Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Department of Economics

A French Meat Tax - An Effective Climate Mitigation Policy?

Sanna Dahlberg

Master's thesis • 30 hec • Advanced level
Environmental Economics and Management - Master's Programme
Degree thesis No 1099 • ISSN1401-4084
Uppsala 2017

A French Meat Tax – An Effective Climate Mitigation Policy?

Sanna Dahlberg

Supervisor: Sarah Säll, Swedish University of Agricultural Sciences, Department of Economics

Examiner: Rob Hart, Swedish University of Agricultural Sciences, Department of Economics

Credits: 30 hec
Level: A2E
Course title: Independent Project in Economics
Course code: EX0811
Programme/education: Environmental Economics and Management
- Master's Programme

Place of publication: Uppsala
Year of publication: 2017
Part number: 1099
ISSN: 1401-4084
Online publication: http://stud.epsilon.slu.se

Keywords: Consumption tax, Greenhouse gas emissions, Climate, France, Meat demand elasticities

Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Natural Resources and Agricultural Sciences

Abstract

Since the agricultural sector is responsible for 14.5% of global greenhouse gas emissions, the mitigation potential of this sector might play a crucial role to reach the international agreed temperature target. In this study, we therefore investigated the effect of internalise the environmental effect of meat consumption in France, by implementing a Pigouvian tax levied on consumers to reduce greenhouse gas emissions. In the main analysis, we adopted a tax rate of €0.87 per kg beef, €0.21 per kg pork and €0.15 per kg poultry in the main analysis, corresponding to an increase between 4-8% of the initial price per kg per category in 2016. The reduction in demand was conducted by estimating a non-linear almost ideal demand system for meat. The result of the own-price elasticities indicated a slightly elastic demand for the three meat categories investigated. We concluded an absolute reduction of 5 198 217 metric ton carbon dioxide equivalent per year, equal to a decrease of GHG emissions by 9% per year compared to current level.

Key words: Consumption tax, Greenhouse gas emissions, Climate, France, Meat demand elasticities

Acknowledgement

Firstly, I would like to give a special thanks to my supervisor Sarah Säll, for the encouragement, engagement and all the useful comments throughout the process of writing this Master thesis. Secondly, I would like to thank my family, for all the love and support during my master studies in Economics at the Swedish University of Agricultural Science in Uppsala. Finally, a special thanks to all my fellow classmates and friends particularly Sachintha Fernando, Franziska Klein, Mia Lundh, Filippa Pyk and Linda Hoff Rudhult.

Table of Content

1 Introduction

Within the research community there exists common consensus that the main driver of climate change is the increase of atmospheric anthropogenic greenhouse gases (GHG), which was announced by the Intergovernmental Panel on Climate changes in their fifth assessment report (IPCC, 2013). In December 2015, the Conference of the Parties (COP) recognized that climate change is an urgent and potentially irreversible threat to humankind and the planet. The parties committed to a challenging plan by signing the legally binding contract, the Paris Agreement at COP 21 that included an international temperature target, that limits the global average temperature to 2 degrees Celsius over pre-industrial level (UNFCCC, 2015).

To reach this international agreed target several studies have indicated that the mitigation potential in the livestock sector might play a crucial role, since livestock production alone stands for approximately 14.5% of the global GHG emissions (Gerber et al., 2013). Livestock production is not only associated with climate impacts in the acknowledged report "Livestock's long shadow" by (Steinfeld et al., 2006) but is connected to other environmental issues as well, such as water depletion, land degradation, loss of biodiversity, air and land pollution.

A growing research base is debating about the potential benefits policymakers can generate by considering the regulation of drivers affecting the demand for livestock products, by imposing changes to dietary pattern as an alternative mitigation strategy (McMichael et al., 2007; Hedenus et al., 2014; Wirsenius et al., 2011;Bajželj et al., 2014; Springmann et al., 2016). McMichael et al., 2007 stress the nutrition transition that is occurring in the developing and primarily the BRIC[1] countries. This nutrition transition implies that these countries are adopting the dietary patterns of the western world with a larger share of animal-based protein, as their disposable income grows. Hence, this transition might increase the global environmental pressure even further. Westhoek et al., (2014) concludes that reducing the consumption of livestock products with 50% and replacing them with plant-based protein, for the EU-27 member states alone would result in a reduction of GHG emissions by 25-40%. Hedenus et al., (2014) emphasises that increased livestock productivity and technical mitigation would not result in a reduction sufficient to reach the international temperature target, unless a simultaneous reduction in meat and dairy consumption is made. Other studies have also indicated that changing dietary patterns towards a plant-based protein diet and reduce the animal-based protein might give potential health benefits (Springmann et al., 2016; Tilman and Clark, 2014).

Within the European Union, France is one of the countries that have the largest meat consumption per capita, with an aggregate consumption of roughly 83kg per capita, with beef standing alone at 24kg per capita (FranceAgriMer, 2014). Dietary preferences are highly influenced by social and cultural norms, and voluntary engagement to change the dietary pattern to the extent that would reduce GHG emissions seems highly unlikely. A reduction in livestock products in a large country like France might lead the way for a rational collective following. An appropriate measure to reduce livestock production might be to influence consumer behaviour by introducing a consumption tax on meat. This study therefore aimed to investigate, the effectiveness of a Pigouvian tax levied on meat consumption to reduce GHG emissions in France. The choice of only focusing on the meat is based on existing literature such as (Leip et al., 2010; Edjabou and Smed, 2013; Springmann et al., 2016; Säll and Gren, 2015), since they concluded that ruminant meat is the main contributor of GHG emissions and would result in the highest reduction levels when policies are imposed.

[1] Brazil, Russia, India and China

The specific research question that this study addressed was; what effect will an implementation of a Pigouvian tax on meat consumption in France have on greenhouse gas emissions? We expected that there was to be a reduction in GHG emissions imposed by the consumption tax though the effect was expected to be small due to results from previous studies (Edjabou and Smed, 2013; Säll and Gren, 2015; Wirsenius et al., 2011; Springmann et al., 2016). To provide an answer to the research question and achieve the objective of this study, the empirical analysis was conducted by estimating the demand and income elasticities for beef, pork and poultry by applying a weakly-separable two-stage demand system. The econometric analysis was performed using a non-linear almost ideal demand system (AIDS) model and annual time-series data of consumer price indices and consumption quantities, between the years 1990-2016 for France. Then the optimal consumer tax level was calculated by using average GHG emission intensity for production multiplied with the assumed social cost of carbon for each of the meat products. The estimated demand and price elasticities was used to calculate the change in demand induced by the consumption tax so that the total reduction in GHG emissions could be determined.

1.1 Contribution

The literature contains very few studies that have examined the effect of a meat tax as a potentially effective climate mitigation policy measure. Hence, this study makes a contribution to the existing literature on how effective an introduction of a consumption tax placed on meat products is in reducing the GHG emissions. The modelling framework in approaching the research objective of this study has not been applied in studying consumption taxes on meat in France before, making the setting of this study another novelty and contribution to existing literature.

1.2 Structure of the Thesis

This thesis consists of total seven sections, in *section 2*, a discussion about the motivation behind the choice of levying a consumption tax is presented and previous literature within the research area. *Section 3* presents the conceptual framework of this study, which explains the underlying theoretical background of the problem. In *section 4* the data used in this study was presented. *Section 5* specifies the stepwise research methodology that was adopted. *Section 6* presents and gives an interpretation of the results from the empirical analysis. *Section 7* consists of conclusions and a discussion focusing mainly on validity of the results and gives recommendations for future research.

2 Meat tax – Policy instruments and Previous Literature

In this section, a discussion of the choice of policy instrument is presented to regulate the GHG emission associated with the livestock production. Followed by a literature review of existing studies within the research area.

2.1 Choice of Policy Instrument

To change certain consumption patterns policymakers can choose either to apply voluntary agreements (VA), command-and-control regulations or price-based instruments. The use of voluntary agreements within the environmental policy area has increased due to the low compliance cost and its potential cost-effectiveness. Though very few analyses are performed to investigate their effectiveness in increasing environmental quality. Segerson and Miceli (1998) state three condition where a VA can resolve in a first best level of abatement; when the bargaining power of the regulator is high, when the probability of a legislative threat is high and public funds are available. They stress that historically the regulators within the agricultural sector have had low political support for imposing a legislative threat, though VA with subsidies has been commonly used. Hence, we can argue that a VA solution might not be an appropriate policy measure to reduce GHG emissions in the livestock sector, since the conditions mentioned above are not fulfilled. This implies that there is a low probability for the VA to result in a higher level of abatement. If a VA with subsidies was to be implemented, it would impose a larger cost to society in terms of funds. Since there is a low probability that this would bring a significant reduction of GHG emissions it might lead to reduced social welfare.

The regulator could also choose to focus on education and increasing the awareness of the public about the link between meat consumption and climate changes, to influence a voluntary reduction. Within the existing literature, very few studies have examined the effect of voluntary reduction of the consumption level concerning meat products (for an overview Traill et al., (2013)). It could also be questioned if the results from the previous studies can be generalized. However, it seems unlikely that voluntary reduction would influence consumers to reduce the amount consumed to a sustainable level, since our meat consumption behaviour is deep-rooted into our lifestyle.

