series data is more applicable relative to panel data. An important contribution from Caraher and Cowburn (2005) is the design of a consumption tax should be based at population level rather than on individual level. With regards to avoided carbon emissions it does seem sensible to model the tax at population level.

3.2.2 Social groups

The Kantar dataset records a sample of Scottish household purchases (excluding the Shetland Islands) made each year. This dataset contains many variables with some of the most useful such "social class" shown in Table 17.

Table 17 Kantar variables

Variable	Description
Social Class	A
	B
	C1
	C2
	D
	E
	Unknown
Volume	Represents quantities
Net spend	Provides price paid after discount (£) (This is normally used for Price paid)
Product	Provides product number
Desc	Provides product description

Source: Kantar Worldpanel

A coding was created for categorising the various food groups. However, there was still a need to use Microsoft Access structured query language (SQL) to select unique products from the receipt description which was used particularly for identification of the different ready-made meals which will be addressed in chapter 4. The "Like" statement allowed selection of particular products which matched the carbon footprint data. The availability of the carbon footprint data determined the grouping of food products.

The dataset records social groups which corresponds to the groups used in the most recent 2011 Scottish census (National Records of Scotland, 2013). These groups provide an idea of the household income as the group is determinant on chief income earner or respondent's employment status, tenure, qualification and working status (Meier and Moy, 2004). Due to these characteristics it seems likely that higher social groups will have a higher income and thus may be less price sensitive.

The three different social groups formed for this chapter are medium to high income earners (A, B & C1), Lower income earners (C2 &D) and non-active in the labour market along with casually employed workers (E) (Ipsos-Mori, 2009). The total Kantar sample population was 2,118 households and Table 18 provides a breakdown of the sample population.

Table 18 Population sample data

Social Group	Kantar household numbers	Kantar household population shares (%)
A, B & C1	742	35
C2 & D	1,105	52
E	271	13

Source: Own elaboration based on Kantar Worldpanel data

In order to calculate the population shares of these groups which is important in attributing the likely reduction in GHG emissions of each group (this will be further explained in the methods) it was found that there were no Scottish sources of this data. Instead the National Readership Survey (2013) provided a breakdown for an estimation of the 2014 UK population. From this source it can be ascertained that that the: A, B & C1 group represents 51%, C2 &D group represents 41% and E represents 9%. According to Table 18 this is not very different from the Kantar sample obtained. However in terms of calculating carbon emission reduction associated with taxes, the National Readership Survey figures were used.

It should be highlighted that these groups are typically given as AB, C1, C2 and DE (National Records of Scotland, 2013). Chapter 5 forms the groups in this manner, yet, it was decided that isolating group E would be important in order to understand the potential effect in terms of carbon reduction for the poorest group. Chapter 4 takes this further and considers potential health effects. A breakdown of the corresponding Scottish population of these social groups was also obtained.

Table 19 shows a breakdown of meat budget shares by the different social groups and as only meat budgets are considered then the combination of meat shares for each social group sums to 100% (since it is a conditional demand system being estimated). It can be observed that red meats have a higher budget share for the wealthier households who subsequently represent a larger share of the population. This would suggest that a carbon consumption tax may reduce demand for high carbon red meat products for particularly these social groups. However, the price elasticity will be important as it is likely that the wealthier groups are least price sensitive relative to the lower income groups such as E.

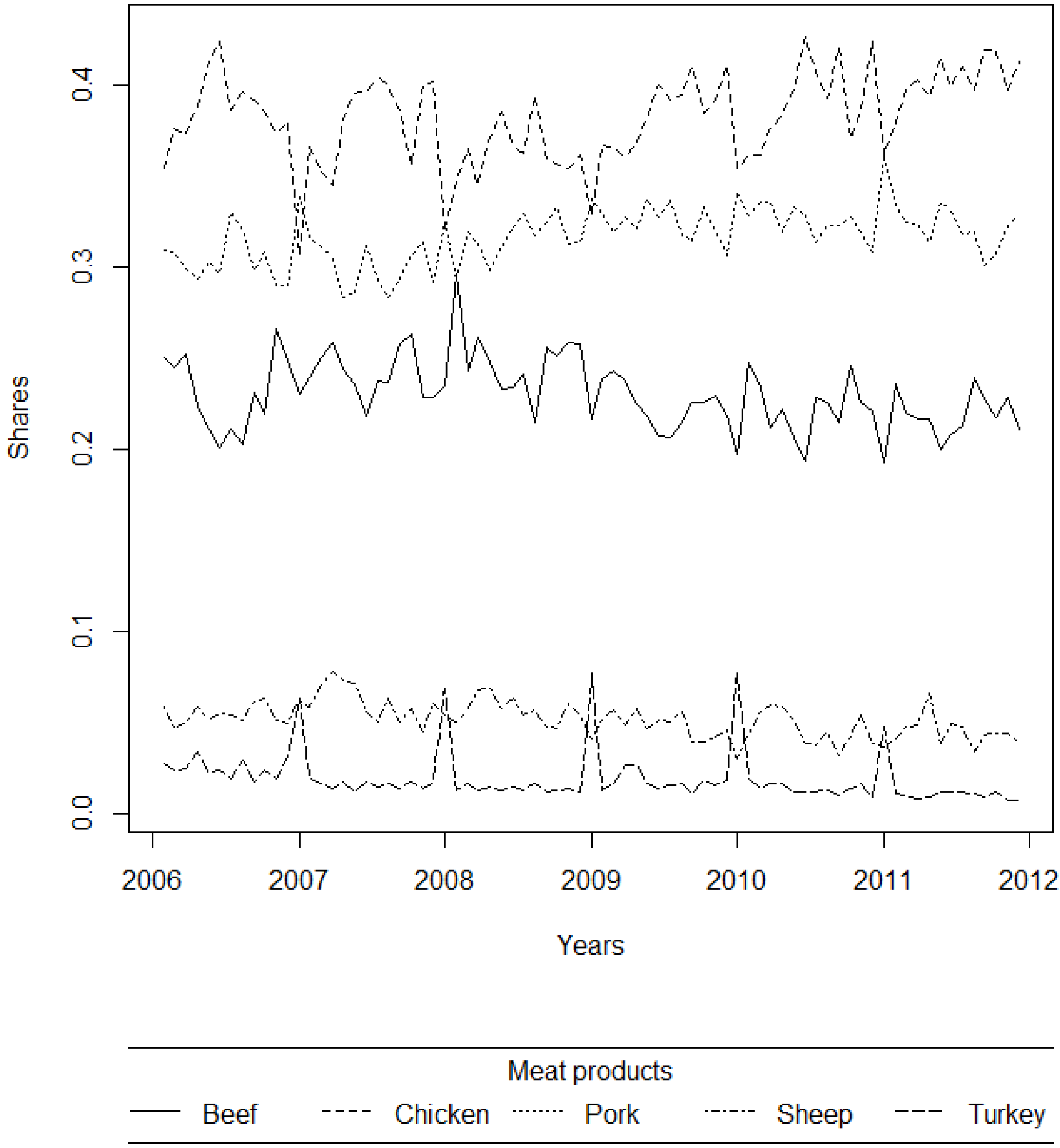
Table 19 Social group budget shares (%)

Meat products	Social group		
	A, B & C1	C2 &D	E
Beef	23	24	21
Chicken	38	36	40
Pork	32	35	34
Sheep	5	4	4
Turkey	2	2	1

Source: Own elaboration based on Kantar Worldpanel data

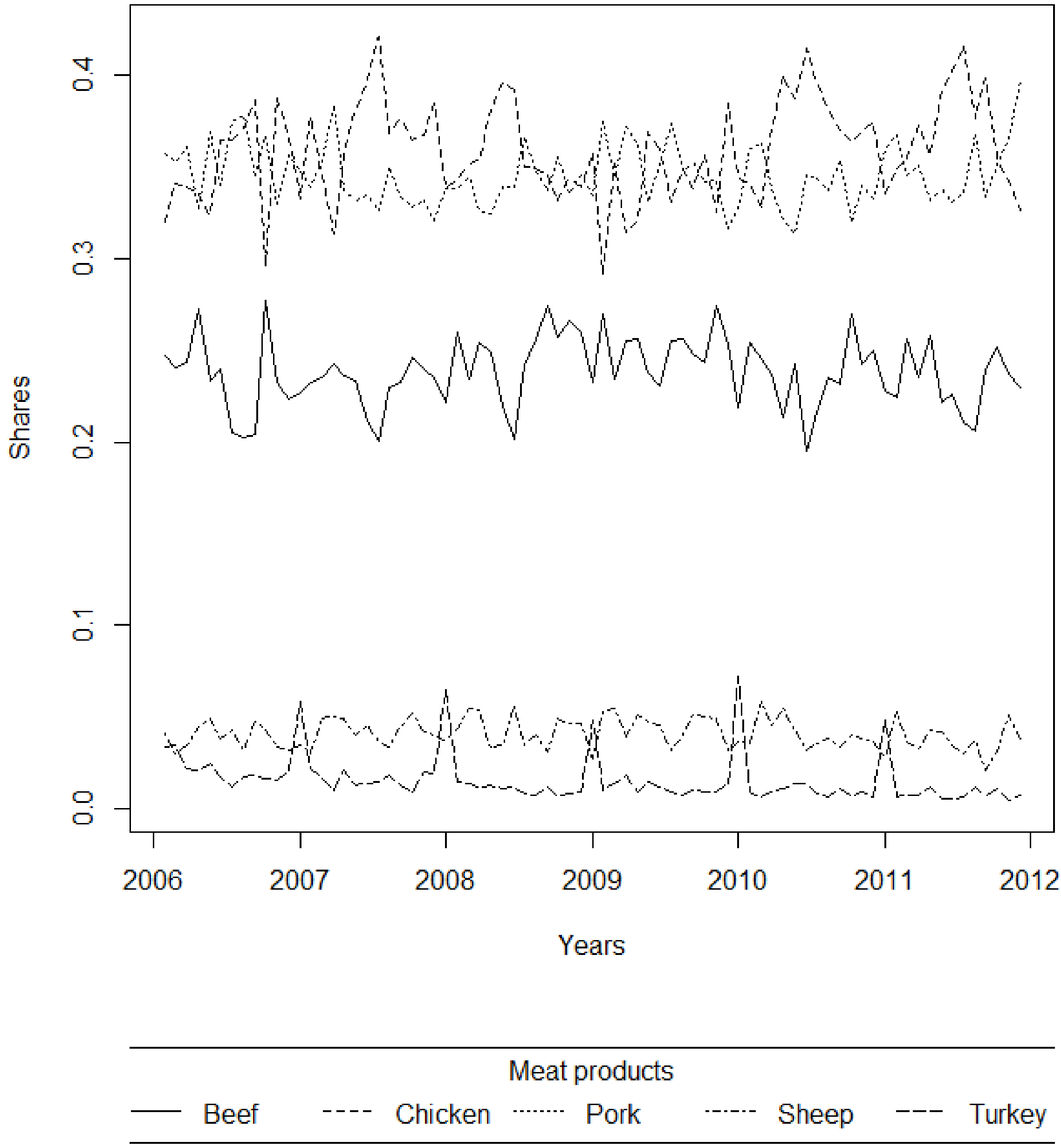
The evolution of meat expenditure shares for the different social groups is shown by Figure 4 to Figure 6.

Figure 4 Social groups A, B & C1 - Evolution of meat expenditure shares for years 2006-2011



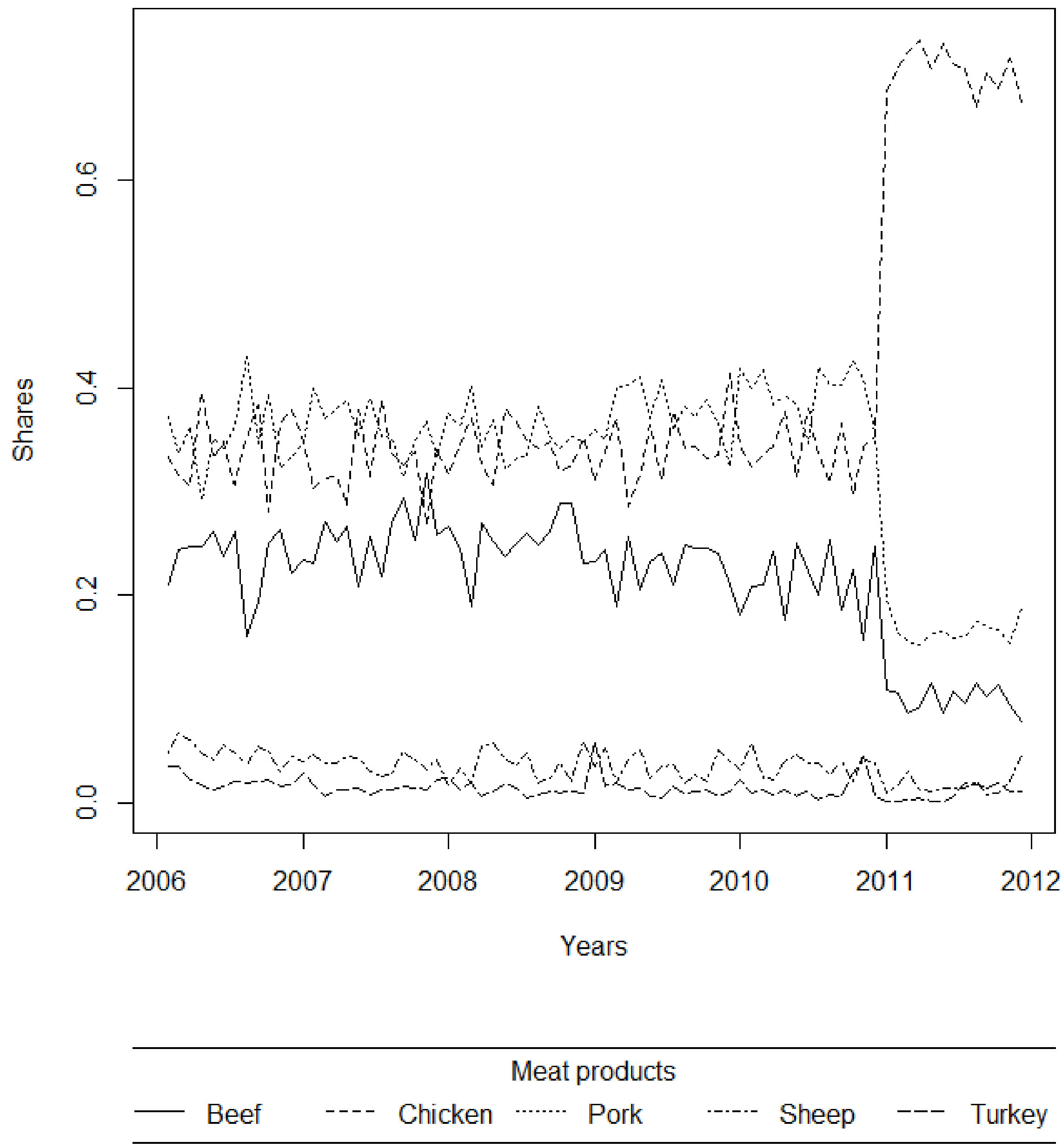
Source: Own elaboration based on Kantar Worldpanel data

Figure 5 Social grade C2 & D - Evolution of meat expenditure shares for years 2006-2011



Source: Own elaboration based on Kantar Worldpanel data

Figure 6 Social grade E - Evolution of meat expenditure shares for years 2006-2011



Source: Own elaboration based on Kantar Worldpanel data

3.2.3 Carbon emissions

Chapter 2 reviewed the carbon emissions literature and the taxation part of the next section will also briefly discuss meat based emissions. This chapter uses Audsley et al (2009) carbon footprint data which covers both domestic and imported meat products. Chapter 4 uses mainly PAS 2050 compliant data. The methods section of this chapter describes the total emissions allocated to consumption of the meat group in Scotland.

Carbon footprints from British produced meat were used as there was little difference in carbon footprint values for other European countries (Audsley et al., 2009). The majority of meat products consumed in the UK are also produced in the UK (83%) or imported from other EU countries (7%) (Defra, 2014b). Therefore, the carbon footprints used in this paper are likely to reflect a realistic situation for the Scottish food chain[19]. Table 20 shows the difference between the carbon footprints of the different meat categories with ruminant animals having a higher carbon footprint relative to poultry. The data from the table is used in the carbon elasticity calculations and is modified to be g CO2e/g instead of kilogram.

Table 20 Carbon footprints of meat products

Meat categories	Carbon footprints (Kg CO2e/Kg)
Beef	12.14
Chicken	2.84
Pork	4.45
Sheep meat	14.61
Turkey	3.76

Source: (Audsley et al., 2009)

The previous chapter provided evidence that reducing demand for whole milk could reduce emissions. However, taxing the five milk products using the same basic one percent tax seems problematic given the different carbon footprint of the products (whole milk should have a higher tax rate relative to the other products to account for

[19] Audsley et al., (2009) calculated the meat emissions of the Scottish food chain

the greater damage in carbon emissions). These emissions represent an externality to society (Tol, 2014) which needs a value (i.e. cost) in order for a carbon consumption tax to be calculated. Assigning a value (i.e. cost/price) to carbon is important in order for the carbon consumption tax to be effective in addressing the externality of food emissions.

Forming a social cost of carbon is a complex task as it needs to incorporate areas such as the marginal damage cost and placing a value on the potential damage of climate change while discounting (back in time) the period of interest (Pizer et al., 2014). The social cost of carbon is the damage caused to the world represented in monetary form for releasing an additional one tonne of carbon into the atmosphere (Pearce, 2003). Pearce (2003) emphasise that the social cost at the social optimum will not be zero as mitigating against emissions rarely involves zero costs. The social cost is also likely to increase over time due to the cumulative nature of GHG staying in the atmosphere and causing more damage (Pearce, 2003). The methods section will detail the social cost value chosen for this chapter.

3.3 Methods

3.4.1 The Dynamic Almost Ideal Demand System

Eakins and Gallagher (2003) study Irish alcohol demand for the years 1960-1998 using a dynamic error correction AIDS model (conditional) and find that both long run and short run demands for beer and spirits are relatively price inelastic which they suggest is important as government alcohol duties are likely to provide the government more revenue (the calculation of government revenue obtained from taxes is estimated in chapter 5). It is interesting that they seem to focus primarily on the long run results, despite the fact that wine is only price inelastic in the short run. Short run results are still of interest in order to understand how consumers will initially react to price changes. Karagiannis et al (2000) use a similar dynamic error correction AIDS model to study Greek demand for meat products for the period 1958-1993 which has relevance to this chapter. The authors find that short run

Marshallian price elasticities are less price sensitive relative to long run Marshallian price elasticities though all are price inelastic (Karagiannis et al., 2000).

The dynamic AIDS equation shown in equation 7 is based on Want et al (2010) whereby: λ the speed of short run adjustment which is calculated from the error residuals of the static LA-AIDS model shown in equation 5. The consumer habit coefficient (Ψ) is the dependent variable of meat expenditure share lagged by one period. Expenditure is represented by m whilst the stone price index is represented by P_t^* with real expenditure being derived from division of the two parameters. ϒ represents relative prices and D_k incorporates the 12 seasonal dummy variables. Where Δ = first difference, Ψ = consumer habit coefficient, w_{iht}= the budget share of meat product i at household per capita level (h) with the inclusion of time (t). To emphasise the subscripts[20] i indexes the products of the shares (i = 1, 2, …,N) while j indexes the products in the price variables (j = 1, 2, …,N) (Sun, 2015). Subscript k indexes the dummy variables (k = 1, 2,…,N) (Sun, 2015).

$$w_{it} = \alpha_i + \beta_i \ln\left(\frac{m_t}{P_t^*}\right) + \sum_{j=1}^{N} \gamma_{ij} \ln(p_{jt}) + \sum_{k=1}^{K} \beta_{ik} D_{kt} + u_{it} \quad (5)$$

$$\ln(P_t^*) = \sum_{j=1}^{N} w_{jt} \ln(p_{jt}) \quad (6)$$

$$\Delta w_{iht} = \psi \Delta w_{ith,t-1} + \lambda_i u_{it} + \beta_i^d \Delta \ln\left(\frac{m_{th}}{P_t^*}\right) + \sum_{j=1}^{N} \gamma_{ij}^d \Delta \ln p_{jt} + \sum_{k=1}^{K} \varphi D_{ik}^d + \xi_{iht} \quad (7)$$

With regards to the Dynamic-AIDS, the first property which must be ascertained is the time series nature of the variables of interest (e.g. shares, prices and expenditures) and more importantly understanding if the variables are cointegrated within the share equations (Karagiannis et al., 2000). Karagiannis et al (2000) focus on the idea of cointegration as the dynamic element of the model is measuring the "deviations from the long run equilibrium". The authors point out that the actual time series property of order of integration (i.e. unit roots) is not a necessary condition for using the model provided cointegration of the variables is present (Karagiannis et al., 2000).

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[20] For the empirical study of this chapter: N = the five meat products, K = 12 dummy variables as there are 13 periods within each year (this avoids the problem of the dummy variable trap)

The short run price elasticities are calculated from Equations 9 and 10 which are provided by Sun (2015). The expenditure elasticities represented by equation 8. Marshallian price elasticities are represented by equation 9 and the Hicksian elasticities by equation 10. Only the Marshallian price elasticities are useful for this thesis. All the elasticities use the parameters from equations 5 and 7 with the Kronecker delta equal to one, only for own price elasticities and ϖ_i is the average budget shares for the 2006-2011 (Sun, 2015). The dynamic price elasticities are calculated by changing the γ_{ij}^s and β_i^s parameters to those from equation 7 and obtaining the variances for both static and dynamic elasticities allows for the t-ratio to be calculated (Sun, 2015).

$$\eta_i^s = 1 + \frac{\beta_i^s}{\varpi_i} \quad (8)$$

$$\epsilon_{ij}^s = -\delta_{ij} + \frac{\gamma_{ij}^s}{\varpi_i} - \frac{\beta_i^s \varpi_j}{\varpi_i} \quad (9)$$

$$\rho_{ij}^s = -\delta_{ij} + \frac{\gamma_{ij}^s}{\varpi_i} - \varpi_i \quad (10)$$

Both demand systems use per capita data which was also used by Säll and Gren (2015) for their tax modelling. The reason per capita data were used is the suggestion in Deaton and Muellbauer (1980a) for allowing “a limited taste variation across households”. Deaton and Muellbauer (1980b) elaborate this issue of aggregation across households whereby the budget share of the ith good (*w* bar) “depend on prices and a representative level of total expenditure” which allows for an understanding of market behaviour through a representative household. Therefore, the elasticities calculated from the per capita demand system are assumed to be representative of the Scottish population.

With regards to separability, Jensen and Smed (2007) assumed separability of different food groups without statistical tests which they justify by explaining the issue of too few observations which would likely lead to statistical issues. They also highlight the problem of separating processed meals into different groups (Jensen and Smed, 2007). This does raise an issue as processed meals are purchased in Scotland and will be dealt with in chapter 4 whereby ready-made meals is studied for the different meat products. Testing weak separability using the log likelihood test (LR) found that fish products and meat products for Canadian households should be estimated together in a demand system since weak separability was rejected (Salvanes and DeVoretz, 1997).

It seems that few authors use separability tests and instead reply on priori information for the formation of the different food groups. The food groups used in this thesis are similar to existing published and government literature, therefore, weak separability tests are considered of little use to this study.

The LA-AIDS and dynamic AIDS models used in this chapter are based on the work by (Wan et al (2010) using R package “Erer” (Sun, 2014). This package estimates the models using seemingly unrelated regressions.

3.4.2 Computation of carbon consumption taxation

As highlighted in chapter 2, Edjabou and Smed (2013) provide the basis for the computation of carbon consumption taxes. The compensated scenario takes into account the existing VAT on the food product. The uncompensated scenario is shown in equation 11 where the tax ($\Delta\mathbf{p}$) is calculated by taking the CO_2e (i.e. carbon footprint) of food group i ($\boldsymbol{k_i}$) and multiplying it by the carbon price ($\mathbf{p_k}$) (Edjabou and Smed, 2013). Subscript k represents the cost of carbon which is present considering that two different carbon prices were used in their study.

$$\Delta p_{ik} = k_i \, . \, p_k \tag{11}$$

The compensated scenario is similar to equation 12 yet, includes x which is the tax revenue neutral factor and p_{i0} which is the original price of food group i inclusive of the value added tax (VAT) (Edjabou and Smed, 2013).

$$\Delta \mathbf{p_{ik}} = \mathbf{k_i} \, . \, \mathbf{p_k} - \mathbf{x} \, . \, \mathbf{p_{i0}} \tag{12}$$

Edjabou and Smed (2013) develop scenario 1A for referring to the carbon price based on Tol's estimate while 1B is based on Stern's estimate. Scenario 2 follows the same logic and is based on equation 12. For the purposes of adapting this tax calculation to the thesis, Scenario 1 is of most interest as most food products in Scotland do not have any VAT applied (HMRC, 2013). Therefore, as meat and dairy are largely excluded from VAT, there is no requirement to adapt equation 12.

The approach to formulating a tax taken by Säll and Gren (2015) has similarities with both Briggs et al (2013) and Edjabou and Smed (2013) with the emphasis that it is based on the carbon content of food products. However, Briggs et al (2013) did not tax all products and instead exempted some products when the product exceeded a certain threshold of emissions.

Säll and Gren (2015) tax calculations for each commodity (j) are shown in equation 13 where the tax is equal to the average emissions per kg of meat multiplied by the average damage cost of each pollutant (i).

$$tax_j = \sum_i^h e_{i,j} AD_i \qquad (13)$$

Säll and Gren (2015) based their price of carbon (and other pollutants though these are not of interest to this thesis) on political revealed costs which they report as being slightly higher than the Stern average value. As the authors are considering other pollutants it means they calculate an environmental tax which does not "just" take into account Carbon emissions. Säll and Gren (2015) calculated the change in demand from a tax (i.e. price increase) through the use of equation 14. This is a useful equation for this thesis as it allows for the change in demand associated with introduction of a tax to be calculated.

$$\frac{\Delta Q_j}{Q_j} = \sum_k^m \frac{\Delta P_k}{P_k} \varepsilon_{j,k}^{M*} \qquad (14)$$

Equation 11 is used as the basis for calculating tax rates for the thesis which is similar to Säll and Gren (2015) except that they use more pollutants (e.g. Phosphorous and ammonia etc.) than just carbon footprint (i.e. carbon emissions).

This thesis will adopt equation 11 from Edjabou and Smed (2013) for the purposes of calculating the price level which allows the percentage increase to be obtained (this creates the tax rate). The average prices for each meat category were sourced from the most recent complete year of the Kantar data (2011) and were calculated by the marginal damage cost (commonly referred to as social cost of carbon) which was obtained from Tol (2005)[21] and was largely reflective of the social damage of Pearce et al (1996) publication being approximately $50 per tonne of carbon emissions. Adjusting the social cost of Tol (2005) for a 2011 value also involved using a range of Tol's values explained in Defra (2005) and Edjabou and Smed (2013) who converted the social cost into carbon dioxide equivalent. These results allowed for a comparison with the values from the Forestry Commission (2011) report. Based on the range of values from the Forestry Commission (2011) and Defra (2005) the social cost of Tol (2005) was adjusted to equal approximately £78 tCO_2e for 2011.

The UK government favours Defra's shadow price of carbon over the sole use of SCC (Defra, 2007) and was the main reason behind chapters 4 and 5 using Defra's shadow price of carbon. Chapter 4 will provide more detail on Defra's shadow price of carbon.

The 2011 prices obtained from the Kantar data did not account for social grade. The reason for this is because of the possibility of supermarket practices such as price discrimination which could result in meat prices differing depending on the location of retailer i.e. prosperous or deprived areas.

In order to understand the change in demand resulting from the tax rate, equation 14 from Säll and Gren (2015) will be used.

3.4.3 Computation of carbon elasticity

The purpose of modelling consumer demand for different food products is: firstly the need to identify the substitutes and complements of different food products (this was

[21] The price index was obtained from the House of Commons (2012) and spot rates were obtained from Bank of England (2014) in order for adjusting prices

highlighted in chapter 2) in order to understand how a carbon consumption tax delivered through price changes could affect consumer demand for different food products. Secondly the responsiveness of a change in demand for different food products to a change in price is important in order to get an idea of the change in emissions from substitutions of the food groups of interest.

In order to understand the likely effect of a carbon consumption tax, the elasticity of a one percent price increase is multiplied by the tax rate and applied directly to Marshallian price elasticity matrix. The use of price elasticities with regards to food products has great relevance to food policy as they allow for an understanding of how potential pricing will impact on demand and nutrient consumption (Nhung et al., 2013).

The nutrient elasticity method proposed by Huang (1996) has been altered in the sense that instead of using nutrient shares of food products, carbon shares are used instead. The original method proposed that the nutrient matrix (N) is calculated through multiplying the food shares of each nutrient (S) by the demand price elasticities (D) as shown in Equation 15 (Huang, 1996).

$$\mathbf{N} = \mathbf{S} \times \mathbf{D} \tag{15}$$

The food share of each nutrient is replaced with the carbon dioxide equivalent (carbon footprints) of the different meat groups (S). With regards to this chapter, data from Audsley et al (2009) allowed for these shares to be calculated. The matrix of demand price elasticities (Marshallian) are calculated from the AIDS model.

Edjabou and Smed (2013) require the change between post tax (q_{i1}) and pre-tax (q_{i0}) quantity demand of food product i. The carbon footprint elasticity estimates the change in carbon emissions associated with the corresponding tax rate.

The additional step of ensuring the elasticities are representative of the population was mentioned in the data section of this chapter. The carbon footprint elasticities were applied to the approximate overall Scottish meat emission value of 2,340,900 tCO2e/y which is pre regional distribution centre (RDC) and includes both foreign and domestic meat products. Chapter 2 highlighted the carbon emission hotspots for meat products occurred in farm gate stage of the LCA, therefore, as long as the carbon footprints follow a similar LCA methodology (which they do) then they should still be representative in terms of the highest carbon footprint meat will have the highest carbon share thus in effect ranking occurs. The carbon footprints from Audsley et al (2009) were used to calculate the carbon share term of equation 15.

In order for the carbon footprint elasticities to calculate how a one percent price increase changes the emissions consumed (i.e. purchased) it is important to weight the overall emission value by the population representation of the group. The weights are based on the UK population representation e.g. the total emissions reduced through the tax which are calculated from the carbon footprint elasticities being applied to the overall meat emissions. This figure would then be weighted to account for the 51% population representation of social group: A, B & C1.

3.4 Results and Discussions

3.5.1 Diagnostic results for Dynamic-AIDS

The results from the Phillips-Perron unit root test (results shown in Table 32 to Table 34 in the annex) suggest that all the share and price series do not contain unit roots in the first difference form (except for in level form where the Augmented Dickey Fuller test suggested that most series did contain unit roots). The cointegration (Phillips-Ouliaris cointegration results) results suggest that the meat expenditure shares are cointegrated with their respective independent variables (prices and expenditure). Therefore the error correction version of the dynamic AIDS can be justified for using this chapter’s purchasing data.

Table 21 to Table 23 show the results from the same diagnostic tests as described in chapter 2. For the purposes of acquiring these results, the sheep equation was dropped through the estimation of demand system. The Breusch-Godfrey (BG) tests for serial correlation highlights how generally speaking less serial correlation is observed in the dynamic demand system which is similar to the elasticity results of

Wan et al (2010)[22]. The main concern arises from Table 23 whereby the Jarque-Bera test which would imply that many of the error terms for the equations are not likely to be normally distributed.

[22] Only the dynamic results are shown in this chapter

Table 21 Diagnostic test results for Dynamic AIDS models (Social grade A, B & C1)

Budget share equation	Breusch-Godfrey (BG) test		Breusch-Pagan (BP) test		Ramsey's Regression Specification Error test (RESET)	Jarque-Bera (JB) test	
Beef	0.182		19.472		0.24	2.195	
Chicken	1.023		19.475		09	0.509	
Pork	2.26		32.106	***	1.143	0.87	
Turkey	01		39.095	***	1.215	22.009	***

Notes: Statistical significance: '*'=10%, '**'=5% or '***'=1%

Source: Own elaboration based on Kantar Worldpanel data

Table 22 Diagnostic test results for Dynamic AIDS models (Social grade C2 & D)

Budget share equation	Breusch-Godfrey (BG) test		Breusch-Pagan (BP) test		Ramsey's Regression Specification Error test (RESET)	Jarque-Bera (JB) test	
Beef	0.605		20.454		2.115	0.494	
Chicken	0.848		21.266		2.258	0.58	
Pork	0.056		11.429		0.335	6.913	***
Turkey	4.472	***	24.478		1.889	25.232	***

Notes: Statistical significance: '*'=10%, '**'=5% or '***'=1%

Source: Own elaboration based on Kantar Worldpanel data

Table 23 Diagnostic test results for Dynamic AIDS models (Social grade E)

	Breusch-Godfrey (BG) test		Breusch-Pagan (BP) test		Ramsey's Regression Specification Error test (RESET)		Jarque-Bera (JB) test	
Beef	0.01		17.19		2.784	*	9.06	***
Chicken	106	***	30.58	**	15.087	***	5.186	*
Pork	4.28	**	24.13		6.277	***	6.061	**
Turkey	2.467		25.976		0.267		137.883	***

Notes: Statistical significance: '*'=10%, '**'=5% or '***'=1%

Source: Own elaboration based on Kantar Worldpanel data

3.5.2 Marshallian price elasticities and tax rates

Table 24 shows the tax rates which are applied to the different meat categories. As discussed in the methods section of this chapter, the tax rate incorporates the carbon footprint and the marginal damage cost of the meat categories. The tax rates highlight that the highest emitters such as sheep and beef attract a higher tax rate which is not surprising given the nature of the carbon consumption tax being dependent upon the carbon footprint of the product. It is important to note that equation 11 calculates price levels which is then calculated into the respective tax rate.

Table 24 Tax rate

Products	Tax rate %
Beef	13.04
Chicken	3.16
Pork	6.27
Turkey	4.15
Sheep	12.04

Source: Own elaboration based on Kantar Worldpanel data

Table 28 to Table 30 show the effects of the respective meat taxes on the Marshallian price elasticities. This approach was similar to the working paper of Säll and Gren (2012) and it provides for an idea of how the tax will affect the quantity demanded of the food product. Before discussing the effects of the respective tax rates on the price elasticities, it is worth discussing the cross price elasticity results of Table 28 to Table 30.

As the meat products are based on an aggregation of different cuts then it will not be possible to observe either the possible varying own price elasticities or the potential cross price elasticities as in the case of Tiffin et al (2011). The data section has already explained that the carbon footprints are not available for different cuts.

Table 25 shows the Marshallian price elasticities for the A, B and C1 social group. The result suggests that few statistically significant cross price elasticities exist. A 1% price increase in the price of chicken would likely result in sheep meat being a substitute though the vice versa relationship is not statistically significant. A similar situation of a white meat having a red meat substitute arises whereby a 1% price increase in the price of pork would also likely result in sheep meat being a complement (vice versa relationship is not statistically significant). These results suggest that the more expensive red meats are substitutes for lower priced white meats though there are few statistically significant cross price elasticities.

Table 25 Social group A, B & C1 –Short term demand elasticities for meat

	Marshallian elasticities								
	Beef		Chicken		Pork		Turkey		Sheep
Beef	-0.628	***	0.017		-0.089		-0.036		-0.101
Chicken	-0.059		-1.103	***	-0.054		-0.028		0.104
Pork	-0.092		05		-0.754	***	0.011		-0.127
Turkey	-0.426		-0.419		0.255		-0.402		0.231
Sheep	-0.501		0.809	*	-0.809	*	0.079		-0.622

Notes: Statistical significance: '*'=10%, '**'=5% or '***'=1%

Source: Own elaboration based on Kantar Worldpanel data

Table 26 shows the Marshallian price elasticities for the C2 and D social groups and unlike Table 25 there are more cross price elasticity effects. An interesting result is how beef (a red meat) and turkey (white meat) are both substitutes to one another. The potential of this cross price elasticity relationship on carbon emissions is described at the end of this section. The cross price elasticity of chicken unlike the previous social group is only related to other white meats. Pork is a complement of chicken (and vice versa).

