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Pigouvian Consumption Taxes on Beef in Sweden

- A step towards climate mitigation

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Abstract As the anthropogenic share of emissions from agricultural (GHG) emissions exceeds those of the transport sector, there is a profound need to start mitigating the climate impact from the agricultural sector. Eighty percent of emissions from Swedish livestock production emanate from beef production. The high emission intensity of beef production indicates that a weighted tax would capture a large share of its GHG emissions. The purpose of this paper is to investigate by how much a GHG emissions differentiated Pigouvian tax of beef placed on the consumer level would reduce the negative environmental impacts through reduced consumption. The method used is a partial equilibrium competitive model where a Pigouvian tax based on the carbon footprint of 1 kg beef is imposed on the consumer level. The carbon footprint of each production system is based on life cycle assessments. Four production methods of beef are investigated: domestic conventional production in Sweden, organic production in Sweden, beef imported from the EU and beef imported from Brazil. A basic sensitivity analysis for sensitivity ratios was performed on the elasticities to capture the uncertainty estimates of the model and their effect on output variables. Results show that the total beef consumption in Sweden was reduced by 7.88% and the total carbon footprint was reduced by 788 467 ton CO_2 eq, thus indicating that a differentiated tax on beef placed on consumer level in an attempt to mitigate climate effects can be a cost-effective approach to abate GHG emissions.

Keywords: Beef consumption, Elasticities, GHG abatement, Pigouvian tax

Definitions

Carbon footprint – The total set of direct greenhouse gas emissions into the atmosphere caused by a firm, organization, even, product or person; Measured by greenhouse gas emission assessments or other forms of carbon accounting to calculate the climate changing impact of the subject in question; Often presented in the unit of CO_2 equivalents.

CO_2 – Carbon dioxide

CO_2 equivalents – Carbon dioxide equivalents; Quantity which defines the amount of carbon dioxide that would have the same global warming potential as a given composition and concentration of greenhouse gas; Obtained by multiplying the mass of the gas with its global warming potential.

EU – European Union

FAO – Food and Agriculture Organization of the United Nations

GHG – Greenhouse gases; Gases in the atmosphere that absorbs and emits radiation and greatly affect the planet's temperature; Primary gases are carbon dioxide, methane, nitrous oxide, ozone and water vapour.

Green taxation – Taxes intented to restrict envrionmentally destructive market activites through economic incentives.

LCA – Life cycle assessment; Life cycle inventory of a production system which can either be performed from the bottom up using process life cycle assessment at, in this case, farm-gate level, or from the top down using national accounts and statistics.

Pigouvian taxation – Taxes that internalizes the social cost of negative market externalities, such as pollution. Often used in green taxation.

PMB – Private marginal benefit

SMB – Social marginal benefit

WTO – World Trade Organization

Table of Contents

1. Introduction

The Introduction section contains general background of the problem in question, the purpose and research question of the thesis, its scope and limitations, and a brief discussion of ethics surrounding the topic. It also contains the disposition of the thesis, a literature review, specific problem background, and expected results.

1.1 Background

In recent years has the debate of agriculture in general, and the livestock sector in particular, been in focus for its share of climate changing impacts. The Food and Agriculture Organization of the United Nations (FAO) describes the role of livestock as:

"The livestock sector emerges as one of the top two or three most significant contributors to the most serious environmental problems, at every scale from local to global." (FAO, 2006)

Livestock production gives rise to several significant environmental impacts. Some are positive, like open landscapes from grazing animals, but the majority is negative, causing long term damages. The intensification and industrialization of the sector shifts the production into a more competitive state over land, water and other resources. It is the largest anthropogenic user of land, accounts for 70 percent of all agricultural land, and occupies 30 percent of land surface on the planet. Deforestation, land degradation, and water pollution from animal wastes, antibiotics, hormones, chemicals, fertilizers, and pesticides are severe negative side-effects of industrialized livestock production (FAO, 2006).

Viewing the livestock sector from a climatic perspective, it is a major source of greenhouse gas emissions. It is responsible for 9 percent of the anthropogenic carbon dioxide emissions, or 18 percent measured in CO_2 equivalents. This is a higher percentage than for the transport sector. The high percentage is much due to the global warming potential of methane gas emissions, for which it accounts for 37 percent of anthropogenic total methane emissions. With projected growth of population and income, the environmental impact of livestock production per unit needs to be cut in half – only to avoid increasing damage level beyond its current levels (FAO, 2006).

The core problem is that the livestock sector does not pay for its negative environmental and climatic impact. The potential of reducing emissions through improved production is limited since a large share of the emissions is a natural effect of the animal in question and the land use associated with raising it. A change in consumption patterns through economic instruments is likely to have the largest impact to save the environment from further deterioration.

1.2 Purpose

The primary purpose of this paper is to investigate to what extent beef consumption and GHG emissions associated with its production are reduced by imposing a climate tax on the consumer side. The study aims to construct a Pigouvian tax per kilogram sold beef in order to internalize the negative externality of GHG emissions and to see how consumption patterns change after the tax is imposed. The tax is based on the carbon footprint of the production method from life cycle assessments at farm-gate level. A partial equilibrium model will be used, using elasticities to compute new consumption levels. The analysis will focus on the environmental gains of a climate tax on beef, and welfare will be measured in terms of consumer surplus.

1.3 Research Question

The main research question of this thesis is: By how much is beef consumption in Sweden decreased by imposing a tax on consumer level, thus reducing the environmental impact through reduced GHG emissions?

1.4 Scope and Limitations

The study is geographically limited to the Swedish market and will only consider beef. Four different production methods for beef are considered:

- Domestic conventional production
- Domestic organic production
- Imported conventional, EU
- Imported conventional, Brazil

The commodity of beef is considered not to be homogenous as most consumers differentiate between domestically produced and imported beef, as well as between conventionally produced and organically produced beef.

The data is collected over a period of eight years, from 2005 to 2012. The eight observations are annual totals for respective category.

The pollutant in focus is greenhouse gas emissions (GHG) measured in CO_2 equivalents. The impact of other pollutants from production, such as hormones, antibiotics, ammonia, or phosphor, will not be included unless specifically specified.

Due to the time limit of the study, European Union (EU) and World Trade Organization (WTO) trade rules and regulations are not taken into account.

1.5 Ethics

Discussions surrounding the ethics of beef consumption – whether one should or should not eat meat – will not be touched upon in this study. Health aspects regarding beef consumption or the absence of it will also be excluded. It is not in the author's interest or place to neither judge nor promote either side of the "meat-eaters versus vegetarians" debate, but to investigate the economic effects of a tax that could potentially reduce environmental impact by internalizing the social cost of GHG emissions. The subject of animal welfare will lightly be touched upon in sections concerning production systems, primarily as a cost function as increased animal welfare increases costs (larger stalls, more land use through free grazing, etc.), and will be mentioned in the discussion. Again, the author would like to point out that this is a paper in the field of *economics*, not ideology.

1.6 Disposition of Thesis

The paper is structured as follows: Section 1 continues with the problem background and why a tax on beef should be considered, previous studies, and expected results. Section 2 describes the methodological approach used in the theoretical structure of partial equilibrium, elasticities and model calibration as well as taxation scenarios and sensitivity analysis. Section 3 explains the process behind data retrieval for consumption, domestic production and prices of beef in Sweden, the carbon footprints of the different production systems through life cycle assessments, and the cost of CO2. In section 4 presents the results from the taxation scenarios and the sensitivity analysis. Section 5 discusses the results found in previous section, and final concluding remarks are found in section 6.

1.7 Problem Background: Why to Consider a Tax on Beef

The global climate change that we are beginning to see consequences of can lead to extensive global problems if GHG emissions are not restricted in the near future. As the anthropogenic share of emissions from agricultural GHG emissions exceeds those of the transport sector, there is a profound need to start mitigating the climate impact from the agricultural sector.

There is an established link between consumption of meat and global warming, where the global average daily meat consumption needs to be reduced from 100 gr to 90 gr per person per day if the reduction targets of GHG emissions are to be met in 2050 (Edjabou, 2012). The economic factors behind recent years increased meat consumption in Sweden are increased disposable income and a relative low price of meat. Of all the meats, beef is the largest emitter of CO_2 equivalents: eighty percent of emissions from Swedish livestock production emanate from beef production (Cederberg et al., 2009). Regulations on consumer behavior are already in place for selected products such as alcohol and tobacco. The high emission intensity of beef indicates that a weighted tax would capture a large share of its GHG emissions. A tax-induced reduction of consumption would also decrease land area used (Wirsenius et al., 2010).

