The Effect of an Environmental Tax on the Consumption of Dairy and Plant-based Drinks

The case of Sweden

Daniel Törnqvist

Degree project/Independent project • 30 hp
Swedish University of Agricultural Sciences, SLU
Faculty of Natural Resources and Agricultural Sciences/Department of Economics
Environmental Economics and Management – Master's Programme
Degree project/SLU, Department of Economics, 1447 • ISSN 1401-4084
Uppsala 2022

The Effect of an Environmental Tax on the Consumption of Dairy and Plant-based Drinks. The case of Sweden.

Daniel Törnqvist

Supervisor:	**Sarah Säll, Swedish University of Agricultural Sciences, Department of Economics**
Examiner:	Rob Hart, Swedish University of Agricultural Sciences, Department of Economics

Credits:	30 hp
Level:	A2E
Course title:	Master thesis in Economics
Course code:	EX0905
Programme/education:	Environmental Economics and Management – Master's Programme
Course coordinating dept:	Department of Economics
Place of publication:	Uppsala
Year of publication:	2022
Title of series:	Degree project/SLU, Department of Economics
Part number:	1447
ISSN:	1401-4084

Keywords:	consumer demand, consumption taxation, dietary transition, GHG mitigation, plant-based drinks, Sweden

Swedish University of Agricultural Sciences
Faculty of Natural Resources and Agricultural Sciences
Department of Economics

Abstract

In the light of global greenhouse gases (GHG) mitigation targets, this study aims to investigate if a consumption-sided CO_2e weighted tax scheme on dairy and plant-based drinks can shift consumption towards plant-based drinks and thereby lower GHG emissions. Using scanner data from a Swedish supermarket ICA Maxi Nacka located in Stockholm, Sweden, we construct a multistage Quadratic Almost Ideal Demand System (QUAIDS) to evaluate changes in demand due to the tax implementation. The results show that net GHG emissions are reduced by 4.27 percent where 100 percent of the reductions stem from reduced dairy consumption and 100 percent of the increases from increased plant-based drinks consumption. In the sensitivity analysis we exempt oat drinks from the taxation which marginally increased the demand resulting in increased net GHG reductions of 4.40 percent.

Keywords: consumer demand, consumption taxation, dietary transition, GHG mitigation, plant-based drinks, Sweden.

Table of contents

List of tables **6**

List of figures **7**

Abbreviations **8**

1. Introduction **9**

2. Theoretical Perspective and Environmental Policy **13**

2.1 Negative Environmental Externalities 13

2.2 Environmental Policy 15

3. Literature Review **17**

4. Data **20**

4.1 In-store Data 20

4.2 Data Management and Descriptive Statistics 20

4.3 Climate Footprints 22

4.4 Limitations 23

5. Methods **25**

5.1 The Demand System 25

5.2 Quadratic Almost Ideal Demand System 26

5.3 Elasticities 28

5.4 Tax Levels 29

5.5 Changes in Consumer Demand and GHG Emissions 30

6. Results and Discussion **32**

6.1 Price Sensitivity 32

6.2 The Impact of Consumption Taxes 37

6.3 Sensitivity Analysis 40

7. Concluding Remarks **42**

References **44**

Acknowledgements **48**

Appendix **49**

List of tables

Table 1. Descriptive statistics of dairy and plant-based drinks 21

Table 2. Climate footprints 23

Table 3. Second stage elasticities.. 33

Table 4. Third stage elasticities, dairy.. 34

Table 5. Third stage elasticities, plant-based drinks 35

Table 6. Baseline scenario: Impact of the CO_2e weighted consumption tax scheme....... 37

Table 7. Sensitivity analysis: Impact of the CO_2e weighted consumption tax scheme..... 41

List of figures

Figure 1. The market for food 13

Figure 2. Internalization of negative externalities continuum 14

Figure 3. Utility tree for dairy and plant-based drinks 26

Figure 4. Total and marginal effects of 1 SEK taxes 40

Abbreviations

AIDS	Almost Ideal Demand System
CF	Climate footprint
CO_2e	Carbon dioxide equivalents
GHG	Greenhouse gases
LCA	Life cycle assessment
QUAIDS	Quadratic Almost Ideal Demand System

1. Introduction

In recent years, the public debate regarding the effects of greenhouse gases (GHG) on climate change has intensified. Increased global awareness has resulted in the internationally joint commitment to limit global warming to 2° C outlined in the 2015 Paris Agreement (see UNFCCC, 2022). GHG emissions stem from all human activity and as Mbow et al., (2019) show approximately 21-37 percent of global GHG emissions are linked to the current food system. Food production needs to increase by approximately 50 percent by 2050 to feed the population given the current food system and expected population growth, thereby threatening climate and biodiversity through further increases in GHG emissions (ibid). Thus, there is an urgent need to decrease GHG emissions stemming from the food system to abate the associated negative environmental impacts, without compromising the food production.

Consumption taxation has been theoretically proven to be an efficient policy in mitigating GHG emissions through dietary change, especially through reduced meat consumption (e.g., Edjabou & Smed, 2013; Säll et al., 2020; Springmann et al., 2017). However, considering that meat is the most emission-intensive and researched food commodity in this field (see Clune et al., 2017; Karlsson Potter et al., 2020), few studies have researched the GHG mitigation potential of a dietary transition towards less emission-intensive plant-based substitutes and changes in consumer demand. In this paper we show that implementation of a consumption-sided tax scheme in the context of Sweden has the potential to shift consumption away from dairy towards plant-based substitutes, causing GHG emissions to decrease.

Research on the food system's impact on the climate has expanded in the last decade, especially on possible strategies of reducing GHG emissions from the livestock sector as it accounts for approximately 14.5 percent of the total global GHG emissions (Gerber et al., 2013). Approximately 65 percent of the livestock sector emissions stem from beef and dairy cattle (ibid). Various studies show that transitioning to a diet consisting of more plant-based alternatives to animal products have the potential to mitigate GHG emissions due to the comparatively lower emission-intensity (e.g., Clune et al., 2017; Springmann et al., 2018). The high emission-intensity of animal products can be explained by the large amount of methane produced by ruminants, a GHG which has an atmospheric warming potential almost thirty times larger to that of carbon dioxide (IPCC, 2014).

Consumption of animal products in rich industrialized countries is currently significantly higher than the scientifically sustainable and healthy diet proposed by Willett et al., (2019), whereas consumption of plant-based alternatives is well below the recommended level. Subsequently, if consumption and production of animal products continues along the current trajectory, GHG emissions may increase by approximately 90 percent, where animal products account for almost 75 percent of the increase (Willett et al., 2019). Furthermore, it would increase the need for land for food production resulting in habitat fragmentation and biodiversity loss, increased chemical pollution and use of pesticides, and freshwater usage. Consequently, people need to make dietary changes towards plant-based alternatives to animal food products if international targets on climate change mitigation are to be met (CCAC, 2021).