Table 26 Social group C2 & D –Short term demand elasticities for meat

	Marshallian elasticities									
	Beef		Chicken		Pork		Turkey		Sheep	
Beef	-0.794	***	-0.089		0.112		-0.155	***	0.033	
Chicken	-0.14		-0.736	***	-0.400	***	0.089	***	-07	
Pork	0.066		-0.311	**	-0.627	***	-0.036		06	
Turkey	-1.287	***	2.128	***	-0.857		-0.757	***	0.251	
Sheep	0.167		0.022		0.029		0.096		-1.281	***

Notes:1/ Statistical significance: '*'=10%, '**'=5% or '***'=1%

Source: Own elaboration based on Kantar Worldpanel data

Table 27 shows the Marshallian price elasticities for the E social group and there are less statistically significant cross price elasticities compared to Table 26. The cross price elasticity of beef indicates that chicken is a complement which shows similar findings as the previous social group in the sense that a red meat has a white meat as a substitute. However, when chicken increases in price there are no statistically significant cross price relationships which makes the substitution argument less clear. The cross price elasticity result of a 1% increase in pork suggests a similar finding of sheep being a complement as was the case of social group A, B &C1. Though for social group E there is a more price sensitive response.

It is worth highlighting how the cross price elasticities are less sensitive for this social group compared to the C2&D group which is interesting as the lowest income group may be expected to be the most price sensitive.

Table 27 Social group E –Short term demand elasticities for meat 1/

	Marshallian elasticities									
	Beef		Chicken		Pork		Turkey		Sheep	
Beef	-0.562	*	-0.302		-0.132		0.012		0.075	
Chicken	-0.312	**	-0.965	***	-0.242	*	-0.047		-0.044	
Pork	0.021		0.189		-0.510	***	-0.01		-0.106	*
Turkey	0.479		-0.474		-0.074		-0.036		0.461	
Sheep	0.485		-0.163		-1.126	**	0.168		-0.148	

Notes:1/ Statistical significance: '*'=10%, '**'=5% or '***'=1%

Source: Own elaboration based on Kantar Worldpanel data

The potential regressive nature (the expression used in later chapters will be in terms of distributional effects) of taxes can be ascertained by studying the lower income groups and it is important to ascertain the likely effects of the carbon consumption taxes on their demand. It should be emphasised that the burden of tax is not being calculated and the regressive nature is being inferred from the Marshallian elasticities. Chapter five introduces health related measures (in the form of nutrients) to help understand more about the distributional nature of carbon consumption taxes.

With regards to the taxes applied in Table 28, the wealthier households would likely reduce their demand for beef by 8.19% and sheep by 7.49%. However, when the taxes are applied to chicken it may result in an increase in the demand for higher carbon sheep products by 2.56%. This may render the chicken carbon consumption tax of little use for reducing demand of higher carbon food products. However, this result does highlight the importance of understanding the substitution/complement relationship of the different products.

The likely effects of the meat taxes on demand for meat products with regards to the lower income households (Table 29) demonstrates an interesting outcome of the Beef taxes as they will likely reduce demand for beef by 10.35% and turkey by 23.82%. This outcome may be counterproductive as the demand for Turkey reduces by a greater proportion than that of beef. With regards to sheep meat, the lower income households are more price sensitive relative to wealthier households. A 15.42% reduction in demand for sheep is likely to occur due to the consumption tax.

The change in demand for lower income households with regards to chicken meat is relatively small. This implies that the taxes may not affect demand for this lower carbon and relatively healthier white meat (McMichael et al., 2007). If the tax is applied to chicken products then demand for turkey is likely to increase by 6.73% which demonstrates these households substituting into similar white meats. This chapter does have concerns regarding creating a separate group for turkey due to the relatively low budget shares seen in Figure 4, Figure 5 and Figure 6.

Table 30 demonstrates that the likely effect of a beef tax could be effective in reducing demand for the lowest income households. However as these households are likely to be on low incomes due to their non-participation (in addition to casually employed workers) in the labour market, this is the group where taxes are of particular concern. It should be noted that this group also contains retired households which may have savings thus the group is not totally representative of the poorest in society. Taxing beef products alone may result in demand for lower carbon and healthier chicken experiencing the largest drop in demand by 4.07% and yet a larger decrease of 7.33% for beef products. This may concern policy makers that the poorest households may experience a large reduction in their meat intake and yet it can help to reduce household carbon footprints. The effect on nutrient intake with regards to social groups will be studied in chapter 5 as this is an important area to understand.

Table 28 Effect of taxes on price elasticities of demand (Social grade A, B & C1)

	Effect of taxes on demand %				
	Beef	Chicken	Pork	Turkey	Sheep
Beef	-8.19	--	--	--	--
Chicken	--	-3.49	--	--	1.25
Pork	--	--	-4.73	--	-1.53
Turkey	--	--	--	--	--
Sheep	--	2.56	-5.07	--	-7.49

Notes: -- Elasticities are not statistically significant

Source: Own elaboration based on Kantar Worldpanel data

Table 29 Effect of taxes on price elasticities of demand (Social grade C2 & D)

	Effect of taxes %				
	Beef	Chicken	Pork	Turkey	Sheep
Beef	-10.35	--	--	-0.48	--
Chicken	--	-2.33	-2.51	0.37	--
Pork	--	-0.98	-3.93	--	--
Turkey	-23.82	6.73	--	-3.14	--
Sheep	--	--	--	--	-15.42

Notes: -- Elasticities are not statistically significant

Source: Own elaboration based on Kantar Worldpanel data

Table 30 Effect of taxes on price elasticities of demand (Social grade E)

	Effect of taxes %				
	Beef	Chicken	Pork	Turkey	Sheep
Beef	-7.33	--	--	--	--
Chicken	-4.07	-3.05	-1.52	--	--
Pork	--	--	-3.20	--	-1.28
Turkey	--	--	--	--	--
Sheep	--	--	-11.78	--	--

Notes: -- Elasticities are not statistically significant

Source: Own elaboration based on Kantar Worldpanel data

3.5.3 Carbon elasticities

Table 31 shows that lower income households (C2 and D) would see their carbon footprint reduce by 131,393.72 tCO2e/y through the net application of meat taxes to their respective products. This is a likely result of the households being more price sensitive relative to the other groups. Contrasting this result with the high income group of A, B and C1 which would see a likely decrease through net application of taxes of 95,817.40 tCO2e/y. Considering that these results are weighted by population representation with the A, B and C1 group representing 51 percent of the population, it does question whether a carbon consumption tax is equitable.

Table 31 shows that for the two higher social groups (A, B & C1 and C2 & D), the largest reduction in carbon emissions occurs due to taxing beef products. Säll and Gren (2015) also found that taxing beef products was also responsible for the largest reduction in the carbon emissions. The overall total (all households) reduction of 246,327.26 tCO2e/y as a result of net applications of meat taxes to their respective products would correspond approximately to a 10.5% reduction in meat emissions from the Scottish meat chain (these emissions include both imported and domestically produced meats for Scotland and were obtained from Audsley et al (2009)). Säll and Gren (2015) found that taxing their seven food products would likely reduce livestock sector emissions by 12% which provides an interesting comparison for this thesis (though different products were used). It does seem that taxing beef products is important for reducing carbon emissions.

Table 31 Simulation of carbon footprint (CF) elasticities through application of carbon consumption tax

Products	Social grade	1% Price Change Implied	Tax Implied	Social grade	1% Price Change Implied	Tax Implied	Social grade	1% Price Change Implied	Tax Implied	Total
	A, B & C1	reduction	reduction	C2 & D	reduction	reduction	E	reduction	reduction	
	CF Elasticity	tCO2e/y	tCO2e/y	CF elasticity	tCO2e/y	tCO2e/y	CF elasticity	tCO2e/y	tCO2e/y	tCO2e/y
Beef	-0.3	-3,547.11	46,254.32	-0.64	-6,174.79	80,519.30	-0.3	-632.93	8,253.36	
Chicken	0.34	4,041.71	12,771.79 **1/**	0.18	1,693.28	5,350.77	-0.11	-225.02	711.05	
Pork	-0.59	-7,060.23	44,267.67	-0.15	-1,468.51	9,207.56	-0.76	-1,593.46	9,991.00	
Turkey	--	--	--	-0.16	-1,492.26	17,966.87	--	--	--	
Sheep	-0.36	-4,353.54	18,067.20	-0.73	-7,000.18	29,050.76	-0.02	-38.73	160.72	
Total		10,919.18	95,817.40		14,442.47	131,393.72		2,490.13	19,116.14	246,327.26

Notes: **--** Elasticities are not statistically significant
Source: Own elaboration based on Kantar Worldpanel data

With regards to these particular examples it demonstrates the importance of applying all meat taxes to their respective products in order for a reduction in demand of higher carbon red meats.

The overall elasticity results suggest that if all taxes were simultaneously applied (i.e. net application) to their respective meat products then this would provide for the maximum impact on reducing households’ carbon footprints and is a similar result to Säll and Gren (2015). There is the potential problem highlighted by Tiffin et al (2014) and potentially applicable to meat products whereby retailers' discount their meat products or sell at below cost prices (due to promotions) which could distort the effectiveness of the carbon consumption taxes on household behaviour. However, as discussed in the taxation section, it is the responsibility of the policymaker to decide which consumption tax to use.

3.5 Summary

The main conclusions which can be inferred from this chapter are: The carbon consumption tax is likely to encourage either a reduction in meat products purchased or in some cases a small substitution into lower carbon footprint products for all the income groups. This results in an overall reduction in carbon emissions thus carbon emissions are likely to decrease if the taxes were applied to meat products. The decrease in meat emissions represents approximately 10.5% reduction in emissions from the Scottish meat chain (cradle to distribution centre). Taxing the two highest carbon emitters of sheep and beef were the main reason for the relatively large reduction in emissions mainly because very few meats acted as substitutes to these products particularly with regards to beef.

Secondly, it seems that the lower income group (C2 & D) is the most price sensitive and would likely experience the largest effect in terms of reducing their overall meat products purchased. This does raise the question of fairness. This income group (C2 & D) would experience their carbon footprint reduce by 131,393.72 tCO2e/y which represents a 5.6% reduction in meat emissions from the Scottish meat chain. However, to counteract this point the lowest income group was relatively price inelastic (when compared with C2 & D) and the effect of the taxes in terms of reducing GHG emissions is small. This is likely to be the result of their budget shares being dominated by chicken and pork which are both relatively low carbon footprint.

The results do not consider the nutrient effects induced through a carbon consumption tax which will be studied in the next chapter. Also with meat being incorporated into ready-made meals, it seems that the modelling of these products is likely to be of importance (Chapter 4 will cover this area).

3.6 Annex

Table 32 Phillips-Perron unit toot test results

		Social grade A, B & C1				Social grade C2 & D				Social grade E			
		Static	P-value	Dynamic	P-value	Static	P-value	Dynamic	P-value	Static	P-value	Dynamic	P-value
Shares	Beef	-6.073	0.010	-14.543	0.010	-6.593	0.010	-14.720	0.010	-5.005	0.010	-18.642	0.010
	Chicken	-5.911	0.010	-14.489	0.010	-5.840	0.010	-15.239	0.010	-2.605	0.329	-11.691	0.010
	Pork	-7.025	0.010	-16.981	0.010	-7.125	0.010	-17.556	0.010	-2.685	0.296	-12.109	0.010
	Sheep	-6.025	0.010	-18.685	0.010	-7.624	0.010	-17.827	0.010	-7.420	0.010	-13.400	0.010
	Turkey	-8.671	0.010	-13.908	0.010	-8.379	0.010	-15.673	0.010	-6.290	0.010	-18.498	0.010
Prices	Beef	-3.583	0.041	-13.394	0.010	-7.211	0.010	-15.230	0.010	-4.079	0.011	-16.735	0.010
	Chicken	-5.673	0.010	-14.493	0.010	-3.735	0.027	-14.235	0.010	-5.868	0.010	-16.812	0.010
	Pork	-3.674	0.033	-15.823	0.010	-3.831	0.022	-15.671	0.010	-5.801	0.010	-15.471	0.010
	Sheep	-6.095	0.010	-17.596	0.010	-7.211	0.010	-19.353	0.010	-6.434	0.010	-14.708	0.010
	Turkey	-5.765	0.010	-16.055	0.010	-7.474	0.010	-18.959	0.010	-6.842	0.010	-16.029	0.010
Expenditure		-2.882	0.215	-10.192	0.010	-2.965	0.181	-10.665	0.010	-3.255	0.085	-11.647	0.010

Notes:
Null hypothesis is that the variable has a unit root against a stationary alternative

Table 33 Augmented Dickey-Fuller Test

		Social grade A, B & C1		Social grade C2 & D		Social grade E	
		Static	P-value	Static	P-value	Static	P-value
Shares	Beef	-3.09	0.13	-3.52	0.05	-1.37	0.83
	Chicken	-4.32	0.01	-3.65	0.03	-1.63	0.73
	Pork	-2.33	0.44	-2.10	0.54	-1.65	0.72
	Sheep	-4.23	0.01	-3.75	0.03	-3.46	0.05
	Turkey	-4.19	0.01	-4.73	0.01	-4.55	0.01
Prices	Beef	-3.01	0.16	-1.71	0.01	-2.38	0.42
	Chicken	-3.51	0.05	-3.04	0.15	-2.74	0.27
	Pork	-2.65	0.31	-2.33	0.44	-3.50	0.05
	Sheep	-3.07	0.14	-1.86	0.63	-2.74	0.27
	Turkey	-3.07	0.32	-3.24	0.09	-3.82	0.02
Expenditure		-3.61	0.04	-4.00	0.01	-2.08	0.54

Notes:
Alternative hypothesis: stationary

Table 34 Phillips-Ouliaris (PO) cointegration test results

		Social grade A, B & C1				Social grade C2 & D				Social grade E			
		P-O value Static	P-value	P-O value Dynamic	P-value	P-O value Static	P-value	P-O value Dynamic	P-value	P-O value Static	P-value	P-O value Dynamic	P-value
Shares	Beef	-50.325	0.010	-104.819	0.010	-57.315	0.010	-106.779	0.010	-35.568	0.010	-120.920	0.010
	Chicken	-57.792	0.010	-96.441	0.010	-50.773	0.010	-111.710	0.010	-30.650	0.022	-100.177	0.010
	Pork	-70.894	0.010	-98.871	0.010	-67.633	0.010	-113.774	0.010	-34.220	0.010	-101.304	0.010
	Sheep	-47.810	0.010	-101.740	0.010	-71.054	0.010	-97.116	0.010	-69.949	0.010	-104.351	0.010
	Turkey	-73.471	0.010	-103.480	0.010	-71.378	0.010	-104.490	0.010	-58.009	0.010	-113.707	0.010

Notes:
Null hypothesis is that the variable is not cointegrated

Chapter 4. Carbon consumption taxation and nutrient intake[23]

4.1 Introduction

This chapter models the change in nutrient intake of Scottish households resulting from the application of a carbon consumption tax. The chapter provides support for objectives one (Estimating demand systems for the purpose of understanding the substitutions of high carbon food products), two (Developing carbon footprint elasticities in order to understand emission changes induced through carbon consumption taxes) and three (Estimating nutrient elasticities in order to understand the likely effect on nutrient intake of taxes).

Improving public health in Scotland through healthier diet has posed a challenge to policymakers for some time. However, it must be emphasised that this thesis is not trying to design nutrient/health taxes but rather understand the potential effects on nutrient intake (as the primary aim is reducing carbon emissions) of applying carbon consumption taxes to food products.

This chapter models relatively disaggregated food products which differs from the existing literature. The main contribution of this chapter is estimating the price elasticities for the disaggregated food products of meat, fish and milk (all three represent the highest carbon footprint food products) and applying these elasticities to the carbon and nutrient elasticities in order for the effects of the carbon consumption tax to be estimated. With regards to the nutrient intake, the chapter estimates the absolute change in nutrients and compares this to Scottish Government recommended daily intakes. The results suggest the importance of applying carbon consumption taxes to all products instead of exempting the lower carbon footprint meats and milk as this will maximise the decrease in carbon emissions and have some likely positive nutrient intake changes.

[23] This chapter is based on the paper "The environmental and nutrient effects of taxing high carbon footprint food products", which was submitted to the Journal of "Ecological Economics". The paper can be found in the final appendix.

4.2 Nutrient intake in Scotland

While the focus of this thesis is on reducing carbon emissions, this chapter will also focus on the resulting change of a tax to nutrient intake with a focus on the nutrient of Vitamin D intake. To a lesser extent total fat and salt intake will also be studied. There are many different food nutrients and it seems important to focus on the nutrients for which the Scottish Government are highlighting.

During the winter months in Scotland, the population cannot obtain vitamin D from the sun and vitamin D can be obtained from " dietary vitamin D"(Food Standards Agency Scotland, 2013). Vitamin D is found in relatively large quantities in only a few food products (e.g. oily fish (salmon), eggs and fortified breakfast cereal) and deficiency of this nutrient can cause bone development problems such as osteomalacia (National Health Service, 2012).

The chief medical officer in Scotland highlighted in his 2011 annual report, concerns regarding poor vitamin D intake amongst sections of the Scottish population (Scottish Government, 2012a). The recommended daily average intake of vitamin D in Scotland is 2-4 µg/day, however, at risk groups such as pregnant woman would require 10 µg/day of vitamin D (NHS Health Scotland, 2011). This does highlight the problem with using the average recommended vitamin D intake but Kantar Worldpanel does not provide information on households containing pregnant mothers.

The Scottish Health Survey 2010-2011, found that 17% of the sample had suboptimal levels of vitamin D and during the winter months (October – March) the level of sunshine in Scotland is too low for the body to develop vitamin D naturally from the sun (Food Standards Agency Scotland, 2013). Therefore, the significance of foods such as salmon would appear to be important especially during the winter months.

In contrast to vitamin D, the intake of total fat in 2012 represented 39% of household food energy which is higher than the recommended food energy share of 35% (Scottish Government, 2014).

The Food Standards Agency Scotland (2014) recommended a daily intake not exceeding 6 grams of salt which corresponds to 3.2 grams of sodium. The sodium content of many processed ready-made meals has been raised as often exceeding World Health Organisation goals (Howard et al., 2012). The Food Standards Agency (2014b) highlight how 44% of their sample (aged four and upwards) exceeded the recommended salt intake. Food Standards Agency (2014b) research found that the majority of respondents within each demographic group (except children ages 7-10) in Scotland exceed sodium intake guidelines. Therefore, assuming this sample represents the wider Scottish population, this highlights how a carbon consumption tax may cause health problems if intake of salt is increased. The ideal effects would be a decrease in salt intake though it must be emphasised that the carbon consumption tax aim is to reduce emissions associated with food consumption. Therefore, improving nutrient intake is not the primary aim of the tax.

The use of applying consumption taxes to food and drink products which are deemed to be unhealthy in order to improve diet, is not a new concept. Perhaps the most famous recent example would be the Danish fat tax which lasted from October 2011 until January 2013 (Toft et al., 2014a). The early research of Jensen and Smed (2013) suggests that for data covering a period from January 2008 until July 2012, consumption for high fat food products reduced by 10-15% relative to the period before the introduction of the tax. This suggests that the tax may have been successful in changing consumer behaviour. An interesting finding of Jensen and Smed (2013) is that the actual findings of the Danish fat tax are not so different from the simulation study of Smed et al (2007) which finds that a tax would influence demand.

4.2.2 Potential synergies between low carbon diet and a nutritious diet

Previous studies which have researched the synergies between low carbon and healthy diets will be reviewed in this section. The literature is not based on how to change consumer preferences but rather explains the potential low carbon and nutritious diets available.

A recent project studied how a low carbon diet could reduce carbon emissions and remain nutritious by using the government's "Eatwell plate" as a guide for nutritional intake (Macdiarmid et al., 2011). This (non-peer reviewed) report offered interesting suggestions such as consumers consuming seasonal British produced fruit and vegetables, then using imported products when they are no longer in season in order to ensure that nutrient consumption does not suffer (Macdiarmid et al., 2011). Chapter 2 highlights how carbon footprints are not necessarily lower for seasonally produced products such as tomatoes. Therefore, caution should be attached to any study which places too much reliance on seasonal products to help reduce carbon emissions. This is not to suggest that the authors are incorrect with regards to healthy diet and highlights the paradox between nutritious diet and reducing carbon emissions.

The idea of incorporating nutrient data into a low carbon diet is important as it is likely that a low carbon diet will only be viewed (by policy makers and consumers) as feasible if consumers receive similar nutrient levels. McMichael et al (2007) make reference to the health benefits which can be gained through reducing consumption of particularly red meat products (high carbon footprint) and the likely reduction in colorectal cancer (McMichael et al., 2007). Therefore the potential synergies which exist between health and a lower carbon diet are a major motivation for this chapter.

Berners-Lee et al (2012) studied how to eradicate consumption of high carbon food groups such as dairy and meat, and replace these groups with a vegetarian or vegan option. Scenario 3 of their study is a vegetarian diet which replaces meat with plant based food, yet leaves dairy consumption unchanged (Berners-Lee et al., 2012). Berners-Lee et al (2012) find that this scenario could result in a 25% emissions reduction compared to the UK average diet based on National Diet and Nutrition Survey (NDNS). de Boer et al (2013) discussed how it is likely that some consumers would not be willing to remove either meat or dairy from their diet and policymakers should focus also on the health side of food choice . Macdiarmid et al (2011) highlighted how meat and dairy provide important nutrients (such as: Iron, amino acids and Vitamin B) which are required for a healthy diet.

Macdiarmid et al (2011) raise concern over their carbon footprint data which is not BSI PAS 2050 compliant. Both authors use the National Diet and Nutrition Survey (NDNS) in order to obtain the various nutrients consumed, yet both authors mention that under reporting (from respondents) is a problem with this data (Macdiarmid et al., 2011, Berners-Lee et al., 2012).

Macdiarmid et al (2011) report did highlight how the Eatwell plate needs to include hot drinks as they contribute GHGs. Chapter 5 incorporates the carbon footprint of drinks such as tea and coffee into the demand system. Another interesting observation is that animal protein based consumption has increased by 11% in the 2005/06 period relative to the base period of the year 1990 while vegetable based protein consumption has only increased by 5% during the same time interval[24] (Defra, 2008a). Therefore it is important to understand how to increase vegetable based consumption relative to animal consumption. Chapters 2 and 3 showed the ability for consumers to substitute into lower carbon footprint milk or meat but other groups were not studied.

A study based on the 2006-07 French Individual and National Survey on Food Consumption (i.e. cross-sectional data) found that the more nutritional rich diets of French households were also those associated with high carbon emissions (Vieux et al., 2013). While this conclusion could have potential to impact upon this topic of demand for low carbon food products, there are some weaknesses with the paper. The FCRN (Food Climate Research Network) make reference to how the paper described a low carbon diet (i.e. one with reduced GHG emissions) as containing sweets and carbohydrates which gave per unit equivalence more energy relative to fruit or vegetables (higher GHG) yet both diets differ little in their consumption of meat and dairy which is the main emitter of GHG (FCRN, 2013). In addition to this the FCRN (2013) mention how a vegan diet could be very high in GHG emissions if all the food is air freighted. The FCRN’s main point is the importance of a low GHG

[24] Consumption is per person per day

diet is how meat is substituted for other goods which provide similar nutrients (FCRN, 2013).

A similar study to Vieux et al (2013) whereby carbon emissions of self selected diets is estimated was that of Scarborough et al (2014). The study uses data from the UK EPIC-Oxford cohort study (conducted in the 1990s) where participants were classifed into different dietary groups such as meat eaters, vegetarians and vegans (Scarborough et al., 2014). Scarborough et al (2014) found that as the diet of meat reduced within the different dietary groups then there was asubsequent reductions in carbon emissions and decreased saturated fat consumption, increased consumption of fruit and vegetables and increased sugar consumption. This highlights the possible improvements of a low carbon diet, though the increased sugar consumption is interesting.

Scarborough et al (2012) demonstrate the synergies between improving public health (reducing meat consumption) and reducing GHG emissions through the use of the UK government's Committee on Climate Change (CCC) three "dietary scenarios" which all involve a reduction in meat consumption (the scenarios are based on agricultural supply with the focus being on UK agriculture emissions). The study used a baseline diet based on the 2008 Family Food Survey (FFS) and a health based model (Dietron) to estimate that a significant number of deaths could be delayed or avoided from either of the three scenarios. Thus demonstrating the health benefits between of a low carbon diet (Scarborough et al., 2012). An interesting finding for this thesis is that it seems that the nutrients of vitamin D would experience a slight decrease, total fat would either experience a decrease or remain the same and salt consumption[25] would decrease by a very small quantity (Scarborough et al., 2012).

Recent work by Milner et al (2015) suggests that if consumers reduce animal and processed foods then this would likely result in a healthier and more environmentally friendly diet. This finding seems to support some of the other literature in this

[25] Scarborough et al (2012) appear to use both terms of intake and consumption when referring to nutrient changes

section. Without actually modelling taxes, the literature (in this section) suggesting the merits of a healthy and low carbon diet only serve to highlight the possibility of beneficial change. In terms of understanding whether the consumer would make these changes then caution should be applied to this literature as the effects of consumer substitution (consumer preferences) are not taken into account. This chapter models carbon consumption taxes and the resulting change in nutrients consumed using demand system modelling which are based on underlying consumer preferences.

4.3 Data

Kantar Worldpanel data is used in this chapter. This chapter involves the use of more food groups relative to the previous chapter which allows for a greater understanding of the substitution relationships which entail from a carbon consumption tax.

4.3.1 Purchase data

The time series dataset used in this chapter covers the years 2006-2012 (with each year comprising of 13 periods of four weeks) and is obtained from Kantar Worldpanel. The number of households contained in each year of data varied from 2,287 for 2006 to 2,631 for 2007.

Table 35 shows the food groups (and associated food products with the groups) studied in this chapter. With regards to the readymade meals of Table 35, the four groups of data are: Beef based (Lasagne, Shepherd’s Pie, Pie, Chilli, Bolognese), Chicken based, Vegetarian based, Fish based (Cod, Haddock, Fish, Mariners, Salmon, Captain, Tuna and Plaice is missed out as there is not a Tesco match).

The food products were grouped into the groups of Table 35 by using Kantar’s product codes which were matched to the relevant codes. With regards to the Beef and pork group, it was decided that sausages and burgers should be included in these groups rather than the ready meal group.

Table 35 Food products

Food Groups	Food Products	Number of observed Purchases (2006-2012)
Readymade meals	Beef based process products	168,518
	Chicken based process products	
	Fish based process products	
	Pizza	
Milk	Semi-Skimmed milk	776,634
	Skimmed milk	
	Soy milk	
	Lower fat milk	
	Whole milk	
Fish and Meat	Beef	1,160,042
	Chicken	
	Haddock	
	Pork	
	Salmon	
	Sheep meat	
	Tuna	
Numéraire good	Numéraire good	

Source: Own elaboration based on Kantar Worldpanel data

The descriptive statistics of the share, price and expenditures variables used for the demand system are shown in Table 36. Many of the product budget shares are very low due to the inclusion of the numeraire group.

Table 36 Descriptive statistics

	Share											
	Beef based	Chicken based	Fish based	Pizza	Semi-Skimmed	Skimmed	Soy	Lower fat	Whole	Beef	Chicken	Haddock
min	0	0	0	0	0.02	0	0	0	0.01	0.02	0.03	0
max	0	0	0	0	0.03	0	0	0	0.01	0.03	0.05	0
range	0	0	0	0	0.01	0	0	0	0	0.01	0.02	0
sum	0.14	0.19	0.08	0.29	1.97	0.32	0.04	0.12	0.84	2.41	3.77	0.05
median	0	0	0	0	0.02	0	0	0	0.01	0.03	0.04	0
mean	0	0	0	0	0.02	0	0	0	0.01	0.03	0.04	0
std.dev	0	0	0	0	0	0	0	0	0	0	0	0

	Share				Price							
	Pork	Salmon	Sheep	Tuna	Numéraire	Beef based	Chicken based	Fish based	Pizza	Semi-Skimmed	Skimmed	Soy
min	0.03	0	0	0	0.82	1.03	1.12	1.20	1.12	-0.70	-0.75	-0.15
max	0.05	0.01	0.01	0	0.88	1.37	1.38	1.79	1.38	-0.37	-0.35	0.09
range	0.02	0.01	0	0	0.06	0.34	0.27	0.59	0.26	0.33	0.40	0.24
sum	3.33	0.40	0.55	0.30	75.18	108.52	111.13	131.66	114.35	-43.93	-43.76	-6.15
median	0.04	0	0.01	0	0.83	1.22	1.23	1.45	1.28	-0.48	-0.44	-0.08
mean	0.04	0	0.01	0	0.84	1.21	1.23	1.46	1.27	-0.49	-0.49	-0.07
std.dev	0	0	0	0	0.01	0.09	0.06	0.14	0.05	0.09	0.12	0.05

	Price									Expenditure
	Lower fat	Whole	Beef	chicken	Haddock	Pork	Salmon	Sheep	Tuna	Numéraire
min	-1.08	-0.66	1.61	1.64	2.03	1.48	2.18	1.83	1.11	1.02	3.19
max	-0.43	-0.33	2.02	1.98	2.43	1.75	2.68	2.17	1.71	1.36	3.49
range	0.65	0.33	0.41	0.34	0.40	0.27	0.51	0.34	0.60	0.34	0.30
sum	-61.07	-41.46	166.23	165.38	203.94	147.85	217.98	179.59	128.70	107.36	298.92
median	-0.68	-0.45	1.88	1.85	2.27	1.67	2.42	2.00	1.48	1.20	3.32
mean	-0.68	-0.46	1.85	1.84	2.27	1.64	2.42	2.00	1.43	1.19	3.32
std.dev	0.11	0.09	0.11	0.08	0.08	0.07	0.14	0.08	0.18	0.09	0.06

Source: Own elaboration based on Kantar Worldpanel data. Price is in natural logarithm form.

Turkey meat products have not been included in this analysis for the following reason: the budget share of the product is only high around December (i.e. Christmas time) which was seen in chapter 3. The Kantar data was adjusted to include unit prices (which include discounts by the retailer). The data has also been adjusted using the Scottish population to create per capita data.

4.3.3 Carbon data

This chapter used carbon footprint (CF) data which is mainly based on PAS 2050 cradle to grave which is in contrast to chapter 3 which used Audsley et al (2009) CF data on cradle to regional distribution centre.

Table 37 shows the carbon footprints of ready-meals which were selected to closely match the Kantar data and vice versa. With regards to pizza, there is little difference between a vegetarian pizza and meat based pizza which may be due to the low meat content of a meat based pizza. This meant that a representative CF value (4.85 kg CO2e Kg) of pizza entailed calculating an average of the two products.

Table 37 Carbon footprints of readymade meals

category	**Ready-made meal Products**	Carbon Footprint (Kg CO_2e Kg)
Pizza	Cheese and Tomato Pizza	4.4
	Thin & Crispy Pepperoni	5.3
Chicken based	Chicken & Broccoli Pie	4
	Chicken Korma & Pilau Rice	5.3
	Chicken Enchiladas	4.6
Beef based	Cottage Pie	10.4
	Steak & Ale with Cheddar Mash	11.3
	Chilli con carne and rice	10.7
Fish based	Fish pie	4

Source: Tesco (2012)

Table 38 shows the carbon footprints for the different milk products which as mentioned earlier are ALCA. The explanation in chapter 2 highlighted how the carbon footprint is largely dependent upon the wet mass (DairyCo, 2010) thus the higher carbon footprint for whole milk relative to skimmed milk.

Table 38 Carbon footprints of milk products

Products	Carbon Footprint (kg CO_2e Litre)
Skimmed	1.23
Semi Skimmed	1.41
Whole	1.58
UHT Skimmed	1.23
UHT Semi-Skimmed	1.41
UHT Whole	1.58
Unsweetened Soy	0.70

Sources: Tesco (2012)

Table 39 shows the various meat and fish carbon footprints which have been obtained from various sources and comply with PAS 2050 or similar methodology. Meat and to an extent fish have the highest carbon footprint out of all the food groups and are therefore a group of particular focus for this study. The New Zealand (NZ) lamb value has been selected as a proxy for Sheep meat products as NZ lamb has a lower carbon footprint relative to British lamb (Webb et al., 2013). As both NZ lamb and British lamb dominate the Scottish market, it is not possible to differentiate between the two products based on the Kantar data. Therefore, as a cautionary approach it was decided to underestimate the emissions rather than overestimate. The carbon footprint value is still greater than all the other meat and fish products.

Table 39 Carbon footprints of meat and fish

Products	Carbon Footprint (Kg CO_2e Kg)	Source
Salmon	8.33	The Co-operative Group (2012)
Haddock	5.60	The Co-operative Group (2012)
Tuna	3.29	Poovarodom et al (2012)
Beef	12.65	Houses of Parliament (2013)
Chicken	2.90	Defra (2010)
Pork	3.58	Aarhus university (2014)
NZ Lamb	19.00	Ledgard et al (2011)

Sources: Listed in table

For the purposes of using the carbon footprint elasticities in order to obtain actual change in emissions resulting from a price change, the total Scottish consumption based on emissions for the three food groups were derived from Audsley et al (2009) and are shown in Table 40. This data is cradle to regional distribution centre (i.e. includes manufacturing stage) (Audsley et al., 2009) and this could make it slightly unrepresentative as the consumer stage is not included. What is most important is how the stages leading up to the farm gate are captured (which they are) since fifty percent of the food chain emissions occur at these stages with the rest being “evenly distributed” among the other stages (Garnett, 2011). An advantage of the Audsley et al (2009) dataset is that it provides for Scotland per capita emissions which can be scaled up to form an approximate Scottish total emissions.

The only group which was largely omitted from the Audsley et al (2009) dataset is the readymade meal food group shown in Table 40. This paper has chosen to use the combined meat and fish emissions as a proxy. While this is not ideal, there seemed no other way of obtaining this emission source.

Table 40 Total Scottish consumption based emissions

Food group	Emissions tCO2e/y
Ready-meal	2,626,614.60
Milk	1,417,953.30
Meat and Fish	2,626,614.60
Total emissions	6,671,182.50

Notes: Data has been sourced from Audsley et al (2009)

4.3.3.1 Price of carbon emissions

In order to select the relevant social cost value of CO_2e emissions, it is important to refer to the IPCC models of atmospheric concentrations (shown at the beginning of this chapter in Figure 1). The Intergovernmental Panel on Climate Change (2014) report recommends that in terms of mitigation policies for 2100, CO_2e should be approximately 450 parts per million (ppm) in order for a likely temperature change of less than 2^{o}C.

At UK level it has been suggested that setting a social cost is problematic since it rests on assumptions regarding the actions of climate change mitigation policies of other countries (Defra, 2007). Defra (2007) raise concern that the social cost of carbon refers to the world’s stabilisation trajectory and not the UK’s and they raise the issue of more uncertainty surrounding the social cost relative to the marginal abatement cost curve (MAC). For these reasons Defra (2007) suggests using the shadow price of carbon (SPC) which estimates the MAC for a certain stabilisation policy. This method is also supported by Dietz and Fankhauser (2010) which explain that the MAC displays less uncertainty in meta-analysis relative to the social cost of carbon as MACs are based on "proven" technologies rather than the more theoretically based Social costs. It should also be emphasised that the SPC is essentially equal to the MAC (Dietz and Fankhauser, 2010).