Consumption taxes are optimal if high monitoring costs and comparatively low technical potential for emission reductions exists on the production side, and if possibilities for output substitution is great. Production of beef fulfills all these criteria for GHG emissions thus indicating that a tax at consumer level is a better choice. A tax levied at consumer level also prevents emission leakage and will not disadvantage domestic producers (Wirsenius et al., 2010).

However, a conflict of interest exists between climate mitigation goals and other aspects of beef production. Free range grazing animals contribute to biodiversity and preserve open landscapes, but the slower growth rate means that the animal is older when slaughtered. An intensified production on stall can thus be argued to be preferred to a slow outdoors rearing as the slaughter age is lower, hence GHG emissions are minimized, but an intensified production requires high energy feed grown with unsustainable nutrient leakage and pesticide use. Intensified production is not viable from an animal welfare perspective. Animals raised under conditions similar to their natural environment, allowed to practice natural behavior, are healthier and less prone to infection. Less antibiotics are used and hence a reduced development of antibiotic-resistant bacteria (Jordbruksverket, 2013).

1.8 Previous Studies

In recent years, the subject of taxation on consumer products, especially meat products, has been popular in political debates and several studies have been published. One of the largest from a global policy perspective is FAO's report "Livestock's long shadow" (2006), which assess the livestock sector's full impact on the environment. It discusses livestock as a globally important sector from a social and political point of view, structural changes in technology and geography, the land degradation livestock causes, livestock with respect to atmosphere and climate, its increased water use, effects on biodiversity, and policy framework to improve the situation. The report stresses the urgency at which the issue must be addressed, and that major reductions in environmental impact can be done at a reasonable cost.

A study performed at EU level to investigate GHG taxes on animal food products was conducted by Wirsenius et al. (2010), with rationale, tax schemes and climate mitigation effects. Output taxes were considered an efficient policy instrument due to the high monitoring costs and comparatively low technical potential for emissions reductions on the production side. The emission mitigation potential of GHG weighted consumption taxes on animal food products was assessed and results indicated that an emission reduction of circa 32 million ton of CO_2 equivalents in the EU-27. An estimation of land use changes from altered food production was also presented together with additional mitigation potential in allocating land to bioenergy production. The results showed that most of the effect of such a tax can be captured by taxing the consumption of ruminant meat alone.

The effect of using consumption taxes on foods to promote climate friendly diets was investigated in Denmark by Edjabou (2012). Twenty-three different food groups were taxed based on CO_2 equivalents in the attempt to internalize the social cost of GHG emissions. Changed dietary compositions for different taxation scenarios, both compensated and uncompensated, were compared and health consequences derived. Scenarios where consumers were not compensated for the increased tax level resulted in a decrease in total daily amount of kJ consumed, whereas compensated scenarios lead to an increase. In most scenarios the consumption of saturated fat decreased. The consumption of beef decreased the most with between 12 – 33 percent in the scenarios presented due to its high climatic impact. In general, the results in the Danish study showed a low cost potential for using consumption taxes to promote climate friendly diets.

Several Swedish and international studies have been made in the field of life cycle assessment to measure the carbon footprint and environmental impact of agricultural production methods. A study conducted by SIK, the Swedish Institute for Food and Biotechnology, in 2009 was conducted to gain insight of the current life cycle greenhouse gas emissions from the production of meat, milk and eggs in Sweden from 1990, the base year of the Kyoto protocol, to 2005. It uses hybrid-life cycle assessment approach to analyze the activities and emissions linked with the production of selected products. They conclude that livestock and agricultural production in Sweden have reduced its greenhouse gas emissions over the time period investigated but that about one-third of the reductions are due to lowered domestic production, with the exception of poultry (SIK, 2009).

There is much ongoing research. The Swedish University of Agricultural Sciences has an ongoing investigation of green consumption taxes in Sweden, looking at cattle, pork and poultry meat using an Almost Ideal Demand System (AIDS). Three pollutants are included in this study – greenhouse gases, nitrogen and phosphorus – and the study is designed to evaluate the impact of a tax, reflecting environmental damage at the margin. Results indicate that a tax on all three meats could decrease above pollutants with at least 27 percent (Säll, 2012).

This paper aims to fill the void of the much debated consumption of meat from a climate perspective by focusing only on beef consumption in Sweden and effects of a tax based on the production system's carbon footprint. It is to be an aid for policy makers in the context of livestock production and climate change, with the intention to quantify the environmental gains of reduced consumption.

1.9 Expected Results

According to the Law of Demand, quantity demanded decreases as price increases. In post-tax scenarios quantity demanded is expected to decrease for all four production methods as the price is higher. The production with the largest carbon footprint is believed to display the largest change in demanded quantity due to it being subjected to the largest impact of the tax. The hypothesis is that imported meat has a higher carbon footprint than domestic and will therefore decrease more in quantity demanded. Organic beef is predicted to have the smallest carbon footprint and will therefore be least affected by the tax. Total carbon footprint will be reduced and resulting in an overall positive effect on the environment. Welfare measured in consumer surplus will decrease.

2. Method

The Method section is divided into two parts. Part 1 explains the economic theory behind to model, such as partial equilibrium, elasticities, Pigouvian taxation, the imposition of a specific tax, and economic welfare. Part 2 explains the empirical application of the theoretical framework, how the method is applied and how the model is calibrated.

2.1 Theoretical Framework

2.1.1 Partial Equilibrium

As we learn in basic economics courses, a market consists of supply and demand. The demand curve is defined as "showing the quantity demanded at each possible price, holding constant the other factors that influence purchases". Likewise, the supply curve is defined as "the quantity supplied at each possible price, holding constant the other factors that influence firm's supply decisions" (Perloff, 2008). In other words, the aggregated demand curves of consumers in a market illustrate how much they want to consume at different prices, and the aggregated supply curve show how much the producers are willing to supply at different prices. The point where the two curves intersect on a graph – where the two functions are equal – is where the market reaches its equilibrium. At equilibrium, the market is in balance and the quantity demanded equals the quantity supplied at a certain price, giving the equilibrium quantity and the equilibrium price. The Law of Demand states that if the price of a good increases the quantity demanded decreases, and if the price of a good decreases the quantity demanded increases – all else being equal (Perloff, 2014).

In a partial equilibrium, one only considers one market in isolation. Prices and quantities of other goods are fixed and one only looks at changes in equilibrium in that particular market, thus ignoring the possibility that changes in the one market affects other markets and their equilibriums. The partial equilibrium model is very useful if one wants to analyze the effect of, for instance, a tax on a specific market. It is the isolation perspective that separates a partial equilibrium from a general equilibrium, where one considers multiple or all markets and determines their equilibrium simultaneously (Perloff, 2008).

2.1.2 Elasticities

There are different kinds of elasticities: own-price elasticity of demand, own-price elasticity of supply, cross-price elasticities, income elasticity, and so on. The own-price elasticity of demand (or simply elasticity of demand) and the own-price elasticity of supply (elasticity of supply) are used in this study. An elasticity is a summary statistic of the responsiveness of the quantity demanded or quantity supplied. It measures percentage change and describes the relationship between the supply or demand of a good and the price of the good.

The demand elasticity is denoted ε and is calculated by dividing a percentage change in quantity demanded of a good by a percentage change in price of the same good.

$$\varepsilon = \frac{\partial Q}{\partial P} \times \frac{P}{Q}$$

Where ∂Q/∂P is the partial derivative of the demand function with respect to price (Perloff, 2008). It indicates the price sensitivity of consumers: if the elasticity of demand is -0.5 and the price increases by 1 percent, the demand decreases by 0.5 percent. Usually Q is written as a function of other variables, Q(P, P', I), to keep in mind that the demand is affected by a multiple of factors such as its price, the price of other goods, and the income of potential demanders, but these factors are held constant when computing the market demand elasticity (Snyder & Nicholson, 2009). A demand is called perfectly inelastic when ε is equal to zero. If ε is between 0 and -1 it is inelastic, and elastic if below -1. The elasticity usually varies along the demand curve except for a special type of curve. Constant-elasticity demand curves have the same elasticity at every point on the demand curve and have an exponential function form (Perloff, 2008).

The elasticity of supply indicates the responsiveness of quantities supplied. It is denoted as η and is the percentage change in quantity supplied of a good divided by the percentage change in price, and is calculated in the same way as the demand elasticity.

$$\eta = \frac{\partial Q}{\partial P} \times \frac{P}{Q}$$

Due to the upwards-sloping curve of the supply function, the supply elasticity is always positive. If η is equal to 0, the supply is perfectly inelastic, meaning a 1 percent increase in price results in a 0 percent change in the supplied quantities and the supplied quantities do not change. If η is between 0 and 1, the supply is inelastic, and it is elastic if η is larger than 1 (Perloff, 2008). High values for η thus means that small increases in market price lead to relatively large responses in supply.