Overconsumption of animal products is still prevalent in Western countries in spite of the fact that progress has been made in recent years and Sweden is no exception. Increased consumer awareness alone cannot cause the dietary shift needed to mitigate GHG emissions as consumers likely need to be incentivized to switch into more plant-based diets (Röös et al., 2016). Thus, there is a need for efficient environmental policy to mitigate GHG emissions and according to Pigou (1957) this can be achieved by internalizing the negative environmental effects through taxation on food production set equal to the social cost of carbon for each individual good. However, as multiple studies conclude (e.g., Edjabou & Smed., 2013; Säll & Gren., 2015; Wirsenius et al., 2010), there are problems associated with Pigouvian taxes and drawbacks levying the tax on the production-side. Regarding the former, the cost of monitoring GHG releases for every production entity and good would be very high as explained by Wirsenius et al., (2010). Furthermore, if an import dependent country, such as Sweden, alone implements a tax scheme levied on the production it will result in lower relative prices of imported foods which in practice would reduce domestic producers' competitiveness and potentially lead to higher emissions (ibid).

Instead, a second-best approach is to implement policies on the consumption-side, steering consumers away from meat and dairy heavy diets and towards plant-based diets to mitigate GHG emissions and therethrough suppress the associated environmental damages (Röös et al., 2021). Several studies (e.g., Edjabou & Smed, 2013; Säll & Gren, 2015; Wirsenius et al., 2010) highlight opportunities to accelerate a dietary transition and thereby reduce GHG emissions through the implementation of GHG weighted consumption taxes. Regarding Swedish food consumption, Säll et al., (2020) show that meat and dairy products account for almost 90 percent of potential reductions in GHG emissions when implementing consumption taxes over the majority of food commodities.

The literature investigating changes in consumer demand regarding animal products and plant-based substitutes as a consequence of consumption taxes is very limited. Overall, the literature is focused on finding ways to accelerate a dietary shift away from meat as it is the most emission-intensive food (e.g., Clune et al., 2017; Karlsson Potter et al., 2020). Less attention is put on the mitigation potential of shifting dairy consumption towards plant-based alternatives. There are studies, such as Clune et al., (2017), which assess the climate footprint (CF) of dairy relative to plant-based substitutes in a global context, but do not explicitly examine how consumers might switch towards plant-based substitutes because of changing prices. Furthermore, Carbon Dioxide Equivalent (CO_2e) emissions per kg of oat drink, soy drink, and almond drink are lower than amount of CO_2e emissions per kg of dairy in a Swedish cradle-to-store bounded system as shown by Karlsson Potter et al., (2020). This suggests that there is a possibility mitigate GHG emissions from dairy consumption if consumers shift away from dairy and towards plant-based drinks.

The case of oat drinks is especially interesting since the Swedish agricultural sector has the potential to produce oat drinks domestically on a large-scale relative to other plant-based substitutes such as almond or soy drink, thereby allowing for shorter transports (Karlsson Potter et al., 2020). Additionally, considering that approximately two thirds of the beef produced in Sweden comes from dairy farms (Swedish Board of Agriculture, 2016), potential future reductions in meat consumption will likely affect dairy consumption. Furthermore, although official statistics on total consumption of plant-based drinks does not exist, retailers confirm a growing demand for plant-based drinks from Swedish consumers (Rundgren, 2019). Thus, GHG emissions can potentially be mitigated by steering consumers away from dairy and towards plant-based substitutes. It is therefore of interest to investigate how consumers respond to price changes in dairy and their propensity to switch towards plant-based substitutes.

This study contributes to the existing pool of literature studying the mitigation potential of consumption taxes by examining the effects of a consumption tax on dairy on the demand for plant-based substitutes in the context of Sweden. To the best of our knowledge, this is the first study quantifying changes in demand for plant-based dairy substitutes arising from environmental consumption taxation. Thus, we aim to investigate whether a CO_2e weighted consumption tax scheme can shift dairy consumption towards plant-based substitutes and thereby lower GHG emissions. Consequently, in the baseline scenario, CO_2e weighted consumption taxes are implemented over all dairy variants and plant-based drinks.

In contrast to similar studies on the effects of consumption taxes on consumer demand (e.g., Edjabou & Smed, 2013; Säll & Gren, 2015; Säll et al., 2020), this study utilizes scanner data on dairy and plant-based substitutes. Furthermore, data on CO_2e emissions per kg for each food category are obtained from previous Life Cycle Assessment (LCA) studies and LCA databases (see CarbonCloud, 2022; Karlsson Potter et al., 2020). Consumers' price and income elasticities for the various products are calculated utilizing a Quadratic Almost Ideal Demand System (QUAIDS). Thereafter, tax levels for each commodity are determined based on the associated CF. Lastly, changes in demand and GHG emissions are calculated based on own- and cross-price elasticities and tax levels. The results show that implementation of a CO_2e weighted consumption tax has the potential to reduce net GHG emissions by 4.27 percent through reduced dairy consumption. Furthermore, 100 percent of the reduction in GHG emissions is attributable to reduced dairy consumption whereas 100 percent of the increase is attributable to increased consumption of plant-based drinks. Among all plant-based drinks considered, consumers primarily shift into oat drinks. In the sensitivity analysis, we exclude oat drinks from taxation which results in marginally higher net GHG reductions of 4.40 percent and slightly higher demand for oat drinks.

The remainder of the paper is structured as follows. Section 2 explains the theoretical perspective on environmental externalities and environmental policy. Section 3 reviews previous studies on dietary change and consumption taxation. Section 4 gives a description of the data and its limitations. Section 5 describes the methods and models used. Section 6 presents and discusses the baseline scenario results followed by a sensitivity analysis. Lastly, section 7 concludes the paper, followed by the Appendix and reference list.

2. Theoretical Perspective and Environmental Policy

In this section we explain the theory of negative environmental externalities and how to internalize them through environmental policy. Furthermore, we discuss and argue for why levying the tax scheme on consumers is preferable in the context of mitigating GHG emissions stemming from the food system.

2.1 Negative Environmental Externalities

A negative external effect occurs when a third party is negatively affected by the transaction between two or more other parties (Unerman et al., 2018). GHG emissions is one among many sources generating externalities such as climate change or loss of biodiversity. Emissions of individual pollutants are inherently difficult to monitor which complicates calculations of the monetary value of the associated environmental damages (Säll & Gren, 2015). In the context of the agricultural sector, GHG emissions stemming from food production have several detrimental effects on the environment and the human population, such as global warming or premature deaths (see CCAC, 2021), which allocate costs on other parties than those responsible. When firms do not account for the damages of their production, it generates inefficiencies in the market, or market failures (Gravelle & Rees, 2004). Damages from GHG releases that are not reflected in prices are analogous to societal costs, resulting in too high production and consumption from the perspective of a social planner (Pigou, 1957). This is illustrated in Figure 1.