Defra uses the Stern Review (2006a)'s cost of carbon[26] which the Stern Review notes is for 550 ppm. This clearly differs from the IPCC (2014) reported value of 450 ppm which does raise concern that the social cost of carbon does not reflect the current climate science. The Defra (2007) SPC value of £25/tonne CO_2e is based on the atmospheric concentrations pathway range of 450 ppm to 550ppm.

The use of carbon markets falls under the supply side of climate change mitigation, whereby permits are exchanged. This has been suggested as a possible way of reducing carbon emissions for some situations (Tol, 2014). However, in terms of forming a carbon consumption tax based on the marginal damage of CO_2e emissions, it does not seem applicable to use emissions trading. Speck (2013) highlights how if the social cost of carbon had been used in July 2012 then the European Union's Emissions Trading Scheme (ETS) allowance price would have been lower than this cost. The UK department of Energy and Climate change (DECC) make reference to how only certain sectors are covered in the ETS price and this price would not equal the social cost (Department of Energy and Climate Change, 2009).

HM Treasury highlight the issue of double counting the externality and the importance of trying to avoid this (Defra, 2007). This study does not see this as an

[26] They justify this as it is similar to a previously estimated MACC for Europe. More detail will be given in the following chapter on the uprating of this cost.

issue for two reasons: Firstly British Standards Institution (2011) draws attention to areas such as if CO_2e emissions are recorded in the process then double counting is likely to occur because of the fuel combustion process (which is also recorded). Despite the tax being based on the cost of carbon emissions it is still difficult to fully establish the cost of climate change and Spangenberg and Settele (2010) highlight the problem of attaching a value to an activity such as pollution and Chalmers and Shackley (2015)[27] conclude that it should not be viewed as "a panacea for establishing the full potential costs of climate change".

There has been recent discussion regarding the potential for carbon emission mitigation being focussed on the actual cumulative emissions rather than emission rates which cover a shorter time period (Allen et al., 2009). Currently this literature is confined to the supply side i.e. producers and it is difficult to work out how it could apply directly to the demand side especially with regards to food. This is not to say that using cumulative emissions and carbon capture to meet the sequestered adequate fraction of extracted (SAFE) carbon as in Allen, Frame, & Mason (2009) paper is not worthwhile, instead this set up would appear complex to achieve. Allen, Frame, & Mason (2009) make reference to the need for either a few firms or countries to demand that fuel suppliers adhere to SAFE, yet it is difficult to find what incentive a profit maximising globalised firm would have to join such a scheme unless there was a world binding agreement.

4.3.3 Nutrient data

The nutrition data used for this chapter was obtained from the recently released "National Diet and Nutrition Survey" (NDNS) for 2008-2012 (NatCen Social Research, 2015). The NDNS collects dietary behaviour data on adults (aged 19-64) living in the UK (Food Standards Agency, 2011). Table 41 shows the nutrient shares with respect to each food product.

[27] Chalmers and Shackley (2015) book review is based on Tol (2014)

Table 41 NDNS 2008-12 nutrient shares

Product	Share (%) of		
	Vitamin D	Fat	Sodium
Ready meal Beef	1.99	10.06	7.73
Ready meal Chicken	1.58	9.58	10.65
Ready meal Fish	6.08	5.55	6.26
Pizza	0.47	9.93	10.59
Semi skimmed milk	0	1.67	1.03
Skimmed milk	0.19	0.22	1.06
Soy milk	0	1.93	1.02
Low fat milk	0	1.00	1.00
Whole milk	0	3.92	1.04
Beef	3.92	8.52	2.82
Chicken	1.72	5.53	3.05
Haddock	0	0.78	10.62
Pork	5.37	13.96	23.54
Salmon	54.23	12.89	9.96
Sheep	4.26	12.59	1.97
Tuna	20.19	1.86	7.66

Source: Own elaboration based on 2008-12 NDNS data

With regards to the meat group, only meat products which did not contain sauces or other condiments were selected. This is because each meat product is aggregated into the corresponding meat category which allows for matching with the carbon footprint data. Products such as lamb's liver or pork kidney were excluded as certain nutrients can be concentrated in these products thus there was concern that it may distort the overall meat nutrient share.

It did not seem practical to use weighted shares from the Kantar data for these offal products since the main focus of this study is the emissions associated with purchasing meat products regardless of the cut (please see chapter 2 for an explanation surrounding meat carbon footprints sourced from attributional LCA). If weighted meat shares were used then it would be appropriate to use consequential LCA in order to understand how emissions are affected by a change in demand for different cuts of meat as the attributional LCA is for the whole animal. This would be a complex task given the considerations of the marginal product as used in chapter two for milk products (Chalmers et al., 2015a).

The Kantar data ready-made meals were matched with the relevant “National Diet and Nutrition Survey” (NDNS) products. The Kantar dataset provided many different combinations of ready-made meals, while the NDNS provided a more limited sample. Using Structured Query Language (SQL) enabled the different meat products to be selected. The groups also had to correspond to the Tesco plc (2012) or other carbon footprint values in order for the carbon elasticity values to be calculated.

The Vegetarian based group was omitted from the study after concerns regarding the very low budget shares of less than one percent. In addition to this, despite the data being time series thus aggregated, the few households involved in purchasing vegetarian meals appeared to bulk buy the product.

With regards to milk products the process of matching the products to nutrient data was possible as different milk products are relatively standardised products. The relatively new product of one percent fat milk was addressed in the second year of the NDNS 2008-12 survey which included one percent milk (NatCen Social Research, 2015). Prior to 2008 one percent milk would not have been classed as milk and instead a milk drink (The Dairy Council, 2015). The nutrient elasticities will be described in the methods section of this chapter and it was important that the shares of nutrients contained in each product were calculated. The shares per 100 grams or 100 ml were calculated in order for a comparison to be made.

The actual nutrients consumed from each food group matching Table 40 were recovered from the Food Standards Agency (2014a) which categorised the dietary intakes of different nutrients by sex or age and not by socio-economic group which is not relevant to this chapter (though elaborated on in chapter 5). A more detailed explanation surrounding how the nutrient elasticities were applied to these two data sources allows for the change in nutrients purchased (calculated in International Units) to be estimated which will be explained in the next section.

It is worth highlighting the terminology used by the Food Standards Agency (2014a) of "nutrient intake", this thesis will also use this term. The Food Standards Agency (2014b) explain that nutrient intake includes both food consumed in addition to nutrient supplements. However, other authors studying carbon consumption taxes use the term nutrient consumption such as Edjabou and Smed (2013). Both terms should be interpreted as implying a similar behaviour.

4.4 Methods

This chapter used an incomplete demand system (Exact Affine Stone Index) and modelled all the main food groups in order to understand the substitution relationship between the different products.

4.4.1 Exact Affine Stone Index

4.4.1.1 Model

The Exact Affine Stone Index (EASI) originally modelled by Lewbel and Pendakur (2009) extended the work on demand systems to allow Engel curves to be less restricted. This chapter estimated both the linear EASI and the EASI based on cubic income systems in order understand which form is applicable to the data being modelled and to compute price elasticities. A further improvement of the EASI relative to the AIDS is how unobserved preference heterogeneity can be observed through the error terms of the budget shares (Pendakur, 2008) though this is of little use for time series data. As the EASI is relatively new, there are only a few published peer reviewed papers (Li et al., 2015, Castellón et al., 2015, Lewbel and Pendakur, 2009).

The useful feature of the EASI capturing unobserved preference heterogeneity for either panel or cross sectional data (Pendakur, 2008) is likely not to be so useful with time series data whereby households are aggregated.

The EASI system starts from the use of a cost function (Equation 16) which is the minimum total expenditure (x) necessary to equal the consumer's utility level (u) given a set of prices (p) (Pendakur, 2008).

$$x = C(p, u) \tag{16}$$

Pendakur (2008) demonstrated that through the use of Shephard's lemma the cost function can become Hicksian budget shares which can (for reasons of heterogeneity) become unrelated to one another as shown in Equation 17. The budget share function ($m(u)$) is unrelated across the budget shares of j (Pendakur, 2008).

$$\ln C(p, u) = u + \textstyle\sum_{j=1}^{J} m(u) \ln p \tag{17}$$

Equation 17 can be manipulated through using the assumption of observable variables of prices (p), expenditure (x) and budget shares (w) to form an expression for utility (Pendakur, 2008).

$$u = \ln x - \textstyle\sum_{j=1}^{J} w \ln p \tag{18}$$

This expression of utility in equation 18 can be substituted into the Hicksian budget share function of equation 19 to form the implicit utility Marshallian demands of equation 20 which are important for the EASI system (Pendakur, 2008).

$$w^j(p, u) = m^j(u) \tag{19}$$

$$y = \ln x - \textstyle\sum_{j=1}^{J} w^j \ln p^j \tag{20}$$

Pendakur (2008) explains how the implicit Marshallian demands arise through substituting the utility term of the Hicksian demand function with the implicit utility function (y) which is based on observable data of prices (p), expenditure (x) and budget shares (w). The implicit utility function (y) can be described as the "log real expenditure" as it represents the utility associated with a unit price vector (Pendakur, 2008).

The "log real expenditure" price index used for the implicit Marshallian demand system is deflated by the Stone Price Index shown in equation 21 (Lewbel and

Pendakur, 2009). The stone price index contains the following variables: x = expenditure, p= prices and $\overline{\mathrm{w}}$ are the budget shares (Li et al., 2015). The EASI system is estimated using three stage least squares (Lewbel and Pendakur, 2009) and package EASI estimates the system using this procedure (Hoareau et al., 2012b).

$$\tilde{\mathrm{y}} = \mathrm{x} - \mathrm{p}'\overline{\mathrm{w}} \quad (21)$$

The "approximate" model of the linear EASI demand system is shown by Equations 22 and 23 (Lewbel and Pendakur, 2009). The two equations are similar but equation 23 removes some of the demographic interaction terms which are not applicable to the EASI system estimated in this thesis.

$$\mathrm{w} = \sum_{\mathrm{r}=0}^{r} \mathrm{b_r}\, \tilde{y}_r + \mathrm{Cz} + \mathrm{Dz}\tilde{\mathrm{y}} + \sum_{l=0}^{L} z_l\, A_l\, \mathrm{p} + \mathrm{Bp}\tilde{\mathrm{y}} + \tilde{\varepsilon} \quad (22)$$

$$\mathrm{w} = \sum_{\mathrm{r}=0}^{r} \mathrm{b_r}\, \tilde{y}_r + \sum_{l=0}^{L} z_l A_l\, \mathrm{p} + \mathrm{p}\tilde{\mathrm{y}} + \tilde{\varepsilon} \quad (23)$$

Equation 23 which represents the linear approximate EASI and is similar to Castellón et al (2015) as the demographic interaction terms with prices have been removed. As this paper does not include demographic variables it is therefore not required to have this term. Both equations 22 and 23 show the implicit Marshallian budget shares (w) with the stone price index ($\tilde{\mathrm{y}}$) and z is equal to the demographic shifters which interacts with the parameters to be estimated (these parameters are C, D, A and B). It should be reiterated that the demographic shifters are not applicable to this study. Lewbel and Pendakur (2009) use term z to represent the taste shifter such as the time variable. The b parameter represents the Engel curve and the B parameter which is not present would allow for interactions between the demographic variables and expenditure (Lewbel and Pendakur, 2009).

4.4.1.2 Estimation

Monthly dummies and a time trend are the only demographic shifters contained in z of equation 23. Other parameters which are of little use for this study are C and D which enables the demographics to be reflected through intercept and slope terms of y's budget shares (Lewbel and Pendakur, 2009), therefore have been removed. A is the main parameter of interest as it contains the compensated price effects which are central to the EASI demand system. The final variables of equation 23 are p being log prices and the error term ε represented random utility parameter (Lewbel and Pendakur, 2009).

Lewbel and Pendakur (2009) made reference to how expenditure (y) will be endogenous because of the relation to budget shares in equation 23 and therefore instrumental variables can be estimated in three stage least squares (3SLS). Previous literature such as (Zhen et al., 2013, Li et al., 2015). Li et al (2015) used Hoareau et al (2013) package "EASI" to estimate three stage least squares using instrumental variables. It should be noted that Hoareau et al (2013) package "EASI" estimates these instrumental variables. The IVs used in this chapter (and chapter 5) were estimated by package "EASI" and consist of only time dummies and the time trend. It seems likely that monthly dummies and the time trend may be (partially) correlated with expenditure but uncorrelated to the error terms. There could be correlation with the error term, however, the Kantar dataset did not contain any other possibility for estimating IV.

The underlying cost function should be monotonic and concave in order for the following demand conditions to be satisfied: adding up, homogeneity and symmetry (Hoareau et al., 2012a). Lewbel and Pendakur (2009) describe how the last equation is dropped (J equation) and J equation can then be estimated from the adding up condition in estimation of the EASI. Lewbel and Pendakur (2009) emphasise that the Slutsky matrix can be checked for negative semi-definitiveness which is also used for studies using the AIDS model.

Equation 23 (represented the linear EASI) was estimated in R using package "easi" by Hoareau et al (2013). The implicit Marshallian price elasticities (will referred to in the rest of this chapter and chapter 5 as Marshallian price elasticities) were also estimated through the use of Hoareau et al (2013) package based on the description by Hoareau et al (2012a) which used the calculations in the appendix of Lewbel and Pendakur (2009).

4.4.2 Computation of carbon consumption tax

The carbon consumption tax used in this chapter is based on the calculation from chapter 3 whereby the method from Edjabou and Smed (2013) is used as shown in equation 24.

$$\Delta \mathbf{p_{ik}} = \mathbf{k_i} \text{ x } \mathbf{p_k} \qquad (24)$$

The setting of the tax rate differs slightly to chapter 3 as Defra's (2007) shadow price of carbon (SPC) is used instead of the social cost of carbon (this is explained in "4.3.3.1 Price of carbon emissions" of this chapter). The SPC for 2013 is calculated (despite 2012 being the latest year, using 2013 allows for consistency with for next chapter) as the price of £28.32 t/CO_2e.

The carbon consumption tax for this chapter and for chapter 5 takes the form of a single consumption tax rate. This consumption tax rate is based on the carbon consumption tax rate of chapter 3. However, instead of applying the tax excise e.g. £0.35/ Kg CO_2e to the mean price of a product in order to estimate the corresponding price increase, the consumption tax rate would directly equate to 35%. Thus the overall tax rate is still based on the carbon footprint. Table 24 in chapter 3 showed that despite sheep products having a higher carbon footprint relative to beef, the latter had a higher tax rate due to mean absolute (pre-tax) sheep prices being larger than beef.

Taking the example of mince, prices are often lower to other beef cuts and if tax is based on e.g. beef products of £0.35/ Kg CO_2e (essentially an excise duty like alcohol) then the rate of relative price increase will be greater for cheaper meat products such as mince which contain more fat and less units of actual meat relative to steak etc. Despite very few LCA studies which have studied the carbon footprint of the different cuts of meat it would seem likely that a meat product which contains a higher share of actual meat such as steak would have a higher carbon footprint than a meat product which contains a large share of fat. However, steak will often have a much larger absolute price thus the relative price increase of applying the £0.35/ Kg CO_2e price will be much lower thus undermining the nature of the carbon consumption tax of higher rates equating to higher carbon footprints. Also from a policy perspective it would be likely easier to administer this chapter's form of carbon consumption tax rate.

Briggs et al (2013) highlighted, the problem of applying the price increase (the method of chapter 3) to the existing price of meat in order to calculate the relative price increase as this price increase can vary. The authors found that the price increase of beef could vary between 15-35% (Briggs et al., 2013).

4.4.3 Computation of carbon elasticity

The idea behind the carbon elasticity was explained in chapter 3 and is used again in this chapter. The total emission value used to calculate the implied reduction of a price change is for Scotland.

4.4.4 Computation of nutrient elasticity

Huang (1996) developed the idea of applying price elasticities to nutrient shares in order to understand the likely effect of price increases on nutrient availability. More recent applications of this method can be found in Allais et al (2010). Huang and Huang (2011) provides an interesting idea of the effects of different price increases for the nutrient elasticities of different food products when using a complete demand system. They find that a 10% increase in price on fish products will result in a 1.65% reduction in total fat (Huang and Huang, 2011). Unfortunately they only study aggregated food groups which means that the substitution relationships within say the meat or fish group cannot be accounted for. Tiffin et al (2011) also used Huang (1996) approach and applied the older version of NDNS data to aggregated food groups of the "Living costs and food survey".

This is a limitation of their research. The authors could counteract this claim by pointing out that by accounting for all the main food groups, then the nutrient elasticities will be more representative. However, it seems that disaggregating the food groups, while not able to capture every food group will at least provide for an idea of the effect of tax on nutrient intake.

Some of the papers applying nutrient elasticities are based on studies which have used panel data and censoring (which is briefly described in chapter 3). There are also studies which use aggregated time series using an AIDS model such as: Smed et al (2007) use monthly aggregated weekly data and to an extent Allais et al (2010) aggregated the data over four weeks. Smed et al (2007) was used as the basis for Edjabou and Smed (2013) and for appendix paper 5.1. This approach of aggregating time series data is used throughout this thesis as explained in chapter 3.

It is important to provide more detail on how the nutrient elasticities will be used to calculate the international units. By estimating the international units as a resulting change in intake of a nutrient it allows a comparison with government recommended daily intake of nutrients. The Food Standards Agency (2014a) report allows for an understanding of the average daily amount of a particular nutrient which is currently consumed in Scotland from the different food groups.

It is important to note that the NDNS provides this on a daily per person basis and not yearly or monthly which would have created a better match for the price elasticities (chapter 5 addresses this issue). However, as the purpose of this chapter is to compare the change in international units to the government's recommended daily intake value, then this form of data are acceptable. Measuring nutrient intake as a result of taxation arose from Edjabou and Smed (2013), though they did not use the carbon nutrient elasticity method developed by Huang (1996).

4.5 Results and discussions

4.5.1 Exact Affine Stone Index

The EASI based on cubic income whereby y (implicit utility) was equal to 3 (polynomial) and linear EASI (y=1) were both estimated and the results for these parameters are shown in Table 46 of this chapter's annex. Overall there is little statistical difference between the two EASI systems considering the polynomial income terms and a linear income term. Therefore, the linear version was chosen for the computation of the carbon/nutrient elasticities.

This chapter found that the statistically significant Marshallian price (calculated from the implicit Marshallian demands) elasticities shown in Table 42 adhere to negativity and symmetry (Table 47 in the annex of this chapter shows the EASI based on cubic income price elasticities which are not used for this chapter). It should also be highlighted that the Hessian matrices derived from the cost function indicated that 90% of these cost functions were semi-negative definite. This would imply a similar result to Lewbel and Pendakur (2009) of the cost function being weakly concave. However, the EASI estimated some very large price elasticities which is possibly a result of the very small budget shares for some products.

4.5.2 Marshallian price elasticities

The linear EASI price elasticities shown in Table 42 suggest that the substitutes of high carbon beef meat are semi skimmed milk. However, there are many complements for beef meat. Many of the cross price elasticities for the respective products show more complement relationships, rather than substitutions. Due to the food groups chosen and the relatively innovative groupings of ready meals it is not possible to compare the results to a similar study. The cross price elasticity of beef meat to chicken meat (and vice versa due to symmetry) implies that the products are substitutes to one another. As chicken is often a lower priced meat, it may be the case that when higher priced beef increases in price then households favour a cheaper meat product. There may also be health reasons for this relationship.

The cross price elasticity of pizza finds that (excluding the numeraire good) whole milk acts as a substitute (and vice versa) which is surprising given that pizza may constitute a meal while whole milk could be considered a complementary drink. As the numeraire good is included in the demand system then this may help to explain the unusual relationship. However, the milk products serve largely as complements (some exceptions do occur) to the meat products which may be explained by milk products acting as a complementary drink or milk products being used in the preparation of cooking meat products. Overall more statistically significant complementary cross price elasticities are present in the results.

Some of the cross price elasticities of the meat products are similar to some of the findings of chapter 3 such as the white meats (chicken, pork) having red meats (beef and sheep) as substitutes and vice versa. This finding is important since it suggests that households underlying preferences allow high carbon red meats to be substituted by low carbon white meats. The result of the ready-meals group suggests that very few cross price elasticities exist (except for Fish meal having chicken meal as a substitute and vice versa). This may be due to these groups being aggregated, whereby consumer preferences are very specific for the individual ready meal type of product.

The only statistically significant own price elasticities of the meat and fish products are beef (-0.59), salmon (-1.18) and sheep (-1.48) which suggests that the latter two products are relatively price elastic, thus an increase in their respective prices will reduce demand to a greater extent than a 1% price increase in beef products. Chapter 3 found that the own price elasticity of beef was -0.63 which despite different demand systems being estimated does demonstrate a similar finding that beef is a relatively price inelastic product.

Table 42 Linear EASI price elasticities

	Ready meal Beef		Ready meal Chicken		Ready meal Fish		Pizza		Semi skimmed milk	
Ready meal Beef	0.26		0.41		0.35		0.09		-0.05	
Ready meal Chicken	0.55		0.32		0.75	*	-0.11		-0.09	
Ready meal Fish	0.22		0.34	*	-0.56	**	0.03		-0.02	
Pizza	0.2		-0.17		0.09		-0.84	**	-0.09	
Semi skimmed milk	-0.68		-0.92		-0.37		-0.6		-0.36	*
Skimmed milk	-0.22		0.8	*	0.36		0.18		-0.1	
Soy milk	0.48	*	0.24		0.37		-0.12		-0.06	
Low fat milk	0.04		0.29		0.01		0.19		0.2	***
Whole milk	1.65	**	-0.41		-0.1		0.61	*	0.27	*
Beef	0.91		0.6		0.83		-0.27		0.22	***
Chicken	-1.85	**	-2.55	***	1.3		0.18		0.38	***
Haddock	-0.12		0.02		0		-0.21		-0.03	
Pork	-0.47		-0.78		0.48		-0.13		0.01	
Salmon	0.12		0.32		-0.22		0.31		0.05	
Sheep	-0.74	*	-0.34		0.68		-0.3		0.05	
Tuna	-0.37		-0.32		0.16		0.14		0	
Numeraire group	-1.68	***	-0.53	***	-5.95	***	-0.64	***	-1.3	***

	Skimmed milk		Soy milk		Low fat milk		Whole milk		Beef	
Ready meal Beef	-0.1		1.5	*	0.04		0.27	**	0.05	
Ready meal Chicken	0.47	*	0.98		0.43		-0.09		0.05	
Ready meal Fish	0.1		0.71		0		-0.01		0.03	
Pizza	0.16		-0.8		0.45		0.21	*	-0.03	
Semi skimmed milk	-0.62		-2.73		3.19	***	0.64	*	0.16	*
Skimmed milk	-0.04		1.99		0.37		-0.18		0.03	
Soy milk	0.28		-0.04		0.15		0.11		0.01	
Low fat milk	0.15		0.45		-1.66	***	-0.08		0.03	
Whole milk	-0.48		2.13		-0.56		-0.65	*	0.02	
Beef	0.22		0.43		0.55		0.08		-0.59	**
Chicken	-1.44	**	-5.23	**	-4.84	***	-0.15		0.45	**
Haddock	0.01		-0.02		0.39	*	-0.07		-0.02	
Pork	0.86	*	-3.21		-2.66	**	-0.4	*	-0.07	
Salmon	-0.14		1.68	*	0.22		-0.09		-0.14	**
Sheep	-0.89	***	-1.66		1.09	**	-0.17		0.13	*
Tuna	0.34	*	-1.87	**	0.02		-0.04		-0.03	
Numeraire group	-0.3	***	3.33	***	2.41	***	-0.32	***	-1.93	***

	Chicken		Haddock		Pork		Salmon		Sheep	
Ready meal Beef	-0.08	**	-0.36		-0.04		0.04		-0.2	*
Ready meal Chicken	-0.13	**	0.05		-0.06		0.15		-0.13	
Ready meal Fish	0.02		0		-0.01		-0.04		0.09	
Pizza	0.01		-1.26		-0.03		0.22		-0.17	
Semi skimmed milk	0.19	**	-1.17		-0.02		0.23		0.16	
Skimmed milk	-0.13	***	0.06		0.06		-0.11		-0.53	***
Soy milk	-0.07	**	-0.02		-0.06	**	0.19	*	-0.15	
Low fat milk	-0.17	***	1.02	*	-0.12	***	0.07		0.23	
Whole milk	-0.05		-1.25		-0.12	**	-0.19		-0.27	
Beef	0.30	**	-0.97		-0.06		-0.81	**	0.55	
Chicken	-0.01		6.04	***	0.51	***	0.11		1.05	**
Haddock	0.07	**	-0.7		0.02		0.02		0.06	
Pork	0.47	***	2.85		0.07		-0.37		1.29	***
Salmon	0		0.14		-0.07		-1.18	***	0.06	
Sheep	0.15	**	0.85		0.20	***	0.11		-1.48	***
Tuna	-0.02		0.79		0.06		-0.22		0.05	
Numeraire group	-1.84	***	-6.86	***	-2.08	***	0.59	***	-2.8	***

Source: Based on own elaborations

Statistical significance: '*'=10%, '**'=5% or '***'=1%

	Tuna		Numeraire group	
Ready meal Beef	-0.17		-0.01	
Ready meal Chicken	-0.2		0	
Ready meal Fish	0.05		-0.01	***
Pizza	0.13		0	
Semi skimmed milk	0.04		-0.04	***
Skimmed milk	0.35		0	
Soy milk	-0.27	**	0	
Low fat milk	0.01		0	
Whole milk	-0.12		-0.01	
Beef	-0.23		-0.04	***
Chicken	-0.19		-0.09	***
Haddock	0.13		-0.01	**
Pork	0.88	**	-0.08	***
Salmon	-0.3		0	
Sheep	0.12		-0.02	***
Tuna	-0.6	**	-0.01	
Numeraire group	-1.24	***	-0.69	**

Source: Based on own elaborations

Statistical significance: '*'=10%, '**'=5% or '***'=1%

In the first run of the EASI, the vegetarian group was included despite concerns that the budget shares were very low. It would appear that these concerns were well founded since one of the price elasticities (being statistically significant) reported a very high value of 14.11, which judging from all the literature contained in this thesis, is too high. Therefore, the food group was omitted from the analysis.

4.5.3 Carbon elasticities

This section presents the results and a discussion on the effectiveness of carbon consumption taxes for reducing carbon emissions associated with reduced purchasing of food products. Table 43 shows the tax rates applied in this chapter. It can be seen that the tax for ready-meal beef products (RM Beef) is 30.59% which is lower than the rate for beef at 35.83% which is to be expected since a unit of beef will contain more beef meat relative to a unit of a processed ready-made meal of beef.

Table 43 Tax rates

Product	Tax rate %
Ready meal Beef	30.59
Ready meal Chicken	13.12
Ready meal Fish	11.33
Pizza	13.74
Semi skimmed milk	3.99
Skimmed milk	3.49
Soy milk	1.98
Low fat milk	3.49
Whole milk	4.49
Beef	35.83
Chicken	8.21
Haddock	15.86
Pork	10.14
Salmon	23.60
Sheep	53.81
Tuna	9.61

Source: Own elaborations

Table 44 has the useful feature of modelling many different food groups (and including the numéraire) for simultaneous application of the tax to all the different food products listed in the table which allows for a greater understanding of the net effects of the carbon consumption taxes in terms of emission reduction.

Table 44 shows an interesting result regarding the carbon footprint elasticities as chicken, haddock, pork and Tuna have positive elasticities which differs to the other products in the table and is likely a result of more substitution relationships being possible due to the modelling of more food groups relative to other chapters. The total reduction in emissions with the application of the tax to meat products (i.e. ready meal and meat products but not fish or milk products) is likely to be 1,460,316.65 tCO2e/y. The total implied change for all products shown in Table 44 is 1,628,666.89 tCO2e/y which corresponds approximately to a 24% reduction in emissions compared to the total emissions derived for this group based on Audsley et al (2009) data[28].

[28] Total emissions for all the products were calculated at 6,671,182.50 t/CO2e/y

Table 44 Simulation of carbon footprint elasticities through application of carbon consumption tax

Products	Carbon footprint elasticity	1% Price Change Implied reduction tCO2e/y **1/**	Tax Implied reduction tCO2e/y **1/**
Ready meal Beef	-0.19	- 12,806.67	-391,713.72
Ready meal Chicken	-0.06	-3,929.73	- 51,566.15
Ready meal Fish	0.01	955.91	10,828.98
Pizza	-0.04	- 2,417.37	- 33,204.25
Semi skimmed milk	0.05	3,147.06	12,549.23
Skimmed milk	-0.17	-11,402.05	-39,783.46
Soy milk	-0.03	-2,287.55	-4,535.00
Low fat milk	0.02	1,374.26	4,795.01
Whole milk	0.03	1,845.25	8,277.88
Beef	-0.05	-3,595.57	- 128,815.10
Chicken	0.08	5,519.00	45,328.09
Haddock	0.22	14,592.41	231,432.28
Pork	0.06	3,807.11	38,600
Salmon	-0.23	-15,492.75	-365,642.12
Sheep	-0.27	-18,066.36	-972,149.76
Tuna	0.01	721.09	6,931.21
Total		-38,035.95	- 1,628,666.89

Source: Own elaboration based on Kantar Worldpanel data

Within the appendix papers Chalmers et al (2015b) and Chalmers et al (2015c) it is worth highlighting the results of both in order for the similar trends to be identified. With regards to the results of Chalmers et al (2015b) whereby two scenarios were estimated, scenario one which excluded tax on fish products and scenario two which did not. Chalmers et al (2015b) found that carbon elasticity is positive for only chicken. This is due to chicken having the substitute of salmon which has a higher carbon footprint, hence the positive elasticity. Scenario 2 reduces household carbon footprints by the larger quantity of 224,592.98 tCO2e/y. This is in contrast to Scenario 1's reduction in carbon footprint by 46,304.02 tCO2e/y. Overall applying the two scenarios demonstrates how important the two fish products are for reducing emissions. Yet, with regards to this chapter, excluding fish products from taxation does not affect the overall reduction in emissions. Thus the importance of modelling many different food products.

Chalmers et al (2015c) find larger emissions being reduced through a carbon consumption tax. The results from Chalmers et al (2015c) suggest that nearly all the carbon footprint elasticities are negative (except for skimmed milk and pizza) implying that a carbon consumption tax could potentially reduce emissions by 832,419.21 tCO_2e/y. This is nearly four times greater than the implied tax reduction when modelling just for meat and fish in as appendix paper Chalmers et al (2015b) (though different demand system methods have been used).

4.5.4 Nutrient elasticities

Table 45 shows the various nutrient elasticities and the implied change in international units per day, per person. Net application of carbon consumption taxes will result in a total decline in vitamin D of 0.377 µg per person per day, which represents an 18.85% reduction of the Scottish government's recommended intake of the vitamin. This result is likely to have partially arisen from vitamin D rich salmon and tuna being complements to other goods such as beef and pork. If the carbon consumption tax is applied to only meat products (i.e. ready meal and meat products but not fish or milk products) as discussed in the previous section then the decline in vitamin D intake is much less at 0.08 µg per person per day.

The conditional demand system of Chalmers et al (2015b) finds that exempting fish products from tax would increase vitamin D intake though this is not the case for this chapter. The results of Chalmers et al (2015c) broadly support the main findings of this chapter as it seems that the total decline in vitamin D of 0.276 µg per person per day represents a 13.82% reduction of the Scottish government's recommended intake of the vitamin.

With regards to the total fat reduction induced through application of the carbon consumption taxes, it would likely result in a reduction of 2.18 grams/person/day. This suggests that the carbon consumption tax could have beneficial effects as fat consumption in Scotland is expected to increase in the future (Scottish Government, 2010). If only the meat products are taxed, then it would likely result in a reduction of 1.51 grams/person/day. One of the reasons behind this result is the salmon group has beef as a complement thus taxing salmon would encourage a reduction in relatively high fat beef and salmon. This highlights the importance of applying the full carbon consumption tax as the larger increase in fat reduction is likely to be beneficial from a nutrient intake perspective.

The overall sodium figure of 3.58 grams per person per day corresponds to an increase of 8.96 grams of salt per day which exceeds the maximum recommended daily intake of 6 grams per person per day[29]. When considering taxing only the meat products there would be an increase in sodium intake of 4.42 grams. This is likely because high sodium pork and to a lesser extent chicken are substitutes for sheep meat hence the rise in sodium/salt intake. This also highlights a situation whereby net application of carbon intake taxes not only helps to reduce carbon emissions but also has the least negative effect on salt intake. It should be highlighted that least negative effect still represents an increase in salt consumption. Thus, exempting relatively low carbon footprint products from taxation is not appropriate with regards to the effect on salt/sodium intake.

[29] The next chapter provides reasoning on why daily measures may not be the most effective measurement of dietary change

Table 45 Simulation of nutrient elasticities through application of carbon consumption tax

Products	Vitamin D			Total fat			Sodium		
	Nutrient elasticity	Change due to 1% price increase	Total implied change	Nutrient elasticity	Change due to 1% price increase	Total implied change	Total implied change elasticity	Change due to 1% price increase	Total implied change
		µg/day/person			g/day/person			g/day/person	
Ready meal Beef	-0.06	0	-0.04	-0.12	-0.06	-1.70	-0.05	-0.02	-0.48
Ready meal Chicken	-0.02	0	-0.01	-0.12	-0.06	-0.72	-0.05	-0.02	-0.20
Ready meal Fish	-0.02	0	-0.01	0.04	0.02	0.21	0.04	0.01	0.16
Pizza	0	0	0	-0.06	-0.03	-0.38	-0.08	-0.03	-0.36
Semi skimmed milk	0.02	0	0	0.05	0.02	0.09	0.02	0.01	0.02
Skimmed milk	0.06	0	0	-0.02	-0.01	-0.03	0.22	0.07	0.24
Soy milk	0.30	0.01	0.01	-0.40	-0.19	-0.37	-0.78	-0.25	-0.49
Low fat milk	-0.18	0	-0.01	-0.46	-0.21	-0.74	-0.69	-0.22	-0.78
Whole milk	-0.02	0	0	-0.02	-0.01	-0.05	-0.05	-0.02	-0.07
Beef	-0.09	0	-0.06	-0.02	-0.01	-0.40	-0.01	0	-0.15
Chicken	0.04	0	0.01	0.09	0.04	0.34	0.11	0.03	0.28
Haddock	0.10	0	0.03	0.34	0.16	2.50	0.19	0.06	0.99
Pork	0.02	0	0	0.05	0.02	0.22	0.02	0.01	0.05
Salmon	-0.67	-0.01	-0.32	-0.22	-0.10	-2.35	-0.14	-0.04	-1.05
Sheep	0.02	0	0.02	0.03	0.01	0.75	0.29	0.09	4.92
Tuna	-0.07	0	-0.01	0.11	0.05	0.47	0.16	0.05	0.49
Total		-0.01	-0.38		-0.34	-2.17		-0.26	3.58

Source: Own elaboration based on Kantar Worldpanel data

Allais et al (2010) provide a useful comparison of the effects of price increases (in the form of a fat tax) on nutrient elasticities. The study models the effect of a fat tax using French TNS Worldpanel data from the years 1996-2001 and finds that the resulting nutrient elasticities would be inelastic which highlights that while saturated fat is inelastic so too is Vitamin C (Allais et al., 2010). However, without calculating the corresponding international units, it seems hard to draw the conclusion that inelastic nutrients pose a problem for public health as they cannot be compared to daily recommendations. While it is difficult to compare the nutrient elasticities in this chapter with the socio economic and food groups of Allais et al (2010), many of the nutrient elasticities were relatively inelastic. Though the fat and sodium groups had relatively larger nutrient elasticities with regards to the different food products.