Command-and-control regulations imply that the reduction should be enforced by laws and regulations, such as quotas, standards and product bans. Stavins (2003, p.359) argue that in theory, it is possible to reach a cost-effective regulation with a command-and control regulation. In practice however, this would require the government to have perfect information concerning each producers’ emission levels, something that would require information concerning each of the emitters’ cost to comply with the set standard. Such detailed information is not attainable within the livestock sector. Hahn and Stavins (1992) emphasise that many economists claims that these types of less flexible regulation also tend to reduce the initiatives for development and implementation of new improved abatement technologies.

The price-based instruments regulators can apply are either taxes or subsidies. Subsidies can be introduced to encourage producers to invest in cleaner mitigation technologies, or relieve subsidies that give raise to a perverse effect. According to economic theory, it is possible to achieve an optimal level of abatement by imposing subsidies at every level that the producer undertakes. However, subsidies give the initiatives for new producers to enter the market if we are assuming perfect competition, and this might resolve in a higher level of emissions at aggregated market than the initial level. Even though new farmers might not enter the market, subsidies would encourage a behaviour that are increasing the external cost to society. According to Baumol and Oates (1988, p.217) the implementation of subsidies will not generate a Pareto efficient equilibrium and the imposition of a tax is able to internalise the environmental effects so that the producer or the consumer pay the full price of their activities.

Since the imposition of a tax seems like the appropriate choice as a policy measure to reduce GHG emissions there is a choice between an emission or output tax. Schmutzler and Goulder (1997) argues that this choice depends mainly on the monitoring costs. If the monitoring costs are low, levying a tax on the emission associated with the individual firm production would be the most effective policy measure to reduce aggregated emissions from a sector. Unfortunately, the livestock sector is associated with high monitoring costs due to the production system since it is of a non-point source character, which does not allow for end-pipe abatement technologies. It would thus be a demanding work for the regulator to conduct and monitor on individual farm level. The second-best solution would thus according to Schmutzler and Goulder (1997) be to levy a tax on the emissions associated with the individual producer's output. An output tax can either be imposed on the consumers or the producers. Hedenus et al., (2014) emphasises in their study that the livestock sector is associated with potential "carbon-leakages". This implies that when taxing the domestic producers generating a higher price for French meat. This could potentially increase the incentive for consumers to buy a larger share of imported products. A large share of the imported beef to the EU region origins from the Latin American countries. According to Leip et al., (2010), Brazil has a much higher GHG intensive production than France. Thus, increasing imports might therefore induce an increase in total GHG emissions compared to the current level due to the existence of "carbon-leakages". According to the argumentation above, the appropriate policy measure to reduce the climate impact generated by GHG emissions associated with livestock production would be to levy a consumption tax on meat products based on their variation in GHG intensity.

2.2 Consumption Taxes

The concept of levying consumption taxes on food and stimulants as alcohol and tobacco to induce changes to consumer behaviour is a common notion. Over the last decade several countries have imposed consumption taxes as a policy regulation for promoting a healthier lifestyle. Taxes on sugar-sweetened beverage in Brazil and France a "junk food tax" in Hungary and soft drinks tax in Finland (Mytton, et al., 2012). The Danish government introduced a tax on saturated fat products in 2010 in order to reduce the adverse health effects associated with a high consumption of saturated fats and raise public revenue. Jensen and Smed (2013) evaluated the effect of this tax and concluded that consumption of these products reduced with 10-15%. Furthermore, Allais et al., (2010) investigated the effect of the efficiency of a "fat tax" on nutrition's purchased by French households. To evaluate the decrease in consumption they estimate price- and income elasticities using a complete almost ideal demand system. They conclude that the decrease was ambiguous on the nutrients consumed, though the tax generated substantial tax revenue.

2.3 Meat and Dairy Taxes

Several studies have investigated the effectiveness of levying consumer taxes to decrease the environmental pressure associated with a high consumption of GHG intense food commodities. Edjabou and Smed's (2013) study indicated that it was possible to achieve dietary changes by implementing a differentiated consumption tax placed on food, to reduce emissions and reach positive health effects in Denmark. To predict the change in consumption behaviour the authors use elasticities estimated with a linearized specification of the almost ideal demand system model in a previous study (Smed et al., 2007).The authors conclude that with a tax level of 0.26 DKK and 0.76 DKK per kg CO_2 -equivalent[2]

[2] CO_2-eq or carbon dioxide equivalent is measurement of GHG that takes into consideration that the different gases has different warming potential (GWP-values) and will therefore affect the climate differently. To aggregated methane and nitrous oxide emissions to the global warming potential of carbon dioxide equivalents are used as a reference.

the most significant decreases in food carbon footprint with 10.4-19.4%, mainly arise due to reduction in consumption of beef, pork, other meat, cheese, and milk.

Säll and Gren (2015) investigated the effect of introducing a Pigouvian tax on meat and dairy consumption in Sweden on GHG, nitrogen, ammonia and phosphorous emissions. To estimate the elasticities the authors', use a dynamic form of the non-linear AIDS model, and data from the Swedish Board of Agriculture's statistical database showing per capita consumption and consumer prices from year 1980 to 2012. The authors found that taxing all seven products simultaneously could result in reductions up to 1.5% of all the included pollutants, compared to current total emissions in Sweden. Moreover, they also found beef to be the main polluter, and most important to regulate due to the environmental impacts that are caused by its GHG and nutrient emissions.

Wirsenius et al. (2011) argue that a differentiated consumption tax based on GHG emission intensity per food unit is an effective climate policy to reduce GHG emissions in EU. The authors used data on consumption per capita compiled from FAOSTAT and expenditure data from Eurostat's database to estimate the initial prices and estimations of demand elasticities from previous studies. The authors found that a tax level of €60 per ton CO2-eq would give a total reduction of 7% level GHG emissions in EU, corresponding to the agricultural sector and current level. They further conclude that it is mainly food production of ruminant meat that contributes to total GHG emissions within EU.

Springmann et al. (2016) investigated the change in food demand, nutrition security and reduction in GHG emissions that could result from imposing a consumption tax on GHG emissions on a global scale. The authors used an agriculture-economic model (IMPACT) to project future food consumption for 62 commodities in 150 world regions using data compiled from FAOSTAT. The study found that a GHG tax placed on food commodities can be an appropriate climate-change mitigation policy in high-income countries. With a tax level of $52 per ton CO2-eq a 9% reduction in food-related GHG emission will be reached. Furthermore, beef had the largest carbon footprint of all the food commodities in the study.

Previous studies show that imposing consumption taxes on commodities which have inefficient markets to internalise negative externalities is a well-known concept. The results from these studies both the ex-ante and ex-post evaluations of the policy measure, indicate that changes in consumer behaviour can be induced. The studies summarized above also emphasises that there exists a strong link between a high intake of ruminant meat and GHG emissions. They specifically conclude that levying consumption taxes based on GHG intensity would generate a change to the average diet, in countries within EU area. They further stress that more research within this area is needed to increase the knowledge and understanding of the effectiveness of this policy instrument as a climate mitigation policy. The main differences between this study and previous research was the assumption regarding the optimal tax level and choice of country. The findings from these previous studies supported the research objective for this study, since it empirically tested the validity of these conclusions.

3 Conceptual framework

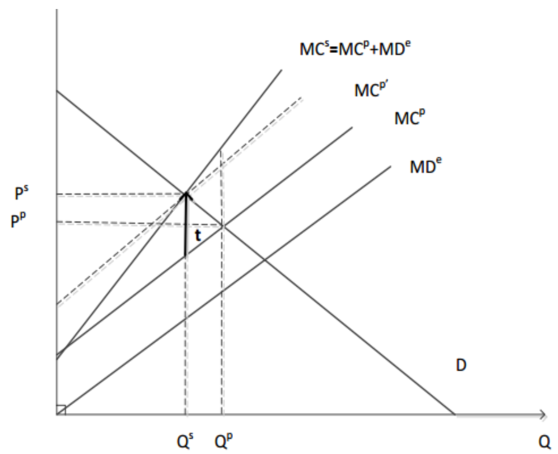
In this section, the theoretical background of regulating the market for meat by internalising the environmental externalities with a Pigouvian tax is presented and what the optimal tax rate according to economic theory should be equal to.

3.1 Environmental Externalities

The spill over effect of meat production in terms of GHG emissions is generating an environmental cost to society. This affect agents who did not consume these products and moreover, the effect of the emissions is not being priced at any market in the economy. The spill over effect with these characteristics is in economics known as a negative externality. The environmental externalities that are associated with agricultural production have four attributes that are highlighted by Pretty et al., (2017), (i) their environmental costs to society is often neglected (ii) they often occur with a time-lag (iii) they are often damaging people living in poverty, whose interest are not usually represented in the public debate (iv) it is problematic to identify the individual producer of these externalities.

This external cost is creating market distortion in the economy, since it is encouraging a behaviour that generates a social cost that is higher than the private cost for consumption or production. The producers and consumers in this market are not operating where the social cost is equal to the private cost and this results in market inefficiency, where the resources in the economy are not optimally allocated. The environmental damage generated by the meat production is an increasing function of the production level, denoted as (MD^e) in *figure 1*. The initial equilibrium for this market is where the marginal private cost (MC^p) is crossing the aggregated market demand curve (D).