There is a difference in short-run and long-run elasticities due to the time it takes for consumers or firms to adjust for a specific good. When modeling in a partial equilibrium, short-run elasticities are used (Perloff, 2014).

2.1.3 Pigouvian Taxation

In reality, markets are not perfect and real world economics suffer from a variety of market failures, giving rise to externalities (Salanié, 2011). An externality is when the well-being of a person or the production capability of a firm is directly affected by the actions of firms or other consumers, rather than being indirectly affected through price changes (Perloff, 2014). The GHG emissions is a negative externality with a global impact on both people and the environment. In order to adjust for such a negative externality, corrective taxes can be used, thus attempting to bring a second-best economy back to the first-best Pareto frontier. The thought behind it is that the prices of an economy characterized by market failures do not serve their allocative function well, and by imposing a proper set of taxes a correct price incentive will be restored (Salanié, 2011).

Pigouvian taxation is named after the economist Arthur Pigou, who also developed the concept of externalities. A Pigouvian tax is a corrective tax which aims to internalize the negative externality of a market activity. It is motivated when the private cost is lower than the social cost for the market activity: when the private marginal benefit (PMB), given by the inverse demand function, exceeds the social marginal benefit (SMB). The quantity at the private equilibrium (q_m) is larger than at the social equilibrium (q_s), hence the quantity should be reduced to the social optimum. In order for the tax to incorporate the entire negative externality, it should be set the equal the difference between market quantity of the private marginal benefit and the social optimum quantity of the social marginal benefit (Salanié, 2011).

If the government imposes a specific tax of the consumption of a dirty good, the tax, *t*, should be fixed at:

$$t = PMB(q_m) - SMB(q_s)$$

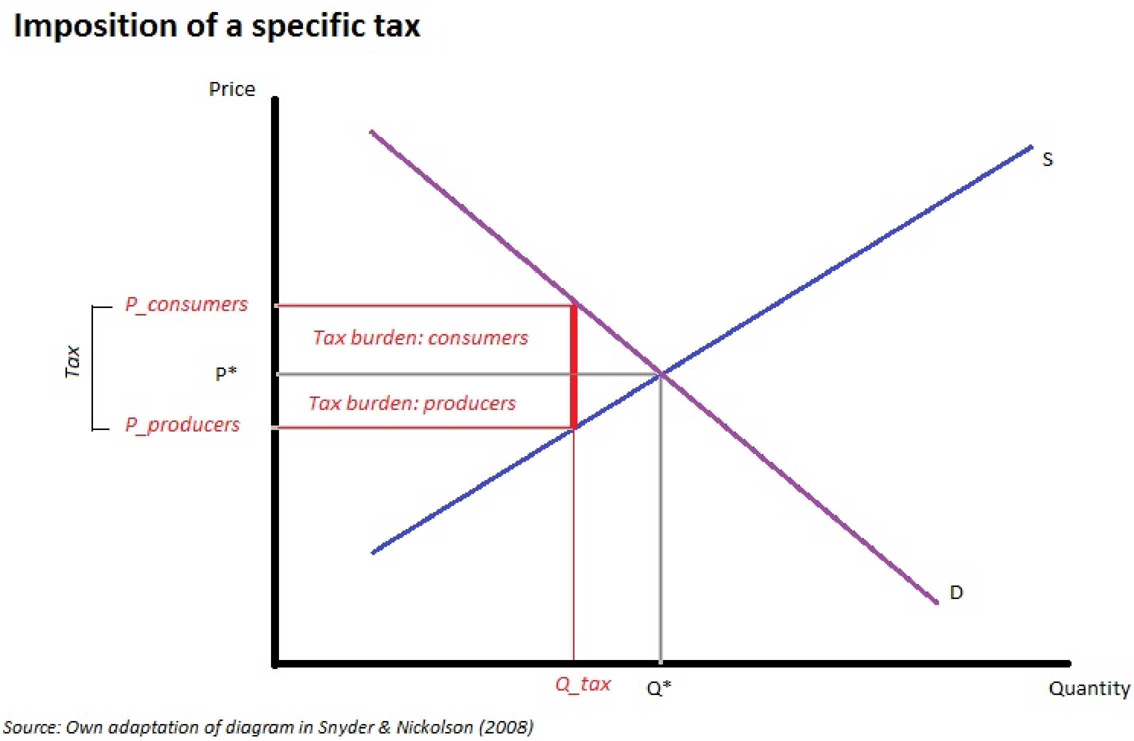
The market equilibrium then corresponds to a production quantity q so that PMB(q) – t = MC(q), which holds for $q = q_s$. Thus the Pigouvian tax internalizes the externality and brings the economy back to its first best option (Perman et al, 2011; Salanié, 2011).

As with all taxes, green taxation creates distortions in several markets. One example is the labour market: by construction the green tax increases the price of the dirty good, making it more expensive, but the consumer still buys it, hence reducing the purchasing power of wages. In turn, this discourages the labour supply (Salanié, 2011). If the imposition of a direct tax does not accomplish optimal redistribution, then the dirty good may be a poor target for taxation, if it for instance is heavily consumed by the poor.

2.1.4 Imposition of a Specific Tax

Even though a tax is imposed on only the consumers or only the producers, the tax burden is shared between consumers and producers. This is showed in Figure 1, which displays a classic supply and demand-diagram with price on the y-axis and quantity on the x-axis. The downwards-sloping purple line is the demand curve marked "D" and the upwards-sloping blue line is the supply curve marked "S". In equilibrium, the price is P* and the quantity is Q*. When imposing a specific tax, the thick red line in between the supply and demand curves, it creates a wedge between the price the consumers pay and the price the producers receive. No matter how the tax burden falls, the tax per unit is the same: price of consumers minus price of producers equals the tax (Snyder & Nicholson, 2008).

Figure 1. Imposition of a specific tax (Own adaptation of diagram in Snyder & Nicholson (2008))



How the tax burden is allocated between the two, is determined by the elasticities of supply and demand. By deriving the price of the supply and demand functions with respect to the tax, one arrives at a tax burden allocation consisting of the elasticities. P_D is the consumer price, P_S is the producer price, Q_D is quantity demanded, Q_S is quantity supplied, t is the tax, and D_P and S_P are the price derivatives of demand and supply.

$$dP_D - dP_S = dt$$

$$D_P dP_D = S_P dP_S = S_P(dP_D - dt)$$

Resulting in

$$\frac{dP_D}{dt} = \frac{S_P}{S_P - D_P}$$

Which is equal to the elasticity of supply divided by supply elasticity minus demand elasticity, or

$$\frac{\eta}{\eta - \varepsilon}$$

If the demand is perfectly elastic, dP_D/dt is equal to 1, and the tax burden is completely shouldered by the consumers. Hence we can see that the actor with the least elastic response, in absolute terms, will experience most of the tax burden (Snyder & Nicholson, 2008).

2.1.5 Economic Welfare

The term welfare in economics refers to the well-being of different groups and the efficient allocation of resources. This is because economists and policy-makers want to know how the concerned groups are affected, positively or negatively, by changes in equilibrium prices and quantities from various policy instruments (Perloff, 2008). This paper will focus on the welfare of producers and consumers in terms of surpluses.

The consumer welfare is the benefit a person receives by consuming a good in excess in relation to the cost of the good. It is based on the inverse demand curve which reflects the marginal willingness to pay: how much a consumer is willing to spend for one extra unit. It reflects the marginal value a consumer places on the last unit of output. If thought of graphically, it is the area below the inverse demand function and above the market price up to the quantity demanded. The advantage of using consumer surplus instead of utility to measure welfare is that the consumer surplus is measured in dollars and can therefore be easily combined and compared. Another advantage is that it is easy to measure: only calculate the area below the inverse demand function and above the market price (Perloff, 2008).

Producer surplus is similar to consumer surplus but concerns the supply side of the market. It is a measure of the benefits for a firm by engaging in market activity and is the difference between the minimum amount necessary at which the producer is willing to sell the good and the amount for which the good is actually sold. If displayed graphically, it is the area above the supply curve and below the market price of the good (Perloff, 2008).

2.2 Empirical Application

2.2.1 Method Used

The model used is a partial equilibrium competitive model as it clearly illustrates taxation effects on a chosen market (Snyder & Nicholson, 2008; Perloff 2008). A Pigouvian tax will be placed on beef to internalize the negative externality of greenhouse gas emissions. Consumption taxes are preferred if monitoring costs are high and there is low technical potential for emission reduction on the production side (Wirsenius et al., 2010). By placing the tax on consumers rather than on the producers, one can also prevent carbon leakage (Edjabou et al, 2013) and domestically produced products will not be disadvantaged on the competitive market.