Another paper which questions the merits of taxation on nutrient elasticities is Beatty and LaFrance (2005) who study the price and income elasticity of nutrients. The authors suggest that taxing food products high in certain nutrients may have little effect on nutrient intake (Beatty and LaFrance, 2005). As reported in this chapter, it seems that the increase in salt is worth 25.66% of the overall recommended daily intake of salt. Therefore, it could be argued that taxing food products can have a negative effect from a health perspective.

Caillavet et al (2014) provide an interesting working paper on modelling consumption taxes on French panel data (1998-2010) in order to calculate the environmental and health effects. Their paper does not model a differentiable carbon consumption tax and instead opts for a figure of a 20% tax for two scenarios: Scenario one which is focussed on the environment and places a 20% tax on most food products and Scenario two which is focussed on both the environment and health and therefore omits the tax on healthier products such as fish and yoghurt products (Caillavet et al,. 2014). While this approach is interesting, the carbon footprints reviewed in chapter 2 along with the carbon consumption taxes calculated in this chapter and chapter 3 suggest that a uniform 20% tax will unlikely reflect the damage of the particular food product to the environment. 20% tax would overestimate the damage done for milk products, while underestimating the damage for sheep related products.

The idea of exempting certain food products from tax for nutritional reasons would cause concern with regards to the sodium group whereby taxing only the meat group would likely increase the corresponding salt intake.

4.6 Summary

This chapter focussed on modelling the effects of a carbon consumption tax on the major high carbon food products. The incomplete demand system used in this chapter is an improvement in terms of demand system modelling over the previous chapters, mainly because it contains more food groups and the numéraire group.

The net application of carbon consumption taxes to food products would likely reduce emissions by 1,628,666.89 tCO_2e/y. This represents a 24% reduction in meat and milk consumption emissions. This is mainly due to a reduction in demand for high carbon footprint meat products such as beef. Also beef (not ready-meal beef which is a complement to chicken) is a substitute for lower carbon chicken, but primarily many of the different price elasticities were complements to one another. This also helps to explain the decline in emissions after the net application of taxes.

The subsequent effects in terms of nutrient intake offer a mixed outcome. Vitamin D was highlighted in this chapter as a nutrient which is lacking in the average Scottish individual and would likely reduce by 0.38 µg per day per person which represents an 18.85% reduction of the Scottish government's recommended intake. This result alone may cause policymakers to be wary of using a carbon consumption tax and demonstrates to an extent the trade-off between environment and dietary intake.

However, the effect of the tax on intakes of total fat offers some support for a carbon consumption tax as intake reduces the nutrient. Net application of taxes would likely result in a decrease in fat. However, the likely outcome of salt intake increasing as a result of the tax is worrying. Therefore, as the nutrient effects are mixed, a government may wish to introduce carbon consumption taxes if they consider reducing greenhouse gas emissions to be a priority. In order to understand the distributional impacts on nutrient intake as a result of a carbon consumption tax, the different socio-economic groups need to be considered. This will be the basis of chapter 5 with a discussion provided for the possible exclusion of some food products for taxation.

4.7 Annex

Table 46 y (implicit utility) parameters estimated from EASI

	Linear			Non Linear (cubic)		
Equation	Estimate	t value		Estimate	t value	
Ready meal Beef	0.001	0.938		-0.670	-0.275	
				0.329	0.291	
				-0.053	-0.307	
Ready meal Chicken	0.004	1.890	.	-3.540	-0.970	
				1.675	0.993	
				-0.263	-1.014	
Ready meal Fish	0.001	0.724		-0.325	-0.191	
				0.156	0.199	
				-0.025	-0.206	
Pizza	0.002	1.015		0.838	0.276	
				-0.379	-0.270	
				0.057	0.265	
Semi skimmed milk	-0.003	-1.037		8.516	1.642	
				-3.935	-1.641	
				0.605	1.639	
Skimmed milk	0.002	0.922		3.777	1.246	
				-1.745	-1.245	
				0.269	1.244	
Soy milk	0.001	0.569		-0.082	-0.034	
				0.044	0.039	
				-0.008	-0.044	
Low fat milk	-0.001	-0.501		2.435	0.755	
				-1.108	-0.743	
				0.168	0.731	
Whole milk	-0.001	-0.333		3.702	0.959	
				-1.741	-0.975	
				0.272	0.990	
Beef	0.023	3.450	***	34.601	2.495	*
				-15.902	-2.480	*
				2.436	2.467	*

	Linear			Non Linear (cubic)		
Equation	Estimate	t value		Estimate	t value	
Chicken	0.006	0.529		72.296	3.095	**
				-33.233	-3.078	**
				5.090	3.062	**
Haddock	0.000	-0.081		-0.803	-0.340	
				0.369	0.338	
				-0.057	-0.336	
Pork	0.015	2.141	*	42.276	3.113	**
				-19.309	-3.077	**
				2.940	3.041	**
Salmon	0.001	0.397		4.613	1.049	
				-2.080	-1.023	
				0.312	0.998	
Sheep	0.006	1.909	.	5.550	0.930	
				-2.574	-0.933	
				0.398	0.937	
Tuna	0.002	0.964		7.835	1.979	*
				-3.625	-1.981	*
				0.559	1.983	*

Notes: Parameters were estimated using three stage least squares. Significance: 0 '***' 01 '**' 0.01 '*' 0.05 '.' 0.1

Table 47 EASI (based on cubic income) price elasticities

	Ready meal Beef		Ready meal Chicken		Ready meal Fish		Pizza		Semi skimmed milk	
Ready meal Beef	0.03		0.39		0.24		0.1		-0.04	
Ready meal Chicken	0.52		0.46		0.64		-0.11		-0.11	*
Ready meal Fish	0.15		0.29		-0.62	**	0.03		-0.02	
Pizza	0.21		-0.18		0.09		-0.83	**	-0.09	
Semi skimmed milk	-0.5		-1.13	*	-0.41		-0.62		-0.39	*
Skimmed milk	-0.53		0.69		0.25		0.15		-0.06	
Soy milk	0.35		0.1		0.38		-0.09		-0.06	
Low fat milk	0.11		0.38		-0.05		0.23		0.18	***
Whole milk	1.72	**	-0.55		0.21		0.62	*	0.31	*
Beef	0.46		0.17		0.55		-0.23		0.24	**
Chicken	-1.19		-1.44		0.75		0.2		0.36	***
Haddock	-0.11		-0.01		-0.04		-0.2		-0.03	
Pork	-0.5		-0.5		-0.81		-0.17		-0.05	
Salmon	0.27		0.57		-0.43		0.31		0.03	
Sheep	-0.79	*	-0.82	*	0.86	*	-0.29		0.08	
Tuna	-0.46		-0.5		0.13		0.13		0	
Numeraire group	-1.03	***	0.03	***	-3.84	***	-0.78	***	-1.35	***

	Skimmed milk		Soy milk		Low fat milk		Whole milk		Beef	
Ready meal Beef	-0.23		1.09		0.12		0.29	**	0.03	
Ready meal Chicken	0.41		0.42		0.57		-0.12		0.02	
Ready meal Fish	0.07		0.72		-0.03		0.02		0.02	
Pizza	0.14		-0.57		0.53		0.21	*	-0.03	
Semi skimmed milk	-0.4		-2.67		2.95	***	0.73	*	0.17	*
Skimmed milk	-0.18		1.6		0.29		-0.16		0.01	
Soy milk	0.23		0.16		0.23		0.11		0.03	
Low fat milk	0.12		0.66		-1.51	***	-0.12	*	0.04	
Whole milk	-0.43		1.98		-0.82	*	-0.73	*	0.06	
Beef	0.08		1.34		0.82		0.2		-0.54	**
Chicken	-1.27	**	-3.34		-3.55	***	-0.07		0.4	*
Haddock	0.04		0.16		0.33		-0.06		-0.02	
Pork	0.92	*	-3.67		-1.93	**	-0.34		-0.19	
Salmon	-0.12		1.58		0.4		-0.13		-0.16	**
Sheep	-0.81	***	-1.23		0.57		-0.14		0.16	*
Tuna	0.38	*	-1.98	**	-0.01		-0.02		0	
Numeraire group	-0.51	***	1.91	***	0.35	***	-0.66	***	-2.17	***

	Chicken		Haddock		Pork		Salmon		Sheep	
Ready meal Beef	-0.08	**	-0.32		-0.05		0.09		-0.22	**
Ready meal Chicken	-0.11	**	-0.03		-0.06		0.27		-0.29	*
Ready meal Fish	-0.02		-0.06		-0.05	**	-0.09		0.12	
Pizza	-0.02		-1.22		-0.05		0.22		-0.17	
Semi skimmed milk	0.13	*	-1.2		-0.08		0.15		0.25	
Skimmed milk	-0.15	***	0.24		0.06		-0.1		-0.49	***
Soy milk	-0.08	**	0.15		-0.08	**	0.18		-0.11	
Low fat milk	-0.16	***	0.84		-0.1	***	0.12		0.11	
Whole milk	-0.06		-1.07		-0.12	**	-0.27		-0.24	
Beef	0.23	*	-1.16		-0.16		-0.95	**	0.67	*
Chicken	-0.28		4.53	*	0.38	**	0.07		0.83	*
Haddock	0.02		-0.8		0		0		0.07	
Pork	0.33	**	2.13		-0.06		-0.4		0.95	**
Salmon	-0.03		-0.01		-0.08		-1.15	***	-0.09	
Sheep	0.09		0.93		0.13	**	-0.09		-1.31	***
Tuna	-0.04		0.87		0.06		-0.25		0.08	
Numeraire group	-2.15	***	-4.73	***	-2.03	***	0.74	***	-2.64	***

	Tuna		Numeraire group	
Ready meal Beef	-0.22		-0.01	
Ready meal Chicken	-0.31		0	
Ready meal Fish	0.04		-0.01	***
Pizza	0.12		0	
Semi skimmed milk	-0.02		-0.04	***
Skimmed milk	0.4	*	0	
Soy milk	-0.29	**	0	
Low fat milk	-0.01		0	
Whole milk	-0.08		-0.01	
Beef	-0.06		-0.04	***
Chicken	-0.02		-0.07	***
Haddock	0.14		-0.01	**
Pork	0.96	*	-0.06	***
Salmon	-0.35	*	0	
Sheep	0.17		-0.01	**
Tuna	-0.53	**	-0.01	*
Numeraire group	-2.26	***	-0.66	*

Source: Based on own elaborations
Statistical significance: '*'=10%, '**'=5% or '***'=1%

Chapter 5. The distributional effects of carbon consumption taxes on carbon emissions and nutrient intake[30]?

5.1 Introduction

The purpose of this chapter is to explore the distributional effects of carbon consumption taxes on Scottish social groups in terms of carbon emissions and nutrient intake. This chapter provides support for objectives one (Estimating demand systems for the purpose of understanding the substitutions of high carbon food products), two (Developing carbon footprint elasticities in order to understand emission changes induced through carbon consumption taxes), three (Estimating nutrient elasticities in order to understand the likely effect on nutrient intake of taxes) and four ("Applying carbon consumption taxes to all major food products").

The previous chapters highlight how emissions associated with food consumption can be reduced through taxation. Yet, a problem chapter 3 highlighted is the largest distributional effect of taxes in the form of reduced quantity demand fell on the lowest Scottish socio-economic households (i.e. social groups). While this is likely to be regressive in economic terms, it may have potential improvements in nutrient intake. This chapter addresses the distributional impact on social groups in terms of the whether the nutrient effects are beneficial in reducing currently over-consumed nutrients or problematic in the form of reducing currently the under-consumed nutrient of vitamin D.

5.1.1 Problems associated with Scottish diets

The previous chapter focussed on vitamin D in addition to fat and salt intakes. This chapter will study these nutrients but will also focus on sugar and energy[31] intake. Due to recent evidence suggesting that excessive sugar intake could cause a variety of health problems such obesity and diabetes (Lustig et al., 2012), it seems important to model the likely change in sugar intake resulting from a carbon consumption tax.

[30] This chapter is based on the paper "Changing nutrient consumption using a carbon consumption tax", which was submitted to the "The European Journal of Health Economics" journal. The paper can be found in the final appendix.

[31] It is acknowledged that Energy is not a nutrient but due its relationship with the nutrients of fat and sugar and it appears in the NDNS dataset

There is also evidence to suggest that the risk of cardiovascular mortality increases after the added sugar based share of daily consumed calories becomes greater than 15% (McCarthy, 2014). Food Standards Agency (2014b) research highlighted how all age groups failed to meet the maximum guideline of energy share derived from non-milk extrinsic sugars (NMES) of 11 %. Therefore, this highlights a nutrient for which a reduction is likely to be necessary to improve diet.

Energy intake is largely correlated with both total fat and sugar intakes. The most recent results for Scotland suggest that in 2012, the energy households obtained from food was 39%, which is greater than the 35% guideline (Scottish Government, 2014).

Salt intake is also of interest and can be converted by using the nutrient of sodium. The maximum recommended daily intake of salt is 6 grams of salt per person which corresponds to 3.2 grams of sodium (Food Standards Agency Scotland, 2014). Food Standards Agency (2014b) research suggests that the majority of respondents within each demographic group (except children ages 7-10) in Scotland exceed sodium intake guidelines.

Wirsenius et al (2011) highlight similar concerns regarding the carbon consumption tax being regressive with the burden of cost falling on the most basic food products. Mytton et al (2012) highlight the potential for health related taxes to be progressive if the impact on dietary change of the poor is beneficial. This chapter uses the term “distributional impact” which is used by Tiffin and Arnoult (2011) in relation to the nutrient intake of different households being considered beneficial in terms of diet (described in some papers as progressive) or problematic for dietary change (described in some papers as regressive).

5.2 Data

This section provides an overview of the various sources of data used in the chapter and highlights any similarities with the existing literature on data use.

5.2.1 Purchase data

The data used for this chapter was time series and covered the years 2006-2013 (with each year comprising of 13 periods of four weeks). The descriptive statistics of the share, price and expenditures variables used for the demand system models are shown in Tables 45 to Table 48. Due to space constraints table 44 provides for an explanation of the share and price abbreviations contained within Tables 45 to Table 48. This study uses time series data constructed from Kantar Worldpanel data for the years 2006-2013 covering a sample of Scottish households. The number of households contained in each year of data varied from 2,287 for 2006 to 2,631 for 2007.

Table 48 Reference table for descriptive statistic tables

Food group	**Number of household Observed purchases (2006-2013)**	Shares abbreviation	Prices abbreviation
Alcohol	468,609	ShAlc	PrAlc
Cakes & biscuits	1,571,015	ShCake	PrCake
Cheese	553,392	ShCheese	PrCheese
Confectionery	887,96	ShConf	PrConf
Eggs	212,110	ShEggs	PrEggs
Fats & oils	365,253	ShOil	PrOil
Fish	102,021	ShFish	PrFish
Fruit	1,095,942	ShFruit	PrFruit
Fruit juices	267,612	ShFJ	PrFJ
Grain based group	1,967,875	ShGrain	PrGrain
High carbon meat	290,469	ShHCmeat	PrHCmeat
High carbon milks	624,121	ShHCmilk	PrHCmilk
Low carbon meat	833,507	ShLCmeat	PrLCmeat
Low carbon milks	123,519	ShLCmilk	PrLCmilk
Other dairy	6,484,609	ShOdairy	PrOdairy
Ready-made meals (meat based)	635,977	ShRM	PrRM
Sugar sweetened beverages	254,226	ShSSB	PrSSB
Hot beverages	271,689	ShBev	PrBev
Vegetables	1,950,233	ShVeg	PrVeg
Numeraire		ShNum	PrNum

Table 49 Descriptive statistics for group AB

	ShAlc	ShCake	ShCheese	ShConf	ShEggs	ShOil	ShFish	ShFruit	ShFJ	ShGrain	ShHCmeat	ShHCmilk	ShLCmeat	ShLCmilk
min	0.04	0.03	0.01	0.02	0	0.01	0	0.02	0	0.03	0.01	0.01	0.02	0
max	0.13	0.06	0.01	0.05	0	0.01	0.01	0.04	0.01	0.05	0.02	0.01	0.04	0
range	0.08	0.02	0	0.04	0	0	0	0.02	0	0.02	0.01	0.01	0.01	0
sum	7.83	4.19	1.23	3.04	0.36	0.68	0.37	2.90	0.57	3.91	1.23	0.99	2.90	0.24
median	0.07	0.04	0.01	0.03	0	0.01	0	0.03	0.01	0.04	0.01	0.01	0.03	0
mean	0.08	0.04	0.01	0.03	0	0.01	0	0.03	0.01	0.04	0.01	0.01	0.03	0
std.dev	0.02	0	0	0.01	0	0	0	0	0	0	0	0	0	0

	ShOdairy	ShRM	ShSSB	ShBev	ShVeg	ShNum	PrAlc	PrCake	PrCheese	PrConf	PrEggs	PrOil	PrFish	PrFruit
min	0.01	0	0.01	0.01	0.03	0.57	1.70	1.06	1.78	0.15	-2.05	0.90	1.80	0.65
max	0.01	0	0.02	0.01	0.05	0.68	2.14	1.56	2.15	1.44	-1.59	1.38	2.39	1.13
range	0	0	0.01	0.01	0.02	0.11	0.45	0.50	0.36	1.29	0.47	0.49	0.59	0.48
sum	1.05	0.32	1.62	0.98	4.47	64.11	195.85	132.64	199.47	53.63	-180.19	120.53	208.08	95.93
median	0.01	0	0.02	0.01	0.04	0.62	1.91	1.29	1.95	0.44	-1.67	1.18	2.00	0.92
mean	0.01	0	0.02	0.01	0.04	0.62	1.90	1.29	1.94	0.52	-1.75	1.17	2.02	0.93
std.dev	0	0	0	0	0	0.02	0.11	0.12	0.07	0.27	0.14	0.14	0.13	0.11

	PrFJ	PrGrain	PrHCmeat	PrHCmilk	PrLCmeat	PrLCmilk	PrOdairy	PrRM	PrSSB	PrBev	PrVeg	PrNum	Expenditure
min	-0.15	0.43	1.66	-0.67	1.60	-0.71	0.78	1.25	-0.32	2.44	0.85	1.70	2.55
max	0.19	0.92	2.16	-0.34	1.95	-0.31	1.15	1.55	-0.02	2.81	1.27	2.05	2.96
range	0.34	0.49	0.50	0.33	0.35	0.39	0.37	0.30	0.31	0.36	0.42	0.35	0.42
sum	6.98	69.51	200.28	-47.54	186.27	-47.43	97.47	142.34	-18.58	269.08	110.24	194.26	280.02
median	0.06	0.68	1.95	-0.45	1.84	-0.43	0.95	1.38	-0.20	2.61	1.08	1.89	2.71
mean	0.07	0.67	1.94	-0.46	1.81	-0.46	0.95	1.38	-0.18	2.61	1.07	1.89	2.72
std.dev	0.07	0.13	0.10	0.09	0.08	0.10	0.08	0.06	0.08	0.09	0.09	0.08	0.09

Source: Own elaboration based on Kantar Worldpanel data. Table 44 provides for a reference to the various abbreviations. Price is in natural logarithm form.

Table 50 Descriptive statistics for group C1

	ShAlc	ShCake	ShCheese	ShConf	ShEggs	ShOil	ShFish	ShFruit	ShFJ	ShGrain	ShHCmeat	ShHCmilk	ShLCmeat	ShLCmilk
min	0.06	0.04	0.01	0.02	0	0.01	0	0.02	0	0.03	0.01	0.01	0.03	0
max	0.17	0.06	0.02	0.07	0	0.01	0.01	0.04	0.01	0.05	0.02	0.01	0.04	0
range	0.11	0.02	0.01	0.05	0	0	0.01	0.03	0.01	0.02	0.01	0.01	0.02	0
sum	8.94	4.60	1.18	3.20	0.38	0.74	0.38	2.74	0.52	4.33	1.34	1.13	3.12	0.23
median	0.08	0.04	0.01	0.03	0	0.01	0	0.03	0	0.04	0.01	0.01	0.03	0
mean	0.09	0.04	0.01	0.03	0	0.01	0	0.03	0.01	0.04	0.01	0.01	0.03	0
std.dev	0.02	0	0	0.01	0	0	0	0.01	0	0	0	0	0	0

	ShOdairy	ShRM	ShSSB	ShBev	ShVeg	ShNum	PrAlc	PrCake	PrCheese	PrConf	PrEggs	PrOil	PrFish	PrFruit
min	0.01	0	0.01	0.01	0.03	0.44	1.69	1.07	1.73	0.08	-2.11	0.84	1.70	0.55
max	0.01	0.01	0.03	0.01	0.07	0.65	2.40	1.49	2.08	1.28	-1.64	1.35	2.34	1.09
range	0.01	0	0.01	0.01	0.04	0.21	0.70	0.42	0.35	1.20	0.47	0.51	0.64	0.54
sum	0.99	0.42	1.83	1.00	4.26	61.67	194.08	128.61	194.22	43.71	-183.43	114.20	203.37	86.59
median	0.01	0	0.02	0.01	0.04	0.61	1.88	1.25	1.90	0.36	-1.72	1.08	1.98	0.84
mean	0.01	0	0.02	0.01	0.04	0.60	1.88	1.25	1.89	0.42	-1.78	1.11	1.97	0.84
std.dev	0	0	0	0	0.01	0.04	0.11	0.10	0.08	0.28	0.14	0.15	0.13	0.13

	PrFJ	PrGrain	PrHCmeat	PrHCmilk	PrLCmeat	PrLCmilk	PrOdairy	PrRM	PrSSB	PrBev	PrVeg	PrNum	Expenditure
min	-0.22	0.39	1.69	-0.68	1.57	-0.61	0.75	1.24	-0.37	2.38	0.74	1.49	2.59
max	0.14	0.90	2.21	-0.35	1.92	-0.35	1.15	1.54	-0.04	2.73	1.17	1.94	3.39
range	0.36	0.51	0.52	0.33	0.35	0.26	0.40	0.30	0.33	0.35	0.44	0.45	0.80
sum	1.40	66.32	199.94	-49.01	181.08	-48.93	95.12	139.67	-22.54	261.45	100.93	183.69	315.36
median	0	0.64	1.95	-0.48	1.77	-0.47	0.93	1.35	-0.23	2.52	0.99	1.79	3.08
mean	0.01	0.64	1.94	-0.48	1.76	-0.48	0.92	1.36	-0.22	2.54	0.98	1.78	3.06
std.dev	0.08	0.14	0.11	0.08	0.09	0.06	0.09	0.06	0.09	0.10	0.10	0.10	0.16

Source: Own elaboration based on Kantar Worldpanel data. Table 44 provides for a reference to the various abbreviations. Price is in natural logarithm form.

Table 51 Descriptive statistics for group C2

	ShAlc	ShCake	ShCheese	ShConf	ShEggs	ShOil	ShFish	ShFruit	ShFJ	ShGrain	ShHCmeat	ShHCmilk	ShLCmeat	ShLCmilk
min	0.05	0.04	0.01	0.02	0	0.01	0	0.01	0	0.03	0.01	0.01	0.03	0
max	0.15	0.06	0.01	0.06	0	0.01	0	0.03	0.01	0.05	0.02	0.01	0.04	0
range	0.10	0.02	0	0.04	0	0	0	0.02	0	0.02	0.01	0.01	0.01	0
sum	9.33	4.71	1.14	3.58	0.37	0.80	0.28	2.25	0.45	4.39	1.48	1.19	3.31	0.18
median	0.09	0.05	0.01	0.03	0	0.01	0	0.02	0	0.04	0.01	0.01	0.03	0
mean	0.09	0.05	0.01	0.03	0	0.01	0	0.02	0	0.04	0.01	0.01	0.03	0
std.dev	0.02	0	0	0.01	0	0	0	0	0	0	0	0	0	0

	ShOdairy	ShRM	ShSSB	ShBev	ShVeg	ShNum	PrAlc	PrCake	PrCheese	PrConf	PrEggs	PrOil	PrFish	PrFruit
min	0.01	0	0.02	0.01	0.03	0.56	1.61	1.00	1.71	-0.04	-2.20	0.78	1.54	0.47
max	0.01	0.01	0.03	0.01	0.04	0.67	2.50	1.50	2.05	1.15	-1.67	1.25	2.36	1.08
range	0	0	0.01	0	0.02	0.11	0.89	0.50	0.34	1.18	0.54	0.47	0.82	0.61
sum	0.89	0.48	1.98	0.98	3.73	61.47	190.87	126.14	191.43	35.70	-191.28	107.44	195.02	82.44
median	0.01	0	0.02	0.01	0.04	0.60	1.86	1.23	1.86	0.26	-1.79	1.04	1.88	0.79
mean	0.01	0	0.02	0.01	0.04	0.60	1.85	1.22	1.86	0.35	-1.86	1.04	1.89	0.80
std.dev	0	0	0	0	0	0.02	0.12	0.12	0.08	0.29	0.15	0.14	0.17	0.14

	PrFJ	PrGrain	PrHCmeat	PrHCmilk	PrLCmeat	PrLCmilk	PrOdairy	PrRM	PrSSB	PrBev	PrVeg	PrNum	Expenditure
min	-0.35	0.42	1.64	-0.68	1.52	-0.66	0.75	1.21	-0.41	2.31	0.65	1.49	2.36
max	0.16	0.91	2.17	-0.36	1.87	-0.36	1.15	1.47	-0.02	2.73	1.07	1.97	2.99
range	0.51	0.49	0.53	0.32	0.35	0.29	0.41	0.27	0.39	0.42	0.42	0.48	0.63
sum	-2.15	67.12	195.31	-50.08	177.07	-51.42	95.67	136.99	-23.09	256.27	89.50	176.88	275.40
median	-0.04	0.63	1.91	-0.49	1.73	-0.48	0.93	1.34	-0.24	2.48	0.88	1.71	2.68
mean	-0.02	0.65	1.90	-0.49	1.72	-0.50	0.93	1.33	-0.22	2.49	0.87	1.72	2.67
std.dev	0.11	0.14	0.13	0.08	0.09	0.08	0.09	0.06	0.09	0.11	0.11	0.10	0.12

Source: Own elaboration based on Kantar Worldpanel data. Table 44 provides for a reference to the various abbreviations. Price is in natural logarithm form.

Table 52 Descriptive statistics for group DE

	ShAlc	ShCake	ShCheese	ShConf	ShEggs	ShOil	ShFish	ShFruit	ShFJ	ShGrain	ShHCmeat	ShHCmilk	ShLCmeat	ShLCmilk
min	0.05	0.05	0.01	0.03	0	0.01	0	0.01	0	0.03	0.01	0.01	0.03	0
max	0.13	0.07	0.01	0.09	0.01	0.01	0	0.03	0	0.06	0.02	0.02	0.04	0
range	0.09	0.03	0	0.06	0	0	0	0.02	0	0.03	0.01	0.01	0.01	0
sum	7.21	5.67	1.10	4.08	0.40	0.90	0.29	2.17	0.37	4.71	1.28	1.38	3.17	0.21
median	0.07	0.05	0.01	0.04	0	0.01	0	0.02	0	0.05	0.01	0.01	0.03	0
mean	0.07	0.06	0.01	0.04	0	0.01	0	0.02	0	0.05	0.01	0.01	0.03	0
std.dev	0.02	0	0	0.01	0	0	0	0	0	0	0	0	0	0

	ShOdairy	ShRM	ShSSB	ShBev	ShVeg	ShNum	PrAlc	PrCake	PrCheese	PrConf	PrEggs	PrOil	PrFish	PrFruit
min	0.01	0	0.02	0.01	0.03	0.54	1.64	0.95	1.65	-0.07	-2.25	0.77	1.44	0.45
max	0.01	0.01	0.03	0.01	0.04	0.65	2.12	1.49	2.01	1.10	-1.76	1.22	2.20	1.05
range	0.01	0	0.01	0	0.02	0.11	0.49	0.54	0.36	1.17	0.49	0.45	0.75	0.60
sum	0.82	0.60	2.22	1.04	3.59	61.79	191.93	119.05	188.98	28.47	-198.64	105.14	189.47	79.21
median	0.01	0.01	0.02	0.01	0.03	0.60	1.86	1.16	1.85	0.19	-1.87	1.02	1.86	0.77
mean	0.01	0.01	0.02	0.01	0.03	0.60	1.86	1.16	1.83	0.28	-1.93	1.02	1.84	0.77
std.dev	0	0	0	0	0	0.02	0.13	0.11	0.08	0.29	0.14	0.14	0.16	0.15

	PrFJ	PrGrain	PrHCmeat	PrHCmilk	PrLCmeat	PrLCmilk	PrOdairy	PrRM	PrSSB	PrBev	PrVeg	PrNum	Expenditure
min	-0.27	0.36	1.60	-0.70	1.49	-0.73	0.72	1.21	-0.36	2.20	0.55	1.44	2.81
max	0.10	0.82	2.14	-0.38	1.85	-0.39	1.06	1.38	-0.06	2.64	1.05	1.84	3.30
range	0.37	0.46	0.54	0.32	0.36	0.34	0.34	0.17	0.30	0.44	0.50	0.39	0.50
sum	-9.06	60.04	189.86	-51.40	172.40	-54.01	91.26	133.13	-22.58	247.76	81.74	168.40	311.78
median	-0.10	0.58	1.86	-0.50	1.69	-0.51	0.89	1.29	-0.24	2.39	0.81	1.63	3.04
mean	-0.09	0.58	1.84	-0.50	1.67	-0.52	0.89	1.29	-0.22	2.41	0.79	1.63	3.03
std.dev	0.09	0.12	0.12	0.08	0.08	0.08	0.08	0.04	0.10	0.12	0.12	0.09	0.10

Source: Own elaboration based on Kantar Worldpanel data. Table 44 provides for a reference to the various abbreviations. Price is in natural logarithm form.

The data used in this chapter corresponds with the food groups shown in Table 53 which details the composition of each food group with the second column (second from left) detailing the individual products which are contained within each food group. The final columns detail the range of carbon footprints (CF) of the food products contained within each food group and the sources of the CF.

The reasoning behind the composition of the different food groups of Table 53 is largely based on how the Kantar data can be matched to both the carbon footprint data and nutritional data. For this reason the food groups do not resemble those of Defra's family food (Defra, 2014a). Druckman et al (2011) while modelling the rebound effect and therefore having little relevance to this chapter (as this chapter only considers food products) appear to highlight the incompatibility between the "Living Costs and Food Survey" food groups and subsequent carbon emission groups.

Both the carbon and health literature are in consensus regarding the need to disaggregate the meat group into red and white meats which has been called the high carbon meat and low carbon meat groups. The same reasoning applies to the creation of the two milk groups. The formation of the "Sugar sweetened beverages" group is due to the health concern regarding this group and these products tend to have a lower carbon footprint relative to other food products.

The Kantar dataset provided descriptions which along with coding (described in the previous chapter) helps to create the products for each food group. However, the Kantar descriptions could be misleading as it seems products such as milkshakes and yoghurt based drinks are also included under "Take Home Soft Drinks". These products were subsequently removed from the soft drink group as their ingredients are dominated by dairy products. This does highlight how the categorisation of Kantar Worldpanel requires changes in order to be applicable to a study such as this thesis which focusses on carbon footprint and nutrient data of food products.

Defra's family food (2014a) also separated the grain and bread groups, this did not seem applicable for this study as the carbon footprints were relatively similar and only non-sweetened breads were included. Products such as pastries were included in the cake group mainly for the nutritional reasons.

Table 53 Food purchase data

Food Group	Products	Range of Carbon Minimum g CO2e (source in brackets)	Footprint (CF) (g CO2e /Unit) Maximum g CO2e (source in brackets)	Unit
1. Alcohol	Alcohol based drinks (e.g. wine, lager, sprits)	180 Lager (Tesco plc, 2012)	75 Spirits (Berners-Lee et al., 2015) 250 Strong lager (Tesco plc, 2012)	Per 250ml
2. Cakes & biscuits	Biscuits Some bakery products	120 Croissants (Carbon Trust, 2008)	450 Biscuits (Berners-Lee et al., 2015)	Per 100 grams
3. Cheese	Cheese	1110 (Sheane et al., 2011)		Per 100 grams
4. Confectionery	Chocolate bars Boiled sweets	344.90 Chocolate bar (Food Manufacture, 2008)	446 (Hoolohan et al., 2013)	Per 100 grams
5. Eggs	Eggs	260 Free range Medium (Tesco plc, 2012)	280 Organic (Tesco plc, 2012)	per egg
6. Fats & oils	Butter Margarine Cooking oils	110 Margarine (Tesco plc, 2012)	950 Butter (Tesco plc, 2012)	Per 100 grams
7. Fish	Haddock Salmon Tuna	329.4 Tuna (Poovarodom et al., 2012)	833.3 Salmon (The Co-operative Group, 2012)	Per 100 grams

Food Group	Products	Range of Carbon Minimum g CO2e (source in brackets)	Footprint (CF) (g CO2e /Unit) Maximum g CO2e (source in brackets)	Unit
8. Fruit	Fruit	32 Apples (Defra, 2010)	379 Fresh tomatoes (Audsley et al., 2009)	Per 100 grams
9. Fruit juices	Pure Juices Tomato Juice	120 Orange juice drink (Tesco plc, 2012)	360 freshly squeezed (Tesco plc, 2012)	Per 250 millilitres
10. Grain based group	Pasta Rice Porridge Noodles Dry Pulses Cereal Bread based products (non-sweet)	150 White bread (Espinoza-Orias et al., 2011)	933.3 Chocolate based cereal (Tesco plc, 2012)	Per 100 grams
11. High carbon meat	Red meat	1265 Beef (Houses of Parliament, 2013b)	1900 NZ lamb (Ledgard et al., 2011)	Per 100 grams
12. High carbon milks	Semi skimmed Whole	1408 Semi Skimmed (Tesco plc, 2012)	1584 Whole (Tesco plc, 2012)	Per litre
13. Low carbon meat	White meat	290 Chicken (Defra, 2010)	358 Pork (Aarhus University, 2014)	Per 100 100g
14. Low carbon milks	Soy milk Skimmed Lower fat	700 Unsweetened Soy (Tesco plc, 2012)	1232 Skimmed (Tesco plc, 2012)	Per litre
15. Other dairy	Milk Drinks (including shakes) Cream Yoghurt Drinks And Juices Yoghurt Frozen Cream (not ice-cream)	236.1 Yoghurt (Sheane et al., 2011)	612.48 Double cream (Tesco plc, 2012)	Per 100 millilitres

Food Group	Products	Range of Carbon Minimum g CO2e (source in brackets)	Footprint (CF) (g CO2e /Unit) Maximum g CO2e (source in brackets)	Unit
16. Ready-made meals (meat based)	Cheese and Tomato Pizza Thin & Crispy Pepperoni Chicken & Broccoli Pie Chicken Korma & Pilau Rice Chicken Enchiladas Cottage Pie Steak & Ale with Cheddar Mash Chilli con carne and rice Fish pie	400 Fish pie (Tesco plc, 2012)	1130 Steak & Ale with Cheddar Mash (Tesco plc, 2012)	Per 100 grams
17. Sugar sweetened beverages	Take Home Soft Drinks Excludes “No Added Sugar” based drinks	55 Diet cola (Tesco plc, 2012)	70 Lemonade (Tesco plc, 2012)	Per 250 millilitres
18. Hot beverages	Tea Coffee Instant hot drinks	53 Coffee (Berners-Lee, 2010)		per cup (250 ml)
19. Vegetables	Vegetables (excludes pulses)	480 Loose Large Open Mushrooms (Tesco plc, 2012)	79 Carrots (Tesco plc, 2012)	Per 100 grams
20. Numeraire group				

Source: Own elaborations based on Kantar Worldpanel data and various sources of carbon footprint data.