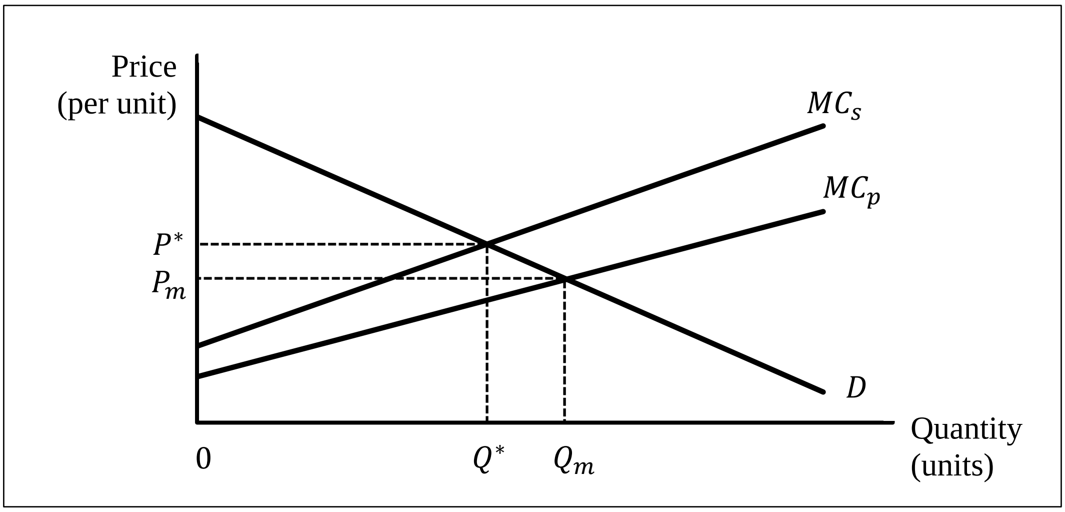

Figure 1. The market for food
Source: Own illustration based on Tietenberg & Lewis (2018).

We adapt a scenario based on Tietenberg & Lewis (2018), to fit the context of this paper as illustrated in Figure 1. Consider a market for food where firms operate under the condition of profit maximization. In equilibrium, a representative firm will produce the quantity Q_m priced at P_m i.e., the private marginal cost of production (MC_p), given the demand (D) and little consideration regarding the flow of pollution stemming from the production. However, from the perspective of society, the cost of pollution which originates from the firm's production should be reflected in the price of the commodity. Consequently, the socially optimal price P^* should be equal to the marginal social cost (MC_s), i.e., the cost of producing the food plus the associated cost of pollution, and the socially optimal quantity produced (Q^*) should be lower. The discrepancy between the firm's optimal solution and society's optimal solution generates a negative externality, a cost which falls upon society if left unhandled.

The process of making the responsible party bear the associated cost is called internalization. Externalities are progressively internalized over time according to Unerman et al., (2018). The continuum of internalization is displayed in Figure 2.

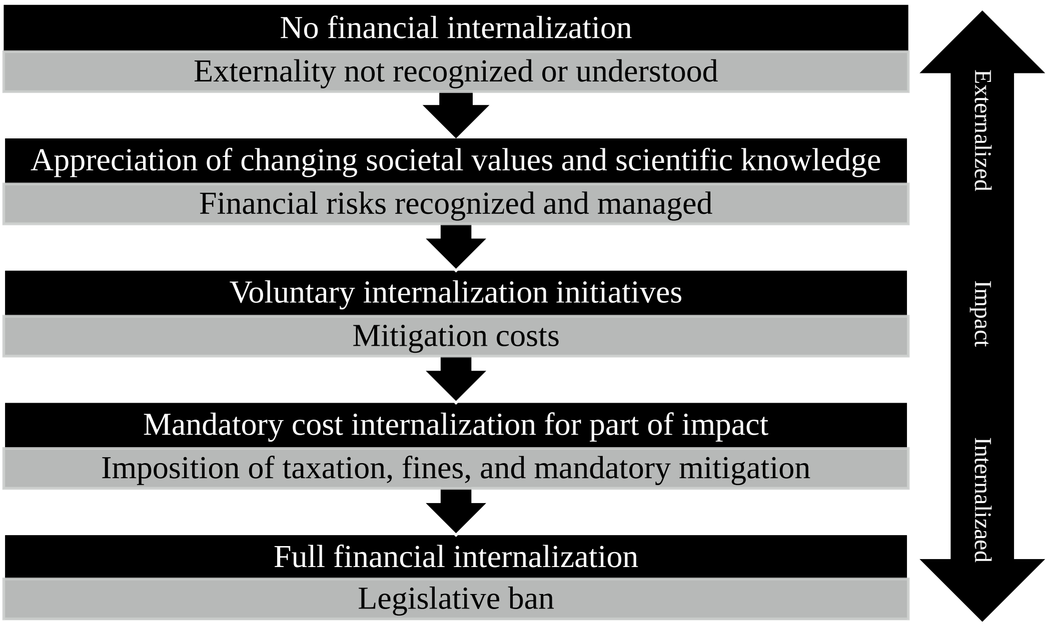

Figure 2. Internalization of negative externalities continuum
Source: Own illustration based on Unerman et al., (2018).

Previous research on mitigating GHG emissions through dietary change emphasize the importance of providing information to consumers about the impact of food on the environment (see Arrieta & González 2018; Dagevos & Voordouw 2013; Kiff et al., 2016). Increasing the voluntary internalization by making consumers switch towards less emission-intensive food through raised awareness regarding the environmental impacts is important. However, as displayed in Figure 2, a larger share of the social costs stemming from GHG emissions can be accounted for by making the internalization mandatory through implementation of taxes or fines. Considering that implementing a legislative ban on GHG emissions is currently unfeasible, the second-best alternative is to make consumers or producers bear the associated costs rather than the society, and thereby approaching the socially optimal solution.

2.2 Environmental Policy

According to Pigou (1957), regulators can impose taxes on commodities causing externalities, such that the price for each individual product is equal to the marginal social cost, to fully internalize the negative externalities. In practice, this could be achieved by imposing a unit tax, unique for every single commodity, which is set equal to the social cost of emitting one kilo of CO_2e. According to theory, it does not matter whether the tax is levied on the production-side or the consumption-side. However, in the context of the food system, there are several problems with implementing this tax scheme. Schmutzler and Goulder (1997) find that optimal output taxes may generate large social costs through extensive emissions monitoring at farms and also cause high administrative burden. This is problematic as monitoring would need to be performed at farm level on a regular basis and since GHG emissions vary across farms depending on e.g., feed or method of production as pointed out in Wirsenius et al., (2010). A solution to these problems (e.g., Säll & Gren, 2015; Wirsenius et al., 2010) is to determine tax levels based on average emission levels within a specific market, such as the dairy market. Even though variation in GHG emissions across producers would be omitted resulting in a less cost-effective tax scheme, the benefits are that the tax scheme would be easier to implement, maintain and have substantially lower administrative costs (Wirsenius et al., 2010).

Furthermore, if Pigouvian taxes are levied on producers in an open economy there is a risk of carbon leakage as this would incentivize increasing the share of imported foods (Jansson & Säll, 2018). In the context of Sweden, Säll & Gren (2015) argue that domestically produced food will be less competitive relative to foreign food products due to higher relative prices stemming from taxation. Consumers may thus shift into imported food commodities and thereby exporting GHG emissions whilst implicitly rendering domestic production less competitive on the global market. Consequently, the tax scheme may not be effective in mitigating GHG emissions if it is levied on the production side.

On the other hand, by levying the tax on consumers all products would be taxed equally independent of whether the commodities are produced domestically or if they are imported (Jansson & Säll, 2018). Although, this does not guarantee that carbon leakage will not occur. It will, however, be much lower compared to the tax being carried by the production-side as Wirsenius et al., (2010) point out. Additionally, since the tax is weighted on GHG emissions, prices of emission-intensive food commodities will increase much more in comparison to food commodities associated with low GHG emissions, thereby increasing the financial incentive to shift into less emission-intensive goods.