The tax will be constructed from a lifecycle assessment of greenhouse gas emissions measured in CO_2 equivalent for the four different production systems for beef. This is multiplied by the social cost of CO_2, giving:

$$\text{Tax imposed: } t = e_i \cdot p_e \quad (1)$$

Where the t is the tax imposed; e_i is the carbon footprint from the life cycle assessment measured in kg CO_2 equivalents for 1 kg beef; and p_e is the price per kg of CO_2 equivalents.

However, even though the tax is placed on the consumers, both consumers and producers will share the tax burden as the imposition of a specific tax per unit creates a wedge between the price consumers pay and the price producers receive (Perloff, 2008; Snyder & Nicholson, 2008). The tax burden is calculated using elasticities of demand and supply:

$$\text{Tax burden, consumers} = \frac{\eta}{\eta - \varepsilon} \quad (2)$$

Where η is elasticity of supply and ε is the elasticity of demand. The tax burden for producers is obtained by subtracting the tax burden of consumers from 1.

To calculate the new consumption levels after tax, a rewriting of the elasticity expression is used.

$$\varepsilon = \frac{dq}{dp} \cdot \frac{p}{q} \quad (3)$$

Where q is the quantity of beef and p is the price of beef. If the elasticity is assumed to be constant, it can be considered a differential equation as followed (Snyder & Nicholson, 2008), where k is a constant:

$$q = k \cdot p^{\varepsilon} \quad (4)$$

To prove that $q = k \cdot p^{\varepsilon}$, the $\frac{dq}{dp}$ expression is differentiated, and then q and $\frac{dq}{dp}$ are inserted into the original elasticity expression:

$$\frac{dq}{dp} = \frac{d(k \cdot p^{\varepsilon})}{dp} = k \cdot \epsilon \cdot p^{(\epsilon-1)} \tag{5}$$

$$\frac{dq}{dp} \cdot \frac{p}{q} = k \cdot \varepsilon \cdot p^{(\varepsilon-1)} \cdot \frac{p}{k \cdot p^{\varepsilon}} = \varepsilon \cdot \frac{k \cdot p^{\varepsilon}}{k \cdot p^{\varepsilon}} = \varepsilon \qquad \text{(6) and (7)}$$

If a pair of corresponding values of p and q are known (p_0, q_0), the constant k is determined by inserting p_0 and q_0 into the constant elasticity expression, which gives q in terms of p_0 and q_0:

$$q_0 = k \cdot p_0^{\varepsilon} \rightarrow k = \frac{q_0}{p_0^{\varepsilon}} \tag{8}$$

$$q = k \cdot p^{\varepsilon} = \frac{q_0}{p_0^{\varepsilon}} \cdot p^{\varepsilon} = q_0 \cdot \left(\frac{p}{p_0}\right)^{\varepsilon} \tag{9}$$

This can then be rewritten using the natural logarithm:

$$ln(q) = ln(q_0) + \varepsilon \cdot ln\left(\frac{p}{p_0}\right) \tag{10}$$

$$q = exp\left(ln(q_0) + \varepsilon \cdot ln\left(\frac{p}{p_0}\right)\right) \tag{11}$$

Where the last equation, eq (11), is used to calculate new consumption levels of beef after the environmental tax is imposed.

The change in carbon footprint is calculated as the difference in climatic impact before and after the tax, where E is total carbon footprint in CO_2 equivalents; e_i is the carbon footprint of the production method per kg beef; q_{i1} is the quantity post-tax, and q_{i0} is the quantity before the tax.

$$\Delta E = (e_i \cdot q_{i1}) \cdot (e_i \cdot q_{i0}) \tag{12}$$

Total change in carbon footprint for all production methods:

$$\Delta E = \sum((e_i \cdot q_{i0}) \cdot (e_i \cdot q_{i0})) \tag{13}$$

The welfare effects are measured in change in consumer surplus. ΔCS is the change in consumer surplus; p_{i1} is the price after tax; and p_{i0} is the price before the tax.

$$\Delta CS = 0.5 \cdot (p_{i1} - p_{i0}) \cdot (q_{i1} - q_{i0}) \tag{14}$$

2.2.2 Elasticities Used

The demand elasticities for different food groups from Jordbruksverket (2009) are based on data collected from 1960 to 2005, and shows that consumers are more price sensitive during the last two decades than previously. One of the most price sensitive product groups is meat, where consumption increased as the price of other product groups investigated increased. The study also showed a strong correlation between increased income and increased meat consumption. Agricultural price control mechanism was applied during the majority of the time period in question, resulting in relative stable pricing trends. Parts of the regulations were discontinued during the 1990's, causing the relative prices of screened product groups to fall. Other events triggering increased consumption were entering the European Union in 1995 and a VAT reduction in 1996.

The demand elasticities from Jordbruksverket (2009) and Säll (2012) are calculated from a dynamic LA/AIDS[1] model. The LA/AIDS model estimates economic effects on consumption and distinguishes the effect of price from other factors. It uses SURE, Seemingly Unrelated Regression Equations, which is a more effective estimate which compares and estimates elasticities for each product separately. The model explains short term demand behavior as the consumption pattern is affected by habitual consumption, unstable preferences over time, household costs associated with consumption changes, and incomplete information that prevents households to fully adjust each time period (Jordbruksverket, 2009).

Comparing the two studies, the own-price elasticity for beef was -0.394 (Säll, 2012) and -0.658 (Jordbruksverket, 2013). In Säll's calculations, a 1 percent increase in price would lead to a 0.394 percent decrease in quantity demanded, while the calculations from Jordbruksverket show that a 1 percent increase in price would lead to a 0.658 percent decrease in quantity demanded. As the elasticities calculated by Säll are Marshallian, which means that they are uncompensated for income effect (Perloff, 2008), -0.394 will be used in the model. This elasticity estimate is also close to a study conducted in Denmark, finding the own-price elasticity of beef to be -0.398 (Edjabou, 2010).

For the supply side, an assumed elasticity of 1 will be used as there was no available data.

2.2.3 Data and Model Calibration

The partial equilibrium model will be calibrated in Excel 2010 using the equations explained in "Method Used". An average of the total annual beef consumption for the time

[1] Linear Approximative Almost Ideal Demand System

period investigated will be calculated. Domestically produced and imported percentages of the total consumption are calculated using a geometric mean of the allocation percentages from the eight observations. Of the total consumption of beef produced domestically, a 2 percent allocation is used for organic production, meaning that it is assumed that 2 percent of domestic production is organic. Of the total consumption originating from imports, 67 percent is allocated to imports from the EU and 33 percent to imports from Brazil. Further explanations of how these allocations were decided are presented in the section "Collection of Data".

2.3 Taxation Scenarios

The principal calculation goal is to assess the impact on GHG emission levels from tax-induced higher consumer prices. In order to obtain the most effective reduction of GHG emissions, consumer taxes are differentiated to the GHG emissions level per kg of beef in each production system. Therefore, the tax scheme is assumed to be weighted according to the production emission intensities.

Two taxation scenarios will be investigated. Scenario 1 is a so-called neutral scenario where each of the initial parameters are applied. Scenario 2 aims to illustrate a sustainable scenario where climate mitigation and long term sustainable consumption of beef are strictly prioritized. The model scenario is calibrated so that the production method with the lowest carbon footprint faces the lowest post-tax consumer prices by regulating the social cost of CO_2 to increase to climatic impact of the tax.

Scenario 1: Neutral Scenario

A neutral scenario where initial model parameters are applied in order to see how a tax will affect the variables of the beef market.

Scenario 2: Sustainable Scenario

The model is calibrated to illustrate a long term sustainable scenario where the production method with the lowest carbon footprint receives the lowest post-tax consumer price by increasing the cost of CO_2.

2.4 Sensitivity Analysis

A basic sensitivity analysis will be performed in order to assess and understand which uncertainties and risk factors that are driving the model. The model input variables which significantly contribute to the largest model output variances are the elasticities of supply and demand. They are characterized as highly sensitive and uncertain with profound impact on the distribution of results and there is little comparable data on the same disaggregated level.

All input variables will be set to their base values as presented in the Collection of Data-section. The model will then be calibrated with ± 50 percent of the initial elasticity (US EPA, 2001). The demand elasticity will be held constant at -0.394 while the supply elasticity is altered and vice versa in order to isolate variation outcomes from each variable.

Table 1. Elasticities used in sensitivity analysis

Elasticity	**Demand**	**Supply**
- 50 %	-0.197	0.5
Initial value	-0.394	1
+ 50 %	-0.591	1.5

3. Collection of Data

This section describes the procedure behind the data retrieval for consumption, domestic production and prices of beef in Sweden. It also explains the life cycle assessments of the four production systems to get the carbon footprint for each, and pricing process of carbon dioxide.