5.2.2 Carbon emissions data

As this chapter studies all the main food groups, the total emissions attributed to food consumption as described in chapter 2 were used. This differs to the other chapters which used Audsley et al (2009) emissions data since these chapters only studied select food groups and not all the major food groups. While chapter 4 used mainly PAS 2050 carbon footprint, the overall emissions value was sourced from Audsley et al (2009). This chapter focusses mainly on the food emission shares being estimated to be approximately 20% of Scotland's total greenhouse gas (GHG) emissions. Briggs et al (2013) accounted for LUC in their study which is the only UK based carbon consumption tax modelling study. It was considered necessary to also include LUC in the overall carbon emissions value of this study in order for a comparison to be possible. It should be noted that the focus of this chapter is on non LUC emissions based on the problems of measuring LUC (as highlighted in chapter 2, section 2.2).

The majority of carbon footprints (CF) used in this chapter comply with PAS 2050 (described in chapter 2) specifications or follows a similar method and are cradle to grave. However, there are CFs which are not cradle to grave and these will be highlighted in this section.

With regards to the alcohol group (group 1 of Table 53), there is some difference between lagers and spirits. One UK unit of alcohol would equate to 250 ml of beer (4% alcohol) and 25ml of spirit (Aware, 2015) which is difficult to compare on a volume basis for beers and spirits. The spirit CF value is cradle to regional distribution centre which is in contrast to the beer CF which is cradle to grave. For the year 2013, the individual purchases of whisky accounted for approximately 5.4% of total alcohol purchases[32], coupled with the issue of the carbon footprint being distorted when made to represent litres, it was not included in in estimating a representative value for the carbon consumption tax.

[32] Based on own elaborations of the Kantar Worldpanel dataset

The CF value chosen uses strong lager as a representative value. It should be noted that as mentioned in chapter 3, alcohol already has taxes applied. The chosen alcohol carbon consumption tax does not account for this consideration as the purpose is to reduce demand for high carbon food products based on applying the tax to product's existing price.

A recent consultancy report on the UK retailer "Booths", found that the cakes and biscuits group (group 2 of Table 53) is likely to have little difference in CF (Berners-Lee et al., 2015). However, a BSI study shows that the CF of croissants do differ to cakes. The methodologies between the two sources does differ slightly though both follow cradle to grave (the latter is PAS 2050 compliant). The difference between values may also be attributed to Booths using more locally sourced ingredients (Berners-Lee et al., 2015), which as chapter 2 discussed can in some cases increase the CF value.

The confectionery group (group 4 of Table 53) used CFs from Hoolohan et al (2013) literature survey of different values. Unfortunately no UK based confectionery CFs could be sourced. The CF of chocolate is assumed to be compliant with the PAS 2050 cradle to grave as the carbon trust worked with Cadbury's for this value (Food Manufacture, 2008).

The unit price per egg (group 5 of Table 53) was calculated from the Kantar data. As explained in previous chapters, the unit price from the Kantar Worldpanel is usually per kilogram or litre and the CFs are also per kilogram or litre.

The range for the "Sugar sweetened beverages" (group 17 of Table 53) is relatively small yet it seems the container is the main hotspot within the LCA and this will largely determine the size of footprint. If diet cola was consumed from cans then the CF value would increase to 130 gCO2e per 250ml, yet the size of cans is usually 330ml thus a comparison being slightly difficult due to the size of can (Tesco plc, 2012). Lemonade appears to have one of the highest carbon footprints within this group.

Hot beverages (group 18 of Table 53) have used a CF for black tea/coffee (Berners-Lee, 2010). If a consumer purchases milk for their beverage then this may show as a complement relationship. It is assumed that Berners-Lee (2010) CF value is cradle to grave as the author makes the assumption that the consumer boils only the water required. This would typically classify as the consumer end stage thus being cradle to grave.

The numéraire (group 20 of Table 53) in this chapter represents all the products not selected in the other table groups but present in the Kantar dataset. Therefore, this includes products which may be typically purchased from food retailers such as toiletries etc. These products are not of interest to this chapter or any within this thesis.

Table 53, allows estimation of the representative carbon footprint (CF) value which for most cases was an average between the maximum and minimum values. For the purposes of calculating the carbon footprint elasticity, the representative CF value were created based on the products being expressed in terms of Kg/ Kg of CO_2e as shown in Table 54. This then allowed for the carbon shares to be estimated.

Some caution needs to be applied when using the carbon footprint values since the existing data is limited. In the future, more LCA studies will likely create a situation whereby CF data can be updated and offer a better representation of the differing food products.

Briggs et al (2013) represented their CF in a similar format as Table 54. However, it is notable that some of their CF results do broadly match this study's data such as for the Fish group. There are some notable exceptions as Briggs et al (2013) have a relatively large value for the coffee group. Also Briggs et al (2013) do not seem to have groups such as ready-made meals (meat based) and it is unclear how they formed their meat groups (i.e. are processed meat products included) considering that as discussed in chapter 3, Living Costs and food survey (LCFS) data for which they base their groups, is difficult to disaggregate.

This study has not used as many food groups as Briggs et al (2013) (their study used 29 food groups) as forming groups based on primarily carbon footprint did not require this number. The carbon footprint data is considered superior as the majority of the data is based on post regional distribution centre stages of the LCA. The CF data used in this study will be explained in greater detail for the remainder of this section.

Table 54 Carbon footprint and shares

Number	Food group	Kg/Kg CO_2e	%
1	Alcohol	1.00	1.27
2	Cakes & biscuits	2.85	3.61
3	Cheese	11.10	14.05
4	Confectionery	3.95	5.01
5	Eggs	3.86	4.88
6	Fats & oils	5.30	6.71
7	Fish	5.81	7.36
8	Fruit	2.06	2.60
9	Fruit juices	0.96	1.22
10	Grain based group	5.42	6.86
11	High carbon meat	15.83	20.04
12	High carbon milks	1.50	1.89
13	Low carbon meat	3.24	4.10
14	Low carbon milks	0.97	1.22
15	Other dairy	4.24	5.37
16	Ready-made meals (meat based)	7.65	9.69
17	Sugar sweetened beverages	0.25	0.32
18	Hot beverages	0.21	0.27
19	Vegetables	2.80	3.54

Source: Based on own elaborations

5.2.3 Nutrient data

Chapter 4 detailed the main source of nutritional data being the 2008-2012 “National Diet and Nutrition Survey” (NDNS). This chapter uses more food groups and therefore requires more use of the NDNS and the Food Standards Agency (2014a) dataset on the average daily quantity of a particular nutrient which is currently consumed in Scotland from the different food groups (i.e. nutrient intake). This section will start by detailing how the Food Standards Agency (2014a) dataset is modified to account for the new food groups and then will detail the matching of the NDNS data to food groups such as "fruit" which have not been previously used. The nutrients of interest are: Vitamin D, total fat, salt, sugar and energy. By studying these nutrients it allows some comparisons with Smed et al (2015).

The process for organising the nutrient content of data for the purposes of calculating nutrient elasticities were described in the previous chapter and is based on the method by Huang (1996). This chapter is based on aggregated food groups which are primarily based on the grouping of similar food products and those containing similar carbon footprints. As mentioned in the previous chapter, only respondents from Scotland were extracted from the NDNS data in order to reduce bias in the dataset.

As described in chapter 4, the nutrient elasticities are applied to the Food Standards Agency (2014a) dataset of the average daily quantities of nutrients consumed per person. In chapter 4, the three food groups were matched to the dataset. For this chapter since all the main food groups are studied it requires taking the whole dataset and removing the few food categories which are not applicable to the study[33].

There are, however, some issues with the following data groups from this study which could not be matched to this dataset. For the "fats & oil" group, there appears to be no actual oil products. There is no match for "fruit juices" which is likely to partly fall under the "Non-alcoholic beverages" category. Some categories from this study may belong to another category of Food Standards Agency (2014a) group e.g. pizza based products are in the Food Standards Agency (2014a)'s "Cereals and cereal products"- though this is not an issue. Since the Food Standards Agency (2014a) data provides a fairly aggregated food grouping, it does not seem possible to identify and match individual food products. This is beneficial for this chapter but as

[33] Products removed were: Savoury snacks, Nuts and seeds, Savoury sauces, pickles, gravies and condiments and Commercial toddler foods

discussed in chapter 4 (which was interested in more disaggregated groups) such aggregated groups could pose problems for data representation.

After the data is categorised, the shares of the different nutrients can become available and are shown in Table 55. The reason the shares are used is for calculating the nutrient elasticities as explained in chapter 4. It is worth highlighting that the vitamin D shares for cakes & biscuits and cheese are the same yet would differ very slightly if expressed to four decimal places.

Table 55 Nutrient shares (%)

	Vitamin D	Fat	Sodium	Sugar	Energy
Alcohol	0	0	0.19	1.61	2.27
Cakes & biscuits	2.37	9.19	7.83	15.04	11.66
Cheese	2.37	15.08	17.23	0.46	10.14
Confectionery	0.20	9.04	2.31	34.44	12.14
Eggs	15.27	5.28	3.51	0.01	4.04
Fats & oils	30.60	32.40	11.51	0.18	16.10
Fish	30.36	3.18	9.53	0.02	4.25
Fruit	0	0.32	1.68	9.49	2.18
Fruit juices	0	0.05	0.18	5.13	1.09
Grain based group	2.28	2.54	7.84	3.93	7.31
High carbon meat	3.91	4.40	2.70	0.10	5.10
High carbon milks	0	1.30	1.03	2.29	1.49
Low carbon meat	4.31	5.71	18.12	0.36	5.71
Low carbon milks	0.13	0.29	1.05	2.15	0.93
Other dairy	1.57	4.77	1.38	5.93	4.12
Ready-made meals (meat based)	4.37	4.71	8.95	1.10	5.74
Sugar sweetened beverages	0	0	0.34	7.36	1.46
Hot beverages	2.18	0.91	3.14	8.72	2.77
Vegetables	0.09	0.82	1.49	1.68	1.50

Notes: Own elaborations based on NDNS data

The main food group from Table 53 which required particularly careful matching with the NDNS data group is that of the “grain based group” as pulses are contained within the NDNS vegetable group. Some of the products found in the Kantar

Worldpanel pulses group, cannot be found in the NDNS group. This is unfortunate but as other food products such as bread and porridge could be matched then it is unlikely to be a major issue in terms of creating matching food groups between the data sources.

All the NDNS groups created in this chapter can be matched to the NDNS "food number" which should allow the results to be updated when the next dataset is released. The groups which correspond to nutrient data from the previous chapter such as milk products could be easily re-categorised using the food number code.

5.2.4 Social group data

The social group categorization were described in chapter 3 and are based on the National Readership Survey (2013). However, this paper categorises the social groups in a slightly different way than chapter 3 after the difficulties of separating group E were found in the chapter. Instead four groups are formed: AB, C1, C2 and DE. The 2011 Scottish census provides for a population breakdown based on these four groups (National Records of Scotland, 2013).

These four social groups are formed from the following descriptions: AB ("Higher and intermediate managerial/administrative/professional"[34]), C1 ("Supervisory, clerical, junior managerial/administrative/professional"), C2 ("Skilled manual workers") and DE ("Semi-skilled and unskilled manual workers, those on state benefit, unemployed, lowest grade workers").

5.3 Methods

5.3.1 Demand Systems

The Linear Approximated Almost Ideal Demand System (LA-AIDS) developed by Deaton and Muellbauer (1980a) and used for chapter 2 and 3 is also estimated in this chapter.

[34] Descriptions within the brackets are direct quotes from National Records of Scotland (2013)

The Exact Affine Stone index is also estimated in this chapter. As chapter 4 found that there was little statistical difference between the two EASI systems considering the polynomial income terms and a linear income term, then this chapter estimated only linear EASI price elasticities.

The reason behind estimating the EASI and LA-AIDS is to compare the own price elasticities in order to understand the similarities. Both demand systems are derived from linear budget shares, hence there should be little difference in the results.

Both demand systems were estimated in R using package “Easi” for the EASI system (Hoareau et al., 2013) which was adjusted for estimation of a linear system and “Erer” for the LA-AIDS (Sun, 2014). The implicit Marshallian price elasticities were calculated within R package “Easi” which in turn is based on the appendix of the Lewbel and Pendakur (2009) paper. The use of the EASI approach differed to that of Briggs et al (2013) which used a an AIDS model.

5.3.2 Computation of carbon consumption tax

The method for calculating the carbon consumption taxes is the same as chapter 4.

5.3.3 Computation of carbon and nutrient elasticities

The same method of estimating the nutrient and carbon elasticities as described in chapter 4 and chapter 3 respectively.

As highlighted in chapter 2, the carbon emissions for Scotland are reducing though the share attributed to food consumption is likely to remain constant (i.e. 20% of Scotland’s total GHG emissions are attributed to food consumption). The uncertainty surrounding the total emissions attributed to food consumption were highlighted in chapter 2. Chapter 4 used Audsley et al (2009) emissions data which was based on 2005 data, while this chapter uses an estimated figure for the total emissions attributed to food consumption (as explained in chapter 2).

The additional nutrients used in this chapter are sugar (non-milk extrinsic sugars such as table sugars, fructose etc.[35]) and energy. These elasticities are estimated in R using a function for multiplying vectors and matrices. More recent application of this method can be found in (Allais et al., 2010, Huang, 1996). Huang (1996) uses a complete demand system and excludes categories such as non-food as obtaining a nutrient value for this category would be complex. With regards to applying nutrient elasticities to the incomplete demand system, it seems that similar problems would occur with the application to the numeraire group which is similar to the non-food group of a complete demand system.

As with the previous chapters, using the income elasticity is not required as the primary interest of this thesis is to understand the effects of tax on demand and more specifically the subsequent substitution/complementary relationship between the food groups.

5.3.4 Computation of carbon consumption tax revenue

In chapter 2 the rebound effect (i.e. how a tax would rebound on other areas such as increase consumer spending on high carbon activities such as flying despite a reduction in demand for high carbon food products) was mentioned as a problem which is beyond the scope of this thesis. However, calculating the potential gain in government revenue arising from the carbon consumption tax could then be used for GHG mitigation purposes. As this thesis is primarily concerned with reducing GHG emissions, then this is the reason for not considering the consumption expenditure or loss in consumer surplus as studied in Smed et al (2015).

The consumer surplus is used in order to understand how taxes affect the change in food budgets and how this affects the level of utility with the new changed prices. Smed et al (2015) calculated the consumption expenditure whereby the new quantities are multiplied with after tax prices. Understanding the change in government revenue collected through the imposition of a carbon consumption tax is a useful measure from a policy perspective, hence being the focus in this section.

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[35] A full list of 29 different Non-Milk Extrinsic Sugars (NMES) is provided by the Scottish Government: http://www.gov.scot/Publications/2008/09/12090355/10

Briggs et al (2013) (scenario A) estimated the total government revenue obtained by their tax for the whole of the UK (£2.02 billion per year) using different methods which were highlighted in earlier chapters such as not all food products being taxed. Total government revenue of consumption taxes can be represented in per person form as used by the Institute for Fiscal Studies (2013) for observations on UK tax revenue.

Chapter 3 highlighted the two forms of consumption taxes: value added tax (VAT) and Goods and Sales tax. The former (i.e. VAT) is evaluated in this section as it is already applicable to some food products sold in Scotland (which are governed by the UK's VAT system) (HMRC, 2014).

Products sold in Scotland such as juice, nuts and alcohol all attract the standard VAT rate of 20%, though most food products are exempt from this tax (HMRC, 2014). As this study takes a non-revenue neutral approach (uncompensated approach) which is similar to Edjabou and Smed (2013) and Briggs et al (2013) first scenario, then the need to account for the existing tax on fruit juice is not required. This creates a more simplified approach relative to countries such as Sweden which already apply VAT[36] to all their food products (Nordström and Thunström, 2009).

The method for calculating the likely change in demand induced from a price increase has already been modelled in chapters 2 to 4. With regards to chapter 2, the likely absolute quantity demanded for milk products were modelled. This is in slight contrast to the change in quantities of carbon emissions and nutrient consumption modelled in chapter 3 and 4. It should be emphasised that the carbon and nutrient elasticities followed Huang (1996) which used shares and not actual quantities (the quantities were calculated from the use of the carbon/nutrient elasticities). The reasoning behind the calculation of the actual quantities is provided in the previous chapters.

[36] Denmark also applies VAT to food and this is why Edjabou and Smed (2013) use a compensated scenario

The change in quantity demand of the individual food groups for the respective social groups (QC_{ij}) is shown in equation 25. This entailed creating a vector of the total quantities of food group i respective to social group j using the latest year of Kantar Worldpanel data (which is 2013) which is represented by Q0ij (initial quantity demanded). D_{ij} is the matrix of price elasticities (D) of food group i for the respective social group j (shown in equation 25).

$$QC_{ij} = D_{ij}.Q0_{ij} \quad (25)$$

The corresponding tax rates of (shown in the results section of Table 60) are then applied to the corresponding results of equation 25 (which represent a 1% price increase) in order for the likely tax induced changes in quantity demanded of QC_{ij} to be obtained. Through the addition of $Q0_{ij}$ and QC_{ij}, the new quantity demanded of food group i ($Q1_{ij}$) is obtained as shown in equation 26.

$$Q1_{ij} = Q0_{ij} + QC_{ij} \quad (26)$$

The average pre-tax price is obtained ($P0_{ij}$) using the latest year of data (2013). The food group net revenue (NR_{ij}) equals $P0_{ij}$ multiplied by $Q1_{ij}$ as shown in equation 27. Whilst the government revenue (GR) is equal to the respective tax of food group i multiplied by the net revenue as shown in equation 28. This method is based on the way UK supermarkets communicate their VAT collected on till receipts[37], whereby a VAT summary is presented with the net value and the subsequent VAT amount before the two are totalled to become the total cost. This matches the Institute for Fiscal Studies (Institute for Fiscal Studies, 2014) explanation surrounding the value of the product being the part that VAT is applied to.

$$NR_{ij} = P0_{ij}.Q1_{ij} \quad (27)$$

$$GR_{ij} = NR_{ij}.t_i \quad (28)$$

The total government revenue (TotalGR) requires aggregation for all 19 food groups and is weighted by the 2011 Census of social group population which provides an

[37] Based on author's observations of UK till receipts

overall likely indication of government revenue raised through the carbon consumption tax. This is shown in equation 29.

$$TotalGR_j = \sum_{i=1}^{19} GR_{ij} \quad (29)$$

5.4 Results and discussions

The concavity test for the linear EASI demand system found that that the cost function is concave on more than 90% of the sample. It is assumed that homogeneity condition has been met (adding up was imposed upon estimation of the system). The conditions of symmetry and negativity have been met and will be discussed in the next section. The results for the LA-AIDS suggest that serial correlation (according to the Breusch-Godfrey (BG) tests for serial correlation) has not been a particular issue and only occurs within a few of the equations within each corresponding demand system.

5.4.1 Marshallian price elasticities

The price elasticities are calculated from a linear EASI (i.e. polynomial degree one). Table 56 to Table 59 show both the linear EASI and LA-AIDS Marshallian price elasticities for the different social groups.

From the tables it can be inferred that negativity condition has been met for both demand systems. The LA-AIDS own price elasticities for all the groups: AB, C1, C2 and DE (those that were statistically significant) were very similar between the linear EASI (L-EASI) and LA-AIDS. This is supported by the findings in Caillavet et al (2014) who found that the ranges of their EASI elasticities were within the same range as Allais et al (2010). Where own price elasticities is statistically significant for one demand system and not for the other occurs usually in a situation whereby a 10% significance value applies.

The findings from this study provide more of a “like for like” comparison and interestingly for group AB the own price elasticities of beverage and the numeraire while similar for both models are only statistically significant for the LA- AIDS. For the group C1, the LA-AIDS (as shown in Table 57) reports a statistically significant value for the numeraire good cross price elasticity (and own price elasticity) for 11 groups in contrast to the L-EASI whereby 18 groups were statistically significant.

With regards to social group C2, low carbon milk the own price elasticities are statistically significant for the L-EASI results though not for the LA-AIDS which is a departure from other group results. The own price elasticities of the numeraire good is not statistically significant for the L-EASI, yet is for the LA-AIDS.

For social group DE, the own price elasticities are of a very similar value and in most cases are statistically significant for both the L-EASI and LA-AIDS as shown in Table 59. An exception occurs for fruit juices whereby fruit juices are statistically significant for only the L-EASI. The opposite situation occurs for hot beverages whereby this time the LA-AIDS is only statistically significant. Overall it seems there is little difference between the own price elasticity results of the L-EASI and LA-AIDS. Therefore, the L-EASI will be used for the rest of the chapter in order to calculate the carbon and nutrient elasticities.

Sections 5.5.2 and 5.5.3 will discuss with reference to the carbon footprint and nutrient elasticities, the underlying cross price elasticity relationships with regards to the different social groups.

The extent to which the own price elasticities differs across the social groups is limited. What may be a statistically significant own price elasticity for one social group is not necessarily statistically significant for the other social groups. The only own price elasticities which are statistically significant for all the social groups are Cakes & biscuits (except for the numeraire group which is of little interest as it represents many goods) and there is little range in price sensitivity as the own price elasticities are: group AB -0.27, C1 -0.60, C2 -0.35 and DE is -0.28. Except for group C1, the price elasticity is relatively price inelastic. Therefore, quantity demanded is therefore not very responsive to a change in price.

This discussion was not very applicable to the previous chapter which did not account for social groups. With regards to the own price elasticities of high carbon meat, only two groups have statistically significant values: C1 the own price elasticity is -0.67 while for C2 the value is -0.34 which is less price sensitive to price changes than group C1. This may be a result of the C2 group purchasing cheaper cuts of meat. A complement of high carbon meat for group C2 is low carbon meat which suggests that a price increase of either high carbon or low carbon meat will result in a decrease in demand for both meat types. Whereas for group C1, low carbon meats form a substitute to high carbon meats.

Another high carbon food product is fish. However, none of the own price elasticities of the social groups were statistically significant. More detail will be provided on the mainly complement cross price elasticities of the different groups when discussing the carbon emissions and nutrient intake results of this section.

Table 56 Group AB EASI and AIDS Marshallian price elasticities

Products	Alcohol				Cakes & biscuits				Cheese				Confectionery				Eggs			
	EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS	
Alcohol	-0.72	***	-0.73	***	0.14		0.07		0.32		0.04		0.42	***	0.18	***	-1.81	***	-0.09	***
Cakes & biscuits	0.06		0.14		-0.27	**	-0.29	**	0.01		0.01		0.16	*	0.14	**	-1.05	***	-0.10	***
Cheese	0.05		0.28		0.01		0.03		-0.63	**	-0.63	**	-0.04		-0.08		-0.02		0	
Confectionery	0.17	***	0.44	***	0.13	**	0.17	**	-0.09		-0.04		-0.38	***	-0.35	***	0.34	*	0.03	
Eggs	-0.09	***	-1.94	***	-0.09	***	-1.15	***	0		0		0.04	*	0.30		0.14		0.17	
Fats & oils	-0.07	***	-0.79	***	-0.07	**	-0.45	**	0.19		0.27		0.03		0.12		-0.07		-0.03	
Fish	-0.07	***	-1.43	***	-0.06	**	-0.77	**	0.05		0.16		0		-0.02		0.22		0.24	*
Fruit	0.13	**	0.34		0.05		0.07		-0.21		-0.09		-0.09	*	-0.09		0.23		0.02	
Fruit juices	0		-0.03		-0.02		-0.23		-0.02		-0.01		-0.01		-0.03		0.02		0.06	
Grain based group	-0.02		0.02		0		-0.02		0.19		0.04		0.01		0.02		0.34		0.03	
High carbon meat	0.03		0.20		-0.10	*	-0.36	**	-0.10		-0.07		-0.02		-0.05		-0.45		-0.13	
High carbon milks	-0.05	**	-0.38	**	-0.10	***	-0.51	***	0.02		0.02		-0.03		-0.11		-0.03		0	
Low carbon meat	0		-0.02		-0.10		-0.15		0.20		0.10		-0.05		-0.05		0.32		0.03	
Low carbon milks	0.07	**	2.17	**	0		0.02		-0.12		-0.71		-0.01		-0.16		-0.19		-0.26	
Other dairy	0.14	***	1.07	***	0.13	**	0.52	**	-0.16		-0.17		-0.06		-0.16		0.28		0.08	
Ready-made meals	0.04		1.09		0.12	***	1.50	***	-0.06		-0.12		-0.03		-0.23		-0.22		-0.26	
Sugar sweetened bev	-0.01		0.01		-0.02		-0.05		0.06		-0.01		-0.02		-0.02		-0.01		0.01	
Hot beverages	-0.07	*	-0.62	**	0.04		0.08		0.04		0.06		0.04		0.12		0.14		0.09	
Vegetables	0.08		0.14		-0.16	**	-0.17	**	-0.04		-0.02		-0.14	**	-0.09	**	0.95	**	0.07	**
Numeraire group	-0.65	***	-0.09	***	-0.28	***	-0.03	***	-0.42	***	-0.01	***	-0.96	***	-0.05	***	0.48	***	0	

Products	Fats & oils				Fish				Fruit				Fruit juices				Grain based group			
	EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS	
Alcohol	-0.75	***	-0.07	***	-1.39	***	-0.07	***	0.38	***	0.11	**	0.05		0		-0.01		-0.01	
Cakes & biscuits	-0.42	**	-0.08	**	-0.71	**	-0.07	**	0.07		0.04		-0.19		-0.03		0		-0.02	
Cheese	0.35		0.15		0.17		0.05		-0.09		-0.22		-0.04		0		0.05		0.12	
Confectionery	0.14		0.02		0.02		-0.01		-0.08		-0.10	**	-0.04		-0.01		0.01		0	
Eggs	-0.03		-0.06		0.23		0.24	*	0.02		0.19		0.02		0.09		0.02		0.33	
Fats & oils	-0.32		-0.31		-0.09		-0.06		0.03		0.19		0.03		-0.02		-0.07		-0.31	
Fish	-0.05		-0.10		0.26		0.25		0.03		0.21		0		0.01		-0.12	***	-1.23	***
Fruit	0.17		0.04		0.26		0.03		-0.37	***	-0.39	***	-0.03		0		0.05		0.06	
Fruit juices	0.03		-0.02		0		0		-0.01		0.02		0.14		0.07		-0.08	**	-0.55	**
Grain based group	-0.31		-0.06		-1.18	***	-0.12	***	0.08		0.04		-0.49	*	-0.08	**	-0.29	***	-0.32	***
High carbon meat	-0.31		-0.20	*	-0.10		-0.03		-0.08		-0.17		0.52	**	0.24	**	0.04		0.14	
High carbon milks	0		0		-0.03		0		0.02		0.05		0.10		-0.02		-0.10	***	-0.40	***
Low carbon meat	0.33		0.07		1.08	**	0.13	***	-0.12		-0.15		0.61	*	0.13	*	0.04		0.07	
Low carbon milks	-0.10		-0.31		-0.15		-0.26		-0.05		-0.62		-0.29		-0.55		-0.03		-0.05	
Other dairy	-0.01		-0.04		0.26		0.08		-0.07		-0.24		-0.13		-0.05		0.07		0.26	
Ready-made meals	0.07		0.05		0.01		-0.01		-0.08		-0.81	*	0.19		0.39		0.05		0.58	
Sugar sweetened bev	0.04		0.01		0.13		0.03		0.02		0.02		-0.28		-0.11		-0.06		-0.13	
Hot beverages	0.14		0.09		-0.12		-0.01		0.09		0.31		-0.01		-0.05		-0.08		-0.33	
Vegetables	0.77	***	0.12	***	0.81	**	0.06	**	-0.17	*	-0.11	*	-0.35		-0.05		-0.06		-0.08	
Numeraire group	-0.02	**	0		0.17	***	0		-0.06	**	-0.02	***	-0.42	***	-0.01	*	-0.21	***	-0.02	***

Products	High carbon meat				High carbon milks				Low carbon meat				Low carbon milks				Other dairy			
	EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS	
Alcohol	0.23		0.04		-0.33	**	-0.05	***	0.02		0		2.17	**	0.06	**	1.02	***	0.14	***
Cakes & biscuits	-0.34	*	-0.10	**	-0.45	***	-0.11	***	-0.15		-0.12		-0.08		0		0.51	**	0.13	**
Cheese	-0.10		-0.08		0.02		0.02		0.08		0.21		-0.62		-0.15		-0.19		-0.14	
Confectionery	-0.06		-0.03		-0.11	*	-0.04	**	-0.04		-0.05		-0.13		-0.01		-0.19		-0.07	
Eggs	-0.13		-0.46		-0.02		0		0.04		0.30		-0.25		-0.16		0.10		0.24	
Fats & oils	-0.17		-0.32		-0.01		-0.01		0.07		0.31		-0.26		-0.08		-0.01		-0.07	
Fish	-0.03		-0.12		-0.02		-0.01		0.14	***	1.08	***	-0.24		-0.16		0.09		0.24	
Fruit	-0.20		-0.09		0.05		0.02		-0.13		-0.14		-0.55		-0.05		-0.20		-0.09	
Fruit juices	0.24	**	0.54	**	0.05		0.04		0.12	*	0.60		-0.70		-0.22		-0.07		-0.09	
Grain based group	0.14		0.04		-0.37	**	-0.10	***	0.06		0.04		-0.32		-0.01		0.28		0.07	
High carbon meat	0.01		-0.01		0.13		0.10		-0.03		-0.08		1.02		0.21		0.08		0.09	
High carbon milks	0.11		0.13		-0.31	**	-0.29	**	-0.02		-0.05		0.53		0.13		0.30	**	0.32	**
Low carbon meat	-0.07		-0.03		-0.05		-0.02		-0.51	**	-0.50	**	-0.97		-0.08		-0.13		-0.04	
Low carbon milks	0.20		1.04		0.12		0.51		-0.08		-0.91		-0.17		-0.30		0.11		0.44	
Other dairy	0.07		0.11		0.31	**	0.30	**	-0.05		-0.12		0.47		0.10		-0.78	***	-0.76	***
Ready-made meals	-0.21		-0.78		0.23	**	0.72	**	-0.05		-0.43		-0.20		-0.11		-0.39	**	-1.15	**
Sugar sweetened bev	0.08		0.08		0.35	**	0.21	**	-0.03		-0.02		0.60		0.09		-0.25		-0.16	
Hot beverages	0.01		0.01		-0.29	***	-0.29	***	0		0.01		-0.17		-0.01		0		0.02	
Vegetables	0		-0.01		0.22		0.05		0.33	**	0.20	**	-0.35		-0.02		-0.58	**	-0.14	**
Numeraire group	-0.70	***	-0.02	***	-0.31	***	-0.01	***	-0.64	***	-0.03	***	-0.48	***	0		-0.68	***	-0.01	**

Products	Ready-made meals				Sugar sweetened beverages				Hot beverages				Vegetables				Numeraire group			
	EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS	
Alcohol	0.95		0.05		-0.02		0		-0.54	*	-0.06	*	0.16		0.07		-0.11	***	-0.68	***
Cakes & biscuits	1.55	***	0.12	***	-0.06		-0.02		0.17		0.03		-0.20	**	-0.19	***	-0.06	***	-0.12	
Cheese	-0.23		-0.05		0.04		-0.01		0.05		0.05		0		-0.02		-0.03	**	-0.35	
Confectionery	-0.30		-0.03		-0.03		-0.02		0.11		0.03		-0.10	**	-0.15	***	-0.06	***	-0.93	***
Eggs	-0.23		-0.24		-0.01		0		0.05		0.16		0.07	**	0.97	***	-0.02	***	0.72	
Fats & oils	0.15		0.02		0.01		-0.01		0.10		0.12		0.11	***	0.79	***	-0.03	***	0.22	
Fish	0.01		0		0.02		0.07		-0.05		-0.12		0.06	**	0.84	***	-0.02	***	0.39	
Fruit	-0.68		-0.09	*	0.03		0.01		0.27		0.09		-0.10	*	-0.19	*	-0.04	***	0.14	
Fruit juices	0.33		0.18		-0.11		-0.28		-0.01		-0.05		-0.10		-0.37		-0.03	***	-0.25	
Grain based group	0.74		0.05		-0.13		-0.07		-0.29		-0.09		-0.10		-0.07		-0.05	***	-0.01	
High carbon meat	-0.81		-0.21		0.06		0.11		0.02		0.01		0		-0.03		-0.04	**	-0.65	**
High carbon milks	0.73	**	0.24	**	0.21	**	0.34	**	-0.29	**	-0.28	***	0.05		0.24		-0.03	***	-0.09	
Low carbon meat	-0.47		-0.05		-0.05		-0.01		0		0		0.21	**	0.31	**	-0.06	**	-0.57	***
Low carbon milks	-0.15		-0.15		0.08		0.62		-0.04		-0.03		0		-0.46		-0.02	**	-1.08	
Other dairy	-1.27	**	-0.36	**	-0.17		-0.25		0		0.02		-0.10	**	-0.60	***	-0.03	**	-0.70	
Ready-made meals	-0.96	*	-0.92		0.23	**	1.11	**	-0.06		-0.18		-0.10		-0.95		-0.02	**	-0.21	
Sugar sweetened bev	1.17	**	0.22	**	-0.39	*	-0.40	**	-0.05		-0.04		0		-0.11		-0.04	**	-0.23	
Hot beverages	-0.17		-0.06		-0.04		-0.07		0.15		0.12		0.02		0.09		-0.03	**	-0.32	
Vegetables	-0.97		-0.07		-0.11		-0.04		0.08		0.02		-0.30	***	-0.33	***	-0.07	***	-0.31	**
Numeraire group	-0.54	***	0		-0.34	***	-0.01	***	-0.57	***	-0.01	**	-0.40	***	-0.04	***	-0.74		-0.78	***

Notes: EASI refers to linear EASI and AIDS refers to Linear approximate AIDS

Source: Based on own elaborations Statistical significance: '*'=10%, '**'=5% or '***'=1%

Table 57 Group C1 EASI and AIDS Marshallian price elasticities

Products	Alcohol				Cakes & biscuits				Cheese				Confectionery				Eggs			
	EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS	
Alcohol	0.04		0.02		0.24	***	0.13	***	0.26	**	0.03	**	0.26	*	0.09	*	0.07		0	
Cakes & biscuits	0.12	***	0.25	***	-0.60	***	-0.59	***	0.29	*	0.06		-0.07		-0.04		0.12		0	
Cheese	0.03	**	0.23	**	0.07	*	0.22		-0.05		-0.03		-0.06	***	-0.10	*	-0.49	*	-0.16	**
Confectionery	0.10	**	0.25	*	-0.04		-0.06		-0.10	*	-0.04	*	0.09		0.10		0.03		0	
Eggs	0		-0.05		0.01		0.04		-0.15	*	-0.50	**	-0.02	*	0.02		-0.36	**	-0.30	*
Fats & oils	0.01		0.19		-0.08	*	-0.42		-0.15		-0.24		-0.02		-0.01		0.32	*	0.12	
Fish	-0.02		-0.54		0.01		0.03		-0.06		-0.13		-0.01		0.06		-0.08		-0.06	
Fruit	0.02		0.12		-0.02		0		-0.14		-0.08		-0.05		-0.04		0.26		0.02	
Fruit juices	0		0.07		-0.08	**	-0.71	**	-0.09		-0.22		0		0.10		0.14		0.11	
Grain based group	0.04		0.11	*	-0.02		-0.02		-0.31	*	-0.11	**	0.01		0.02		0.48	*	0.04	*
High carbon meat	0.03		0.14		0.01		-0.03		-0.30	*	-0.26		-0.03		-0.02		-0.25		-0.03	
High carbon milks	0		-0.05		0.01		0		0.04		0.03		-0.05	**	-0.09		-0.04		-0.02	
Low carbon meat	0.01		0.05		-0.01		-0.02		0.07		0.03		0		0.01		0.70	**	0.07	*
Low carbon milks	0		0.03		0.03		0.51		-0.13		-0.51		-0.02	**	-0.06		-0.23		-0.42	*
Other dairy	0.01		0.14		0.06	**	0.27	*	0.26	*	0.27		-0.05	***	-0.11	**	0.32		0.16	**
Ready-made meals	0		0.08		0.06		0.44		-0.03		-0.10		-0.06	**	-0.24		-0.17		-0.06	
Sugar sweetened bev	-0.01		-0.02		0.04		0.04		0.46	**	0.30	***	0.05	*	0.13	***	-0.45	*	-0.07	
Hot beverages	0.02		0.15		0.05		0.13		-0.05		-0.04		-0.06	**	-0.12		-0.20		-0.08	
Vegetables	0.02		0.07		0.12	*	0.11	*	0.28	*	0.06		-0.05		-0.03		-0.06		-0.01	
Numeraire group	-1.06	***	-0.21	***	-0.47	***	-0.06	***	-0.61	***	-0.02	***	-0.81	***	-0.06	***	-0.70	***	-0.01	***