Thus, based on the advantages of levying a tax on the consumers in trying to mitigate GHG emissions through dietary change we apply a Pigouvian tax scheme using average emission levels. As dairy generally is associated with higher emission levels of CO_2e per kg in comparison with plant-based substitutes (see Clune et al., 2017; Karlsson Potter et al., 2020), we want consumers to shift towards plant-based substitutes. Therefore, in the baseline scenario we impose CO_2e weighted Pigouvian taxes on all commodities to establish a baseline and thereafter alter the tax scheme in the sensitivity analysis.

3. Literature Review

Many studies on the subject of dietary change find that animal products possess the greatest potential in reducing negative environmental externalities (e.g., Röös et al., 2021; Springmann et al., 2016; Willett et al., 2019). Springmann et al., (2016) examine the potential health and environmental consequences of dietary change by evaluating a range of hypothetically implemented diets relative to a baseline scenario. Their baseline scenario yields a 51 percent increase in GHG emissions by 2050, from approximately 7.6 gigatons (Gt) to 11.4 Gt per year. Regarding GHG emissions, Springmann et al., (2016) find that a dietary transition from meats towards plant-based food has the potential to reduce GHG emissions by 29-70 percent when compared to the baseline scenario. Furthermore, such a transition would relieve pressure on land-use, improve the health of the global population, and reduce mortality. The results show that 72-76 percent of the total reductions in GHG emissions stem from dietary change in developing countries However, the reduction in GHG emissions per capita in developed countries was almost double that of developing countries.

Similarly, on a more disaggregate level, Röös et al., (2020) construct a hypothetical diet scenario enforcing a dietary transition away from meat and towards domestically produced legumes in Sweden. Meat consumption is assumed to decrease by 50 percent and replaced by an increase in consumption of legumes. The scenario analysis shows that most macro- and micronutrients can be maintained within Nordic Nutrition Recommendations, whilst reducing the CO_2e emissions per person and year by approximately 20% on average relative to current consumption. However, as Röös et al., (2020) conclude, the dietary transition would require consumers to understand and internalize information regarding the environmental benefits and implementation of policies aimed to reduce meat consumption and increase domestic production and consumption of grain legumes.

In a more comprehensive study, Willett et al., (2019) propose a range of optimal diets based on compliance with the United Nations Sustainable Development Goals (SDGs) and the Paris Agreement. In congruence with the results from Springmann et al., (2016) and Röös et al., (2020), the dietary transition needed to reach global agreements is to increase the intake of plant-based food and significantly decrease the consumption of meat and dairy products. Willett et al., (2019) show that the vegan diet produces the least amount of GHG emissions per year. Although, the largest reduction in GHG emissions occurs when moving from the business-as-usual diet to the optimal diet and is approximately 4 Gt CO_2e per year. However, as expressed by the authors, global dietary change will not occur overnight nor by itself. Thus, there is a need for a wide range of policies and nudges ensuring that this transition will occur.

One policy which have been increasingly debated and researched the last decade, albeit only in a limited number of studies, is consumption taxation. Wirsenius et al., (2010) were among the first to research the potential of consumption taxation in achieving dietary change and therethrough mitigation of GHG emissions. The results show that applying GHG weighted taxes on animal products within the EU27 and setting the price on CO_2e to 60€ per ton may reduce GHG emissions by 32 million tons. However, more rigorous studies have been conducted since that of Wirsenius et al., (2010) which focus on the mitigation potential of a dietary transition through consumption taxation.

Edjabou & Smed (2013) investigate the effect of a consumption tax scheme on 23 food categories on GHG emissions and how the tax affects consumer demand in Denmark. Using monthly data on household food consumption prior to the tax, the authors calculate price-elasticities using the linear form of the Almost Ideal Demand System (AIDS) to determine the changes in food consumption stemming from the tax. The results show that decreases in CO_2e are mainly driven by reductions in beef consumption, where the most efficient tax of 3.53-6.90 DKK per kg of CO_2e decreases the carbon footprint by 10.4-19.4 percent. The optimal tax per kg of CO_2e is substantially higher than the price suggested in Wirsenius et al., (2010).

Similar studies have been conducted in the Swedish context but are still very few. Säll & Gren (2015) analyze the impact of a consumption tax on seven meat and dairy products on GHG emissions and consumer demand. In comparison to Edjabou & Smed (2013), Säll & Gren (2015) also included ammonia, phosphorus, and nitrogen to the taxable emissions. Similarly, the authors utilize the AIDS model, albeit in a non-linear format, to estimate changes in demand. The data used is on Swedish consumption per capita during the period 1980-2012. The findings indicate that a tax level ranging from 8.9 to 33.3 percent of baseline prices results in changes in consumer demand by 1.8 to 13.1 percent, contingent on products and price elasticities. Furthermore, implementing a tax on all products has the potential to reduce the pollutants by 1.5 percent compared to total Swedish emissions, and 12.1 percent in the Swedish livestock sector.

The findings of Säll & Gren (2015) are extended by Säll et al., (2020) and Moberg et al., (2021) who investigate the impact of a climate tax on emissions of pollutants and consumer demand applied on 52 food groups in Sweden. The results are consistent with the overall literature, that dietary change achieved through a consumption tax has the potential to reduce GHG emissions by approximately 10 percent. Furthermore, reducing consumption of animal products has the greatest potential to mitigate GHG emissions, which account for around 90 percent of the total reductions. However, due to lack of data, little effort is spent on exploring changes in demand for plant-based substitutes.

In summary, a dietary transition from animal products towards plant-based food is necessary if international agreements on climate change and sustainable development are to be met within the set timeframe. Furthermore, consumption taxation is seemingly a useful policy for creating dietary change from emission-intensive meat towards less intensive food commodities. However, little work has been done on trying to quantify the changes in demand of plant-based substitutes, especially considering dairy substitutes, even though the literature stress that consumption of plant-based products must increase. This study will take a novel leap towards filling this gap by analyzing consumers propensity to substitute dairy for plant-based drinks, following the introduction of a CO_2e weighted consumption tax scheme.

4. Data

This section describes the data used in the analysis of the study, starting with an explanation of the consumption and price data. Thereafter, we explain the process of how the data has been managed to fit the context of this paper followed by descriptive statistics of the final dataset. Lastly, we compile CFs for the commodity groups based on previously performed LCAs and then discuss potential limitations of the data.

4.1 In-store Data

This study uses daily in-store data on dairy and plant-based drinks collected by ICA Maxi Nacka in Stockholm, Sweden, during the period 2020-08-01 to 2021-03-31. The raw sales data were sampled by the store and sent via e-mail to the research team at SLU. The dataset is comprised of a total of 243 days. Each row in the data contain information about which product was sold, the date it was sold, the quantity sold, the weight of the product, and the aggregated value of all quantities sold expressed in SEK excluding Value Added Tax (VAT).