3.1 Beef Consumption and Production in Sweden

3.1.1 Consumption

In Sweden, the total consumption of meat is just over 85 kg carcass weight per capita and year, and the direct consumption is 50 – 55 kg (Jordbruksverket, 2013b). The numbers are based on production adjusted for import and export. Data for total consumption will be used in this paper since this is most relevant from a climate perspective: it is the amount actually produced that puts stress on the environment and climate.

In 2011 the total consumption of beef was 26.3 kg per capita, compared to 16.5 kg per capita in 1990. The share of domestically produced beef has rapidly declined on the growing market, from 89 percent in 1995 to 53 percent in 2012, making domestic beef the least competitive against imports of all the meats. Entering the EU in 1995 and clearing South American beef for the Swedish market were two major disadvantages for domestic producers (Jordbruksverket, 2013b). However, the lower domestic production is not only due to highly competitive imports but also a decreased diary sector.

Data used in calculations are retrieved from Jordbruksverket and Statistics Sweden. Stated percentages of domestic and imported beef will be applied to allocate total consumption figures. A geometric mean from 2005 to 2012 is calculated, resulting in an allocation 57 percent to domestic production and 43 percent to imports.

Disaggregated data for organic beef is not available. Therefore sales statistics from 2005 to 2012 for meats as an aggregated product group is used, assuming that consumers buy an equal share organic of all meats. Sales for organic meat is divided by total sales for meat, giving a percentage ranging from 1.2 to 1.8 in current prices (Statistics Sweden, 2014). According to KRAV, the percentage is believed to be slightly higher (KRAV, 2014). To compute the organic percentage of domestic consumption, 2 percent will be used in calculations.

Two thirds of total imports originate from the EU (Jordbruksverket, 2013a). An allocation of 67 percent and 33 percent respectively for EU and Brazil will therefore be used for imported beef in further calculations.

3.1.2. Domestic Production

The total domestic beef production was 135 900 ton in 2005 and 125 400 ton in 2012. The general trend for the time period displays decreasing production with a few peak years of 2006 and 2009-2020 (Jordbruksverkets statistikdatabas, 2014).

Disaggregated data for organic beef is not available. Therefore the same allocation of 2 percent as in "Consumption" will be used based on the same assumption of sales statistics from 2005 to 2012. Remaining 98 percent of total domestic production is assumed to be conventionally produced.

3.1.3. Prices

Per kilo consumer prices are not available. Säll (2012) priced 1 kg beef on the Swedish market to 88 SEK. 88 SEK per kg will be used for domestic conventional production. Prices for organic foods are on average 30 percent higher than for conventionally produced foods (Jordbruksverket, 2006). Due to the unavailability of disaggregated data, it is assumed that the general trend applies to beef and a mark-up of 30 percent will be applied.

Wirsenius et al (2010) calculated the price per kg beef to be €8.8 as an EU average which is 84.15 SEK per kilo. Edjabou (2013) uses DKK 64.01 per kg beef, which is approximately 82 SEK per kg. In this paper, 84 SEK per kg beef will be used as the EU average.

Brazilian meat believed to be cheaper than EU average but no data on consumer prices of Brazilian beef is available. Therefore beef imported from Brazil will be priced the same as EU average of 84 SEK per kg beef.

Table 2. Prices in SEK for each production method.

	Domestic, Conventional	Domestic, Organic	Import, EU	Import, Brazil
SEK per kg beef	88	114.40[2]	84	84

3.2 Life Cycle Assessments

3.2.1 Conventional Beef Production, Sweden

The carbon footprint of conventionally produced beef in Sweden ranges from 21 to 28 kg CO_2 equivalents per kg beef. The large span indicates the difficulty of measuring total

[2] 88*1.3 = 114.40

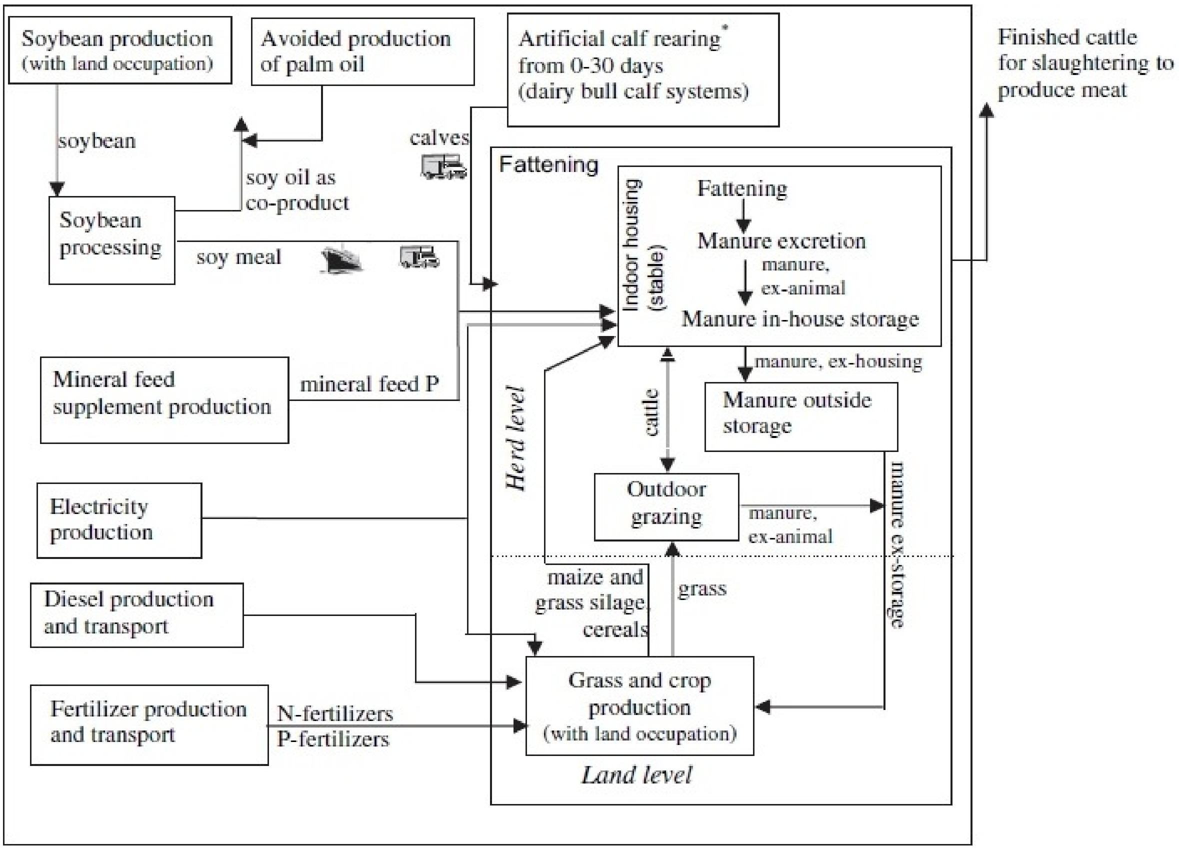
emissions of the production cycle, and can be explained by different choice of methods, such as system boundaries and allocation of environmental damages between product and byproduct, and how the production is managed (Sonesson et al., 2009).

Cederberg et al. (2009) conducted a study for the Swedish Institute for Food and Biotechnology (SIK) in order to estimate the current life cycle GHG emissions from Swedish livestock production and to analyze emission trends. A hybrid-LCA method of combining top-down sector input-output data with bottom-up process data was used, meaning that national accounting and statistics (top-down) were combined with data at farm-gate level (bottom-up) in order to get the whole picture of the production system. GHG emissions from the entire production chain was calculated including emissions embedded in imports, such as feed, and emissions from energy use and manure handling. Emissions from land use changes and from production of pesticides and silage agents are not included in the study.

Figure 2 illustrates an example of what aspects are being considered in life cycle assessments of conventional beef production. Feed in terms of soybean production and processing, mineral feed supplement production, electricity production, diesel production and transport, and fertilizer production and transport are factors taken into account outside of the farm. At the farm level there are roughly three categories to consider. Land level which looks at grass and crop production, herd level which looks at outdoor grazing and outside manure storage, and the fattening process which looks at indoor housing (stable), manure excretion and in-house storage, as well as artificial calf rearing.

Each stage of the production gives rise to one or more greenhouse gases. In the study by Cederberg et al. (2009), they have specifically looked at carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The global warming potential of each gas is 1, 25, and 298 respectively, which are those used in the IPPC report of 2007. The results are presented in CO_2 equivalents, meaning carbon dioxide is used as the reference gas.

Figure 2. An example of LCA of conventional beef production (Nguyen et al., 2009)



The results were presented as life cycle GHG emissions per kg, defined as the product's carbon footprint at farm-gate. The functional unit for beef is in CO_2 equivalents per 1 kg meat with bone, carcass weight, at the farm gate. Taking into consideration that some of the slaughter animals originates from the dairy sector, an allocation factor in milk production of 85 percent to milk and 15 percent to beef was applied, resulting in emissions from Swedish cattle production was 26 kg CO_2 equivalent per functional unit in 2005 (Cederberg et al, 2009).