Figure 1. Pigouvian tax(t) effect of internalising the environmental damage of emission(MD^e), generating a socially optimal consumption level(Q^q)



This unregulated market equilibrium gives a quantity demanded (Q^p) and a market price (P^P), this quantity demanded is too high and the price is too low for it to be a socially desirable optimum. The emissions associated with this production level generates an external cost of the area, following the line from the market equilibrium to the marginal social cost (MC^s), in *figure 1.* This fulfils the criterion for a government intervention of the market, since the private marginal cost is lower than the marginal cost to society due to the exclusion of the marginal damage cost. The optimal equilibrium for society is located at the production level (Q^s) and price (P^s), where the marginal cost to society crosses the demand curve. In the introduction, we argued which policy measure that would be most appropriate to apply in the livestock sector to reduce the GHG emissions and thereby reduce the external cost to society and concluded that affecting the demand to reduce the production by levying a consumption tax would be most efficient.

3.2 Pigouvian tax

A common procedure is to internalize external cost associated with environmental damage is with an Pigouvian tax. The notion of a Pigouvian tax was introduced by Pigou (1920) and according to its theory shall the optimal tax rate be equal the marginal social damage cost of the emissions. When the tax (t) is imposed on the consumers, the external cost becomes included in the private marginal cost. Hence, equalizing the marginal cost to society and the private cost, successfully correct for the market failure. The economic agent should thereby face the full price of their behaviour, generating a new socially desirable equilibrium if the tax is properly designed. According to the laws of demand, a higher price induced by the tax should result in a decrease in demand for meat, if meat is a normal good. The decrease in demand then generates a reduction in GHG emissions. We will in this study assume that the tax levied on the consumers is fully shifted and the increase in consumer prices reflect the tax level, ceteris paribus. Theoretically, it seems straightforward to design an optimal tax rate, however, it is a complex task to monetize the climate impacts and attain a shadow price for the marginal damage cost of GHG emissions. Marginal cost of emitting an additional ton of CO_2-eq. in the literature often denoted as the social cost of carbon (SCC). The SCC is often applied in cost-benefit analysis. This estimated cost is a highly debatable subject among researchers. According to Nordhaus (2014) the criticism against the SCC can be ordered into two categories. The first was that crucial factors are being omitted in the models used to estimate the cost. The second is that there are so many uncertainties influencing the value, for instance the choice of social discount rate. There are many studies performed trying to estimate SCC with an integrated assessments model (IAM), and the results from these are uncertain and varies significantly (Hope, 2006; Nordhaus, 2014; Tol, 2005; Stern, 2007).

4 Data

To estimate the two-stage demand system, annual time-series data between the years 1990-2016 consisting of consumer price indices and consumption and expenditure data per capita was used. The data collecting process for the first and second stage are described in this section as well as the choice of the social cost of carbon and GHG emission intensity.

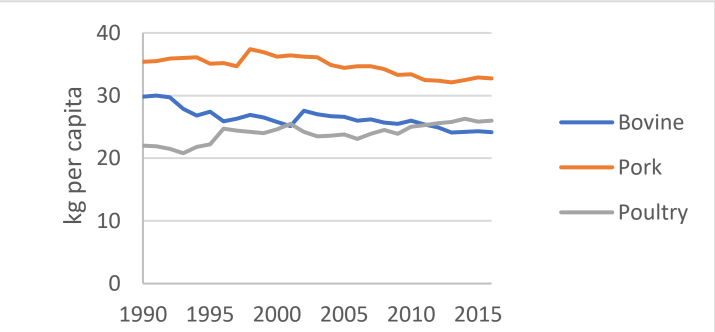
4.1 First Stage of the Demand System

For the first stage consumption data for the aggregated food groups; cereals, meat, vegetables, fruit and dairy was compiled from Eurostat's database (2016) . The data was mean consumption expenditure of private household and was classified according to the Classification of Individual Consumption by Purpose (COICOP) [3]. It consisted of household budget survey data collected 1988, 1994, 1999, 2005 and 2010. The sample for the survey data consisted of representative household with the size of approximately 20 000 households in metropolitan France and 5 000 in overseas departments. The data collection was based on a combination of one or more interviews and dietary logs maintained by the households at a daily basis. The duration period of the survey was 14 days per household and 48 weeks in total. To attain the missing values between the years of the household budget survey data in this study, linear regression analysis was utilized. Assuming a linear relationship between the years and mean consumption expenditure was assumed, this was confirmed by plotting the values in Excel. Then the slope coefficients between two points was calculated to predict the mean consumption expenditure for the missing years. The annual price indices for the aggregated groups were compiled from INSEE's database (2017) (National Institute of Statistics and Economic Studies), with base year 2015 detailed by product and COICOP classified, for the geographical scope of France. During the period, the price index for the aggregated meat group increased from 63.7 in 1990 to 100.41 in 2016.

4.2 Second Stage of the Demand System

For the second stage, meat consumption per capita was compiled from FranceAgriMer (2014)[4] for the categories beef, pork and poultry for the years 1990-2014. The data is based on supply balance sheet data indicating the national availability for human consumption of meat. It is constructed from national production including imports, exports and changes in meat stock from the first and last day of the year in question. Production data are based on statistics from the Ministry of Agriculture, Agri-Food and Forestry of France. The consumption per capita is expressed as carcass equivalent by application of a conversion coefficient to evaluate the weight of the carcass. The import and export figures are based on data from French Customs Department, Directorate-General for Customs and the Ministry of the Economy and Finance. The volumes provided by French Customs are net weight and are adjusted by a conversion coefficient allowing them to be estimated in terms of carcass equivalent before any processing of the product. Estimating the carcass equivalent per capita was made with population estimates conducted by INSEE's database (2017). In this study consumption values of horse, goat and mutton meat was excluded, since the consumption of these categories are negligible compared to the categories beef, pork and poultry. The category beef

Figure 2. Per capita consumption in kg carcass equivalent of beef, pork and poultry in France between the years 1990-2016 Source: FranceAgriMer



[3] An international classification which groups the household's consumption expenditure in to aggregated groups.
[4] National authority for agricultural and sea products in France

includes beef cattle and calves. During the period of investigation, the highest total consumption was identified in 1998, with 88kg per capita. The total consumption of beef, poultry and pork has over the period decreased from 87.2kg per capita to 82.88kg per capita, a reduction of 5%. Consumption of beef was the main contributor to the aggregated reduction, with a decline of 19% during the period of investigation. It was only the consumption of poultry that increased during the period, with 18%. The consumption of pork remained more stable and declined with 9% from initial level. Since the data only was available for 2014, linear regression analysis was applied to conducted predicted data for 2015 and 2016. The same procedure as described above was used. The consumer price indices for this stage was also complied from INSEEs database. For the individual meat products, the largest increase was identified for beef from 57.4 to 100.86, poultry from 61.9 to 99.8 and pork from 65.8 to 99.85. The initial prices (€/kg) on beef, pork and poultry used to calculate the change in demand, was assumed accordingly to calculations made by Wirsenius et al., (2011) for average animal food products in EU27. The prices were then corrected for the new price level, with consumer price index from INSEE's database (2017).

4.3 Social Cost of Carbon (SCC)

The renowned report *Stern Review: The Economics of Climate Change* by Stern (2007, p. 304) estimated SCC to $85 per ton CO_2- eq (2000 year dollars) equivalent to €90 per ton CO_2- eq (2007 years' Euro) based on a literature review of existing estimates, assuming a near zero discount rate. Nordhaus (2014) estimates global SCC to $22,1 per ton CO_2- eq (2005 year dollars), assuming the baseline scenario with no changes in climate policy and a discount rate at five percentage. In one scenario, the author restricts the damage to a 2-degree temperature which gives an SCC to $60.1 per ton CO_2- eq (2005 year dollars). Corresponding to €23 respective €68 (2007 years' Euro) per ton CO_2- eq. Another approach to investigate the SCC is to perform a meta-analysis on existing studies, one example of this approach is Tol (2012), this study reviewed 232 published estimates. The results from this analysis presented a variation from €10-439 per ton CO_2- eq (2007 years' Euro), with a mean of €49 per ton CO_2- eq based on different assumptions concerning the discount rate. The adopted SCC for the main analysis in this study was €0.049 per kg CO_2- eq, based on Tol's estimates. The selection of SCC is based on Edjabou and Smed (2013), which used the estimations from meta-analysis published by Tol (2005). To covert the estimated values by Tol (2012) from U.S dollars to Euro and 2016 years' price, purchasing power parities for private consumption exchange rates compiled from OECD's database was used.