4.2 Data Management and Descriptive Statistics

The raw data from ICA Maxi had to undergo several sorting steps before it could be analyzed. These were performed using Microsoft Excel. The first step was to create the categorical variables relevant for this paper and assign them to the products. The upper stage categories used were dairy and plant-based drinks. The dairy category is comprised of conventional dairy, organic dairy, and lactose-free dairy and the plant-based drinks category of oat drinks, soy drinks, and other plant-based drinks. Other plant-based drinks consist of more exotic drinks such as almond drinks, coconut drinks, and rice drinks. As the complete dataset included dairy and plant-based products irrelevant for this paper, such as yoghurt, cream, or plant-based equivalents, these were omitted from the data. Furthermore, flavored dairy, flavored plant-based drinks, and dairy from other animals than cows were excluded from the data. The initial sorting process resulted in a total of 70 unique cow dairies and 50 plant-based drinks.

The second step was to calculate the amount sold expressed in kilo for each product and day, which was achieved by approximating one liter of beverage to one kilo. Thereafter, the price per kilo of sold product was calculated for each commodity and since the monetary value for each product was excluding VAT, values were multiplied by 1.12 to add the Swedish VAT of 12 percent.

The third and last step was to obtain average prices for each food group and day. The average prices for each category were then reconstructed into price indices using the first observation (2020-08-01) as the base. The final data used in the analysis is comprised of 243 consecutive daily observations of average prices including VAT and total kilos sold for each of the eight categories. Table 1 displays the descriptive statistics of the dairy variants and plant-based drinks.

Table 1. Descriptive statistics of dairy and plant-based drinks

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Q_{Dairy}	243	2932.76	507.94	1492.90	6262.50
$Q_{PlantDrinks}$	243	490.17	97.81	170.00	780.00
P_{Dairy}	243	11.11	0.32	9.41	11.68
$P_{PlantDrinks}$	243	18.74	0.35	17.23	19.64
$Q_{Con.Dairy}$	243	1385.41	228.49	691.00	2892.00
$Q_{Org.Dairy}$	243	821.32	171.73	360.70	1976.20
$Q_{LactoseFree}$	243	726.03	136.96	385.20	1394.30
$P_{Con.Dairy}$	243	9.42	0.26	7.79	9.66
$P_{Org.Dairy}$	243	12.13	0.55	8.88	12.89
$P_{LactoseFree}$	243	13.24	0.73	11.28	14.37
$Q_{OatDrink}$	243	395.35	80.19	121.00	658.00
$Q_{SoyDrink}$	243	26.31	9.65	5.00	54.00
$Q_{OtherPlant}$	243	68.51	17.45	27.00	116.00
$P_{OatDrink}$	243	17.96	0.31	16.27	18.86
$P_{SoyDrink}$	243	18.45	0.58	12.11	19.65
$P_{OtherPlant}$	243	23.36	1.02	20.91	26.43

Source: Own calculations based on data from ICA Maxi.
Notes: The quantities are in kilograms and the prices in SEK incl. VAT per kilogram.

The average quantity of dairy sold per day is 2932.76 kg and conventional dairy is both the most sold and cheapest amongst the dairy variants on average. The aggregate quantity of all plant-based drinks sold per day on average amounts to 490.17 kg which is substantially less in comparison to dairy. Furthermore, oat drinks account for 80.6 percent of all plant-based drinks sold each day on average and is also the cheapest plant-based drink on average priced at 17.96 SEK per kg. The prices of the commodities change little during the period as explained by the low standard deviations. Additionally, the most expensive food group is other plant-based drinks, which is reasonable due to being produced abroad and thus having higher associated costs.

4.3 Climate Footprints

In order to evaluate the effect of consumption taxation on consumption and GHG emissions there is a need for data on CO_2e emissions per kg for each food group. There are several studies determining the CF of various food commodities through LCA in a global context such as Clune et al., (2017). However, since this paper utilizes Swedish consumption data and is set in the context of Sweden, the LCAs by Moberg et al., (2019) and Karlsson Potter et al., (2020) are more suitable since they estimate CFs of commodities in Sweden. Considering that Karlsson Potter et al., (2020) compile data from many LCA studies and databases, including Moberg et al., (2019), we will mainly use their estimates for congruence throughout the analysis.

Karlsson Potter et al., (2020) compile LCA estimates from approximately 200 papers, reports, and documents and adjust them to fit the context of Swedish markets. The authors categorize environmental impacts into five categories, one of which is climate impact measured in kg CO_2e emissions per kg of product. Furthermore, CO_2e emissions per kg for each product are determined from cradle-to-store in Sweden. Additionally, each GHG is weighted by its Global Warming Potential over 100 years (GWP_{100}) thereby adjusting for each individual GHG regarding its impact on the climate. The other four categories having an impact on the environment are land use, biodiversity impact, water-use, and pesticide use. It is important to note that GHG emissions are not the only negative externality stemming from food production, even though this paper is focused on analyzing GHG emissions. Certain plant-based drinks such as almond drinks or coconut drinks may have a lower CF than Swedish dairy but is also associated with higher levels of water use and biodiversity impacts (see Karlsson Potter et al., 2020), which is important to acknowledge.

One problem is that LCA studies generally do not differentiate between conventional, organic, and lactose-free dairy. Consequently, we need to make assumptions regarding the climate impact of one kg of organic dairy and lactose-free dairy respectively. The life cycles of conventionally produced milk and organic milk are very similar in terms of GHG emissions as there are no systematic differences in the amount of CO_2e emissions per kg (Flysjö et al., 2012). Potential differences in CFs mostly depends on how land use change is assumed to be affected, where organic dairy production require more land due to requirements and regulations (see Flysjö et al., 2012). Since the CFs presented in Karlsson Potter et al., (2020) are determined without accounting for change in land use it is reasonable to assume that the CF of organic dairy is equal to that of conventional dairy. Additionally, considering that the major difference in production of lactose-free dairy is the hydrolysis of lactose (see Dekker et al., 2019), the CF of lactose-free dairy should be approximately the same as dairy. Due to this uncertainty, lactose-free dairy may have a higher climate impact if the process of removing lactose is e.g., a very energy-intensive process. However, even if this is the case the difference in CO_2e emissions would likely be marginal at most.

Furthermore, due to lack of CF estimations on rice drinks in Karlsson Potter et al., (2020) there is a need for additional sources to fill in the gap. Rice drink estimates are obtained from CarbonCloud's open access database. CarbonCloud's (2022) estimates are based on a cradle-to-store supply chain, GWP_{100}, and set in the context of Sweden similarly to Karlsson Potter et al., (2020). There could be minor discrepancies between the two sources regarding for example method of calculations. However, they are likely marginal and will not affect the overall results. Table 2 presents the CFs measured in CO_2e per kg.

Table 2. Climate footprints

Food group	**CO_2e emissions/kg**	**References**
Conventional dairy	1.400	Karlsson Potter et al., (2020)
Organic dairy	1.400	Karlsson Potter et al., (2020)
Lactose-free dairy	1.400	Karlsson Potter et al., (2020)
Oat drink	0.300	Karlsson Potter et al., (2020)
Soy drink	0.700	Karlsson Potter et al., (2020)
Other plant-based drinks	0.740*	Calculated based on Karlsson Potter et al., (2020) and CarbonCloud (2022)

Source: Based on data from ICA Maxi, CarbonCloud (2022), and Karlsson Potter et al., (2020).
*Notes: * See Table A1 in appendix for calculations of sales weighted climate footprints.*

4.4 Limitations

There are several limitations associated with the in-store dataset provided by ICA Maxi. First off, all observations in the data are collected from a single store, rather than a variety of stores across all of Sweden and the store is located in Stockholm County which has the highest population density in Sweden (Statistics Sweden, 2022a). This implies that any results about consumer demand may be hard to generalize to fit a representative consumer in Sweden as consumer behavior may differ in e.g., more rural areas of Sweden.