For this report, an average of the carbon footprint based results from several studies is used (Sonesson et al., 2009; Cederberg et al., 2009; Säll, 2012; Köttguiden, 2014), arriving at a carbon footprint of 24 kg CO_2 per 1 kg conventionally produced beef.

3.2.2 Organic Beef Production, Sweden

The data in the report by Cederberg & Nilsson (2004) is collected from the largest free range cattle production in Sweden that is KRAV certified. The framework for the life cycle assessment used is standardized within ISO 14 000, which is an international standard for environmental management (ISO, 2014), and the following environmental impacts have been taken into account when assessing the lifecycle: use of energy, resources, use of land, pesticides, contribution to climate change, fertilization, and acidification. Construction of machines and buildings, medications, and other smaller supplies have been excluded. The functional unit is kg bone-free beef at the farm gate.

The use of energy was roughly 8 MJ per functional unit, of which diesel fuel for tractors accounted for 80 percent, mostly due to production and handling of winter fodder. (All forage was grown on the farm and the only purchased feed supplement was minerals.) The total annual land usage was 154 m^2 per functional unit, where grazing was the dominant type of land usage, contributing to high biodiversity. Due to closed production of forage year around and minimal use of machinery, soil fertility problems like erosion and soil compaction was virtually non-existent. The pesticide usage per functional unit was 0 grams, compared to conventional production which has 1.7 – 3.3 grams active substance per kg bone-free beef, thus not contributing to pollution of ground and surface water.

Total emissions of GHG per functional unit were 21.7 kg CO_2 equivalents and methane emissions from the animals' digestive system were the dominant contributor of the emissions. This is 1.7 kg higher than the result found in Cederberg & Darelius (2000) assessment of self-recruiting organic production and the difference in results is assigned to the longer lifespan of slow-growing free ranging cattle. The longer rearing time of the extensive system gives rise to higher methane emissions than an intensive productions system, while the intensive system emits more carbon dioxide and nitrous oxide. Hence, the allocation of GHG emissions varies with the intensity of production (Cederberg & Nilsson, 2004). As free ranging is a far less common production method for organic beef in Sweden, the lower carbon footprint of 20 kg CO_2 equivalents will be used in this report.

3.2.3 Imported Beef

One of the problems with comparing international studies of life cycle assessments of GHG emissions is that certain parameters of the models are unclear. Allocations between beef and its byproducts, as hides, and between the meat and dairy sector vary. In 2007 the IPPC changed the factor weights of methane from 21 to 25 and nitrous oxide from 310 to 298, with the consequence that older studies underestimate emissions as beef production is dominated by methane emissions (Sonesson et al., 2009).

A life cycle assessment made at EU level by Nguyen et al. (2010) studied environmental consequences of beef produced in intensively reared dairy calves and suckler herds. Global warming, acidification, eutrophication, land-use and non-renewable energy use was taken into account. The results vary from 19.9 to 27.3 kg CO_2 equivalents per kg beef in carcass weight, and the range depends on the production method of the meat. If land opportunity costs, land use change related to grazing, and production for crop feed are included in the model, the contribution to global warming from 1 kg beef would increase by a factor of 3.1 to 3.9, based on a 20 years depreciation period (Nguyen et al., 2010).

Other LCA studies conducted at EU level for beef produced in Ireland and the UK range the carbon footprint between 28 to 32 kg CO_2 eq per kg beef (Sonesson et al., 2009). In this study, a carbon footprint of 30 kg CO_2 eq is used for beef imported from the EU.

One study has been presented for Brazilian beef production conducted by Cederberg et al. The study is based on agricultural statistics and data from researchers and advisors with the intent to quantify GHG emissions for the average beef produced in Brazil. The carbon footprint was found to be 40 kg CO_2 eq per kg beef, excluding effects of deforestation (Sonesson et al., 2009). A carbon footprint of 40 kg will be used in this report.

As the various studies differ in system boundaries and functional units, carbon footprints from reports conducted by or involving Cederberg has been preferred as similar methods for the papers are assumed. When the functional units vary or are unclear, the lowest value for bone-free meat is chosen and the highest value for carcass weight.

Table 3. Carbon footprint in CO2 equivalents for respective production method used in this study

Production Method	**Domestic, Conventional**	**Domestic, Organic**	**Import, EU**	**Import, Brazil**
Carbon Footprint	24	20	30	40

3.3 Cost of CO_2

Determining the cost to society for GHG emissions is complex. Costs does not only depend on past, current and future emissions, but also atmospheric concentration of GHG and composition of different gases and their warming potential. Lack of data for damage and abatement costs also factor in. According to Stern (2006) the estimates in scientific literature vary from \$0 to \$400 per ton CO_2 equivalent in 2000-prices. The Stern Review calculated the cost to be \$85 per ton CO_2 equivalent (2000-prices), while Tol (2005) estimated the cost to be

$29 per ton CO_2 eq (0 – 591.55 SEK and 201.82 SEK respectively in current prices). Politically revealed costs in the Swedish transport sector is 1 SEK per kg CO_2 eq (Säll, 2012), which will be used in this paper.

4. Results

This section presents the results from the two taxation scenarios and from the sensitivity analysis performed on the elasticities of supply and demand.

4.1 Results Taxation Scenarios

4.1.1 Scenario 1: Neutral Scenario

The tax burden in scenario 1 is 28 percent on the producer side and 72 percent on the consumer side when the supply elasticity is 1 and the demand elasticity is -0.394. The post-tax consumer price for domestic conventional beef increased by 19.56 percent to 105.22 SEK per kg, domestic organic beef increased by 12.54 percent to 128.75 SEK per kg, beef imported from the EU increased by 25.62 percent to 105.52 SEK per kg, and beef imported from Brazil increased by 34.16 percent to 112.69 SEK per kg. Consumption decreased by 6.80 percent, 4.55 percent, 8.59 percent and 10.93 percent respectively. The total consumption of beef decreased by 7.88 percent after imposed tax.

Table 4. Summary of results from scenario 1.

Post-tax 1	Consumer Price (SEK)	Consumer Price (Δ%)	Consumption (Δ%)	Domestic Production (Δ%)	C.F. Consumers (% of tot)	C.F. Producers (% of tot)
Swe Conv	105.22	+19.56	-6.80	-7.71	39.88%	98.92%
Swe Eco	128.75	+12.54	-4.55	-4.94	0.45%	1.08%
Imp EU	105.52	+25.62	-8.59		32.51%	
Imp Bz	112.69	+34.16	-10.93		27.16%	
TOTAL			*-7.88*		*541868 ton*	*246599ton*

On a per capita level, the consumption level decreased to 23.57 kg beef per person per year, a total decrease of 2.02 kg compared to the pre-tax scenario. Consumption of domestic conventional beef decreased by 0.97 kg, domestic organic beef by 0.01 kg, EU imported beef by 0.63 kg, and imported beef from Brazil with 0.40 kg per capita.

The domestic production of conventional beef decreased by 7.71 percent at a 7.71 percent lower price received. Domestic production of organic beef decreased by 4.94 percent at a 4.94 percent lower price received.

The carbon footprint from total consumption was reduced by 541 868 ton CO_2 equivalents after imposed tax, resulting in a per capita carbon footprint reduction of 58.47 kg CO_2 equivalents. Domestic conventional beef stood for 39.88 percent of the reduction of the carbon footprint, domestic organic beef stood for 0.45 percent of the reduction, EU imported beef 32.51 percent, and beef imported from Brazil stood for 27.16 percent of the reduction. The carbon footprint from domestic production was reduced by 246 599 ton CO_2 equivalents by the tax, where domestic conventional beef production stood for 98.92 percent of the reduction. The total reduction of carbon footprint from both consumption and domestic production was 788 467 ton CO_2 equivalents.

Welfare in the form of consumer surplus was decreased by 20.97 per capita. Government revenue was calculated for each tax level and quantity and total government tax revenue was 6 086 million SEK.

4.1.2 Scenario 2: Sustainable Scenario

The sustainable scenario aims to display a taxation scenario where a long term sustainable beef consumption is prioritized. The production method with the lowest carbon footprint per kg beef was domestic organic production at 20 kg CO_2 equivalents per kg beef. To make organic beef the most affordable option after the higher tax-induced consumer prices, the lowest cost of CO_2 possible was 10 SEK per kg.