Products	Fats & oils				Fish				Fruit				Fruit juices				Grain based group			
	EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS	
Alcohol	0.16		0.01		-0.35		-0.02		0.09		0.03		0.07		0		0.08		0.05	*
Cakes & biscuits	-0.44		-0.07	*	0.15		0		-0.03		-0.01		-0.67	*	-0.08	**	-0.03		-0.02	
Cheese	-0.23		-0.15		-0.19		-0.04		-0.07		-0.20		-0.19		-0.10		-0.10	**	-0.39	**
Confectionery	0		-0.01		0.10		0.01		-0.04		-0.04		0.12		0.01		0		0.02	
Eggs	0.17	*	0.24		-0.07		-0.06		0.02		0.14		0.11		0.15		0.02		0.42	*
Fats & oils	0.15		0.13		0.23		0.13		-0.09	*	-0.29		0.37		0.25		-0.14	***	-0.70	***
Fish	0.13		0.24		-0.04		-0.10		-0.06		-0.44		0.05		0.09		0.01		0.25	
Fruit	-0.27		-0.08		-0.35		-0.06		-0.07		-0.06		0.19		0.03		-0.02		0.01	
Fruit juices	0.26		0.35		0.06		0.07		0.02		0.16		-0.12		-0.14		-0.11	***	-0.75	**
Grain based group	-0.72	***	-0.12	***	0.29		0.02		-0.01		0		-0.73	**	-0.09	**	0.02		0.02	
High carbon meat	0.80	***	0.32	***	-0.65	**	-0.15	*	0.05		0.04		1.05	***	0.38	***	0.05		0.13	
High carbon milks	0.10		0.07		0.34		0.10		0		-0.01		-0.21		-0.10		0		0.03	
Low carbon meat	0.05		0.02		0.94	**	0.10	**	-0.21	**	-0.18	**	0.52		0.07		-0.03		-0.04	
Low carbon milks	0.15		0.46		-0.17		-0.18		-0.03		-0.37		0.21		0.49		-0.02		-0.22	
Other dairy	0.21		0.11		-0.39	**	-0.12		0.02		0.06		0.28		0.14		-0.08	**	-0.32	**
Ready-made meals	0.09		-0.04		-0.32		-0.13		-0.02		-0.26		0.38	*	0.37		-0.06		-0.61	
Sugar sweetened bev	-0.69	**	-0.28	***	-0.26		-0.04		0.03		0.02		-1.32	***	-0.38	***	0		-0.06	
Hot beverages	0.07		0.01		0.07		0.07		0.07		0.14		0.40		0.19		0.08		0.34	
Vegetables	-0.28		-0.06		0.89	**	0.08	***	0.03		0.01		-0.26		-0.05		-0.05		-0.06	
Numeraire group	0.29	***	0		-0.92	***	-0.01	*	-0.32	***	-0.03	***	-0.24	***	-0.01		-0.48	***	-0.05	***

Products	High carbon meat				High carbon milks				Low carbon meat				Low carbon milks				Other dairy			
	EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS	
Alcohol	0.20		0.02		0		-0.01		0.05		0.02		0.13		0		0.15		0.01	
Cakes & biscuits	0.04		-0.01		0.02		0		-0.01		-0.01		0.73		0.03		0.31	**	0.06	*
Cheese	-0.27	*	-0.29		0.02		0.03		0.02		0.07		-0.67		-0.10		0.31	*	0.23	
Confectionery	-0.02		-0.01		-0.09	*	-0.03		0.01		0.01		-0.07		-0.01		-0.11	**	-0.03	**
Eggs	-0.07		-0.11		-0.02		-0.06		0.08	*	0.60	*	-0.38		-0.25	*	0.12		0.40	**
Fats & oils	0.43	***	0.59	***	0.04		0.11		0		0.10		0.46		0.14		0.15		0.15	
Fish	-0.19	**	-0.51	*	0.10		0.29		0.11	**	0.84	**	-0.30		-0.11		-0.15	**	-0.31	
Fruit	0.13		0.02		0.01		0		-0.18	**	-0.20	**	-0.19		-0.03		0.10		0.02	
Fruit juices	0.40	***	1.00	***	-0.11		-0.21		0.08		0.44		0.46		0.22		0.14		0.27	
Grain based group	0.19		0.04		0.04		0.01		-0.02		-0.03		-0.14		-0.01		-0.25		-0.07	**
High carbon meat	-0.67	***	-0.68	***	-0.19		-0.09		0.20	*	0.44	*	0.46		0.07		0.32	*	0.27	**
High carbon milks	-0.15		-0.10		-0.16		-0.18		-0.02		-0.10		1.16	**	0.24	***	0.22	*	0.22	**
Low carbon meat	0.47	*	0.19	*	-0.04		-0.04		-0.41	**	-0.39	**	-0.91		-0.06		-0.39	*	-0.14	**
Low carbon milks	0.08		0.41		0.22	***	1.19	***	-0.07		-0.80		-0.67	*	-0.61		-0.08		-0.38	
Other dairy	0.23	*	0.37	**	0.18		0.26	**	-0.13	*	-0.45	**	-0.33		-0.09		-0.72	***	-0.73	***
Ready-made meals	-0.10		-0.14		-0.03		0.13		-0.06		-0.45		0.57		0.27		-0.02		-0.04	
Sugar sweetened bev	-0.21		-0.05		0.01		0		0.24	**	0.33	*	-0.44		-0.03		-0.22		-0.13	
Hot beverages	0.14		0.17		-0.20		-0.17		-0.01		0.01		-0.11		0.01		-0.01		-0.03	
Vegetables	-0.38	**	-0.12	**	-0.06		-0.02		0.21	**	0.14	**	0.05		-0.01		0.19		0.03	
Numeraire group	-1.08	***	-0.03	***	-0.56	***	-0.02	***	-0.71	***	-0.05	***	-0.32	***	0		-0.58	***	-0.01	***

Products	Ready-made meals				Sugar sweetened beverages				Hot beverages				Vegetables				Numeraire group			
	EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS	
Alcohol	0.17		0		-0.02		-0.01		0.19		0.02		0.05		0.03		-0.30	***	-1.08	***
Cakes & biscuits	0.67		0.04		0.10		0.01		0.24		0.03		0.12	*	0.10		-0.15	***	-0.36	***
Cheese	-0.09		-0.04		0.28	**	0.46	***	-0.07		-0.03		0.06		0.23		-0.10	***	-0.44	***
Confectionery	-0.28	*	-0.03	*	0.12	**	0.07	***	-0.12		-0.04		-0.04		-0.04		-0.14	***	-0.80	***
Eggs	-0.15		-0.07		-0.10	*	-0.32		-0.07		-0.20		-0.02		-0.09		-0.08	***	-0.55	
Fats & oils	0.15		-0.02		-0.30	***	-0.69	***	0.04		0.01		-0.07	*	-0.33		-0.08	***	0.55	
Fish	-0.29		-0.15		-0.06		-0.18		0.03		0.18		0.06	**	0.88	***	-0.08	***	-1.15	
Fruit	-0.01		-0.04		0.05		0.02		0.22		0.05		0.01		0.02		-0.12	***	-0.14	
Fruit juices	0.45		0.31		-0.39	***	-1.34	***	0.20		0.37		-0.05		-0.36		-0.08	***	0.03	
Grain based group	-0.40		-0.06		0.03		-0.03		0.42	*	0.08		-0.05		-0.06		-0.14	***	-0.30	***
High carbon meat	-0.33		-0.05		-0.16		-0.07		0.19		0.12		-0.13	**	-0.39	**	-0.11	***	-0.93	***
High carbon milks	-0.06		0.05		0		0		-0.21		-0.15		-0.03		-0.07		-0.09	***	-0.52	***
Low carbon meat	-0.40		-0.06		0.41	**	0.19	*	0		0		0.14	**	0.19	**	-0.14	***	-0.58	***
Low carbon milks	0.31		0.50		-0.07		-0.27		-0.03		0.02		-0.01		-0.13		-0.08	***	-0.16	
Other dairy	-0.04		-0.02		-0.13		-0.23		-0.01		-0.03		0.03		0.14		-0.09	***	-0.30	
Ready-made meals	-0.48		-0.45		0.11		0.70		0.06		0.13		0		0.12		-0.08	***	-0.21	
Sugar sweetened bev	0.52		0.16		0.03		-0.04		-0.12		-0.04		0.15	**	0.32	**	-0.12	***	-0.73	***
Hot beverages	0.14		0.06		-0.08		-0.07		-1.09	***	-1.09	***	0.02		0.06		-0.09	***	-0.29	
Vegetables	0.20		0.01		0.36	***	0.14	**	0.14		0.02		-0.21	***	-0.22	***	-0.17	***	-0.63	***
Numeraire group	-0.79	***	-0.01		-0.93	***	-0.03	***	-0.53	***	-0.01	**	-0.83	***	-0.07	***	-0.60		-0.60	***

Notes: EASI refers to linear EASI and AIDS refers to Linear approximate AIDS

Source: Based on own elaborations

Statistical significance: '*'=10%, '**'=5% or '***'=1%

Table 58 Group C2 EASI and AIDS Marshallian price elasticities

Products	Alcohol		Cakes & biscuits		Cheese		Confectionery		Eggs	
	EASI	AIDS	EASI	AIDS	EASI	AIDS	EASI	AIDS	EASI	AIDS
Alcohol	-0.55 ***	-0.55 ***	0.01	0	-0.20 *	-0.03 *	0.29 **	0.10 **	1.81 **	0.06 **
Cakes & biscuits	0	0.02	-0.35 **	-0.39 ***	0.22	0.06	-0.19 **	-0.15 **	-2.54 ***	-0.18 ***
Cheese	-0.03 **	-0.20 *	0.06	0.22	-0.29	-0.29	-0.02	-0.05	0.04	0.04
Confectionery	0.11 **	0.28 **	-0.14 **	-0.20 **	-0.05	-0.02	-0.17 *	-0.17 *	-0.40	-0.04
Eggs	0.07 **	1.53 **	-0.19 ***	-2.38 ***	0.02	0.11	-0.04	-0.41	-1.44 ***	-1.45 ***
Fats & oils	0.03 **	0.40 **	-0.02	-0.15	-0.03	-0.05	-0.02	-0.09	-0.53 **	-0.25 **
Fish	0.01	0.25	-0.07 **	-1.15 **	-0.08	-0.29	-0.01	-0.12	0.08	0.14
Fruit	-0.02	-0.03	0.03	0.04	-0.19	-0.10	-0.11 ***	-0.18 ***	0.43	0.06
Fruit juices	0	-0.03	-0.07 **	-0.75 **	-0.10	-0.28	-0.01	-0.04	-0.50 *	-0.32
Grain based group	-0.04	-0.04	0.23 ***	0.21 **	-0.32 **	-0.09 **	-0.02	-0.02	0.52	0.07
High carbon meat	0.03	0.25 *	0.05	0.12	-0.12	-0.11	0.02	0.06	0.68	0.17 *
High carbon milks	0.02	0.21 **	-0.02	-0.11	0.02	0	-0.02	-0.06	0.03	0.02
Low carbon meat	0.06 *	0.17	0.13	0.16	0.05	0.02	-0.04	-0.05	-0.09	-0.01
Low carbon milks	0	0.12	0	-0.02	0.13	1.00	-0.02	-0.26	-0.09	-0.08
Other dairy	-0.01	-0.08	0.04	0.22	-0.20	-0.23	-0.02	-0.05	0.19	0.09
Ready-made meals	0.02	0.47 *	-0.07 **	-0.68 **	0.27 **	0.61 **	-0.02	-0.06	0.13	0.17
Sugar sweetened bev	-0.04	-0.18	0.12 **	0.26 *	0.22	0.14	0.06	0.10	-0.34	-0.05
Hot beverages	0	-0.05	0.03	0.10	0.05	0.08	-0.02	-0.07	-0.70 **	-0.23 *
Vegetables	0.11 ***	0.28 ***	-0.07	-0.09	0.11	0.02	-0.04	-0.04	2.85 ***	0.27 ***
Numeraire group	-0.75 ***	-0.13 ***	-0.45 ***	-0.04 ***	-0.46 ***	-0.01 ***	-0.51 ***	-0.04 ***	-1.63 ***	-0.01 *

Products	Fats & oils				Fish				Fruit				Fruit juices				Grain based group			
	EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS	
Alcohol	0.40	**	0.03	**	0.43		0.01		-0.05		-0.01		0.05		0		-0.07		-0.03	
Cakes & biscuits	-0.11		-0.03		-1.27	**	-0.07	**	0.05		0.02		-0.81	**	-0.07	**	0.24	***	0.19	**
Cheese	-0.04		-0.04		-0.32		-0.07		-0.10		-0.20	*	-0.26		-0.11		-0.09	**	-0.36	**
Confectionery	-0.08		-0.02		-0.10		-0.01		-0.17	***	-0.11	***	-0.04		-0.01		-0.02		-0.02	
Eggs	-0.24	*	-0.54	**	0.11		0.10		0.06		0.32		-0.40	*	-0.39		0.04		0.74	
Fats & oils	-0.20		-0.24		-0.42	*	-0.14	*	-0.16	***	-0.39	***	0.11		0.07		-0.05		-0.28	
Fish	-0.15	*	-0.40	*	-0.24		-0.28		0		0.07		0.07		0.09		-0.03		-0.28	
Fruit	-0.42	***	-0.14	***	0.10		0.01		0.01		0.06		0.43		0.08		0.09		0.20	*
Fruit juices	0.06		0.12		0.11		0.06		0.08		0.37		0.05		0.05		0.05		0.47	
Grain based group	-0.27		-0.05		-0.37		-0.02		0.19		0.10	*	0.54		0.05		-0.06		-0.10	
High carbon meat	0.32	**	0.16	*	0.10		0.02		-0.06		-0.07		0.38		0.11		-0.02		-0.06	
High carbon milks	0.20		0.16	**	-0.07		-0.03		-0.02		0.01		0.35		0.10		-0.04		-0.09	
Low carbon meat	-0.23		-0.07		0.76		0.06		-0.24	*	-0.19	**	0.16		0.03		-0.03		-0.07	
Low carbon milks	0.17	*	0.64		0.13		0.24		-0.01		-0.36		-0.28		-0.59		-0.02		-0.60	
Other dairy	0.15		0.13		0.13		0.04		-0.07		-0.17		0.21		0.12		-0.08	**	-0.40	**
Ready-made meals	-0.11		-0.20		-0.07		-0.02		-0.01		0.03		-0.02		-0.04		-0.05		-0.38	
Sugar sweetened bev	-0.23		-0.09		0.24		0.02		0.08		0.07		-0.53		-0.11		-0.10		-0.25	
Hot beverages	0.02		0.01		-0.46		-0.13		-0.04		-0.18		0.03		0.05		0.08	*	0.32	
Vegetables	0.45	**	0.11	***	1.01	**	0.06	*	-0.12		-0.06		-0.47		-0.07		-0.36	***	-0.39	***
Numeraire group	-0.48	***	-0.01	***	-0.26	***	0		-0.26	***	-0.02	***	-0.38	***	0		-0.43	***	-0.03	***

Products	High carbon meat				High carbon milks				Low carbon meat				Low carbon milks				Other dairy			
	EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS	
Alcohol	0.22		0.04		0.21	**	0.02	*	0.18	*	0.06	*	0.23		0.01		-0.04		-0.01	
Cakes & biscuits	0.14		0.04		-0.11		-0.03		0.18		0.12		-0.10		0		0.20		0.04	
Cheese	-0.09		-0.15		0.02		0		0.02		0.07		0.80		0.16		-0.26		-0.18	
Confectionery	0.06		0.02		-0.06		-0.02		-0.05		-0.04		-0.29		-0.01		-0.04		-0.01	
Eggs	0.17		0.69		0.01		0.06		-0.01		-0.11		-0.20		-0.04		0.08		0.22	
Fats & oils	0.17	*	0.30	*	0.13		0.24	**	-0.06		-0.26		0.73		0.15		0.13		0.15	
Fish	0.02		0.12		-0.03		-0.13		0.06		0.70		0.19		0.16		0.04		0.13	
Fruit	-0.07		-0.04		-0.03		0		-0.17	*	-0.27	*	-0.02		-0.03		-0.15		-0.07	
Fruit juices	0.12		0.34		0.12		0.25		0.02		0.19		-0.72		-0.24		0.10		0.24	
Grain based group	-0.05		-0.02		-0.13		-0.03		-0.04		-0.04		-0.41		-0.02		-0.35	*	-0.08	**
High carbon meat	-0.34	*	-0.34	*	0.01		0.05		-0.21	*	-0.50	**	0.14		0.01		-0.31	*	-0.22	**
High carbon milks	0.01		0.07		-0.13		-0.16		-0.09		-0.22		0.27		0.02		-0.25	*	-0.20	**
Low carbon meat	-0.47	*	-0.23	**	-0.24		-0.08		-0.51	**	-0.48	**	0.04		0.01		0.61	**	0.17	**
Low carbon milks	0.02		0.09		0.04		0.14		0.01		0.19		-1.27	**	-0.84		0.14		0.83	
Other dairy	-0.19	*	-0.36	**	-0.19	*	-0.27	**	0.16	**	0.64	**	0.64		0.17		-0.31		-0.30	
Ready-made meals	-0.05		-0.20		-0.02		-0.04		0.06		0.38		-0.34		-0.09		-0.05		-0.09	
Sugar sweetened bev	-0.26	*	-0.21	*	0.03		-0.03		0.08		0.19		-1.58	**	-0.11	*	0.06		0.04	
Hot beverages	-0.01		-0.05		-0.04		-0.08		0.06		0.25		-0.03		0.06		0.24	*	0.23	**
Vegetables	0.23		0.10		-0.06		-0.03		-0.14		-0.09		0.51		0.02		-0.15		-0.05	
Numeraire group	-0.47	***	-0.01	***	-0.31	***	-0.01	***	-0.59	***	-0.03	***	-1.62	***	0		-0.59	***	-0.01	***

Products	Ready-made meals				Sugar sweetened beverages				Hot beverages				Vegetables				Numeraire group			
	EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS	
Alcohol	0.48	*	0.02		-0.17		-0.04		0		0		0.29	***	0.11	***	-0.15	***	-0.73	***
Cakes & biscuits	-0.75	**	-0.07	**	0.27	*	0.11	**	0.08		0.03		-0.10		-0.07		-0.06	***	-0.31	
Cheese	0.65	**	0.25	**	0.12		0.24		0.06		0.07		0.03		0.07		-0.02	**	-0.36	*
Confectionery	-0.07		-0.01		0.10		0.06		-0.07		-0.01		-0.04		-0.04		-0.05	***	-0.42	*
Eggs	0.11		0.22		-0.06		-0.26		-0.26	**	-0.63	*	0.28	***	2.76	***	-0.02	*	-2.00	
Fats & oils	-0.17		-0.12		-0.10		-0.22		0.01		0.02		0.09	**	0.53	***	-0.02	**	-0.40	
Fish	-0.04		-0.03		0.03		0.16		-0.14		-0.45		0.07	*	0.86	*	-0.02	**	-0.17	
Fruit	0.03		0.01		0.09		0.06		-0.08		-0.07		-0.07		-0.10		-0.03	**	-0.12	
Fruit juices	-0.02		-0.04		-0.12		-0.47		0.01		0.11		-0.06		-0.57		-0.02	*	-0.28	
Grain based group	-0.37		-0.04		-0.21		-0.11	*	0.35	*	0.08	*	-0.42	***	-0.33	***	-0.06	***	-0.23	
High carbon meat	-0.14		-0.07		-0.20	*	-0.28	*	-0.03		-0.03		0.09		0.26		-0.03	**	-0.30	
High carbon milks	-0.03		-0.02		0.02		-0.04		-0.05		-0.06		-0.02		-0.08		-0.03	**	-0.14	
Low carbon meat	0.40		0.05		0.14		0.11		0.19		0.08		-0.12		-0.11		-0.05	*	-0.56	***
Low carbon milks	-0.12		-0.25		-0.14	**	-1.26	*	0		0.31		0.02		0.29		-0.02	*	-1.80	*
Other dairy	-0.08		-0.05		0.03		0.09		0.21	*	0.26	**	-0.04		-0.19		-0.02	**	-0.53	**
Ready-made meals	-0.42		-0.51		0.10		0.43		-0.04		-0.06		0		-0.04		-0.02	*	-0.18	
Sugar sweetened bev	0.42		0.10		0.18		0.18		-0.16		-0.04		-0.24	***	-0.47	***	-0.03	**	-0.51	***
Hot beverages	-0.06		-0.03		-0.08		-0.09		-0.97	***	-0.88	***	0.01		0		-0.02	*	-0.56	*
Vegetables	0.05		-0.01		-0.44	***	-0.25	***	0.04		0		0.08		0.08		-0.07	***	-0.72	***
Numeraire group	-0.45	***	0		-0.54	***	-0.02	****	-0.51	***	-0.01	*	-0.76	***	-0.05	***	-0.63		-0.67	***

Notes: EASI refers to linear EASI and AIDS refers to Linear approximate AIDS

Source: Based on own elaborations

Statistical significance: '*'=10%, '**'=5% or '***'=1%

Table 59 Group DE EASI and AIDS Marshallian price elasticities

Products	Alcohol		Cakes & biscuits		Cheese		Confectionery		Eggs	
	EASI	AIDS	EASI	AIDS	EASI	AIDS	EASI	AIDS	EASI	AIDS
Alcohol	-0.56 **	-0.57 **	-0.03	-0.04	0.17	0.03	0.11	0.09	-1.07 **	-0.06 **
Cakes & biscuits	-0.04	-0.03	-0.28 ***	-0.28 ***	-0.30 **	-0.06 **	-0.11	-0.07	-0.67 **	-0.05 **
Cheese	0.02	0.19	-0.06 **	-0.33 **	-0.53 **	-0.53 ***	-0.03	-0.10	0.49 *	0.17 *
Confectionery	0.06	0.15	-0.07	-0.12	-0.11	-0.03	-0.34 ***	-0.35 ***	0.23	0.02
Eggs	-0.07 **	-1.01 **	-0.05 **	-0.66 **	0.18 *	0.47 *	0.02	0.18	-0.33	-0.34
Fats & oils	-0.06 *	-0.37	-0.05 *	-0.29	-0.08	-0.11	0.02	0.08	0.02	0.01
Fish	-0.05	-1.02	-0.05 *	-0.83	0.05	0.20	0.04	0.50	0.04	0.07
Fruit	-0.06	-0.13	0.14 ***	0.36 ***	-0.38 **	-0.21 ***	-0.10 **	-0.17 **	0.34	0.06
Fruit juices	0.07 *	1.53 *	0.05	0.62	-0.19	-0.47	-0.03	-0.38	-0.34	-0.42
Grain based group	-0.08	-0.11	-0.03	-0.03	0.18	0.04	-0.13 **	-0.08	-0.21	-0.01
High carbon meat	0	0.02	-0.02	-0.05	0.02	0.02	-0.03	-0.06	0.25	0.09
High carbon milks	0.01	0.07	0.03	0.11	-0.54 ***	-0.41 ***	-0.05 *	-0.14 **	0.21	0.05
Low carbon meat	-0.02	0	-0.15 ***	-0.25 ***	0.73 ***	0.25 ***	0	0.02	0.28	0.04
Low carbon milks	-0.03	-0.91	0.01	0.29	-0.02	-0.11	0.01	0.19	-0.16	-0.26
Other dairy	0.11 **	0.95 **	0.06	0.40	-0.01	0.04	-0.05	-0.19	-0.94 **	-0.43 **
Ready-made meals	0.02	0.30	0.01	0.18	-0.01	0.03	-0.02	-0.06	-0.11	-0.04
Sugar sweetened bev	-0.10 **	-0.31 **	-0.03	-0.05	0.33	0.17	-0.05	-0.08	0.53	0.10
Hot beverages	-0.04	-0.27	-0.01	-0.05	0.09	0.12	-0.02	-0.04	-0.14	-0.05
Vegetables	0.03	0.11	0.05	0.04	0.07	0.03	-0.05	-0.07	1.01 ***	0.09 ***
Numeraire group	-0.44 ***	-0.05	-0.39 ***	-0.05 ***	-0.74 ***	-0.01 ***	-0.30 ***	-0.02	0.04 ***	0

Products	Fats & oils				Fish				Fruit				Fruit juices				Grain based group			
	EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS	
Alcohol	-0.39		-0.05		-1.12		-0.04		-0.15		-0.05		1.40	*	0.08	*	-0.11		-0.09	
Cakes & biscuits	-0.28		-0.05		-0.89	*	-0.04		0.37	***	0.14	***	0.73		0.04		-0.04		-0.02	
Cheese	-0.10		-0.09		0.21		0.05		-0.19	***	-0.41	***	-0.58		-0.15		0.04		0.17	
Confectionery	0.08		0.01		0.56		0.04		-0.17	**	-0.10	**	-0.35		-0.03		-0.11	**	-0.11	**
Eggs	0.01		0.03		0.06		0.05		0.06		0.31		-0.37		-0.38		-0.03		-0.16	
Fats & oils	-0.28		-0.27		0.49	*	0.15	*	0.04		0.13		-0.46		-0.25	**	0.02		0.19	
Fish	0.15	*	0.47	*	-0.37		-0.39		0.01		0.12		-0.14		-0.18		-0.06	*	-0.73	
Fruit	0.10		0.05		0.11		0.02		-0.08		-0.06		0.46		0.04		-0.03		-0.03	
Fruit juices	-0.19		-0.62	**	-0.17		-0.15		0.08		0.18		-0.98	**	-0.63		0.17	***	2.18	***
Grain based group	0.15		0.04		-0.87		-0.05		-0.05		-0.02		2.24	***	0.17	***	-0.06		-0.08	
High carbon meat	-0.11		-0.09		-0.36		-0.08		-0.08		-0.12		0.15		0.05		-0.08		-0.27	
High carbon milks	0.22	*	0.12		0.40		0.08		-0.07		-0.16		-0.14		0.01		-0.09	*	-0.30	*
Low carbon meat	0.04		0.02		-0.43		-0.04		-0.10		-0.06		-0.49		-0.08		-0.17		-0.27	*
Low carbon milks	-0.02		-0.09		0.01		0.03		-0.05		-0.43		-0.04		-0.09		-0.01		0.24	
Other dairy	-0.13		-0.19		-0.37		-0.11		-0.15		-0.43		0.43		0.33		0.16	*	0.80	*
Ready-made meals	0.11		0.19		-0.01		0.02		-0.02		-0.05		0.14		0.20		0.06		0.24	
Sugar sweetened bev	0.38	*	0.15		0.59		0.08		0.05		0.03		0.25		0.06		-0.10		-0.25	
Hot beverages	-0.07		-0.04		-0.17		-0.05		0.03		0.08		-0.43		-0.12		0.06		0.22	
Vegetables	-0.09		-0.03		2.08	***	0.16	***	0.02		-0.01		-2.29	***	-0.23	***	0		0.04	
Numeraire group	-0.35	***	-0.01	*	-0.60	***	0		-0.33	***	-0.02	***	-1.54	***	-0.01		-0.58	***	-0.05	***

Products	High carbon meat		High carbon milks		Low carbon meat		Low carbon milks		Other dairy	
	EASI	AIDS	EASI	AIDS	EASI	AIDS	EASI	AIDS	EASI	AIDS
Alcohol	0.03	0	0.05	0.01	0	-0.01	-0.89	-0.03	1.00 **	0.11 **
Cakes & biscuits	-0.05	-0.01	0.13	0.03	-0.25 ***	-0.14 ***	0.33	0.01	0.43	0.06
Cheese	0.02	0.01	-0.43 ***	-0.52 ***	0.26 ***	0.70 ***	-0.11	-0.02	-0.02	0.03
Confectionery	-0.08	-0.02	-0.13 *	-0.05 **	0.02	0.01	0.25	0.01	-0.26	-0.04
Eggs	0.08	0.29	0.06	0.18	0.04	0.29	-0.28	-0.14	-0.46 **	-0.88 **
Fats & oils	-0.08	-0.13	0.14 *	0.19	0.02	0.06	-0.07	-0.02	-0.15	-0.17
Fish	-0.08	-0.34	0.09	0.37	-0.03	-0.44	0.01	0.02	-0.13	-0.31
Fruit	-0.13	-0.07	-0.11	-0.10	-0.07	-0.08	-0.40	-0.04	-0.40	-0.16
Fruit juices	0.05	0.15	-0.03	0.03	-0.05	-0.68	-0.06	-0.05	0.20	0.72
Grain based group	-0.24	-0.07	-0.29	-0.08	-0.24	-0.18 *	0.10	0.01	0.95 **	0.14 *
High carbon meat	0.17	0.15	0.48 ***	0.53 ***	0.04	0.08	0.53	0.08	0.39	0.21
High carbon milks	0.52 ***	0.48 ***	-0.18	-0.15	0.05	0.11	0.96 *	0.14 *	-0.22	-0.09
Low carbon meat	0.10	0.03	0.11	0.05	0	-0.01	-0.46	-0.03	0.24	0.05
Low carbon milks	0.09	0.51	0.15 *	0.92 *	-0.03	-0.42	-1.88 ***	-1.88 ***	0.14	0.54
Other dairy	0.26	0.33	-0.13	-0.15	0.07	0.19	0.55	0.14	-1.36 ***	-1.34 ***
Ready-made meals	0.05	0.03	-0.07	-0.07	-0.04	-0.27	-0.75	-0.22	-0.31	-0.42
Sugar sweetened bev	-0.22	-0.13	-0.08	-0.04	-0.26 **	-0.41 **	0.80	0.09	0.40	0.14
Hot beverages	-0.10	-0.14	-0.20 **	-0.23 **	-0.01	-0.03	0.28	0.05	-0.08	-0.07
Vegetables	-0.82 ***	-0.29 ***	0	-0.01	0.21 *	0.17 *	0.57	0.02	-0.86 **	-0.16 **
Numeraire group	-0.27 ***	-0.01	-0.58 ***	-0.02 ***	-0.43 ***	-0.03 ***	0.19 ***	0	-0.76 ***	-0.01

Products	Ready-made meals				Sugar sweetened beverages				Hot beverages				Vegetables				Numeraire group			
	EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS		EASI		AIDS	
Alcohol	0.36		0.02		-0.31	**	-0.10	**	-0.22		-0.04		0.08		0.06		-0.05		-0.36	
Cakes & biscuits	0.13		0.02		-0.07		-0.02		-0.05		-0.01		0.07		0.03		-0.06	***	-0.34	**
Cheese	-0.02		0.01		0.16		0.34		0.10		0.12		0.02		0.11		-0.02		-0.81	****
Confectionery	-0.12		-0.01		-0.09		-0.05		-0.06		-0.01		-0.06		-0.06		-0.03		-0.31	
Eggs	-0.06		-0.06		0.09		0.55		-0.06		-0.12		0.11	***	0.85	***	-0.01		0.09	
Fats & oils	0.18		0.13		0.15		0.38	*	-0.06		-0.05		-0.02		-0.11		-0.02		-0.28	
Fish	0		0.03		0.07		0.58		-0.05		-0.17		0.17	***	1.92	***	-0.01		-0.73	
Fruit	-0.04		-0.02		0.04		0.04		0.06		0.04		0.01		0		-0.03	*	-0.25	
Fruit juices	0.09		0.32		0.04		0.36		-0.15		-0.35		-0.23	***	-2.27	***	-0.01		-2.04	*
Grain based group	0.57		0.03		-0.21		-0.12		0.29		0.05		0		0.05		-0.06	**	-0.44	***
High carbon meat	0.10		0.01		-0.13		-0.23		-0.13		-0.12		-0.29	***	-0.80	***	-0.02		-0.08	
High carbon milks	-0.15		-0.03		-0.06		-0.06		-0.26	**	-0.18	**	0		-0.02		-0.02	*	-0.64	***
Low carbon meat	-0.26		-0.05		-0.38	**	-0.29	**	-0.05		-0.01		0.18	*	0.21	**	-0.04		-0.33	**
Low carbon milks	-0.26		-0.62		0.07		0.96		0.06		0.25		0.03		0.34		-0.01		0.15	
Other dairy	-0.41		-0.31		0.14		0.39		-0.06		-0.09		-0.19	**	-0.68	**	-0.02		-0.59	
Ready-made meals	0.13		0.03		-0.12		-0.52		-0.14		-0.28		-0.02		-0.02		-0.01		0.36	
Sugar sweetened bev	-0.40		-0.14		0.03		0.02		-0.04		-0.01		0.18	**	0.33	***	-0.04	*	-0.62	***
Hot beverages	-0.24		-0.16		-0.02		-0.02		-0.24		-0.28	*	0.13	**	0.50	***	-0.01		-0.30	
Vegetables	-0.14		-0.01		0.29	**	0.20	***	0.44	**	0.14	***	-0.31	***	-0.32	***	-0.06	***	-0.99	***
Numeraire group	-0.12	***	0		-0.69	***	-0.03	***	-0.42	***	-0.01		-0.88	***	-0.06	***	-0.68		-0.71	***

Notes: EASI refers to linear EASI and AIDS refers to Linear approximate AIDS

Source: Based on own elaborations Statistical significance: '*'=10%, '**'=5% or '***'=1%

5.4.2 Reduction in GHG emissions

Table 60 shows the various tax rates which are calculated from the previous stated method of chapter 4. As expected the non-animal based food groups have lower rates of carbon consumption taxes. The previous chapters do highlight the importance of disaggregating the groups as the tax rates within the groups do vary. The high tax rate of 12.02% applied to "Other dairy" relative to high carbon milk is largely a result of cream products being contained within the group. As briefly discussed in chapter 2, cream contains a higher wet mass of milk fat thus has a higher carbon footprint.

Table 60 Carbon consumption tax rates

Group	Tax rate (%)
Alcohol	2.04
Cakes & biscuits	8.07
Cheese	31.44
Confectionery	11.20
Eggs	10.92
Fats & oils	15.01
Fish	16.46
Fruit	5.82
Fruit juices	2.72
Grain based group	15.34
High carbon meat	44.82
High carbon milks	4.24
Low carbon meat	9.18
Low carbon milks	2.74
Other dairy	12.02
Ready-made meals (meat based)	21.67
Sugar sweetened beverages	0.71
Hot beverages	0.6
Vegetables	7.92

Source: Own elaborations based on Kantar Worldpanel data

The overall likely change in tCO2e/y after application of the carbon consumption is shown in Figure 7 which overall displays a similar finding as Smed et al (2015). The similarities are that the two highest social groups experience the largest decline in CO_2e emissions relative to the other groups. It should be noted that the Scottish study has weighted the results by population representation based on the 2011 census while the Danish study is based on per person analysis. The overall reduction in carbon emissions through aggregating the weighted groups is 543,208.75 tCO2e/y which represents only 5.12% of the total emissions in Scotland attributed to food emissions (excluding land use based emissions).