Furthermore, Nacka municipality has the 7th highest median income of all Swedish municipalities (Statistics Sweden, 2022b). Consequently, results will not directly reflect the consumer behavior of low-income households. Additionally, although the store is located in Nacka there are several low-income areas in close vicinity to the store, meaning that the income level of the average customer is not necessarily as high as the median income of the municipality. Thus, consumption patterns may differ marginally dependent on income levels, however, it is reasonable to assume that consumer demand for dairy and plant-based drinks is approximately the same in other Swedish municipalities. Nonetheless, consumption of plant-based drinks may differ geographically given the impact of green consumption trends on the local population.

Additionally, CFs had to be approximated for the food groups plant-based drinks, organic dairy, lactose-free dairy, other plant-based drinks due to lack of data as described in section 4.3. Best case scenario is, however, to have a congruent LCA for all specific food groups to ensure that the same method is applied throughout the whole LCA. The lack of this might result in a less efficient tax scheme implementation, however, the effects are likely marginal. Lastly, as we have had no ability to monitor the data collection of the data sent by ICA Maxi there might be potential data entry errors that could bias estimates. However, initial scatter plots on quantity sold and value sold showed no visual outliers and should therefore be no cause for concern.

5. Methods

In this section, we explain and argue for the methodological approach used in this paper. First, we describe how the demand system is constructed and its underlying assumptions. Thereafter, we argue for the QUAIDS model and why it is suitable in the context of the paper. Then, we present calculations of elasticity estimations and optimal consumption tax levels. Lastly, we describe how to obtain the estimated changes in demand and GHG emissions occurring due to implementation of the tax scheme.

5.1 The Demand System

There are several challenges associated with conducting an analysis of consumption patterns, especially regarding the vast quantity of commodities affecting the choices of the consumer. A complete demand system treating commodities individually would translate into the need to solve several thousands of equations, which is neither efficient nor sensible (Edgerton, 1997). The hurdle can be dealt with by assuming weak separability as described in Edgerton (1997), i.e., that preferences of utility maximizing consumers have a structure such that commodities with similar properties can be categorized into groups. This implies that a price change in one commodity and group will affect the demand for all other products within another group. Furthermore, the assumption of weak separability is often used in tandem with the assumption of multistage budgeting, where consumers allocate their expenditure over all available groups. Thereafter, expenditure allocation within each separate group is determined irrespective of the previous allocation.

We apply a similar approach as Edgerton (1997) using a three-stage budgeting process which is displayed in Figure 3. The first stage of interest is dairy and dairy-like drinks. This stage is not directly estimated due to the need for data on all other food groups at the same level, which is beyond the scope of this study. Instead, we utilize results in Säll et al., (2020) to solve the equations presented in section 5.3 and to obtain the final elasticities. The second stage is to allocate consumer expenditure on food over dairy and plant-based drinks contingent on prices. Thereafter, in the third stage, the expenditure is reallocated and distributed over all food commodities within each group, thereby allowing consumers to compare products with similar properties, given their budget.

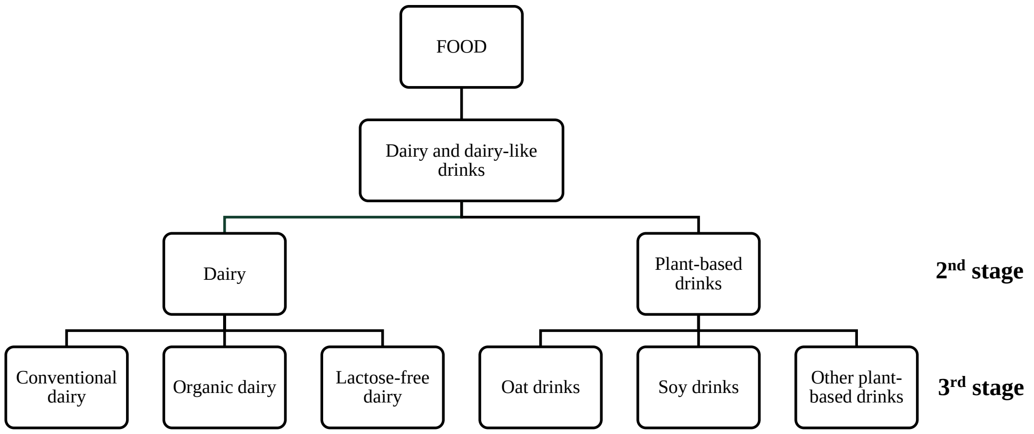

Figure 3. Utility tree for dairy and plant-based drinks
Source: Own illustration based on Edgerton (1997).

The demand system displayed in Figure 3 is a subsystem of a large demand system research project conducted at SLU. The lowest stage of each subsystem will be connected to higher stages through new price- and income elasticities. The structure of each other subsystem is constructed in a similar manner, which in theory should allow for substitutability between subsystems. Whether this is the case or not is not a direct concern for this study as it will be evaluated in the main project.

5.2 Quadratic Almost Ideal Demand System

The AIDS model developed by Deaton & Muellbauer (1980) is a linear demand system used to estimate income and demand elasticities. The model is advantageous compared to the similar demand system models, the Translog model (see Christensen et al., 1975) and the Rotterdam model (see Theil, 1965), since the AIDS model possesses desirable properties of both alternative models. Deaton & Muellbauer (1980) argue that their model is easier to use as it mostly avoids the need for non-linear estimation, allows for testing of homogeneity and symmetry conditions, and can obtain arbitrary first-order estimates for any demand system whilst satisfying the conditions of rational choice. Additionally, the AIDS model can perfectly aggregate over consumers through utilization of Price-Independent Generalized Logarithmic (PIGLOG) preferences which means that market demands are a result of the decisions made by a rational representative consumer (Deaton & Muellbauer, 1980). However, due to non-linearities found in expenditure data from the United Kingdoms, the AIDS model was later extended by Banks et al., (1997) to utilize a quadratic income term resulting in the QUAIDS model. Inclusion of a quadratic income term allows for non-linear Engel-curve preferences and non-linear consumer behavior. The extended model therefore allows for non-linearities in specific commodities (Banks et al., 1997).