At 10 SEK per kg emissions in CO_2 equivalents, the tax burden was unchanged with an allocation of 28 percent on the producers and 72 percent on the consumers as the elasticities of supply and demand were unchanged at 1 and -0.394 respectively. The post-tax consumer price for domestic conventional beef increased by 195.64 percent to 260.17 SEK per kg, domestic organic beef increased by 125.41 percent to 257.87 SEK per kg, beef imported from the EU increased by 256.20 percent to 299.21 SEK per kg, and beef imported from Brazil increased by 341.60 percent to 370.94 SEK per kg. Consumption decreased by 34.67 percent, 27.40 percent, 39.68 percent and 44.30 percent respectively. The total consumption of beef decreased by 37.36 percent after imposed tax.

Table 5. Summary of results from scenario 2

Post-tax 2	Consumer Price (SEK)	Consumer Price (Δ%)	Consumption (Δ%)	Domestic Production (Δ%)	C.F. Consumers (% of tot)	C.F. Producers (% of tot)
Swe Conv	260.17	+195.64	-34.67	-77.08	43.80%	98.92%
Swe Eco	257.87	+125.41	-27.40	-49.41	0.59%	1.08%
Imp EU	299.21	+256.20	-39.68		31.99%	
Imp Bz	370.94	+341.60	-44.30		23.63%	
TOTAL			*-37.36%*		*2 523 088 ton*	*2 465 994 ton*

On a per capita level, the consumption level decreased to 16.03 kg beef per person per year, a total reduction of 9.56 kg compared to the pre-tax scenario. Consumption of domestic conventional beef decreased by 4.97 kg, domestic organic beef by 0.08 kg, EU imported beef by 2.90 kg, and imported beef from Brazil with 1.61 kg per capita.

The domestic production of conventional beef decreased by 77.08 percent at a 77.08 percent lower price received. Domestic production of organic beef decreased by 49.41 percent at a 49.41 percent lower price received.

The carbon footprint from total consumption was reduced by 2 523 088 ton CO_2 equivalents after imposed tax, resulting in a per capita carbon footprint reduction of 272.26 kg CO_2 equivalents. Decreased consumption of domestic conventional beef represented 43.80 percent of the reduction of the carbon footprint, domestic organic beef 0.59 percent, EU imported beef 31.99 percent, and beef imported from Brazil stood for 23.63 percent of the reduction in carbon footprint. The carbon footprint from domestic production was reduced by 2 523 088 ton CO_2 equivalents by the tax, where domestic conventional beef production was accountable for 98.92 percent of the reduction. The total reduction of carbon footprint from both consumption and domestic production was 4 989 082 ton CO_2 equivalents.

Welfare in the form of consumer surplus was decreased by 976.54 per capita. Government revenue was calculated for each tax level and quantity and total government tax revenue was 41 053 million SEK.

4.2 Results Sensitivity Analysis

The most substantial sources of uncertainty in the calculations are the elasticities of demand and supply. After a basic sensitivity analysis where ± 50 percent of each elasticity was preformed while the other elasticity remained constant at initial base value, one can clearly see that the result vary considerably depending on the elasticities.

The basic allocation of tax burden is critical for the outcome of the remaining output results. When η was altered and holding ε constant, the consumers' tax burden varies from 55.9 percent to 79.2 percent. When η was constant and ε altered, the tax burden of the consumers ranged between 83.5 percent to 62.9 percent. As Figure 3 illustrates, the larger the value for supply elasticity and the smaller the value for the demand elasticity, the more of the tax burden is placed on the consumers, resulting in higher consumer prices compared to low tax burden-prices. Higher tax-induced consumer prices consequently result in lower quantities demanded.

Figure 3. Tax burden under different elasticities

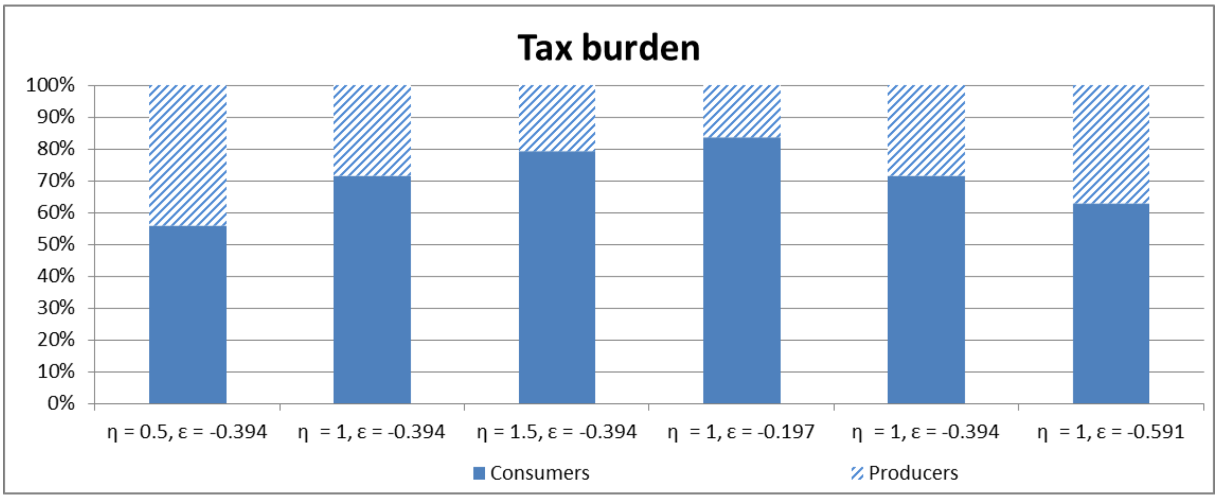
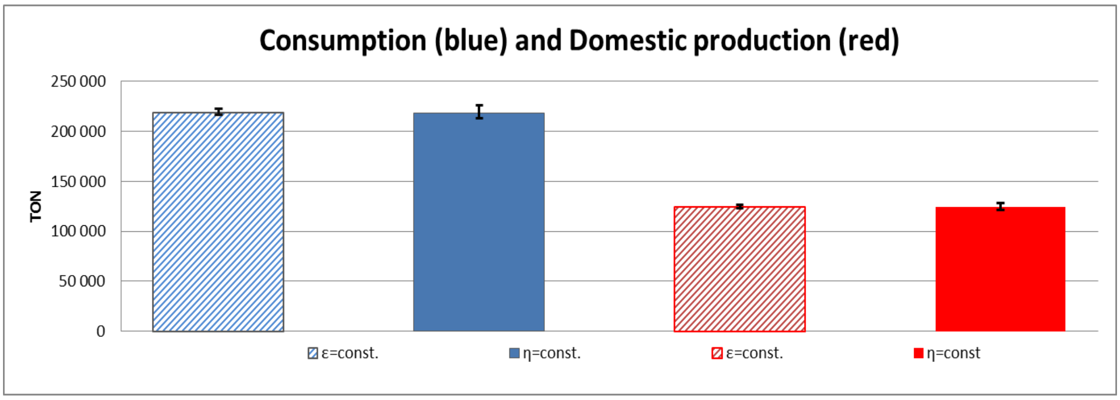


Figure 4 displays the effects of the sensitivity analysis on total consumption and domestic production. The large boxes show the results from the base value calculations with the black vertical lines demonstrating ranging results under different elasticities. The largest span of quantities demanded and domestically produced was seen when altering the demand elasticity, indicating that quantities are more sensitive to changes in elasticity of demand than in elasticity of supply.

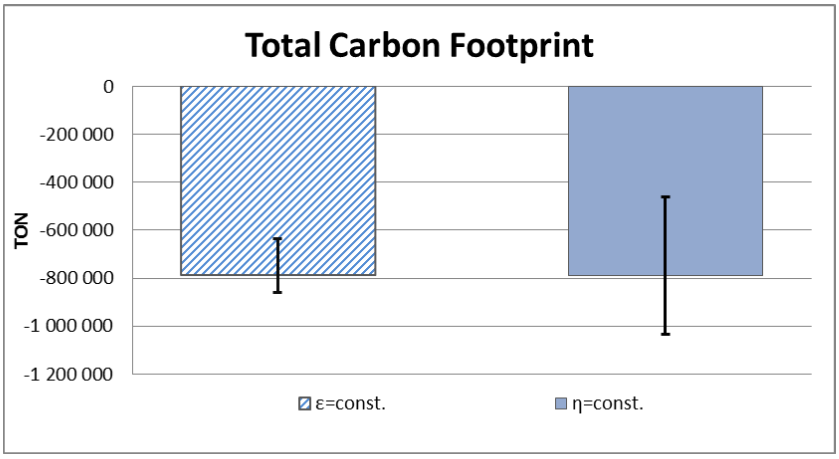
Figure 4. Consumption and domestic production under different elasticities



The most significant effects of the sensitivity analysis were seen in total carbon footprint reduction, loss of consumer surplus and government tax revenue. Basic allocation of tax burden combined with how inelastic the supply or demand is, resulted in substantial variations in output of the three variables. A more elastic supply responds quicker to changes in demanded quantities and a more elastic demand responds quicker to the price changes. Both send rippling effects throughout the model, drastically affecting output variables.