When considering LUC, the reduction of carbon emissions is approximately 3.9%[38]. This is a relatively smaller decrease in emissions when compared to Briggs et al (2013) LUC finding of 7.5% (presented in relative terms due to figure corresponding to UK level), though based on the uncertainty surrounding emissions data, this study has taken a different approach to Briggs et al (2013). There is the question of whether taxes alone provide enough of an incentive in order to reduce consumption of high carbon food products. Modelling the non-food categories[39] could contribute to answering this question. The findings of this thesis would suggest that as Briggs et al (2013) finding is nearly double the reduction of this chapter, then an additional policy instrument may be required.

The net effect (with regards to reducing emissions) of taxing all the individual food groups as shown in Figure 7, whereby the wealthier households decrease emissions more than the poorer households. Therefore there is some equity with regards to social groups' carbon emissions.

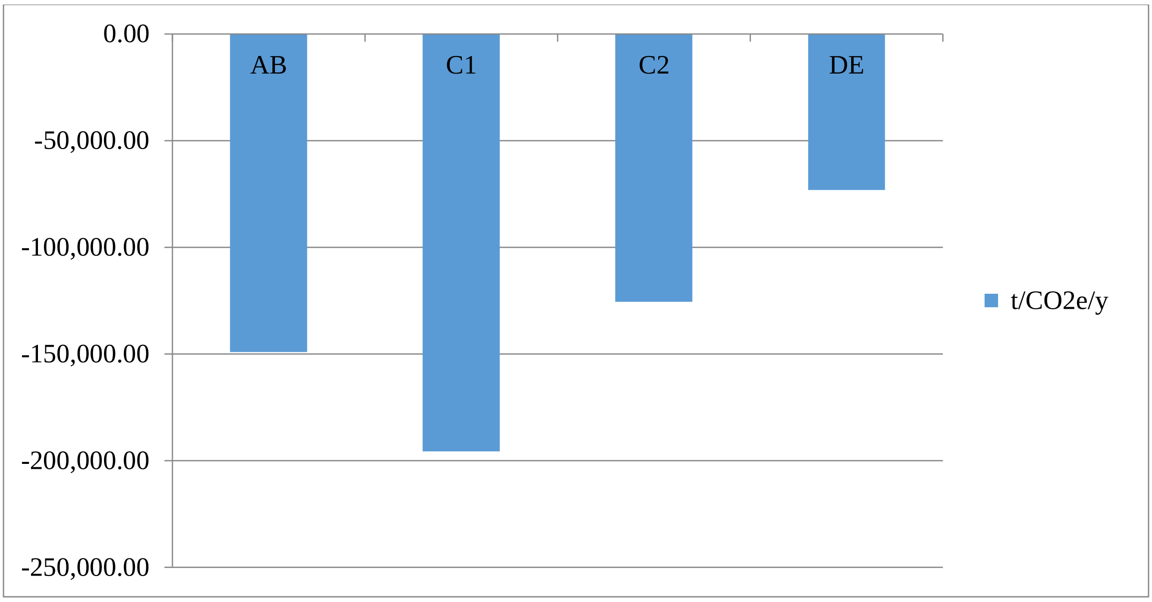
The results from Figure 7 support the idea of Smed et al (2015) in the sense that the distributional impact of the carbon consumption tax falls largely on assumed wealthier households. This is an important result as it shows that for two Northern European countries there is a similarity. The two studies do use different methods and data which is why the focus is on the Scottish study which uses more recent

[38] The carbon footprint elasticities were applied to Scottish based consumption food emissions which included land use change (LUC)
[39] This study did not have the resources to obtain non-food categories and only used Kantar Worldpanel data on the food categories

demand modelling methodology and data (both in terms of household purchase data and CF data). The slight exception to the idea of a beneficial distributional impact is how the change in the C1 group is greater than the AB group, albeit a small change.

The results are in contrast to chapter 3, though in that chapter only meat products were of interest and the social groups were of a different formation (three instead of this chapter's four). This does highlight the importance of modelling all the major food groups for understanding the likely full effects of a carbon consumption tax on carbon emissions.

Figure 7 Change in CO2e



Source: Based on own elaborations

Table 61 shows the implied reduction in tCO2e/y for all the social groups. The AB households were estimated to represent 19% of Scottish households (National Records of Scotland, 2013). Application of the carbon consumption taxes enabled the implied reduction to be estimated. The largest reduction in emissions is attributed to taxing cheese which is likely to reduce emissions by 55,654.33 tCO2e/y. This large reduction is likely as a result of cheese having no statistically significant complements or substitutes as shown in Table 56 to Table 59. The overall decrease in emissions of Table 61 are applied to the total food emissions figure estimate for 2013 which is 10.6 M t/CO_2e (more information on this figure is provided in chapter 2).

Also taxing ready-made meals will likely result in a large decrease in emissions which is partly explained by the own price elasticity and the cross price elasticity complement being other dairy products. A further interesting result is how taxing both high carbon meat and milk groups is likely to decrease emissions associated with food consumption which for the case of high carbon milk is likely due to the substitutes of ready-made meals and other dairy which are both relatively high carbon emissions.

C1 households were estimated to represent 32% of Scottish households (National Records of Scotland, 2013). The largest reduction in emissions is attributed to taxing high carbon meat products which is likely to reduce emissions by 204,868.97 tCO2e/y. This is likely a result of low carbon meat being a substitute group which is shown from the price elasticities of Table 57 but also high carbon food groups such as cheese and fish being complements in addition to the own price elasticities of high carbon meats being statistically significant. Interestingly the situation for taxing high carbon meats for group AB results in a relatively small reduction in carbon emissions which highlights the importance of studying the different social groups. This suggests that the belief in some of the literature that taxing high carbon meat products for a reduction in emissions may be too much of a generalisation.

The C2 households were estimated to represent 22% of Scottish households (National Records of Scotland, 2013). As is the case of group C1, the largest reduction in emissions is attributed to taxing high carbon meats. However, the explanation surrounding the reason differs from C1. Low carbon meats form a complement group along (such as high carbon meats shown in Table 58) with other relatively high carbon emitters such as other dairy.

The DE households were estimated to represent 29% of Scottish households (National Records of Scotland, 2013). The largest reduction in emissions is attributed to taxing cheese which is likely to reduce emissions by 64,416.07 tCO2e/y (this would occur if only taxing cheese and zero rating the other groups). One of the more interesting results is how a relatively large increase in emissions as a result of taxing the fish group. This is attributed to Fats & oil and vegetables being substitutes for fish yet the own price elasticities for fish is not statistically significant as shown in Table 59. As with all the other social groups, there is a net decrease in carbon emissions arising from a net application of taxes.

Table 61 Simulation of carbon footprint elasticities through application of carbon consumption tax

	AB		C1		C2		DE	
Products	Carbon footprint elasticity	Tax Implied reduction tCO2e/y	Carbon footprint elasticity	Tax Implied reduction tCO2e/y	Carbon footprint elasticity	Tax Implied reduction tCO2e/y	Carbon footprint elasticity	Tax Implied reduction tCO2e/y
Alcohol	0	-183.23	0.01	926.85	0.01	299.16	-0.01	-464.98
Cakes & biscuits	-0.03	-4003.46	-0.01	-2010.59	-0.03	-4960.05	-0.03	-7586.69
Cheese	-0.09	-55654.33	0	303.80	0	1478.55	-0.07	-64416.07
Confectionery	-0.01	-2953.48	-0.02	-5713.44	-0.02	-3791.65	-0.03	-10012.23
Eggs	-0.01	-2260.53	-0.01	-1951.45	-0.08	-20699.01	0.02	5185.38
Fats & oils	0	766.82	0.11	53221.95	0.05	18830.38	0.02	7653.07
Fish	-0.05	-16984.01	-0.08	-46651.54	-0.04	-14779.73	0.07	37473.13
Fruit	-0.01	-1285.90	-0.02	-2881.80	-0.03	-3937.99	-0.02	-3999.22
Fruit juices	0.10	5243.12	0.19	17870.10	-0.05	-3103.66	0.08	6562.45
Grain based group	-0.03	-9409.16	-0.03	-15262.55	-0.02	-7095.94	0	-414.34
High carbon meat	-0.01	-8398.21	-0.14	-204868.97	-0.09	-90098.58	-0.02	-26131.46
High carbon milks	-0.02	-1531.39	-0.04	-5591.89	-0.01	-748.32	0.04	5188.25
Low carbon meat	0	396.28	0.03	9906.27	-0.06	-12097.05	0.03	9695.95
Low carbon milks	0.03	1515.97	0.01	1287.22	-0.02	-1310.17	-0.01	-407.24
Other dairy	-0.06	-15392.85	0.05	20847.38	-0.07	-18360.72	-0.05	-17586.19
Ready-made meals (meat based)	-0.09	-37947.35	-0.01	-10278.40	0.07	35481.03	0	-
Sugar sweetened beverages	0.03	352.46	0.05	1104.29	-0.05	-788.54	-0.01	-207.56
Hot beverages	-0.01	-147.96	0.03	523.66	0.02	276.55	0.01	196.86
Vegetables	-0.01	-1170.31	-0.02	-6312.04	0	-141.59	-0.06	-13811.90
Total		-149,047.52		-195,531.14		-125,547.32		-73,082.77

Source: Based on own elaborations

5.4.3 Nutritional effects

Chapter four studied the nutrient change in intake per person per day and so did Edjabou and Smed (2013). However, concerns could be raised that using time series and not panel data makes modelling on a yearly basis a better reflection of the change in food purchases thus the latter measure is more appropriate for daily intake. For this reason, this chapter presents nutrient intake change on per year, per person basis.

The calculation of mean intake for Scottish individuals could not be disaggregated by social group as Food Standards Agency (2014a) categorised the average daily dietary intakes of different nutrients by sex or age and not by socio-economic group. However, these dietary intakes were scaled up to annual format and were subsequently used as the baseline for measuring the effect of the tax. Chapter 4 did not require the relative change in nutrients to be estimated since the absolute change in nutrient intake was compared to government recommended daily nutrient intakes. The resulting change in intake of the various nutrients induced through the carbon consumption tax relative to the baseline is shown in Table 62. The result is included in brackets next to the absolute changes in nutrient intake for the next sections on the different nutrients.

This section will present the absolute and relative changes in nutrient intake as the absolute change has often been discussed in the Scottish health literature. However, as the government nutrient guidelines were provided in daily consumption and not annual, it therefore does not allow for an understanding of whether these government targets have been met. Reporting the absolute changes is still useful from a policymaker's perspective.

Table 62 Change in nutrient intake per year, per person (%)

	Vitamin D	Fat	Salt	Sugar	Energy
AB	-2.27	-5.81	-5.28	-2.44	-6.50
C1	2.22	2.90	2.55	-3.31	-0.52
C2	-8.27	-9.46	-8.93	-14.09	-10.93
DE	3.03	-2.39	1.03	-9.15	-3.36

Source: Based on own elaborations

5.4.3.1 Vitamin D

Figure 8 shows the annual change in vitamin D intake (in μg) per person following application of the respective consumption taxes. From this figure it can be seen that the poorest group (DE) will likely see a relatively small increase in vitamin D intake of 27.36 μg/year/person (3.03%). This is likely to be a positive result from a public health perspective given concern from the chief medical officer in Scotland surrounding concerns of the lack of vitamin D intake. However, the second poorest group (C2) will see a relatively large decline in consumption of the nutrient by 74.56 μg/year/person (-8.27%). This overall result marks a departure from the largely equitable distributional impact of the taxes in terms of GHG emissions. There is a mixed outcome of the carbon consumption taxes as the poorest group benefit but at the cost of the second poorest which makes defining the outcome in terms of equitable distributional (i.e. progressive or regressive) difficult.

Despite Briggs et al (2013) different method, they find that vitamin D intake for the UK population would likely reduce from the baseline of 2.7 μg/day/person to 2.6 μg/day/person. It does seem likely that the variability of intakes for social groups may result in a small decrease in the vitamin D had this study not accounted for social groups.

Figure 8 Change in vitamin D

Source: Based on own elaborations

Table 63 shows the vitamin D nutrient elasticity results for the different social groups. The table provides more details behind negative distributional impact of the taxes on the AB households. The largest reduction is as a result of taxing grain based group which is due to the high vitamin D fish group being a complement, thus the decline in vitamin D of 5.98 µg/year/person. This does highlight the possibility of some groups such as grain being exempt from taxation.

The ready-made meal group also resulted in a decline in the vitamin which is largely due to substitutions into Sugar sweetened beverages which contain no vitamin D and other dairy being a complement in addition to the own price elasticity of ready-made meals being statistically significant which contains a large share of the nutrient relative to the other groups.

The overall increase in vitamin D associated with the C1 group is largely attributed to the effect of taxing the high carbon meat group which would likely increase intake of the nutrient by 19.97 µg/year/person (assuming the tax rate for all the other products was zero). The main reason behind this large value is the substitutes of the high carbon group being fats and oil, low carbon meat and other dairy (shown in Table 57) which all have a relatively high share of vitamin D. While the complement of the fish group has a relatively small elasticity. It is an interesting observation that the effect of the high carbon meat group on social group AB had the exact opposite effect in terms of vitamin D intake.

A potentially negative effect on nutritional intake arises for group C2, whereby there is an overall decline of 74.56 µg/year/person. This is largely a result of the egg group which has a relatively large own price elasticity of -1.44 and having the fats and oils group as a complement. As both of these groups contain a large share of vitamin D, then this largely explains the reduction associated with taxes. A relatively large reduction in the nutrient is also attributed from taxing the fish group.

The most interesting result is that of the vitamin D intake being likely to increase for the poorest group DE by 27.36 µg/year/person. Taxing fish products is likely to increase the intake of the nutrient which appears rather counter initiative given that fish contain the highest share of vitamin D. However, the own Price elasticities of the fish group were not statistically significant as shown in Table 59. As the fats & oil group are substitutes then this helps to explain the increase in the likely vitamin D intake as they contain a relatively large share of the nutrient.

Table 63 Simulation of vitamin D elasticities through application of carbon consumption tax

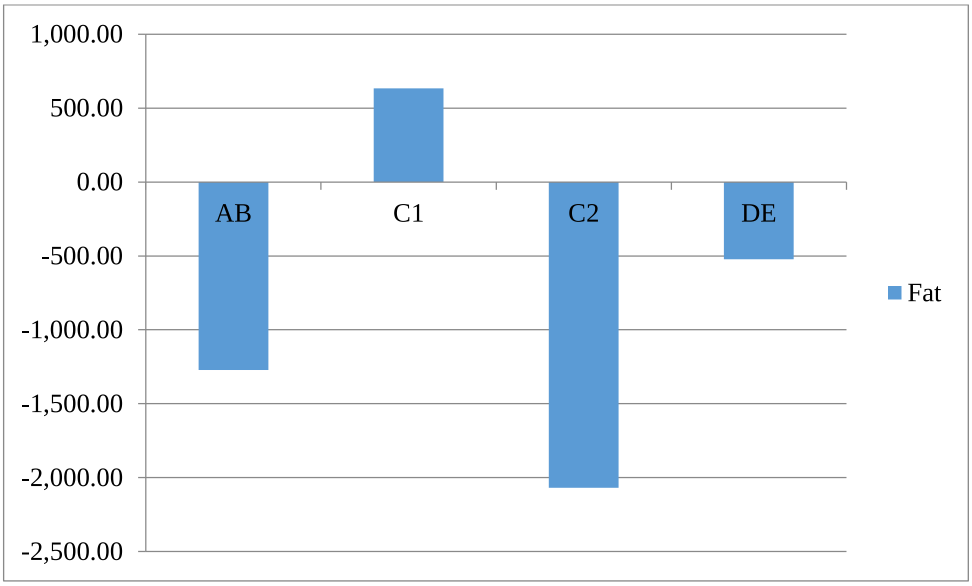
Products	AB			C1			C2			DE		
	Nutrient elasticity	Change due to 1% price increase	Total implied change	Nutrient elasticity	Change due to 1% price increase	Total implied change	Nutrient elasticity	Change due to 1% price increase	Total implied change	Nutrient elasticity	Change due to 1% price increase	Total implied change
		µg/year/person			µg/year/person			µg/year/person			µg/year/person	
Alcohol	-0.06	-0.49	-1.01	0	0.03	0.07	0.02	0.20	0.40	-0.03	-0.23	-0.46
Cakes & biscuits	-0.06	-0.50	-4.08	-0.04	-0.32	-2.56	-0.06	-0.52	-4.24	-0.05	-0.47	-3.82
Cheese	-0.02	-0.13	-4.20	-0.03	-0.24	-7.44	0.01	0.04	1.32	0.04	0.35	10.92
Confectionery	0.01	0.08	0.94	-0.01	-0.08	-0.85	-0.01	-0.04	-0.50	0	-0.03	-0.36
Eggs	-0.02	-0.21	-2.30	0.07	0.64	6.95	-0.45	-4.09	-44.62	-0.02	-0.16	-1.80
Fats & oils	-0.01	-0.08	-1.24	0.03	0.28	4.15	-0.07	-0.61	-9.21	0.05	0.42	6.29
Fish	0	0.03	0.54	0.01	0.08	1.39	-0.16	-1.43	-23.50	0.13	1.17	19.22
Fruit	0	0	-0.01	-0.04	-0.33	-1.94	-0.06	-0.53	-3.08	0	0.03	0.20
Fruit juices	0.04	0.32	0.87	0.14	1.25	3.41	-0.08	-0.73	-1.98	0.05	0.44	1.20
Grain based group	-0.04	-0.39	-5.98	-0.05	-0.43	-6.62	0	0.03	0.53	-0.02	-0.15	-2.30
High carbon meat	-0.01	-0.07	-3.24	0.07	0.60	26.75	0.02	0.14	6.40	0	-0.01	-0.30
High carbon milks	-0.01	-0.10	-0.41	-0.01	-0.06	-0.27	0	-0.03	-0.11	0.05	0.43	1.81
Low carbon meat	0.02	0.18	1.61	0.03	0.30	2.74	-0.03	-0.25	-2.28	0	0	0.04
Low carbon milks	0	0	0	0	-0.01	-0.02	0	-0.01	-0.04	0	-0.02	-0.06
Other dairy	-0.02	-0.16	-1.94	-0.05	-0.43	-5.21	0.01	0.10	1.23	-0.07	-0.64	-7.69
Ready-made meals (meat based)	-0.03	-0.22	-4.85	0	-0.01	-0.11	0	-0.02	-0.46	0	0	0
Sugar sweetened beverages	0.01	0.09	0.06	-0.08	-0.74	-0.52	0	-0.02	-0.01	-0.02	-0.15	-0.10
Hot beverages	0	0	0	-0.01	-0.13	-0.08	-0.05	-0.45	-0.27	0	0	0
Vegetables	0.07	0.61	4.80	0	0.02	0.17	0.08	0.74	5.86	0.06	0.58	4.56
Total		-1.07	-20.43		0.43	19.97		-7.47	-74.56		1.56	27.36

Source: Based on own elaborations

5.4.3.2 Total Fat

The change in total fat intake (will be referred to as "fat") as a result of the taxes is shown in Figure 9, whereby the two poorest households would likely experience a large decline for C2 of 2,069.08 g/year/person (-9.46%) while the poorest group (DE) would see a relatively small reduction of 521.95 g/year/person (-2.39%). This suggests that despite the increase for group C1 of 2.90%, the overall effect of the tax is likely to be considered positive in terms of the poorest households benefiting nutritionally. This is due to concerns regarding obesity. The results overall differ from Smed et al (2015) uncomp scenario (which provides the best comparison) whereby there was an overall decrease in intake though it was only measured saturated fat.

Figure 9 Change in Fat



Source: Based on own elaborations

Table 64 shows the annual change in total fat intake (in g) per person following application of the respective consumption taxes. The AB group is of particular interest as a reduction in fat intake is found. One of the main reasons the intake reduced is due to the application of tax to cheese which as previously mentioned only has the own price being statistically significant[40]. While taxing the ready-made meal group helped price elasticities reduce carbon emissions for this group, it seems that the same tax will likely increase fat intake by 221.63 g/year/person (though this is completely offset by the net effect of taxing other products).

The largest increase in fat intake was associated with group C1 where the high carbon meat products overwhelmingly contributed to this increase. If this group was taxed alone then the increase of 964.94 g/year/person may be concerning from a nutritional perspective (this would be assuming that all the other food products attracted a zero rate tax). This is attributed to the substitutes being groups high in fat such as other dairy, fats & oil and low carbon meats which included pork based products.

The largest decrease in fat intake was experienced for group C2. The largest decline is attributed to taxing both eggs and fish products which alone would reduce fat intake by 1,104.29 and 883.87 g/year/person. In the previous sub section, the eggs group helped reduce the vitamin D intake and was a major contributor for increasing carbon emissions. However, exempting the group from the tax would pose problems for the carbon emission reductions of groups AB and C1. This highlights the difficulty in formulating a consumption tax which has similar effects for all the social groups.

The effect of the taxes on the DE group are interesting considering that this group which is associated with living in areas of deprivation could experience an improvement to their health due to the reduction in total fat by 521.95 g/year/person which is a relatively small reduction. Taxing the cheese group helps to reduce fat intake as it also helped reduce the nutrient with regards to decreasing the carbon emissions, and increasing vitamin D intake. However, on closer examination of the price elasticities of the cheese it is apparent that fruit is a complement along with the less healthy group of cakes & biscuits. While substitutes were products such as eggs

[40] Also the numeraire group had a statistically significant cross price elasticity of demand but for the purposes of nutrient calculations it is not required

and low carbon meats. The reduction in fruit consumption may be deemed an issue from a health perspective when taxing cheese products.

Table 64 Simulation of total fat elasticities through application of carbon consumption tax

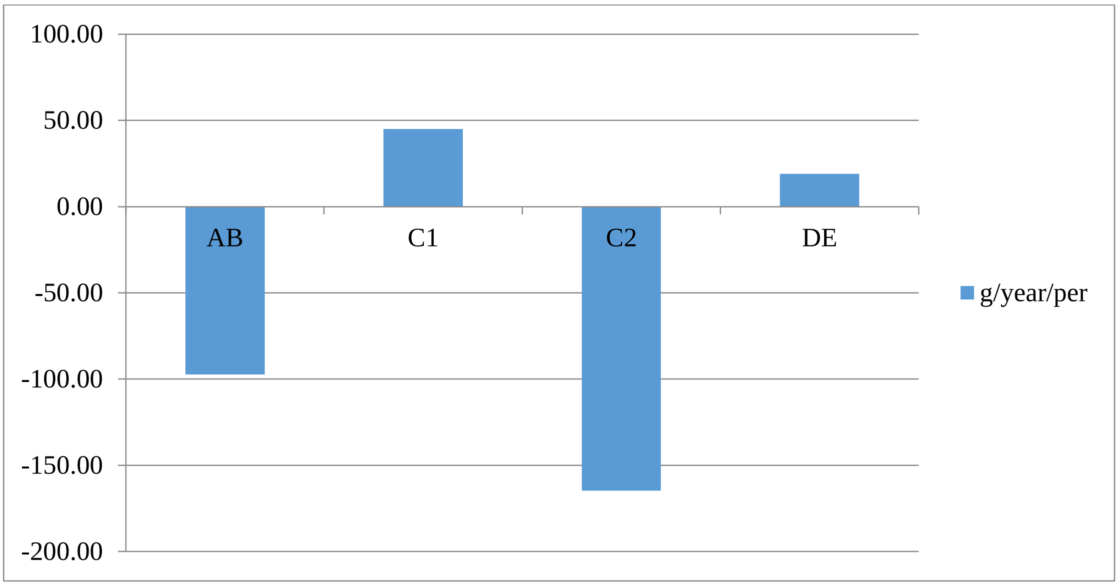
Products	AB			C1			C2			DE		
	Nutrient elasticity	Change due to 1% price increase	Total implied change	Nutrient elasticity	Change due to 1% price increase	Total implied change	Nutrient elasticity	Change due to 1% price increase	Total implied change	Nutrient elasticity	Change due to 1% price increase	Total implied change
		g/year/person			g/year/person			g/year/person			g/year/person	
Alcohol	-0.01	-1.95	-3.97	0.02	5.33	10.88	0.02	5.03	10.25	-0.02	-3.51	-7.15
Cakes & biscuits	-0.04	-8.14	-65.66	-0.07	-14.39	-116.10	-0.06	-12.06	-97.34	-0.06	-13.82	-111.54
Cheese	-0.09	-20.63	-648.62	0	-0.24	-7.42	0.01	1.04	32.64	-0.07	-14.15	-444.74
Confectionery	-0.02	-4.06	-45.45	-0.02	-3.49	-39.03	-0.03	-7.25	-81.24	-0.04	-7.68	-86.03
Eggs	-0.06	-12.67	-138.36	0.06	13.39	146.22	-0.46	-101.13	-1104.29	-0.03	-5.51	-60.12
Fats & oils	-0.03	-6.99	-104.88	-0.01	-3.11	-46.74	0	-0.06	-0.96	0.01	1.68	25.23
Fish	-0.03	-5.84	-96.10	0.01	2.85	46.89	-0.25	-53.70	-883.87	0.09	20.32	334.49
Fruit	0	-0.57	-3.32	-0.04	-9.10	-52.94	-0.08	-17.54	-102.06	-0.01	-2.32	-13.51
Fruit juices	0.05	9.90	26.93	0.11	22.89	62.27	-0.10	-20.97	-57.05	0.04	8.24	22.41
Grain based group	-0.01	-2.72	-41.69	-0.07	-14.41	-220.99	0	0.72	11.08	-0.01	-1.08	-16.52
High carbon meat	-0.03	-6.78	-304.10	0.10	21.53	964.94	0.01	1.01	45.47	0	0.02	0.85
High carbon milks	-0.04	-9.10	-38.57	-0.02	-3.38	-14.33	-0.01	-1.98	-8.38	-0.01	-2.37	-10.05
Low carbon meat	-0.02	-4.81	-44.13	-0.01	-2.64	-24.22	-0.03	-6.78	-62.20	0.02	3.96	36.31
Low carbon milks	0	0	0	0.01	2.88	7.89	0	-0.80	-2.20	0.01	1.53	4.19
Other dairy	-0.01	-2.17	-26.12	0.02	4.58	55.02	0.01	2.47	29.74	-0.07	-15.73	-189.02
Ready-made meals (meat based)	0.05	10.23	221.63	-0.03	-5.52	-119.68	0.03	6.36	137.91	0	0	0
Sugar sweetened beverages	0.01	2.93	2.08	-0.02	-4.78	-3.40	0.01	2.60	1.85	-0.02	-4.25	-3.02
Hot beverages	0	-0.82	-0.49	0	0.15	0.09	0	-0.84	-0.51	0	0.05	0.03
Vegetables	0.02	4.91	38.91	-0.01	-1.89	-14.98	0.04	7.84	62.10	0	-0.47	-3.75
Total		-59.27	-1,271.93		10.66	634.38		-196.03	-2,069.08		-35.08	-521.95

Source: Based on own elaborations

5.4.3.3 Salt

Figure 10 shows the change in salt intake which is calculated by multiplying the sodium by 2.5 in order to obtain an equivalent salt value. The figure shows that salt intake increases by the relatively small quantity of 19.03 grams/year/person (1.03%) for group DE which may be of concern to policymakers. As highlighted in the introduction, an increase in salt is considered negative from a dietary perspective considering the concern that the current Scottish population are likely exceeding dietary guidelines of salt. However, the relatively large decline experienced by group C2 of 164.71 grams/year/person (-8.93%) does help to suggest that some improvements to public health for a low income group are possible.

Figure 10 Change in Salt



Source: Based on own elaborations

Table 65 shows the annual change in salt intake (in g) per person following application of the respective consumption taxes. In a similar situation with cheese helping to reduce carbon emissions and other nutrients, cheese once again results in a similarly large relative reduction of 62.49 grams/person/year for group AB. Cheese contains a large share of salt and the only other statistically significant relationship to its own price elasticity is the numeraire group (which is not useful for the analysis) which explains the large reduction. A concern could be raised that a tax on fish products creates a likely increase in salt intake, which is largely a result of low carbon meat being a substitute.

Group C1 experiences a likely increase in salt intake of 45.07 grams/year/person which is largely attributed to the high carbon meat group. Taxing this group helped to increase vitamin D intake, reduce carbon emissions yet also increased intake of total fat. This highlights not only the potential trade-off in terms of reducing carbon emissions but also the trade-off for the different nutrients. This demonstrates the problem of taxing food products. For products where only the own price elasticity (being statistically significant) is concerned (e.g. such as taxing the cheese group) then it comes as little surprise that this group will also deliver a reduction in salt.

The largest decline in salt intake occurs for group C2, whereby taxing the high carbon meat and eggs groups are the largest contributors to reducing salt intake. The reason the high carbon meats group contributes to a relatively large decrease is because the complements of low carbon meat have a relatively large share of salt.

As highlighted earlier the increase in overall salt intake for the Group DE may be of concern to policymakers from a public health perspective. The large increase in salt intake is attributed to taxing the eggs and Fish groups. As the only price elasticities of the Fish group which were statistically significant were complements of Fats & oil and vegetables then the fats & oil group is where the salt increase is attributed to. This does highlight a slight trade off as increased consumption of vegetables is likely to be important for obtaining other nutrients not discussed in this thesis.

Table 65 Simulation of salt elasticities through application of carbon consumption tax

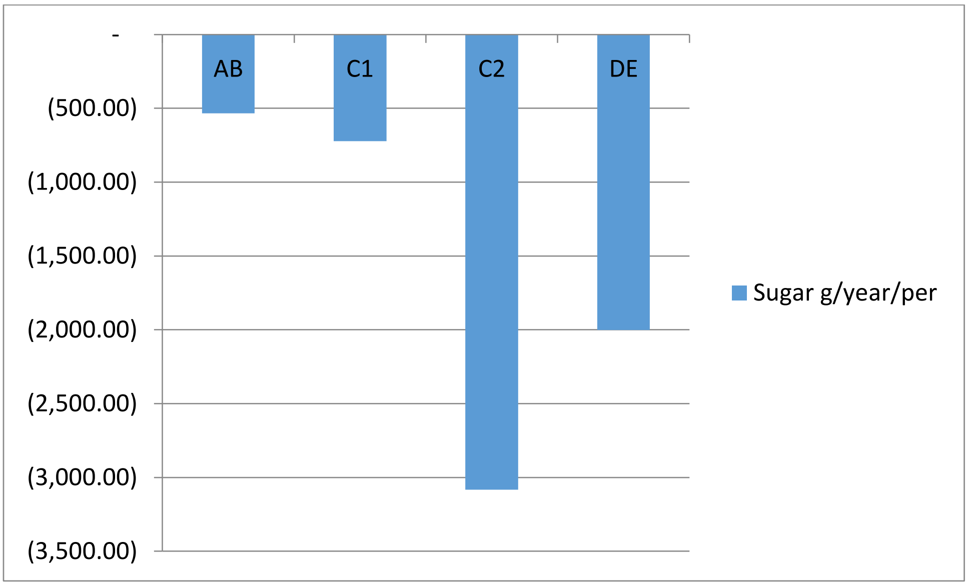
Products	AB			C1			C2			DE		
	Nutrient elasticity	Change due to 1% price increase	Total implied change	Nutrient elasticity	Change due to 1% price increase	Total implied change	Nutrient elasticity	Change due to 1% price increase	Total implied change	Nutrient elasticity	Change due to 1% price increase	Total implied change
		g/year/person			g/year/person			g/year/person			g/year/person	
Alcohol	-0.01	-0.24	-0.50	0.02	0.30	0.61	0.02	0.29	0.58	-0.01	-0.15	-0.32
Cakes & biscuits	-0.03	-0.53	-4.27	-0.04	-0.72	-5.84	-0.03	-0.60	-4.88	-0.07	-1.27	-10.28
Cheese	-0.11	-1.99	-62.49	-0.02	-0.35	-10.90	0	-0.02	-0.51	0.01	0.21	6.65
Confectionery	0	0.05	0.51	-0.02	-0.32	-3.59	-0.02	-0.37	-4.20	-0.02	-0.36	-4.08
Eggs	-0.06	-1.17	-12.82	0.10	1.80	19.69	-0.29	-5.29	-57.72	0.03	0.57	6.26
Fats & oils	-0.02	-0.42	-6.26	-0.07	-1.16	-17.36	-0.01	-0.21	-3.19	0.02	0.33	5.02
Fish	0.06	1.06	17.44	0.16	2.80	46.04	-0.13	-2.46	-40.46	0.02	0.32	5.27
Fruit	-0.01	-0.15	-0.87	-0.05	-0.85	-4.92	-0.07	-1.21	-7.02	-0.01	-0.15	-0.88
Fruit juices	0.09	1.59	4.32	-0.01	-0.16	-0.44	-0.08	-1.43	-3.90	0.14	2.63	7.15
Grain based group	-0.04	-0.65	-9.91	-0.04	-0.63	-9.61	0	0	0.03	-0.01	-0.13	-1.92
High carbon meat	-0.03	-0.48	-21.57	0.05	0.90	40.13	-0.08	-1.43	-64.29	-0.01	-0.12	-5.60
High carbon milks	-0.05	-0.99	-4.18	-0.01	-0.08	-0.35	0	-0.04	-0.17	-0.05	-0.96	-4.06
Low carbon meat	-0.07	-1.37	-12.55	-0.06	-1.00	-9.19	-0.10	-1.80	-16.55	0.03	0.51	4.68
Low carbon milks	0	0.08	0.21	0.01	0.09	0.24	-0.02	-0.34	-0.94	-0.01	-0.18	-0.50
Other dairy	-0.01	-0.18	-2.13	-0.01	-0.16	-1.95	0.08	1.48	17.76	0.03	0.53	6.43
Ready-made meals (meat based)	0.03	0.55	12.01	-0.01	-0.11	-2.48	0.05	1.00	21.62	0	0	0
Sugar sweetened beverages	0.02	0.39	0.28	0.09	1.64	1.17	0.01	0.14	0.10	-0.07	-1.21	-0.86
Hot beverages	0	-0.07	-0.04	0	-0.03	-0.02	-0.01	-0.17	-0.10	0	0.07	0.04
Vegetables	0.04	0.69	5.43	0.03	0.48	3.83	-0.01	-0.11	-0.87	0.04	0.76	6.01
Total		-3.83	-97.40		2.44	45.07		-12.59	-164.71		1.40	19.03

Source: Based on own elaborations

5.4.3.4 Sugar

As discussed in the introduction the recent concerns regarding sugar intake highlighted the need to include this nutrient due to the potentially damaging health effects of overconsumption. An interesting result of the net application of carbon consumption taxes which likely results in some dietary improvements is that of a likely reduction in sugar intake for all social groups shown in Figure 11. The two lowest income groups would likely experience the largest reduction in intake by 3,083.12 grams/year/person (-14.09%) for C2 and 2,001.12 grams/year/person (-9.15%). This result is in contrast to what is likely to occur in Denmark since Smed et al (2015) shows the uncompensated tax scenario will likely increase sugar intake. This highlights the importance of modelling likely change in sugar intake.