Furthermore, The QUAIDS model allows goods to vary between being luxury goods and necessities contingent on households' income, which arguably is a desirable property when analyzing the demand for food. Thus, the QUAIDS model is defined as in equation (1) through (5) following the notation of Säll et al., (2020).

$$s_i = \alpha_i + \sum_{j=1}^{n} \gamma_{ij} \ln p_j + \beta_i (\ln X - \ln P) + \frac{\mu_i}{Q} (\ln X - \ln P)^2 \tag{1}$$

The parameter s_i is the share of expenditure put on commodity i, ranging from 1 to n $(i = 1 \dots n)$, which is a function of all commodity prices p_j, ranging from 1 to n $(j = 1 \dots n)$, and total expenditures $X = \sum_{i=1}^{n} p_i q_i$. This implies that $s_i = \frac{p_i q_i}{X}$. The parameter α_i captures logarithmic share of initial consumption of commodity i, β_i measures changes in the expenditure share due to changes in total expenditure, μ_i captures the changes from the quadratic term, and γ_{ij} captures changes in budget shares due to price changes. The QUAIDS model's aggregated price index P, in its non-linear form, is defined by equation (2).

$$\ln P = \alpha_0 + \sum_{i=1}^{n} \alpha_0 \ln p_i + \frac{1}{2} \sum_{i}^{n} \sum_{j}^{n} \gamma_{ij} \ln(p_i + p_j) \tag{2}$$

Furthermore, the price aggregator Q is defined by equation (3).

$$Q = \prod_{i}^{n} p_i^{\beta_i} \tag{3}$$

Additionally, in order to ensure symmetry and homogeneity we need to impose restrictions on the model parameters in accordance with equation (4) and (5).

$$\sum_{i=1}^{n} \alpha_i = 1 , \qquad \sum_{i=1}^{n} \beta_i = 0 , \qquad \sum_{i=1}^{n} \mu_i = 0 \tag{4}$$

Firstly, the sum of all initial consumption shares α_i must be equal to 1. Secondly, the sum of all β_i, changes in the share of expenditure due to changes in total expenditure, must be equal to 0. Thirdly, the same restriction must be true for the quadratic term as well, i.e., the sum of all μ_i must be 0.

$$\sum_{j=1}^{n} \gamma_{ij} = 0 , \qquad \gamma_{ij} = \gamma_{ij} \tag{5}$$

The homogeneity restriction in equation (5), $\sum_{j=1}^{n} \gamma_{ij} = 0$, ensures that changes in budget shares due to price changes sum to 0. The symmetry condition, $\gamma_{ij} = \gamma_{ij}$ ensures that the marginal effect of a price change in commodity *i* on the share of expenditure on commodity *j* is equal to the marginal effect of a price change in commodity *j* on the share of expenditure on commodity i.

Given the restrictions presented in equations (4) and (5), the model setup described in equations (1) – (3) allows for a baseline estimation of each stage of the demand system, if budget shares are kept constant, i.e., that neither expenditure nor relative prices change.

5.3 Elasticities

In order to evaluate changes in consumer demand due to changes in income and relative prices there is a need to estimate both price and income elasticities. The first step is to calculate compensated elasticities. Following the process in Green & Alston (1990) and the notation of Säll et al., (2020), income elasticities for each budgeting stage is defined by equation (6).

$$\varepsilon_i^I = 1 + \frac{\beta_i}{s_i} \tag{6}$$

β_i defines the change in the share of expenditures due to changes in total expenditure and s_i is the budget share. Regarding the price elasticities, the two most widely used are Marshallian and Hicksian elasticities. The Marshallian elasticities are preferable in this case as they account for the income effect arising from changing relative prices, while Hicksian elasticities only considers substitution effects (Gravelle & Rees, 2004). As the interest lies in how consumer demand changes, given budget constraints, the use of Marshallian elasticities is arguably better suited. Equation (7) defines the Marshallian elasticities for each budgeting stage.

$$\varepsilon_{ij}^M = \left[\frac{(\gamma_{ij} - \beta_i s_j)}{s_j}\right] - \delta_{ij} \tag{7}$$

The Marshallian elasticity for each budgeting change is a function of parameters defined in equation (1), and the Kronecker delta which takes on value 1 if $i = j$ and 0 if $i \neq j$ (see Green & Alston, 1990). In addition, there is a need to impose a restriction on the income and Marshallian elasticities for the homogeneity of degree zero condition to hold, which is defined in equation (8).

$$\varepsilon_i^I + \sum_{i=1}^{n} \varepsilon_{ij}^M = 0 \tag{8}$$

This restriction ensures that the income elasticity for good *i* and the sum of all Marshallian price elasticities sum to zero. In accordance with Edgerton (1997), the income and price elasticities defined in equation (6) and (7) are utilized to calculate the uncompensated income, own-price, and cross-price elasticities, accounting for all stages of the budgeting system. Accordingly, the uncompensated income elasticity is defined in equation (9), the compensated Hicksian price elasticities in equation (10), and the uncompensated Marshallian own-price and cross-price elasticities in equation (11) following the notation of Säll et al., (2020).

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

$$\varepsilon_{ij}^H = \varepsilon_{ij}^M + \varepsilon_i^I s_j \tag{10}$$

$$\varepsilon_{ij}^{M*} = \delta_{ab}\delta_{ru}\varepsilon_{ij}^H + \delta_{ab}s_j\varepsilon_i^I\varepsilon_{ru}^H + s_j s_r \varepsilon_i^I \varepsilon_r^I \varepsilon_{ab}^M \tag{11}$$

Followingly, *a* and *b* denote the first stage food groups, *r* and *u* denote the second stage food groups and *i* and *j* the individual commodities within those groups. Hicksian price elasticities need to be calculated in order to ensure that the own-price elasticities are negative in accordance with theory (Banks et al., 1997).

5.4 Tax Levels

In accordance with the literature on environmental consumption taxation (e.g., Säll & Gren, 2015), the tax on good *i* is determined by multiplying the Average Damage Cost (ADC) with average GHG emissions per kg for commodity *i* as expressed in equation (12).

$$t_i = ADC_i * emissions_i \tag{10}$$

These commodity specific taxes are implemented on the third stage of the demand system. As this study is using data from Sweden, it is appropriate to use the social cost of 1 kg CO_2e, as determined by the Swedish government. The latest revision of the Swedish carbon tax available is from 2021 and is 1.2 SEK per kg of CO_2 (Government Offices of Sweden, 2022). Accordingly, this will be the average damage cost for one kg CO_2e applied in the baseline scenario.

5.5 Changes in Consumer Demand and GHG Emissions

Utilizing the elasticities obtainable from the QUAIDS model allows for calculation of changes in demand and GHG emissions due to tax implementation. Following the same approach as Säll et al., (2020), the change in consumed quantity for each food commodity i can be defined as consumption after tax implementation less initial consumption, $\Delta q = q_i^1 - q_i^0$. Furthermore, linear demand curves are used to simplify the calculations as displayed in equation (13).

$$q_i = k_{ij} p_i + m_i + \Delta h_i \tag{11}$$

Where k_{ij} denotes the slope coefficient, p_i is the price of commodity *i* expressed in SEK per kg, m_i is the initial intercept, and Δh_i captures the aggregated effects on demand stemming from price variations due to the taxes. Consequently, $\Delta h_i = 0$ prior to the introduction of taxes. The slope coefficient for each commodity can be obtained from the final Marshallian elasticities and initial consumption and price levels as expressed in equation (14).

$$\varepsilon_{ij}^{M*} = \frac{\Delta q_i}{\Delta p_j} * \frac{p_j^0}{q_i^0} = k_{ij} * \frac{p_j^0}{q_i^0} \text{ , when } (i = j) \tag{12}$$

Thereafter, using the results from equation (14) we obtain the intercepts for each commodity prior to the tax implementation by rearranging equation (13) and solving for m_i as expressed in equation (15).