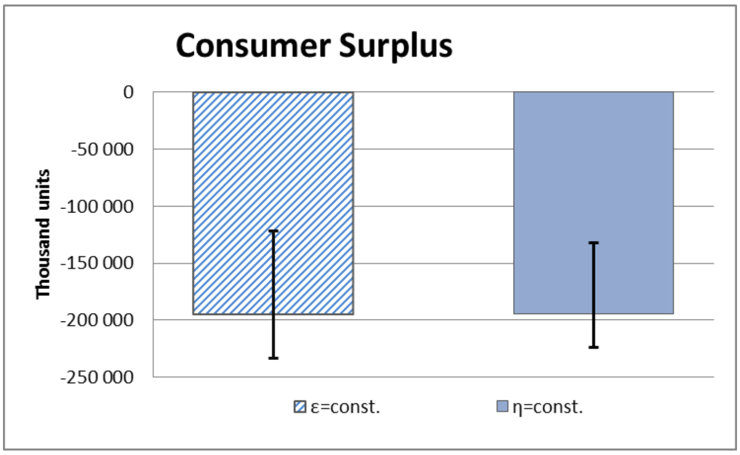
The reduction of total carbon footprint was between 634 731 and 857 815 ton CO_2 eq with constant demand elasticity and altered supply elasticity, and between 459 696 and 1 035 243 ton CO_2 equivalents for a constant supply elasticity and altered demand elasticity. The largest sensitivity range in total carbon footprint reduction was seen when altering the demand elasticity. The price sensitivity of consumers has a critical impact on quantities demanded and thus the reduction of carbon footprint, more so than the ability of the supply side to restrict output under altered demand conditions.

Figure 5. Total carbon footprint under different elasticizes



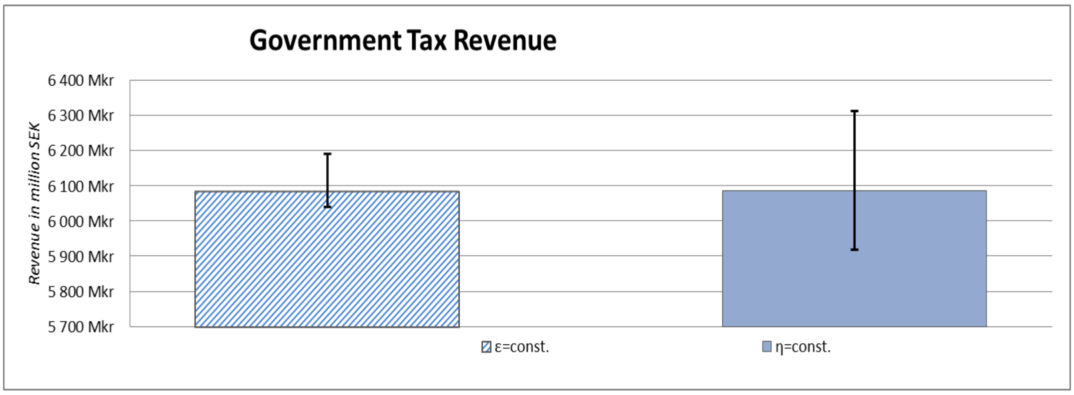
The post-tax range of loss in consumer surplus was greater under variation of supply elasticity than under variations of demand elasticity as can be seen in Figure 6. Under constant ε and altered η the range was between -122 020' and -233 415' while under initial value of η and changed ε the range spread from -132 040' and -223 490'. The sensitivity of changes in consumer surplus can thus be explained by tax burden allocation but also it is also affected by shifts of producer surplus and price sensitivity.

Figure 6. Consumer surplus under different elasticities



Government tax revenue clearly demonstrates a larger range under altered demand elasticities than under altered supply elasticities, illustrated in Figure 7. When ε is constant and η changed, the range stretches from 6 039 million SEK to 6 192 million SEK, compared to 5 917 million SEK to 6 321 million SEK when η is constant and ε altered. The larger sensitivity range for elasticities of demand is explained by tax burden allocation and quantities demanded. As the government only collects tax on quantities sold, the price sensitivity is a crucial factor in determining government revenue.

Figure 7. Government tax revenue under different elasticities



5. Discussion

In this section, the results of the study are discussed: what are the environmental implications, limitations of the study, and suggestions for further research.

5.1 Environmental Impact

The primary purpose of the paper was to investigate by how much a GHG emissions differentiated Pigouvian tax of beef on the consumer level would reduce the negative environmental impacts of beef production through reduced consumption. The four productions systems examined are domestic conventional beef production in Sweden, organic beef production in Sweden, beef imported from the EU, and beef imported from Brazil. By assigning the cost of 1 kg emissions in CO_2 equivalents to 1 SEK, the total consumption was reduced by 7.88 percent, resulting in a total carbon footprint reduction of 788 467 ton CO_2 eq and at a loss in consumer surplus of 20.97 per capita.

The hypothesis presented in Expected Results is for the most part correct. The quantities demanded and produced decreased due to the higher tax-induced consumer prices. The small relative decrease in demand and supply of organic beef was expected, as was the total reduction in carbon footprint and the loss of consumer surplus. However, the decrease in demand of imported beef, especially from Brazil, was expected to be relatively larger as the two production methods had the largest carbon footprints per kg and the highest tax per kg.

It is clear that from a GHG emission perspective, the tax would have a significant positive effect. However, when interpreting the environmental gains from such a tax, one has to be aware that GHG emission is not the only environmental aspect to take into account. The production affects the entire ecosystem where one has to consider the larger picture. The substance residuals of active pesticides in conventionally produced beef do not only affect the environment and the animals but could have potentially harmful effects on human health. Other pollutants that are not included in this study, such as the effect on water organisms from the use of antibiotics or land use changes effect on biodiversity, also need to be included when deciding on policy instruments to mitigate climate change. By re-considering the production system as a whole and introducing cyclic “cradle to cradle” concepts instead of the traditional linear “cradle to grave” mentality on a larger scale, a shift towards a more sustainable production can be done without government interference on consumer prices.

The model indicates that consumption and production of organic beef is least affected when imposing a GHG differentiated tax, suggesting that out of the production methods investigated it is the most sustainable in the long run when considering stress inflicted on the natural environment from beef production. However, it is unlikely that the majority of Swedes will switch to a vegetarian or generally more climate friendly diet with less meat without an economic incentive. Extensive meat consumption is habitual and deeply rooted in our culture. As long as beef is relatively cheap due to "free" pollution and environmental degradation of conventional production methods, reduced consumption levels are not plausible. By imposing a climate tax and using the tax revenue as a double dividend to support organic farmers during conversion when their land is quarantined, a sustainable production and consumption would be promoted as well as keeping production and employment within the country. It would increase the supply of organic beef and facilitate organic products to move away from the premium segment of the market.

5.2 Limitations of the Study

The study indicates that taxing beef would have a significant impact on mitigating climate effects. Yet the results need to be interpreted with care. The uncertainty of the elasticities estimates and how they compare to real life applications are unsure, and it is therefore difficult to predict how a live scenario outcome would compare to the model simulations. The use of a partial equilibrium model is appropriate to estimate the tax induced price changes in consumer demand but it is limiting as the model does not indicate how the effect would translate onto other markets. The assumptions made and the lack of disaggregated data could also have a significant impact if real life values greatly differ from those used in the model. The final limitation was the time limit. Had there been more time, a deeper analysis into the policy perspective would have been possible.

5.3 Further Research

Further investigations of the distribution of disposable income of households and climate mitigation policies in the form of consumer taxes would be a welcomed complement to studies such as this, as the real impact on households has not been included in this study. Future research on how to assert large scale climate friendly production systems of beef for a sustainable consumption will also add further clarity on how GHG differentiated taxes will affect domestic production.

6. Conclusion

This is the final section of the thesis where a brief conclusion of the study is presented.

The study concludes that a Pigouvian tax on beef placed on consumer level in an attempt to mitigate climate effects can be a cost-effective approach to abate GHG emissions. It is in the author's opinion that the loss in consumer surplus is offset by the environmental gains in form of reduced carbon footprint, and that imposing a tax on meat is a first step towards taking responsibility for a sustainable future. Initially, the tax per kg CO_2 equivalents should not exceed the politically revealed cost of 1 SEK, and it is critical that consumers are informed of *why* such a tax is imposed. In order to justify government interference on consumer diets, the majority of the tax revenue must go to further climate adaptation within domestic beef production in order to sustain employment levels and enhance future competitiveness of the domestic sector.

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