4.4 Greenhouse Gas Emission Intensity

The emissions intensity data for France applied in the empirical analysis, was GHG fluxes from Leip et al., (2010)[5]. Conducted with a Life Cycle Analysis (LCA) on the livestock production in EU-27 area for year 2004. This data included both direct (livestock rearing) and indirect (from inputs including like feed, energy and land-use change) emission up to the farm gate. Off-farm gate emissions for example animal transportation, waste and packaging of products are not included. In their study, three different scenarios concerning the origin of additional crop land devoted for livestock feed were investigated. In the first scenario, Leip et al. assumed that all land that were converted was already grassland, with lower emissions then forest. In the third scenario, they considered a maximum scenario where all the original land area was forest area. The second scenario was a transition mix between the first and the second. The authors assigned scenario two with the highest outcome probability. There is a difference of total GHG fluxes between the member states, the EU-27 average is 22.18 kg CO_2 -eq per kg beef, 7.53 kg CO_2 -eq per kg pork and 4.93 kg CO_2 -eq per kg poultry. The average GHG fluxes associated with livestock production in France is higher than EU-27 average for beef with a total 24.51 CO_2 -eq per kg

[5] Annex 1 to Chapter 6 - Quantification of GHG emissions of EU livestock production in form of a life cycle assessment (LCA) in report

and lower for pork production with a total 5.98 kg CO_2 -eq per kg it is also lower for poultry with a total 4.38 kg CO_2 -eq per kg. In this study, the optimal tax rate was constructed by applying the GHG fluxed estimated for France with scenario two.

5 Methodology

To achieve the objective of this study, we followed Edgerton (1997) and Carpentier & Guyomard (2001) applying a two-stage weakly separable budgeting demand system. The empirical analysis was conducted in the following steps, (i) Price and income elasticities for meat per capita was conducted by estimating a conditional demand system in two-stages, with a non-linear specification of the almost ideal demand System (AIDS) model (ii) Optimal Pigouvian tax rate was calculated (iii) Reduction in demand after the implementation of the tax was calculated (iv) The differences of the GHG emissions was calculated, before and after-tax implementation.

5.1 Separability

In this study food demand and specifically meat was analysed, however, this is only a small share of all the commodities and services an individual chooses to consume. To perform the analysis, it was therefore important to assume that the consumers' preferences had á priori structure making it possible to group the food commodities in to aggregated groups. This assumption can be denoted as weak separability and is fulfilled when the commodities within every aggregated commodity group can be ordered by the consumers' preference, independently on the preference and consumption in another group. In this study, the consumers gained utility from consuming three commodities in the lower stage, q1, q2 and q3 these commodities are beef (b), pork (p) and poultry (o), which gave the total utility function expressed by Deaton and Muellbauer (1980a, p. 127) following:

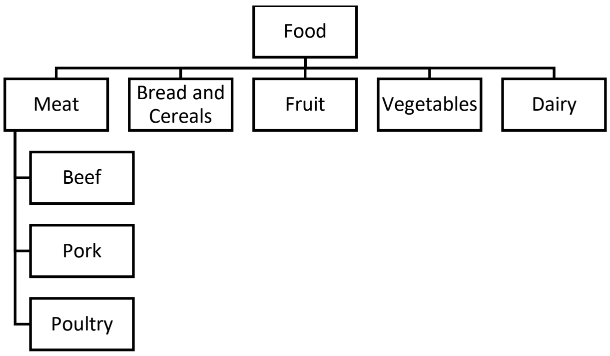
$$U = v(q1, q2, q3) = vb(q1), vp(q2), vo(q3) \quad (1.)$$

This condition is a sufficient and necessary condition for the second stage in a two-stage budget process according to Deaton and Muellbauer (1980a, p. 124).

5.2 Two-Stage Budgeting Process

The two-stage budgeting process allows, accordingly to Strotz (1957), the consumer to allocate its total expenditure in two-stages. In this study, a utility tree according to *figure 3* was assumed where the consumer allocated its budget over the aggregated commodity groups meat, cereals, vegetables, fruit and dairy at the first stage. In the second stage, the consumers allocated its budget within the meat group, on the individual commodities, beef, poultry and pork. Deaton and Muellbauer (1980a, p. 123) emphasises that for each stage information about group prices and expenditure is only required. This implies that the total group expenditure allocated in the first stage, was assumed to be a function of the individual commodities allocated in the second stage.

Figure 3.Shows a utility tree assumed for the estimation process of this study.



5.3 Almost Ideal Demand system (AIDS)

In this study, a model that is applicable on aggregated data was required to be able to analyse the individual consumer response to the market intervention of a consumption tax. To analyse this behaviour the best scenario would have been to use microlevel data. However, due to lack of microlevel data a model that could overcome what the literature referred to as aggregation problem was essential. The AIDS model was developed by Deaton and Muellbauer (1980b) and is accordingly to Buse (1994) commonly used in applied demand work since it is straightforward to estimate, satisfied the "axiom of rational choice" and allowed for exact aggregation over consumers. The AIDS model overcame the aggregation problem since it is based on a specific class of preferences, PIGLOG[6]. These preferences are characterised with an expenditure or cost function that minimizes expenditure to reach a required level of utility at given prices. With these preferences, we can as per the theorems of Muellbauer (1975) interpret the market demand as an outcome of the decision of utility maximizing individuals. A detailed derivation of the AIDS model was presented in Deaton and Muellbauer (1980b). The demand function for AIDS model is expressed, as following:

$$w_{it} = \alpha_{it} + \sum_{i=1}^{n} \gamma_{ij} \, lnP_{jt} + \beta_i(\ln X_t - lnP_t) \quad (2.)$$

$w_{it} = \frac{p_i q_i}{X_t}$, is the budget share of commodity *i* expressed as a function of the logged prices for all commodities *j=1…n*, in time *t*. $X_t = \sum_{i=1}^{n} p_i q_i$, is the total real expenditure in time *t*.

Ln P_t is the non-linear price index, expressed as following:

$$\ln P_t = \alpha_0 + \sum_i \alpha_{it} lnP_{it} + \frac{1}{2} \sum_i \sum_j \gamma_{ij}^* \ln(P_{it}) \ln(P_{jt}) \quad (3.)$$

The parameters $\alpha_i, \beta_i \; and \; \gamma_{ij}$ was estimated by the demand function. The parameter γ_{ij} represents the average change in w_i by a marginal change in prices. β_i represents the average change in w_i by a marginal change in X_t.

The model was founded on three conditions, which are expressed as following:

Slutsky-symmetry condition: $\gamma_{ij} = \gamma_{ji}$ (4.)

Homogeneity: $\sum_i^n \gamma_{ij} = 0$ (5.)

Adding-up: $\sum_i^n \alpha_i = 1, \;\; \sum_i^n \beta_i = 0, \;\; \sum_i^n \gamma_i = 0$ (6.)

When the conditions *(4)*, *(5)* and *(6)* was satisfied the budget share *eq. (2)* was consistent with the laws of demand. These restrictions were imposed and controlled for during the estimation process. The Slutsky-symmetry implied that the change in *i*th budget share by a marginal change in price of commodity *j* was equal to the change in *j*th budget share generated by a marginal change in price of commodity *i*. The adding-up restriction implied that the sum of the budget shares is equal to the real total expenditure. This condition was automatically fulfilled due to the estimation process applied, which automatically drops one equation to avoid singularity of the covariance matrix. The homogeneity condition implied that the consumer is not a subject to monetary illusion, implying that *eq. (2)* was homogenous of degree zero in its prices and total real expenditure.

5.4 Price and Income Elasticities

To investigate how sensitive the demand for meat was to price and income changes, elasticities was calculated with the parameters estimated by non-linear AIDS model. The own-price elasticity for a commodity indicates how sensitive the demand is to a marginal change to its own price. If the own-elasticity was between zero and one in absolute value the demand is noted as inelastic, and defined as price insensitive. If the value was higher than one in absolute value the demand is noted as elastic, and

[6] Price-Independent Generalized Logarithmic

defined as price sensitive. If the value is equal to one in absolute value the elasticity is defined as unitary elastic. With the income elasticities, the commodities are classified as either a normal, luxury or inferior good, depending on how sensitive the demand was to marginal income changes. If the value of the elasticity was higher than one the commodity was classified as a luxury good. If the value is negative it was classified as an inferior good and if it was between zero and one as a normal good. With the cross-price elasticities the related commodities are classified as substitutes or complements, since it indicates the demand sensitivity to marginal price changes for related commodities. If the signs are negative then the commodities are classified as a complement to each other and if they were positive they are substitutes. The elasticities in this study were calculated to predict how the consumers would change their demand for meat when the tax was implemented since it was inducing price- and income changes. In the following section, the uncompensated Marshallian demand is denoted as M. Only the Marshallian elasticities was investigated in this study, because when performing policy work we wanted to encounter both for the income and substitution effect. The income elasticities are denoted as I. We followed Green and Alston (1990) estimating the compensated price- and income elasticities by using following equations:

$$\varepsilon_i^I = 1 + \frac{\beta_i}{w_i} \tag{7.}$$

$$\varepsilon_{ij}^M = -\delta_{ij} + \frac{\gamma ij}{wi} - \frac{\beta_i w_j}{w_i} \tag{8.}$$

Where δ_{ij} is Kronecker delta and $\delta_{ij} = 1\ if\ i \neq j$ and zero otherwise. *Eq. (7)* and *(8)* was used for each stage of the system, first stage the aggregated food groups and second stage beef, pork and poultry. Results from these estimations is named compensated elasticities and shown in section results table *2*. During the estimations, following property must hold $\sum_j \varepsilon_{ij}^M + \varepsilon_i^I = 0$. According to Edgerton (1997) a price change induced by the tax affect both the allocation within the meat group and the allocation of expenditure between the aggregated food groups, since the price indices of group *r* will change. By assuming weak separability, it was possible to combine both the compensated elasticities for stage one and two to obtain total uncompensated price and income elasticities which are denoted with a star, following the formulas derived by Edgerton (1997):

$$\varepsilon_i^{I*} = \varepsilon_i^I \varepsilon_r^I \tag{9.}$$

$$\varepsilon_{i,j}^{M*} = \delta_{r,s}\varepsilon_{i,j}^M + \varepsilon_i^I w_j(\delta_{r,s} + \varepsilon_{r,s}^M) \tag{10.}$$

Kronecker delta and $\delta_{r,s} = 1\ if\ r = s$ and zero otherwise. Indices *r* and *s* denoted the aggregated food commodity groups, *i* and *j* denotes the commodities within the meat group.