Figure 11 Change in Sugar



Source: Based on own elaborations

Table 66 shows the annual change in sugar intake (in g) per person following the application of the respective consumption taxes. Despite the likely reduction in overall sugar intake for all groups, it is important to understand how taxing the particularly sugar rich groups of cakes & biscuits, confectionary and sugar sweetened beverages in addition to the other groups may affect consumption of this nutrient. For group AB, it can be seen that the tax on the sugar rich groups only resulted in a decrease in consumption for the confectionary group while the other two groups would likely see a relatively small increase in consumption. However, taxing the ready-made meal group would likely result in an increase in sugar intake which is partly explained by confectionary and sugar sweetened beverages acting as substitutes.

Group C1, would see a situation whereby taxing the sugar sweetened beverages would increase sugar intake. This is partly because a substitute of this group is confectionary. However, as all the groups are being taxed, then this relationship does not result in an overall increase in sugar intake.

Group C2 experiences the largest reduction in sugar intake which is interesting as most groups contribute to a decline except for: Alcohol, grain based and sugar sweetened beverages. All the other groups overwhelmingly show a reduction in sugar intake. This is particularly true of taxing the eggs group whereby cake is a complement and has a high price elasticity of demand.

Group DE would likely experience a relatively large reduction in sugar consumption from particularly the cheese group which is likely a result of cake being a complement. There would also likely be a decrease from taxing the eggs group which has cake and other dairy as complements. An interesting feature for all the social groups is that the sugar rich groups often act as a complement to each food group which helps to explain the overall reduction in sugar intake.

Härkänen et al (2014) studied the effect of a sugar tax (based on one euro per kg of sugar) using Finish data. The study found that it is likely that such a tax would impact greatest on demand for sugary products from low income households (Härkänen et al., 2014). This is an interesting finding which supports this chapters findings. Smed et al (2007) modelled the effects of various taxation scenarios finding the largest reductions in nutrients occurred for low income households (Smed et al., 2007).

From a dietary perspective the sugar tax would likely lead to the lowest income group having the largest weight loss (Härkänen et al., 2014). This thesis has not modelled the actual health effects though it seems possible that weight loss could occur for Scotland as a result of the carbon consumption tax (though more work would need to be done in this area).

Zhen et al (2013) modelled the effects of a sugar-sweetened beverage tax on the United States using panel data and found an increased fat and sodium intake. This finding does not apply to fat intake and to an extent only applies to sodium intake for this chapter.

Table 66 Simulation of sugar elasticities through application of carbon consumption tax

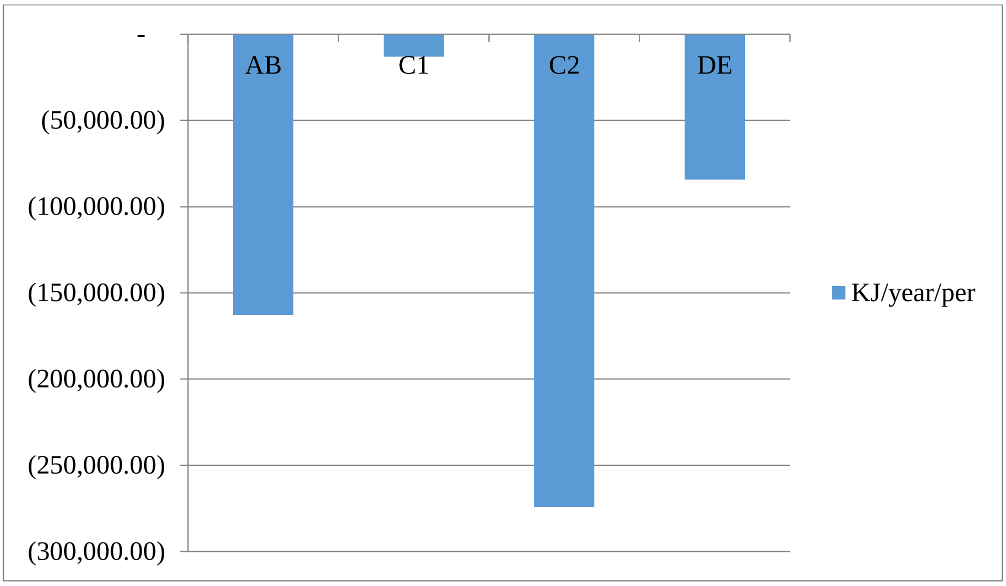
Products	AB Nutrient elasticity	AB Change due to 1% price increase	AB Total implied change	C1 Nutrient elasticity	C1 Change due to 1% price increase	C1 Total implied change	C2 Nutrient elasticity	C2 Change due to 1% price increase	C2 Total implied change	DE Nutrient elasticity	DE Change due to 1% price increase	DE Total implied change
		g/year/person			g/year/person			g/year/person			g/year/person	
Alcohol	0.06	13.20	26.92	0.05	11.32	23.09	0.03	6.57	13.39	-0.01	-1.40	-2.86
Cakes & biscuits	0.01	1.61	12.96	-0.09	-18.55	-149.68	-0.09	-19.30	-155.73	-0.03	-6.71	-54.14
Cheese	0	-0.63	-19.79	0.05	10.13	318.51	-0.01	-2.78	-87.38	-0.09	-20.39	-641.07
Confectionery	-0.11	-24.09	-269.84	0	-0.52	-5.80	-0.09	-20.17	-225.85	-0.13	-29.17	-326.66
Eggs	-0.05	-11.80	-128.83	-0.01	-3.00	-32.71	-0.39	-85.85	-937.45	-0.16	-33.90	-370.19
Fats & oils	-0.06	-13.52	-202.95	-0.13	-28.74	-431.33	-0.02	-4.71	-70.65	0.03	7.26	108.93
Fish	-0.16	-34.55	-568.70	-0.01	-2.01	-33.05	-0.18	-38.37	-631.51	-0.10	-21.38	-351.94
Fruit	-0.03	-7.03	-40.89	0	-0.20	-1.15	-0.06	-13.29	-77.34	-0.01	-0.99	-5.74
Fruit juices	-0.02	-3.61	-9.81	-0.22	-48.29	-131.35	-0.12	-26.74	-72.74	0.02	4.77	12.97
Grain based group	-0.01	-2.97	-45.56	-0.01	-2.35	-36.07	0.03	7.03	107.91	-0.02	-4.39	-67.35
High carbon meat	-0.04	-8.45	-378.69	0.03	6.20	277.80	-0.03	-7.06	-316.21	0	-0.39	-17.31
High carbon milks	-0.11	-24.32	-103.10	-0.03	-5.60	-23.75	-0.01	-1.73	-7.34	-0.06	-13.34	-56.57
Low carbon meat	0.01	2.14	19.66	-0.01	-1.02	-9.39	-0.01	-1.11	-10.23	-0.05	-11.29	-103.68
Low carbon milks	0.04	7.64	20.94	0.01	2.68	7.35	-0.14	-31.40	-86.03	-0.02	-4.03	-11.05
Other dairy	0.04	8.59	103.29	-0.03	-6.06	-72.79	0	0.69	8.27	-0.04	-9.00	-108.20
Ready-made meals (meat based)	0.25	54.87	1188.97	-0.10	-21.04	-455.95	-0.10	-22.21	-481.28	0	-	-
Sugar sweetened beverages	-0.02	-4.71	-3.35	0.03	6.45	4.58	0.03	6.50	4.61	0	-0.35	-0.25
Hot beverages	-0.02	-3.33	-2.00	-0.08	-17.22	-10.33	-0.06	-12.71	-7.62	0	0.32	0.19
Vegetables	-0.08	-16.87	-133.64	0.02	4.86	38.51	-0.03	-6.31	-49.94	0	-0.78	-6.19
Total		-67.83	-534.39		-112.94	-723.51		-272.93	-3,083.12		-145.18	-2,001.12

Source: Based on own elaborations

5.4.3.5 Energy

The consumption of energy is important considering that in 2012 the energy intake from food in Scotland exceeded recommended guidelines by four percentage points (Scottish Government, 2014). Figure 12 shows that energy consumption would likely reduce which is supported by the main components of energy: fat and sugar also seeing a reduction. The change for group C1 of 13,015.23 KJ/year/person (-0.52%) represents a small decrease in consumption relative to the other groups such as C2's reduction of 274,096.05 KJ/year/person (-10.93%).

Figure 12 Change in Energy



Source: Based on own elaborations

Table 67 shows the annual change in energy consumption (in KJ) per person following application of the respective consumption taxes. There is a similar situation for group AB (to the previous nutrients and carbon emissions) whereby taxing the cheese group will help reduce energy intake. A further interesting result is how taxing ready-made meals is likely to increase energy intake by 55,405.80 KJ/year/person. This is due to the substitute of this group being the high energy products of cake.

Group C1 are of particular interest considering that this group would likely experience the smallest relative decrease in energy intake. One of the reasons the decrease is not greater is due to taxing the high carbon meat group which increases energy intake. With regards to reducing carbon emissions, taxing this group was a large reducer of the emissions. Yet, as the substitutes are energy rich foods such as fats & oil, low carbon meats and other dairy then this explains the increase. It should be emphasised that taxing the other food groups does help reduce energy intake and it also highlights that there is no trade-off between reducing carbon emissions and reducing energy intake.

Group C2 experienced the largest decrease in energy intake, which is largely due to taxing the eggs and fish group. What is particularly interesting about taxing both groups is how when considering vitamin D, it was these groups which helped to reduce overall intake. This highlights the trade-off within nutrients as a result of the taxes. The overall result is consistent with the large reductions in overall intakes of fats and sugar.

Group DE experiences a likely decrease in overall intake of energy, though there is concern that taxing the fruit juice group increases energy intake (though overall there is still a decrease in energy consumption through application of all the carbon consumption taxes). Taxing this food group for group DE already contributes to an increase in the undesirable nutrients as shown in the previous tables and a relatively small increase in vitamin D (3.03% increase).

Table 67 Simulation of energy elasticities through application of carbon consumption tax

	AB			C1			C2			DE		
Products	Nutrient elasticity	Change due to 1% price increase	Total implied change	Nutrient elasticity	Change due to 1% price increase	Total implied change	Nutrient elasticity	Change due to 1% price increase	Total implied change	Nutrient elasticity	Change due to 1% price increase	Total implied change
		KJ/year/person			KJ/year/person			KJ/year/person			KJ/year/person	
Alcohol	-0.01	-187.88	-383.27	0.03	724.90	1478.79	0.01	261.05	532.54	-0.02	-509.62	-1039.63
Cakes & biscuits	-0.03	-748.58	-6041.06	-0.07	-1666.59	-13449.37	-0.06	-1388.49	-11205.08	-0.06	-1421.11	-11468.32
Cheese	-0.06	-1590.22	-49996.62	0	-25.02	-786.51	-0.01	-304.59	-9576.36	-0.06	-1410.59	-44348.84
Confectionery	-0.02	-501.61	-5618.03	-0.01	-192.21	-2152.75	-0.04	-967.07	-10831.18	-0.05	-1343.38	-15045.86
Eggs	-0.11	-2709.10	-29583.37	0.06	1374.54	15009.99	-0.38	-9514.89	-103902.64	-0.08	-1931.49	-21091.86
Fats & oils	-0.05	-1356.58	-20362.34	-0.06	-1593.34	-23916.00	0.01	219.33	3292.13	0.02	384.33	5768.73
Fish	-0.13	-3175.90	-52275.27	0.02	399.07	6568.66	-0.20	-5048.02	-83090.35	0.01	147.52	2428.13
Fruit	0	-51.31	-298.62	-0.03	-665.82	-3875.09	-0.06	-1503.19	-8748.58	0	68.09	396.31
Fruit juices	0.03	641.89	1745.95	-0.02	-390.43	-1061.97	-0.11	-2782.68	-7568.88	0.15	3776.72	10272.67
Grain based group	-0.03	-691.88	-10613.38	-0.04	-949.89	-14571.29	0.01	326.86	5014.05	-0.01	-208.09	-3192.17
High carbon meat	-0.04	-924.94	-41455.66	0.04	872.53	39106.72	-0.03	-704.27	-31565.47	0	-111.92	-5016.32
High carbon milks	-0.08	-2048.69	-8686.45	-0.02	-452.59	-1918.99	0	-78.37	-332.28	-0.02	-409.27	-1735.31
Low carbon meat	-0.02	-427.92	-3928.32	-0.01	-200	-1836.01	-0.03	-816.30	-7493.59	0	-81.43	-747.52
Low carbon milks	0.05	1235.07	3384.10	0.01	278.58	763.30	-0.04	-874.01	-2394.78	0	-80.26	-219.92
Other dairy	0.02	589.58	7086.70	0.02	392.60	4719.11	0	-89.87	-1080.29	0.01	128.88	1549.14
Ready-made meals (meat based)	0.10	2556.80	55405.80	-0.03	-850.21	-18423.95	-0.01	-261.00	-5655.97	0	-	-
Sugar sweetened beverages	0.01	260.57	185.01	0.02	398.11	282.66	0.01	331.03	235.03	-0.03	-616.43	-437.66
Hot beverages	-0.02	-412.62	-247.57	0	8.22	4.93	0	-79.86	-47.91	0	68.56	41.14
Vegetables	-0.01	-151.11	-1196.78	0.01	131.64	1042.55	0	40.85	323.56	0	-50.84	-402.65
Total		-9694.43	-162,879.22		-2,405.91	-13,015.23		-23,233.48	-274,096.05		-3,600.33	-84,289.94

Source: Based on own elaborations

5.4.4 Carbon consumption tax revenue

The estimated revenue obtained from carbon consumption taxes is shown in Table 68 which highlights how most revenue would be obtained from social group C1 which would equate to £83,613,232.32 per year (adjusted for 2011 Scottish census population representation of the social group). The overall likely total revenue generated is approximately 201.4 million pounds per year. With regards to Briggs et al (2013) scenario A (their only scenario which is comparable to this study) they estimated the carbon consumption tax would likely bring in 2,023 million pounds per year.

However, the total government revenue of consumption taxes can be represented in per person form as shown by the Institute for Fiscal Studies (2013) observations on tax revenue. Therefore, the per person, per year tax revenue of Briggs et al (2013) would be £31.96 versus this study's figure of £38.04[41]. This is an interesting finding with the two values being broadly similar despite the differences in methods. The slightly higher figure for Scotland is likely a result of all food products attracting the carbon consumption tax instead of the threshold system of Briggs et al (2013). This study supports Briggs et al (2013) idea that the revenue could be spent on GHG mitigation but also public health may also benefit from additional revenue.

It should also be highlighted that the boxes from Table 68 which display "0" is because there is an overall decline in quantity purchased due to taxation but as there was no carbon consumption tax applied pre-calculations then a zero figure is used as the government is not losing any revenue.

As stated in chapter two, understanding the rebound effect is beyond the scope of this thesis as only food purchase data were available. Yet, the overall £201.4 million pounds per year obtained from Scottish based carbon consumption taxes could be used for climate change mitigation activities. It has been highlighted than an

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[41] 2011 Census data for populations of UK and Scotland were used in order to form per person comparisons

important area for investment for the purposes of carbon emissions reduction would be decarbonising energy production and or transport (Sugden et al., 2012).

Table 68 Consumption tax revenue per £1000 per year

	Alcohol	Cakes & biscuits	Cheese	Confectionery	Eggs	Fats & Oil	Fish	Fruit	Fruit Juices	Grain
AB	1,327	2,904	2,520	2,678	293	685	0	1,281	101	4,875
C1	3,559	7,019	16,456	7,431	733	0	9,537	2,897	170	12,875
C2	1,719	3,724	0	3,812	350	1,319	1,747	1,207	96	6,480
DE	1,956	6,602	0	6,404	630	3,346	8,715	1,906	179	10,936

	High carbon meat	High carbon milks	Low carbon meat	Low carbon milks	Other dairy	Ready-made meals (meat based)	Sugar sweetened beverages	Hot beverages	Vegetables	TOTAL Revenue raised From all food groups
AB	511	289	2,220	68	1,292	7,257	88	47	2,529	30,967
C1	7,691	773	5,979	112	2,265	0	232	124	5,760	83,613
C2	0	423	2,874	18	669	258	124	58	2,419	27,297
DE	6,776	710	3,779	93	1,758	1,566	218	96	3,890	59,560
										201,438

Source: Based on own elaborations
Notes: The different social groups are matched with the respective food products and the total revenue raised from taxing all food products for all social groups is £201,437,691.20

5.5 Summary

The effects of using a carbon consumption tax on the different social grades (i.e. socio economic groups) of households would likely result in an equitable distributional effect in terms of reducing carbon emissions. This effect is due to the higher social grade households (likely to be wealthier) experiencing a relatively larger share of emissions being reduced when compared with the lower social groups. These results of a tax being beneficial in this respect are also observed for Denmark. Therefore, the carbon consumption tax has met the aim of reducing carbon emissions.

However, the likely net reduction of carbon emissions from all households is 543,208.75 tCO2e/y which represents approximately five percent of the total emissions in Scotland (attributed to food consumption). In order to compare this figure with the Briggs et al (2013) study, land use change was incorporated into the aforementioned emission figures. The resulting change in carbon emissions through the carbon consumption tax was lower at approximately 3.9%. This is a relatively smaller decrease in emissions when compared to Briggs et al (2013) finding of 7.5%.

The overall likely changes in nutrients consumed induced through the taxes were mostly beneficial in terms of the distributional impact resulting in favourable changes for the lower social groups. However, the increased salt intake for group DE and the relatively large decrease in intake of vitamin D for group C2 shows a slight negative distributional effect. As the average Scottish person is currently consuming less vitamin D and more salt than government guidelines recommend, then a change in these nutrients could create further health problems. Chapter 4 (which did not consider social groups) found a trade-off between reducing GHG emissions and increasing intake of vitamin D. It is interesting that this is largely confined to group C2 (to an extent group AB) which suggests the importance of splitting the data into social groups.

The overall decline in intakes of sugar and total fat for every social group supports the idea of carbon consumption taxes having a positive nutritional effect. The reduction in sugar is particularly pertinent given the recent concern regarding sugar intake and the results of the lowest social groups (C2 and DE) reducing their intakes by 14.09% and 9.15% which suggests potential health benefits may be likely. A conclusion which can be drawn from taxing sugar based products is how the sugar rich food groups mostly (for each social group) act as complements within each food group thus the large reduction when the taxes are applied to each respective group.

A carbon consumption tax is estimated to reduce food based GHG emissions by a relatively small value and provide some beneficial nutrient effects for the lowest social groups. In addition this benefit, the potential gain in revenue of 201.4 million pounds (per year) which is similar to the study by Briggs et al (2013)[42] may be attractive for policymakers as it could potentially finance carbon mitigation activities.

[42] On a per person basis as a means of comparison

Chapter 6. Conclusions

6.1 Conclusions

This chapter provides an overall conclusion on the main points raised in each chapter under the four objectives. This thesis modelled the effects of a carbon consumption tax on demand for food products in order to understand if carbon (representative of Greenhouse gas-GHG) emissions could be reduced due to the substitution effect of encouraging **demand for low carbon food products**. There was also interest in how such a tax may affect nutrient intake. This thesis has shown the importance of modelling the effect of carbon consumption taxes on demand since these taxes are likely to be an effective instrument for reducing GHG emissions, though the change is relatively small.

This thesis has addressed the aims and objectives listed in the introduction and will provide more detail on each aim and how it impacts upon the wider thesis topic of demand for low carbon food products.

1. Estimating demand systems for the purpose of understanding the substitutions of high carbon food products

The purpose of this objective was to understand cross price relationship between high carbon and low carbon food products. Chapter 2 highlighted the effect of a one percent price on the demand for whole milk and its substitutes/complements. Attributional life cycle assessments (ALCA) suggested that whole milk had a higher carbon footprint based on the wet mass. The result of households substituting into the low carbon option (i.e. low fat milk) in place of a high carbon option (whole milk) was particularly interesting. The contribution of this result to forming substitution ratios for the purposes of consequential life cycle assessment (CLCA) highlighted the importance of demand system modelling and effect of price change on consumer demand.

While the CLCA was not the main focus of chapter 2 or indeed this thesis, it did serve as the reasoning in later chapters for not studying the individual cuts of meat as this would verge on creating a CLCA when this study was solely using ALCA data on carbon footprints. This would be a complex task given the considerations used for just two milk products and the marginal product of palm oil (Chalmers et al., 2015a).

The demand for meat products studied in chapter 3 found that increasing the price of the product by the respective consumption tax is likely to encourage either a reduction in meat products purchased or a small substitution into lower carbon footprint meats. Chapter 4 modelled all the major high carbon footprint food products of meat, fish, milk and meat based ready-meals and found that many of the products acted more as complements thus a price increase induced through taxation would likely reduce demand for these high carbon food products. Therefore, it seems price changes induced through carbon consumption taxation encourage demand for lower carbon food products.

2. Developing carbon footprint elasticities in order to understand emission changes induced through carbon consumption taxes

The carbon footprint elasticities are key to this thesis since they allow for estimation of the emission changes resulting from substitutions (and reduced demand) of the food groups of interest. This was a slightly novel approach considering that the method of Huang (1996) had been adapted from nutrients to carbon. The previous literature on modelling carbon consumption taxes did not use as many carbon footprint values, nor were they as recent as this study. This marks an improvement in carbon consumption tax modelling.

Due to demand substitutions it is likely that targeting the meat group would be an effective way of reducing GHG emissions as all the demand systems report a reduction in emissions. The dynamic AIDS found that taxing only meat products would decrease emissions by 246,327.26 tCO2e/y. Therefore, it can be considered necessary to ensure that meat products are taxed for reducing emissions. When the latter incomplete EASI system is used (which includes products such as ready-made meat based products and milk products in addition to the existing fish and meat groups) the emission reduction is likely to be even larger at 1,628,666.89 tCO2e/y.

Chapter 5 took into account the effect of the tax at social group level which builds on the results of chapter 3 using four groups instead of the three corresponding to chapter 3. This acts an extension to all the chapters since more carbon footprint data is covered than presented in chapter 2. Also the EASI system of chapter 4 is extended to cover all 19 major food groups. Therefore, chapter 5 builds on the methodological techniques of all the preceding chapters and provides the most useful results (in terms of carbon reduction and change in nutrient intake) from a policymaker's perspective.

An interesting feature when modelling all the food products is the effect of the different social groups on carbon emissions reduction. The assumed wealthy social groups of AB and C1 would see the largest decrease in their emissions associated with the tax on high carbon meat products. This is further supported by the findings of chapter 3 whereby a conditional dynamic error correction version of the AIDS found that the social group ABC1 (an aggregation of the two previous social groups) would likely experience a large reduction in demand for high carbon meats of beef and sheep. While the lower carbon meats of chicken and pork would not experience decreases in demand on such a large scale.

Chapter 3 found little evidence to suggest that households were substituting low carbon meats in place of high carbon meats. This is in contrast to the findings of chapter 5 which suggested that this form of substitution relationship did occur to an extent for some social groups. This was particularly true for social group C1 whereby the price elasticities implied a substitution relationship between high carbon and low carbon meat products. This cross price relationship differed for group C2 where low carbon meats were a complement to high carbon meats along with other relatively high carbon emitters such as other dairy. This demonstrated the importance of taxing all the major food products in order for carbon emissions to be reduced.

3. Estimating nutrient elasticities in order to understand the likely effect on nutrient intake of taxes

The literature reviewed in this thesis implied that food based taxes would likely result in mixed outcomes when studying nutritional intake. This thesis used Huang (1996) approach to model nutrient elasticities. This allowed for an understanding of the impact of carbon consumption taxes on nutrient intake. The representation of nutrients in chapter 4 and 5 differs slightly. Chapter 5 represented the change in nutrients in international units per year per person in contrast to chapter 4 which used international units per day per person. Also chapter 5 presented the relative change in nutrient intake based on existing intake as a baseline. Chapter 4 instead focussed on how the change in international units associated with the carbon consumption tax compared to Scottish Government's recommended daily intakes. This does raise the issue of not being able to compare daily intake against government recommended intake. However, from a theoretical perspective it is unlikely that individuals will change their nutrient intake in one day to such an extreme level as minimising salt intake. Instead expressing the nutrient elasticities per year as for the case of carbon emissions appears to make more economic sense (though problematic as government guidelines are daily).

From a policymaker's perspective, the change in nutrient intake associated with application of the tax is likely to be of particular interest. Chapter 4 highlighted the trade-off between reducing emissions and improving vitamin D intake as a result of net application of carbon consumption taxes. This is an important outcome of the thesis as Scotland currently experiences dietary problems such as some of the population lacking necessary levels of vitamin D. To illustrate this point further, chapter 4 found that the decline in the vitamin would likely result in a total decline of 0.38 µg per person per day. This represents an 18.85% reduction of the Scottish government's recommended daily intake of the vitamin. This may concern policymakers given evidence that 17% of a sample of the Scottish population had suboptimal levels of the vitamin (Food Standards Agency Scotland, 2013). However, when only taxing meat products (i.e. ready meal based meat products and meat), the vitamin intake decrease lessened to 0.075 µg per person per day.

When vitamin D intake was considered for the different social groups of chapter 5, it was found that the lowest income group DE would likely experience an increase in intake. However, group C2 which is assumed to be slightly wealthier than DE would experience a decrease in intake along with the wealthiest group of AB. This does make it difficult to determine that the resulting effect of the carbon consumption tax is negative (in terms of worsening nutrient intake) considering that the poorest households are likely to benefit.

Two new nutrients were introduced in chapter 5: non-extrinsic sugars and energy. The results for sugar are particularly interesting as the overall decline in intake of sugar for every social group supports the idea of carbon consumption taxes having beneficial distributional nutrient effects. The largest reduction in sugar intake were for the two lowest social groups of C2 and DE. These groups would likely experience a reduction of 14.09% and 9.15% relative to existing annual sugar intake per person. A comparison with a study conducted on modelling carbon consumption taxes for Denmark appeared to suggest the opposite result whereby under the uncompensated tax scenario there would be a likely increase in sugar consumption for all social groups.

The reduction in sugar intake is also particularly interesting given the recent concern by Lustig et al (2012) that excessive consumption can lead to a variety of health problems such obesity and diabetes. The main reason why taxing sugar based products in Scotland causes such a large decline in consumption is that the sugar rich food groups mostly (for each social group) act as complements within each food group hence the large reduction when the taxes are applied to each respective group.

Another beneficial change is that of energy intake whereby all the social groups would experience a reduction in intakes. In a similar situation the two lowest income groups would likely experience relatively large decreases in consumption relative to the existing average intake of 10.93% (C2) and 3.36% (DE).

The result for total fat intake is interesting as the models in chapter 4 suggested that consumption would decrease. However, in chapter 5 where the data were split into social groups it seems that social group C1 would likely experience an increase in fat intake whereby the other groups would see a decrease. This is interesting as it shows the importance of accounting for social groups.

The Danish uncompensated scenario implies that consumption of saturated fat and total energy will likely reduce for every social group. Yet, the consumption of sugar will increase for every social group. This highlights how important it is to model individual countries rather than making assumptions that two Northern European countries would likely experience similar behavioural change with regards to taxation.

When a zero rate carbon consumption tax (i.e. exempting certain food products from taxation) was applied to some lower carbon footprint food products, the results implied that this could increase the intake of some already excessively consumed nutrients. When considering taxing only the meat products (i.e. ready meal based meat products and meat) of chapter 4 the sodium intake increased to 4.43 grams while the carbon emissions decreased slightly (sodium intake increased by a lesser quantity under net application of carbon consumption taxes).

Caution should be applied as taxing the same meat products with regards to vitamin D would likely lessen the reduction of the vitamin's intake. This result alone could make policymakers wary of using a carbon consumption tax and demonstrates to an extent the trade-off between the different nutrients after application of carbon consumption taxes.

4. Applying carbon consumption taxes to all major food products

All the major food groups were estimated using an incomplete demand system of chapter 5 in order to understand how application of carbon consumption taxes would likely affect the emission reduction and nutrient consumption of the different households. The food groups differ to those of previous studies modelling demand as they were based on primarily categorising similar food products by carbon footprint.

The demand systems of chapter 4 modelled the different meat and fish groups which included processed food products in the form of different ready-made meal groups. The issues highlighted from modelling at this level of disaggregated data were low budget shares which is likely to have led to the problem of some of the price elasticity values being relatively high when compared with the literature. While it is important to model these products it seems that modelling all the major food groups is likely to capture a more realistic representation of the potential tax effects on emission reduction.

The net application of carbon consumption taxes to the 19 major food groups would likely reduce emissions associated with Scottish food consumption by 543,208.75 tCO2e/y which represents approximately 5% of the total emissions in Scotland. This is lower than similar studies modelling carbon consumption taxes such as Briggs et al (2013) finding of 7.5%. A particularly policy relevant finding which was discussed in the previous objectives were the trade-off between emission reductions and nutrient intake.

The reason this trade-off is important for this objective, is because no food product should be exempted from the carbon consumption tax since taxing high carbon meats for group AB had relatively little effect on reducing overall emissions. The carbon reductions experienced by this group were largely attributed to taxing cheese and ready-meals. Due to the differing underlying cross price elasticities of the social groups, exempting some products from taxation may induce problematic nutrient intakes for other groups.

This is an important result as net application of carbon consumption taxes would likely lead to households purchasing lower carbon footprint products. Future studies should model all the major food groups as it seems conditional demand systems may overestimate the likely changes of emissions as a result of carbon consumption taxation.

6.2 Concluding remarks

A carbon consumption tax is applied to all the major food groups and is estimated to reduce Scottish food based GHG emissions by approximately 5%. If land use change is included then this figure is smaller at approximately 3.9% relative to the work of Briggs et al (2013) finding of 7.5%. While it is difficult to compare how effective this reduction is with other studies, it does seem that the resulting reduction in carbon emissions is small. The mixed effects on nutrient intake may support a carbon consumption tax as having a dual purpose: reduce carbon emissions and decrease already excessively consumed nutrients such as sugar. The potential revenue gained through the tax could be used for GHG mitigation.

6.3 Potential for future work

This thesis suggests there may be some potential in using carbon consumption taxes as an instrument for reducing GHG emissions. However, there are a few issues which could improve the results. Over time it is expected that more LCA studies will be conducted which should improve the availability of carbon footprint data. This would allow for more representative food groups to be formed. There is also the possibility that food groups could be formed on similar foreign and domestic goods as this may offer interesting results in guiding policy.

Improved precision of carbon footprint data may offer the potential to use panel data in order to understand the relationship between the disaggregated food products and corresponding demographic characteristics of the households (i.e. go beyond social groups and include regions). Though for estimating the overall emissions as a result of a carbon consumption tax, then some caution should be applied to using panel data.

This thesis recommends that an updated food based carbon emission inventory is produced for Scotland. The data from Audsley et al (2009), while useful, did have limitations as it was likely to be obsolete. While this thesis inferred a food consumption value from the Scottish Government's domestic inventory (which provided shipping and aviation emissions), there were uncertainties regarding this value.

A future study should also consider incorporating non-food groups into the demand system in order to understand if a reduction in emissions is offset through an increase in areas such as air travel. The idea behind this rebound effect highlighted by Druckman et al (2011) could help provide further evidence on the usefulness of carbon consumption taxes for reducing emissions. While chapter 5 did account for the likely increase in available revenue through carbon taxation it would still be helpful to understand if the rebound effect is occurring. This analysis could potentially provide greater support for Scotland introducing carbon consumption taxes.

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Appendix papers

The Implications of Empirical and 1:1 Substitution Ratios for Consequential LCA: Using a 1% Tax on Whole Milk as an Illustrative Example

Authors: Neil Chalmers, Matthew Brander and Cesar Revoredo-Giha

This paper was accepted to "The International Journal of Life Cycle Assessment" on the 15th July 2015. The paper is cited as Chalmers et al (2015a). The demand system modelling results of chapter 2 are based on this paper.

Chalmers, N. G., Brander, M. & Revoredo-Giha, C. 2015a. The implications of empirical and 1: 1 substitution ratios for consequential LCA: using a 1% tax on whole milk as an illustrative example. **The International Journal of Life Cycle Assessment**, 20(9)**:** pp.1268-1276.

Contributions:

The demand system modelling involved in the paper was completed by Neil Chalmers (author of this thesis) and his supervisor Dr Cesar Revoredo-Giha helped check the results. The sections of the paper which describes and critiques the CLCA and the convention of 1:1 substitution ratio using carbon emissions data was the work of Matthew Brander.

Do economists really know best?

This book review is cited as Chalmers and Shackley (2015).

Chalmers, N. & Shackley, S. 2015. Do Economists Really Know Best? **Climate Change and Climate Policy**, 26(3)**:** pp.559.

Contributions:

Both Neil Chalmers and Simon Shackley read the book and brought their respective points together for the review.

Socioeconomic effects of reducing household carbon footprints through meat consumption taxes

Authors: Neil Chalmers, Cesar Revoredo-Giha and Simon Shackley

This paper was accepted to the "Journal of Food Products Marketing" on the 19th of January 2015. Chapter 3 is based on this paper.

Chalmers, N. G., Revoredo-Giha, C., & Shackley, S. 2016. Socioeconomic Effects of Reducing Household Carbon Footprints Through Meat Consumption Taxes. **Journal of Food Products Marketing**, 1-20.

Contributions:

Neil Chalmers produced every section of the paper and Cesar Revoredo-Giha checked the paper and provided feedback.

Improving vitamin D intake through carbon consumption taxes

[Neil George Chalmers[1]*,Cesar Revoredo-Giha[2] and Simon Shackley[1]]

[University of Edinburgh[1] and SRUC[2]]

This paper was accepted as a contributed paper at the 89th AES annual conference.

Authors: Neil Chalmers, Cesar Revoredo-Giha and Simon Shackley. The paper is cited as Chalmers et al (2015b).

Chalmers, N. G., Revoredo-Giha, C. & Shackley, S. (2015b) **Improving vitamin D intake through carbon consumption taxes** [Online]. Agricultural Economics Society (AES) 2015 Conference: AES. Available: http://www.aes.ac.uk/upload_area/member_documents/Neil_Chalmers_AES%20Vitamin%20D%20paper%20010415.pdf [Accessed 19.04.2015 2015].

Contributions:

Neil Chalmers produced every section of the paper and Cesar Revoredo-Giha checked the paper and provided feedback.

Reducing Scottish household carbon footprints and improving public health through taxation

Authors: Neil Chalmers, Cesar Revoredo-Giha and Simon Shackley

This paper was accepted as a contributed paper at the 6th EAAE PhD workshop in Rome, Italy from 8 to 10 June, 2015. This paper is not provided via the EAAE PhD workshop but can be obtained from the author. The paper is cited as Chalmers et al (2015c).

Chalmers, N. G., Revoredo-Giha, C. & Shackley, S. (2015c) Reducing Scottish household carbon footprints and improving public health through taxation [not online]. European Association of Agricultural Economists PhD workshop (6th EAAE PhD Workshop) 2015 [Paper presentation].

Contribution:

Neil Chalmers produced every section of the paper and Cesar Revoredo-Giha checked the paper and provided feedback.

The environmental and nutrient effects of taxing high carbon footprint food products

Authors: Neil Chalmers, Cesar Revoredo-Giha and Simon Shackley

This paper was submitted to the journal of “Ecological Economics” on the 21st of January 2016 and therefore, should not be disseminated without the authors’ permission. Chapter 4 is based on this paper.

Contributions:

Neil Chalmers produced every section of the paper which is based on chapter 4 for which Cesar Revoredo-Giha checked and provided feedback.

Does a consumption tax on greenhouse gases disproportionately hurt the poor?

Authors: Sinne Smed, Neil Chalmers and Jørgen Dejgård Jensen

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Contributions:

Sinne Smed undertook all the modelling and design of the methods along with Jørgen Dejgård Jensen. Neil Chalmers wrote the paper using the results and formed the conclusions with the support of the other two authors.

Changing nutrient consumption using a carbon consumption tax

Authors: Neil Chalmers, Cesar Revoredo-Giha and Simon Shackley

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Neil Chalmers produced every section of the paper and Cesar Revoredo-Giha checked the paper and provided feedback.