5.5 Optimal Tax Rate

According to the conceptual framework the optimal tax rate (€/kg) for beef, pork and poultry, was estimated as following:

$$tax_i = e_i SCC \tag{11.}$$

Where e_i is the average emission intensity (CO_2 -eq/ kg meat) for production and SCC (€ /CO_2-eq) the assumed cost of emitting one more kilo of GHG emissions. The tax level was then assumed to be equal to the average marginal damage cost of GHG emissions for each meat product. The consumption tax is assumed to be implemented simultaneously on beef, pork and poultry. In this analysis, it was assumed that there was no difference in GHG emission intensity between domestically produced and imported meat. The appropriate numbers and assumptions regarding the SCC and GHG emission intensity is described under the section data. The individual tax rate for each of the commodities are presented in the *section 6* results.

5.6 Calculating the Difference in Demand

Applying the general formula for own-price elasticity, *eq. (12)* the Marshallian demand curve per capita for each of the meat products was derived accordingly to description below. Using the initial price (p_{i0}) Euro per kilo initial quantity consumed (q_{i0}) kilo per capita for year 2016 in France and the calculated final uncompensated own-price elasticities, shown in *table 2*. The coefficient of slope (k) denoted as ($\Delta q_i/\Delta p_i$) in eq. (12) was determined.

$$\varepsilon_i^{M*} = \frac{\Delta q_i}{\Delta p_i}\frac{p_{i0}}{q_{i0}} \qquad (12.)$$

$$q_{io} = kp_{io} + b \qquad (13.)$$

Since we were assuming linear demand curves for beef, pork and poultry they could be expressed as in *eq. (13)* above. From *eq. (13)* the initial value of the intercept was determined, by solving for b.

$$\Delta b_i = \sum_j^n \Delta p_j \frac{\varepsilon_{ij}^{M*} q_i}{P_j} \qquad (14.)$$

The final uncompensated cross-price elasticities were used to calculate the sum of the complementary and substitutions effect, given by commodity $j = 1 \dots n$ within the meat group *r*. Which determined how the intercept (b) of the demand curve shifts for commodity *i*, expressed by *eq. (14).*

$$\Delta q_i = k(p_{io} + tax_i) + b \qquad (15.)$$

Then the total change in quantity demanded (Δq_i) induced by the consumption tax for each meat category was obtained by *eq. (15).* q_i represents the reduction in demand per capita per meat category. Attaining the absolute reduction (ΔQ_i), was done by multiplying the estimated population size by INSEE for 2016 with reduction in demand per capita for each of the meat categories. Then the reduction in GHG emissions for each of the categories was obtained by, *eq. (17)* as the difference between the emissions before and after the tax multiplied with the GHG emission intensity.

$$\Delta E_i = e_i \Delta Q_i \qquad (16.)$$

The total environmental effect of the consumption tax was calculated as total aggregated reduction of GHG emissions equal to the sum of each of the meat categories, given by *eq. (17)*

$$\sum_i^n \Delta E_i \qquad (17.)$$

The results from *eq. (15), (16)* and *(17)* are presented in the *section 6 results*.

6 Results

This section presents the result from the two-stage econometric estimation process, according to *figure 3*. Furthermore, the consumption tax level used in the main analysis is presented as well as the reduction in demand and associated reduction in GHG emissions. In the end of the section a sensitivity analysis is presented where the value of SCC was alternated. The estimation method applied in this study was SUR (Seemingly Unrelated System of Equations), and the econometric software used was time series processor (TSP). The data used in the empirical analysis are explained in *section 4 data*. The results of estimated parameters and all the demand equations are presented in *appendix 1* and *2*.

6.1 First Stage of the demand system

The first stage consisted of the aggregated food groups meat, cereals, vegetables, fruit and dairy. Using the non-linear AIDS model specified accordingly to *eq. (2)* and adding dynamical features. As a time-trend and one year lagged price indices for meat, fruit and vegetables. Persistence in consumption pattern was capture in the model by introducing lagged budget shares, commodity prices and real total expenditure following. The time-trend was included to capture changes in habits and in consumer preferences over the time-period. Since these are not captured by the independent variables in the model specification. The results of the estimation indicated a good fit of the model, R^2 varied between 0.98 to 0.46 for each of the equations. 12 out of 18 parameters was significant at a 10% level. All the compensated own-price elasticities were negative, which is according to the demand theory. The theory states that there is an inverse relationship between price and quantity, therefore the sign should be negative. The Lagrange multiplier (LM) test indicated that the null hypothesis could not be rejected for any of the demand equations indicating no autocorrelation. The own-price and income elasticities for the aggregated meat group was presented above in *table 1*, which shows that they were both significant at 1% level. The own-price elasticity indicates an inelastic demand (-0.98) close to being unitary elastic. This result was consistent with other studies that have estimated meat demand. Gallet (2010) conducted a meta-analysis on previous studies that has estimated meat demand and the analysis indicated a median elasticity of – 1.054, for Western Europe. The income elasticity is positive which classifies meat as a normal good. Since it was less than one, meat should be considered as a necessity good. The time-trend for the meat group was also significant and negative (-0.087). Which is aligned with the pattern that was observed in the consumption data, illustrated in *figure 2*.

Table 1. Results from the demand estimation of the compensated own-price and income elasticities at the sample mean point for meat for France 1990-2016.

	Meat	Income
Meat	-0.986***	0.520***
	(0.1235)	(0.0557)

***p<0.01, **p<0.05, *p<0.1.
Standard errors in parentheses.

6.2 Second Stage of the Demand System

The second stage of the system consisted of the commodities beef, pork and poultry. Using the same base model specification as in the first stage. Adding the dynamic features of one year lagged budget share, real total expenditure, price indices of beef and poultry to *eq. (2)*, to capture the persistent in consumer behaviour. The result of the estimation provided an R^2 that varied between 0.57 to 0.91. The LM test indicated no autocorrelation for any of the equations in the stage two. 3 out of 7 parameters was significant at 10% level. All the compensated own-price elasticities had the expected negative sign and where significant at a 1% level. The own-price elasticities indicated that the demand for these products are rather elastic since they were varying from -0.634 to -1.639. The compensated cross-price elasticities indicated that beef and pork was complementary goods, since the signs were negative. They also indicated that poultry was a substitute to beef and pork since the signs are positive. The conditional income elasticities indicated that all the commodities are normal goods and beef is a luxury good.

6.3 Final Uncompensated Elasticities

In *Table 2* the results indicated that calculating the final uncompensated elasticities according to eq. (9) and (10). Gives a substantial change for the income elasticities and indicates that beef, pork and poultry all were classified as necessity goods. There are no standard errors for the final uncompensated elasticities. Since they were calculated manually using the estimations made in econometric software from the first and second stage, these elasticities shows almost all a good significant level. We therefore followed Säll and Gren (2015) and assumed that the final uncompensated elasticities was significant at the same level as the compensated elasticities. The difference between the compensated and the final uncompensated elasticities are not that significant since the compensated own-price elasticity for the aggregated meat group is close to one in absolute value.

According to previous studies the value of these final own-price elasticities seems reasonable. Wirsenius et al., (2011) calculated unconditional average long-run elasticities of food demand for EU27 based on existing studies from France, UK and Greece, provided a result of own-price for beef (-1.3), pork (-0.8) and poultry (-1.0). Most sensitive to price changes in this study was poultry (-1.639) this was in line with the conclusions of Lööv and Widell (2009). They concluded that poultry was the most distinct substitute good within the meat group, even though their result was from a study conducted on food consumption behaviour in Sweden between the year 1960-2006. The quantity consumed of poultry increased by four kg per capita in France during the period of investigations, which also underlines the result that poultry was classified as a substitute.

6.4 Consumption tax level

From the calculations described under *optimal tax level 5.5* the optimal tax level for the main analysis was obtained. For beef, the optimal level corresponded to €0.87 per kg meat. With an initial price of €10.30 per kg beef the tax induced a price increase to €11.17 per kg beef, corresponding to an 8.4% increase. For pork and poultry, the tax levels were lower, due to a lower GHG emissions intense production. The tax rate for pork was set to €0.21 per kg meat, with an initial price of €5.94 per kg pork, imposing the tax will generate a new consumer price of €6.15 per kg pork corresponding to a 3.6% increase. For poultry, the tax level was corresponding to €0.15 per kg meat, with an initial price of €4.25 per kg poultry, the after-tax price was equivalent to €4.4 per kg poultry, a 3.6% price increase.

Table 2. Results from the demand estimation of the compensated and final uncompensated price and income elasticities at the sample mean point for beef, pork and poultry for France 1990-2016.

		Beef	Pork	Poultry	Income
Compensated elasticities	Beef	**-1.364*** **	-0.645***	0.451**	1.559***
		(0.1816)	(0.1609)	(0.1452)	(0.1692)
	Pork	-0.246**	**- 0.634*** **	0.099	0.781***
		(0.0874)	(0.1442)	(0.0814)	(0.1279)
	Poultry	0.758***	0.176	**-1.639*** **	0.706**
		(0.2071)	(0.2249)	(0.1940)	(0.2265)

Final uncompensated elasticities

	Beef	Pork	Poultry	Income
Beef	**-1.357**	-0.636	0.457	0.806
Pork	-0.243	**-0.629**	0.102	0.406
Poultry	0.761	0.180	**-1.636**	0.367

***p<0.01, **p<0.05, *p<0.1.
Standard errors in parentheses.

Table 4 shows as expected that imposing the consumption taxes has the largest impact on the demand for beef. With a decrease of 2.90 kg per capita per year compared to the current level, if all the price effects were taken into consideration. For poultry, the result could be contra intuitive when all price changes were taken into consideration, one might expect when imposing the tax that would decrease the demand. This adverse effect could be explained by recalling the elasticity calculations above, were poultry was classified as a substitute to beef and pork and as a normal good. When the tax is implemented it will increase the prices for each of the commodities, for poultry this has a negative effect if only taking the own-price effect into consideration (-1.55kg per capita per year). Though the prices for beef and pork did also increase which generated a positive effect of the demand for poultry. This increase in demand for poultry generated by the substitution effect shifted the demand curve for poultry outwards, since it changed the intercept. The consumers will switch from beef and pork and consume more poultry. The reduction in total GHG emissions was not off-set by the slight increase in demand for poultry, since poultry has a much lower GHG emission intense production than beef.

Table 4. Reduction in demand (% and kg/cap/year) generated by the consumption tax, all and own- price effects

	Own-price effect		All price effects	
	Percentage	Quantity	Percentage	Quantity
Beef	-11%	-2.76	-12%	-2.90
Pork	-2%	-0.73	-4%	-1.28
Poultry	-6%	-1.55	1%	0.28

The absolute changes in demand and GHG emissions induced by the tax is shown in *table 5* below, the populations estimations used from INSEE was 66.99 million inhabitants for year 2016 in France. This resulted in a total absolute reduction of 5 198 217 metric ton CO_2-eq per year, from 60 393 697 to 55 195 480 metric ton CO_2-eq. This reduction corresponds to a decrease of 9% GHG emissions associated with production of beef, pork and poultry compared to current level. Comparing these results with the total anthropogenic GHG emissions for France compiled from OECD's database for year 2014, gives a reduction of 1%, from 464 417 800 metric ton (excluding LULUCF[7]) metric ton CO_2-eq to 459 219 583 metric ton CO_2-eq. Comparing only emission generated from the agricultural sector (excluding LULUCF) from year 2014 gives a reduction of 7% from 79 193 180 metric ton CO_2-eq to 73 994 963 metric ton CO_2-eq. The reduction of CO2-eq for each of the meat categories was 12% for beef, 4% for pork and 1% increase for poultry, compared to current level of emissions shown in *table 5*.

Table 5. Before and after-tax level of demand and GHG emissions and absolute reduction in demand (ton/year) generated by the consumption tax and reduction in GHG emissions (metric ton CO_2-eqFor/year)

	Q_0	Q_1	ΔQ	E_0	E_1	ΔE
Beef	1617828.5	1423296.1	-194532.3	39652975.3	34884988.5	-4767986.8
Pork	2192609.7	2106830.2	-85779.56	13111806.2	12598844.3	- 512961.9
Poultry	1741761.5	1760650.0	18888.5	7628915.3	77116447.0	82731.7

6.5 Sensitivity Analysis

One of the most sensitive factors that generates uncertainty to the results of the analysis in this study, was the choice of SCC. Since there is no recommendation what the appropriate value should be equal to. Therefore a sensitivity analysis has been performed based on the results from the meta-analysis conducted by Tol (2012). In the main analysis, the SCC was assumed to be €49 per ton CO_2-eq which was the mean value in Tol’s study. In this analysis, we applied the modal estimate of the meta-analysis which was €15 per ton CO_2-eq. This assumption resulted in a lower tax level than in the main analysis,

[7] Land-Use, Land-Use Change and Forestry

which resulted in a lower impact on beef demand and a lower reduction in GHG emission. The initial level of GHG emissions for beef, pork and poultry is shown in *table 4*. We can conclude that the lower tax rate had a very small impact on the demand for beef, pork and poultry, this SCC of carbon would not be an optimal choice to affect the demand.

We also assumed the SCC to be €65 per ton CO_2-eq, which was estimated at 67% quantile in the meta-analysis. This tax level resulted in a larger decrease in total GHG emissions than the main analysis. We also analysed a SCC of €204 per ton CO_2-eq, and were estimated at the 95% quantile in Tol's study. Calculating the tax level with this SCC generated a significant reduction in especially beef demand, with 70% of the current level due to the price increase of 49% compared to the initial level. This implied a larger reduction in GHG emissions, by 27 564 923.7 metric ton CO_2-eq per year compared to current level. From this sensitivity analysis, we can conclude that the effect on reduction of GHG emissions induced by the consumption tax varies considerably depending on the assumption concerning the SCC.

Table 5. Sensitivity analysis were the assumption of SCC is varied from €15-204 per ton CO_2-eq, resulting in tax_i (€/kg meat), demand reduction (in ton/year and %) all price effects included and reduction and after-tax levels of GHG emissions (metric ton CO_2-eq/year) in France

	tax_i	ΔQ	Percentage	ΔE	E_1
€15per ton $C0_{2\text{-eq}}$					
Beef	0.38	-85107.9	-5.3%	-2085994.2	37566981.0
Pork	0.09	-37528.6	-1.7%	-224420.8	12887385.4
Poultry	0.07	131006.5	0.5%	36195.1	7665110.4
€65 per ton $C0_{2\text{-eq}}$					
Beef	1.60	-358668.9	-22.2%	-8790975.7	30861999.6
Pork	0.39	-158156.1	-7.2%	-945773.5	12166032.7
Poultry	0.29	50446.9	2.9%	220957.3	7849872.6
€204 per ton $C0_{2\text{-eq}}$					
Beef	5.01	-1124639.9	-69.5%	-27564923.7	12088051.6
Pork	1.22	-495913.2	-22.6%	-2965561.0	10146245.3
Poultry	0.90	109199.3	6.3%	478292.9	8107208.1

7 Conclusion and Discussion

The aim of the study was to investigate the effect of an implementation of a Pigouvian tax on greenhouse gas emissions in France. The main analysis of the study indicated that internalising the environmental damage in terms of climate changes associated with meat consumption by levying a consumption tax on beef, pork and poultry had the desired effect on the demand for these commodities. Calculating an optimal tax based on the GHG intensity of production and SCC for each of the commodities resulted in a level of €0.87per kg beef, €0.21 per kg pork and €0.15 per kg poultry. Imposing this tax resulted in a demand decrease of 2.9kg beef, 1.28kg pork and of an increase 0.28kg poultry per capita and year compared to current levels. This decrease in demand implies an absolute reduction of GHG emissions of 77.6kg CO_2-eq per cap per year and an absolute reduction of 5 198 217 metric ton CO_2-eq per year. Equivalent to a decrease of GHG emissions by 9% compared to current level. The main contributor to this reduction was as expected the decrease in demand for beef. These results are similar to previous studies conducted within this research area. Edjabou and Smed (2013) concluded a reduction of carbon footprint from foods of 2.3-8.8%, with a tax level of 0.15-1.73DKK[8] in their most cost-effective scenario. Säll and Gren (2015) results show that the reduction in beef is most important in reduction of GHG emissions, with a tax level of 24.29kr per kg[9] beef induced a reduction of 7.13% in terms of CO_2-eq. With a differentiated consumption tax on animal food products with a level of €60 ton CO_2-eq Wirsenius et al., (2011) concluded a reduction of 7% of total GHG emissions associated with EU agricultural.

Is it political feasible to impose this type of policy measure to reduce the demand for meat in France, is still ambiguous. The government in France has recently imposed a consumption tax on sugar sweetened beverage to affect the demand of these products, on the claim that a high consumption level should be unhealthy. The average price increase induced for sugar sweetened beverage by the consumption tax, was estimated to 6% from the before-tax price according to (Berardi et al., 2016). This number is comparable to the result from the results of this study where the imposition of the tax induced a price increase for beef 8%, pork 4% and poultry 4%, compared to before-tax prices. There has been some public debate of the effectiveness of this tax in France, though it is still imposed. Hence, there are similarities with the "soda tax" and the meat tax investigated in this study but there are some opposition we could expect. Since France is one of the largest beef producers within the EU area (FAO,2013), the sector is representing a vital part of their economy and offers many job opportunities. Therefore, could a consumption tax that aims to reduce the quantity consumed of these products be opposed by many politicians and their lobby groups, meat producers and meat consumers. Hence, Nordgren (2012) emphasises the importance of combining a consumption tax with other policy measures, that aims to increase the awareness of the link between meat consumption and climate changes.

7.1 Validity of results

Though there are some limitations to this study that needs to be considered when interpreting the findings. The missing values generated by the linear regression analysis might have affected the values of the demand and income elasticities, in both stages. However, since the results seems to be in line with previous estimations of meat demand, this have most likely not affected the results significantly. The calculation of the optimal tax rate is also exposed to some uncertainties concerning, the assumption regarding the value of SCC which is stressed in the sensitivity analysis. Since it is difficult to estimate the environmental effect generated by emitting one more unit of carbon dioxide equivalents. The LCA methodology that Leip et al. (2010) used to compile the data for the GHG emission intensity for beef,

[8] Corresponding to a tax level of approximately €0.020-0.232 in 2007 year prices, www.xe.com.
[9] Corresponding to approximately € 0.0225 in 2009 year prices, www.xe.com.

pork and poultry does also have some limitations. That most likely affected the values used in this study. The assumption of threating the GHG emissions intensity as equal for imported and domestically produced is according to data in the detailed trade matrix from FAOSTAT (2013) not a too stringent assumption. Since this data shows that France mainly imports from other EU countries, which have similar production process as France and comparable levels of GHG emission intensity.

7.2 Further research

There exists a research gap within this area, there exists only a few studies that has examined the environmental effects of levying a consumption tax on livestock products. The one's that has been published are mainly investigating the effectiveness of this measure as a climate mitigation policy in high income countries. With the demand per capita growing for livestock products mainly meat in developing countries and emerging economies this is problem needs to be further investigate. For some emerging economies, Brazil the use of the production process intensive grazing gives rise to a more GHG intense production than the one used by the EU27 countries. It could therefore be very interesting to investigate what policy measure that would be suitable to reduce the GHG emission associated with their livestock production. Many of the studies does only focus on national consumption tax, to address this issue it could be interesting to perform more studies investigating global tax schemes. However, these kinds of studies rely on the availability of data which can be difficult to attain, especially for food prices. Since this study only focused on the climate effects, another possible extension of this study could be to include more environmental effects.

Appendix 1.

Table A.1. Results for the demand system, the last equation in each of the stages where dropped during estimation procedure.

Results from the first stage aggregated food commodities:
Equation 1 Meat
Equation 2 Dairy
Equation 3 Fruit
Equation 4 Bread and Cereals
Equation 5 Vegetables

$W = Budget\ share$

Equation: EQAIDSW1	Equation: EQAIDSW2
Dependent variable: WP1	Dependent variable: WP2
Mean of dep. var. = .325368	Mean of dep. var. = .184574
Std. dev. of dep. var. = .041500	Std. dev. of dep. var. = .558542E-02
Sum of squared residuals = .510861E-03	Sum of squared residuals = .189876E-03
Variance of residuals = .196485E-04	Variance of residuals = .730294E-05
Std. error of regression = .443266E-02	Std. error of regression = .270239E-02
R-squared = .988151	R-squared = .757192
LM het. test = 2.47153 [.116]	LM het. test = 1.63373 [.201]
Durbin-Watson = 1.53155	Durbin-Watson = 1.02375
Equation: EQAIDSW3	Equation: EQAIDSW4
Dependent variable: WP3	Dependent variable: WP4
Mean of dep. var. = .094299	Mean of dep. var. = .239458
Std. dev. of dep. var. = .010621	Std. dev. of dep. var. = .022664
Sum of squared residuals = .224335E-03	Sum of squared residuals = .700798E-02
Variance of residuals = .862826E-05	Variance of residuals = .269538E-03
Std. error of regression = .293739E-02	Std. error of regression = .016418
R-squared = .920548	R-squared = .466678
LM het. test = .120223E-03 [.991]	LM het. test = .930338 [.335]
Durbin-Watson = .727639	Durbin-Watson = .662042

Results from the second stage meat commodities:
Equation 1 Beef
Equation 2 Pork

Equation: EQAIDSW1	Equation: EQAIDSW2
Dependent variable: W1	Dependent variable: W2
Mean of dep. var. = .308026	Mean of dep. var. = .409562
Std. dev. of dep. var. = .011594	Std. dev. of dep. var. = .021732
Sum of squared residuals = .174014E-02	Sum of squared residuals = .107424E-02
Variance of residuals = .669284E-04	Variance of residuals = .413170E-04
Std. error of regression = .818098E-02	Std. error of regression = .642783E-02
R-squared = .575955	R-squared = .912415
LM het. test = 2.01620 [.156]	LM het. test = 1.17136 [.279]
Durbin-Watson = 2.50912	Durbin-Watson = 2.12915

Appendix 2.

Table A.2 Results of estimated parameters for the demand systems.

$\alpha = A$
$\beta = B$
$\gamma = C$
T = Time-trend

1=Meat
2=Dairy
3=Fruit
4=Bread and Cereals
5=Vegetables

Number of observations = 26 Log likelihood = 453.884
Schwarz B.I.C. = -402.795

	Parameter Estimated	Standard Error	t-statistic	P-value
C11	-.047306	.038269	-1.23614	[.216]
C12	-.070055	.022353	-3.13406	[.002]
C13	.080463	.014279	5.63498	[.000]
C14	.049986	.044904	1.11317	[.266]
C22	-.054895	.027708	-1.98124	[.048]
C23	.024195	.014751	1.64027	[.101]
C24	.151279	.034957	4.32761	[.000]
C33	.036751	.011105	3.30937	[.001]
C34	-.170845	.026232	-6.51289	[.000]
C44	-.027844	.129733	-.214621	[.830]
A1	.418903	.353576E-02	118.476	[.000]
A2	.186922	.264375E-02	70.7034	[.000]
A3	.082159	.215582E-02	38.1104	[.000]
A4	.190105	.979442E-02	19.4095	[.000]
T1	-.087019	.276153E-02	-31.5109	[.000]
B1	-.157837	.018341	-8.60571	[.000]
T2	-.292338E-02	.225585E-02	-1.29591	[.195]
B2	-.070217	.011526	-6.09219	[.000]
T3	.013230	.172373E-02	7.67502	[.000]
B3	.099015	.011818	8.37817	[.000]
T4	.045381	.752314E-02	6.03222	[.000]
B4	-.049182	.063652	-.772659	[.440]

$\alpha = A$
$\beta = B$
$\gamma = C$

1=Beef
2=Pork
3=Poultry

Number of observations = 26 Log likelihood = 184.500
Schwarz B.I.C. = -170.671

	Parameter Estimated	Standard Error	t-statistic	P-value
C11	-.059384	.052980	-1.12087	[.262]
C12	-.128431	.033993	-3.77813	[.000]
C22	.112898	.040713	2.77303	[.006]
A1	.101521E-02	.176536E-02	.575071	[.565]
A2	-.367523E-02	.148348E-02	-2.47744	[.013]
B1	.172424	.052238	3.30071	[.001]
B2	-.089565	.052441	-1.70791	[.088]

8 Reference

Allais, O., Bertail, P., & Nichle, V. (2010). The effects of a fat tax on French households' purchases: A nutritional approach. *American Journal of Agricultural Economics*, *92*(1), 228–245. https://doi.org/10.1093/ajae/aap004

Armin Schmutzler and Lawrence H.Goulder. (1997). The choice between emission taxes and output taxes under imperfect monitoring. *Journal of Agricultural and Environmental Management*, *17*(1), 51–64. https://doi.org/10.1006/jeem.1996.0953

Bajželj, B., Richards, K. S., Allwood, J. M., Smith, P., Dennis, J. S., Curmi, E., & Gilligan, C. A. (2014). Importance of food-demand management for climate mitigation. *Nature Climate Change*, *4*(October), 924–929. https://doi.org/10.1038/nclimate2353

Baumol, W. J., & Oates, W. E. (1988). *The theory of environmental policy. Cambridge university press.*

Buse, A. (1994). Evaluating the linearized almost ideal demand system. *American Journal of Agricultural Economics*, *76*, 781–793. https://doi.org/10.2307/3180282

Carpentier, A., & Guyomard, H. (2001). Unconditional Elasticities in Two-Stage Demand Systems: An Approximate Solution. *American Journal of Agricultural Economics*, *83*(1), 222–229. Retrieved from http://www.jstor.org/stable/1244312

Deaton, A., & Muellbauer, J. (180AD). *Economics and consumer behavior*. Cambridge university press.

Deaton, A., & Muellbauer, J. (1980). An almost ideal demand system. *The American Economic Review*, *70*(3), 312–326. https://doi.org/10.1016/0014-2921(94)90008-6

Edgerton, D. L. (1997). Weak separability and the estimation of elasticities in multistage demand systems. *American Journal of Agricultural Economics*, *79*(1), 62–79. https://doi.org/10.2307/1243943

Edjabou, L. D., & Smed, S. (2013). The effect of using consumption taxes on foods to promote climate friendly diets - The case of Denmark. *Food Policy*, *39*, 84–96. https://doi.org/10.1016/j.foodpol.2012.12.004

Eurostat database: Mean consumption expenditure by detailed COICOP level (in PPS). (2016). Retrieved March 20, 2017, from http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hbs_exp_t121&lang=en

FAOSTAT: Detailed Trade Marix. (2013). Retrieved May 5, 2017, from http://www.fao.org/faostat/en/#data/TM

FranceAgriMer. (2014). Consommation des produits carnés en 2014, 35. Retrieved from http://www.franceagrimer.fr/content/download/40104/372599/file/STA-VIA-CONSO 2014-aout2015.pdf

Gallet, C. A. (2010). Meat meets meta: A quantitative review of the price elasticity of meat. *American Journal of Agricultural Economics*, *92*(1), 258–272. https://doi.org/10.1093/ajae/aap008

Gerber, P. J.; Steinfeld, H.; Henderson, B.; Mottet, A.; Opio, C.; Dijkman, J.; Falcucci, A.; Tempio, G. (2013). *Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities*. Food and Agriculture Organization of the United Nations (FAO).

Green, R., & Alston, J. M. (1990). Elasticities in AIDS Models. *American Journal of Agricultural Economics*, *72*(2), 442–445. https://doi.org/10.2307/1242346

Hahn, B. R. W., & Stavins, R. N. (1992). Economic Incentives for Environmental Protection : Integrating Theory and Practice. *The American Economic Review*, *82*(2).

Hedenus, F., Wirsenius, S., & Johansson, D. J. A. (2014). The importance of reduced meat and dairy consumption for meeting stringent climate change targets. *Climatic Change*, *124*(1–2), 79–91. https://doi.org/10.1007/s10584-014-1104-5

Hope, C. W. (2006). The social cost of carbon: what does it actually depend on. *Climate Policy*, *3062*(May 2015), 37–41. https://doi.org/http://dx.doi.org/10.1080/14693062.2006.9685621

INSEE database: Annual Consumer Pice Index. (2017). Retrieved April 20, 2017, from http://www.bdm.insee.fr/bdm2/affichageSeries?idbank=001764363&bouton=OK&codeGroupe=1743&request_locale=en

INSEE database: Consumer price indices - Base 2015 - Detailed products (according to COICOP). (2017). Retrieved March 15, 2017, from https://www.bdm.insee.fr/bdm2/choixCriteres?codeGroupe=1744

INSEE database: Demographic Balance Sheet. (2017). Retrieved April 20, 2017, from https://www.insee.fr/en/statistiques/2382597?sommaire=2382613

IPCC. (2013). *Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.

Jensen, J. D., & Smed, S. (2013). The Danish tax on saturated fat - Short run effects on consumption, substitution patterns and consumer prices of fats. *Food Policy*, *42*, 18–31. https://doi.org/10.1016/j.foodpol.2013.06.004

Leip, A., Weiss, F., T. Wassenaar, Perez, I., Fellmann, T., Loudjani, P., … Biala, K. (2010). *Evaluation of the livestock sectors contribution to the EU greenhouse gas emissions (GGELS) - final report. European Commission, Joint Research Centre.*

Lööv, H., & Widell, L. (2009). *Konsumtionsförändringar vid ändrade matpriser och inkomster. Elasticitetsberäkningar för perioden 1960–2006.Swedish Board of Agriculture, Report 2009:8*.

Mcmichael, A. J., Powles, J. W., Butler, C. D., & Uauy, R. (2007). Energy and Health 5 Food , livestock production , energy , climate change , and health. *The Lancet*, *370*, 1253–1263. https://doi.org/10.1016/S0140-6736(07)61256-2

Muellbauer, J. (1975). Aggregation, Income Distribution and Consumer Demand. *The Review of Economic Studies*, *42*(4), 525–543.

Mytton, O. T., Clarke, D., & Rayner, M. (2012). Taxing unhealthy food and drinks to improve health. *BMJ*, *344*(2), 2931–2931. https://doi.org/10.1136/bmj.e2931

Nicoletta Berardi, Patrick Sevestre, Marine Tepaut, A. V. (2016). The impact of a “Soda tax” on prices. Evidence from Frenach micro data. *Banque de France, Working Paper*.

Nordgren, A. (2012). Ethical Issues in Mitigation of Climate Change: The Option of Reduced Meat Production and Consumption. *Journal of Agricultural and Environmental Ethics*, *25*(4), 563–584. https://doi.org/10.1007/s10806-011-9335-1

Nordhaus, W. (2014). Estimates of the Social Cost of Carbon: Concepts and Results from the DICE-2013R Model and Alternative Approaches. *Journal of the Association of Environmental and Resource Economists*, *1*(1/2), 273–312. https://doi.org/10.1086/676035

OECD database: Greenhouse gas emissions. (2017). Retrieved April 20, 2017, from https://stats.oecd.org/Index.aspx?DataSetCode=AIR_GHG

OECD database: PPPs and exchange rates. (2017). Retrieved April 5, 2017, from http://stats.oecd.org/Index.aspx?DataSetCode=MEI_PRICES#

Pigou, A. . (1920). *The Economics of Welfare*. Macmillan, London.

Pretty, J., Brett, C., Gee, D., Hine, R., Mason, C., Rayment, M., … Hine, R. (2017). Policy Challenges and Priorities for Internalizing the Externalities of Modern Agriculture. *Journal of Environmental Planning and Management*, *568*(2).

Segerson, K., & Miceli, T. J. (1998). Voluntary Environmental Agreements: Good or Bad News for Environmental Protection? *Journal of Environmental Economics and Management*, *36*, 109–130. https://doi.org/10.1006/jeem.1998.1040

Smed, S., Jensen, J. D., & Denver, S. (2007). Socio-economic characteristics and the effect of taxation as a health policy instrument. *Food Policy*, *32*(5–6), 624–639. https://doi.org/10.1016/j.foodpol.2007.03.002

Springmann, M., Godfray, H. C. J., Rayner, M., & Scarborough, P. (2016). Analysis and valuation of the health and climate change cobenefits of dietary change. *Proceedings of the National Academy of Sciences*, *113*(15), 4146–4151. https://doi.org/10.1073/pnas.1523119113

Springmann, M., Mason-D'Croz, D., Robinson, S., Wiebe, K., Godfray, H. C. J., Rayner, M., & Scarborough, P. (2016). Mitigation potential and global health impacts from emissions pricing of food commodities. *Nature Climate Change, 1*(November), 8. https://doi.org/10.1038/nclimate3155

Stavins, R. N. (2003). *Experience with market-based environmental policy instruments*.

Steinfeld, H., Gerber, P., Wassenaar, T. D., Castel, V., & de Haan, C. (2006). Livestock's long shadow - environmental issues and options. *Food and Agriculture Organization of the United Nations*, *3*(1), 1–377. https://doi.org/10.1007/s10666-008-9149-3

Stern, N. H. (2007). *The economics of climate change: the Stern review*. Cambridge university press.

Strotz, R. H. (1957). The Empirical Implications of a Utility Tree. *Econometrica*, *25*(2), 269–280.

Säll, S., & Gren, I.-M. (2015). Effects of an environmental tax on meat and dairy consumption in Sweden. *Food Policy*, *55*, 41–53. https://doi.org/10.1016/j.foodpol.2015.05.008

Tilman, D., & Clark, M. (2014). Global diets link environmental sustainability and human health. *Nature*, *515*(7528), 518–522. https://doi.org/http://www.nature.com/nature/journal/v515/n7528/full/nature13959.html

Tol, R. S. J. (2005). The marginal damage costs of carbon dioxide emissions: An assessment of the uncertainties. *Energy Policy*, *33*(16), 2064–2074. https://doi.org/10.1016/j.enpol.2004.04.002

Tol, R. S. J. (2012). A cost-benefit analysis of the EU 20/20/2020 package. *Energy Policy*, *49*, 288–295. https://doi.org/10.1016/j.enpol.2012.06.018

Traill, W. B., Mazzocchi, M., Niedźwiedzka, B., Shankar, B., & Wills, J. (2013). The EATWELL project: Recommendations for healthy eating policy interventions across Europe. *Nutrition Bulletin*, *38*(3), 352–357. https://doi.org/10.1111/nbu.12048

UNFCCC. (2015). Adoption of the Paris Agreement. *Paris Agreement*. Retrieved from http://ec.europa.eu/clima/policies/international/negotiations/paris/index_en.htm

Westhoek, H., Peter, J., Rood, T., Wagner, S., Marco, A. De, Murphy-bokern, D., … Oenema, O. (2014). Food choices , health and environment : Effects of cutting Europe ' s meat and dairy intake. *Global Environmental Change*, *26*, 196–205. https://doi.org/10.1016/j.gloenvcha.2014.02.004

Wirsenius, S., Hedenus, F., & Mohlin, K. (2011). Greenhouse gas taxes on animal food products: Rationale, tax scheme and climate mitigation effects. *Climatic Change*, *108*(1), 159–184. https://doi.org/10.1007/s10584-010-9971-x