$$m_i = q_i^0 - p_i^0 * \frac{\varepsilon_{ij}^{M*} * q_i^0}{p_j^0} \text{ ,} when\ (i = j) \tag{15}$$

By utilizing these results, it is possible to obtain Δh_i by aggregating all cross-price elasticities as defined in equation (16).

$$\Delta h_i = \sum \Delta p_j * \frac{\varepsilon_{ij}^{M*} * q_i^0}{p_j^0} + \sum \Delta p_r * \frac{\varepsilon_{ru}^{M} * q_u^0}{p_r^0} * s_u \tag{16}$$

Where *r* and *u* refer to the second stage food groups and *i* and *j* to the third stage food groups. Shifts in consumption of commodity *i* and *r* respectively are driven by price changes of all other commodities within the group and also by the second stage group elasticities (Säll et al., 2020). Consequently, Δh_i determines how the intercept shifts due to the price variations in the other food groups. Thus, by using equation (13) through (16) it is possible to obtain the post-tax quantities by solving Δq for q^1 for the second and third stage as expressed in equation (17).

$$q_i^1 = \varepsilon_{ij}^{M*} \frac{q_i^0}{p_i^0} * (p_i^0 + \Delta p_i) + (m_i + \Delta h_i) \tag{17}$$

Thereafter, all changes in quantity across the other commodities within the group are aggregated to obtain the total effect of the tax scheme on consumption. Lastly, the change in GHG emissions for each commodity group *i* is calculated in accordance with equation (18).

$$\Delta E_i = e_i * \Delta q_i \tag{18}$$

Where e_i is CO_2e emissions per kg and Δq_i is the change in quantity of commodity i.

6. Results and Discussion

In this section we present and analyze the results starting with consumers’ price sensitivity estimated with the QUAIDS model. Thereafter, we assess the impact of consumption taxation on consumer demand and GHG emissions followed by a sensitivity analysis. Additionally, all calculations and statistical estimations in this section are performed using the econometric software Time Series Processor (TSP) and Microsoft Excel.

6.1 Price Sensitivity

This subsection presents the results obtained by applying the QUAIDS model on the three-stage demand system derived in section 5.1 through 5.3. As estimation of the first stage of the demand system “dairy and dairy-like drinks” is beyond the scope of this paper the Marshallian own-price elasticity for dairy presented in Säll et al., (2020) is used as an approximation. The elasticity used is -0.212 and is calculated using the same QUAIDS model and assumptions as in this paper. Therefore, the estimate should represent the aggregate group well considering that 85.7 percent of the food commodities within the group sold per day on average are dairy variants. Thus, the QUAIDS model is applied on the second- and third stage of the demand system to obtain the own- and cross-price elasticities of demand.

Regarding the second stage of the demand system, one model for dairy is estimated which is then used to construct the model for plant-based drinks. In the third stage, conventional dairy and organic dairy are estimated and then used to obtain lactose-free dairy estimates. Similarly, oat drinks and soy drinks are estimated to obtain other plant-based drinks estimates. All independent variables in the second stage QUAIDS models are lagged by one day, except for ln(P) of plant-based drinks which is lagged by seven days, to incorporate the consumer behavior of previous purchases. However, using lagged variables may cause problems with autocorrelation i.e., correlation between the variable itself and its lagged value (see Stock & Watson, 2020). Therefore, it is important to validate that autocorrelation is not present in the estimations. No model shows any sign of autocorrelation which is confirmed by the statistically significant Lagrange Multiplier (LM) tests as the null hypothesis that autocorrelation does not exist is accepted (see Table A2-A4 in the Appendix).

Furthermore, the measure of fit R^2 ranges from 0.007 to 0.105 in the second and third stage models (see Table A2-A4 in the Appendix) indicating that the models explain little of the variation of the dependent variable. However, as argued by Stock & Watson (2020) low R^2 values do not conclude that the models' results are necessarily bad, but rather that there are other factors which may be important in determining the budget shares. Thus, given the potential noise arising from daily time series data the low R^2 should not be considered a major issue to the overall results.

Table 3 presents the second stage compensated elasticities within each food group and the final uncompensated elasticities. The parameter values of the second and stage models are presented in detail in the Appendix (see Table A5).

Table 3. Second stage elasticities

Compensated elasticities, within group			
	Dairy	Plant-based drinks	Income
Dairy	**-1.014*** **	0.024	0.990***
	(0.032)	(0.031)	(0.007)
Plant-based drinks	0.084	**-1.144*** **	1.060***
	(0.188)	(0.188)	(0.042)
Final uncompensated elasticities			
	Dairy	Plant-based drinks	
Dairy	**-0.346**	0.136	
Plant-based drinks	0.800	**-1.025**	

Source: Calculated based on data from ICA Maxi.
*Notes: Standard errors in parenthesis, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.*

First off, all compensated own-price elasticities are negative which is expected as an increase in the price of commodity *i* should decrease the quantity demanded (Gravelle & Rees, 2004). Furthermore, the own-price elasticities are both relatively close to unitary elasticity. Regarding the income elasticities, both are close to 1 where the income elasticity for plant-based drinks is slightly higher, suggesting that these commodities are viewed as somewhat more luxurious relative to dairy. Cross-price elasticities, however, are much lower than the respective own-price elasticities. both cross-price elasticities are positive, meaning that dairy and plant-based drinks are substitutes.

The final uncompensated elasticities show that when letting expenditure flow from dairy and dairy-like drinks the elasticities change drastically. The uncompensated own-price elasticities are still negative which is in accordance with the theory (Edgerton, 1997). The final own-price elasticity of dairy (-0.346) is of similar magnitude found in the literature (e.g., Edjabou & Smed, 2013; Säll & Gren, 2015) and imply that the consumers are not very sensitive to changes in dairy prices. This is reasonable as dairy arguably is viewed as a necessity. Plant-based drinks on the other hand, are relatively more elastic which could be explained the higher average price and that they are viewed as more luxurious. This is also supported by the final cross-price elasticities where a one percent increase in dairy price increases the demand for plant-based drinks by 0.136 percent and a one percent increase in the price of plant-based drinks increases the demand for dairy by 0.800 percent. This suggests that consumption taxes on animal dairy have the potential to shift consumption towards plant-based substitutes which is in accordance with the literature on dietary change (e.g., Springmann et al., 2016, Willett et al., 2019). However, consumers propensity to shift towards dairy is much higher than the propensity to shift towards plant-based drinks. This suggests that putting plant-based drinks under taxation may increase rather than decrease GHG emissions. The third stage compensated- and final uncompensated elasticities for the dairy variants and various plant-based drinks are presented in Table 4 and Table 5 respectively.

Table 4. Third stage elasticities, dairy

Compensated elasticities, within group				
	Con. dairy	Org. dairy	Lactose-free	Income
Con. dairy	**-1.090*** **	0.115**	0.052	0.923***
	(0.071)	(0.054)	(0.039)	(0.016)
Org. dairy	0.101	**-1.106*** **	-0.116**	1.121***
	(0.094)	(0.093)	(0.053)	(0.024)
Lactose-free	0.058	-0.100*	**-0.968*** **	1.010***
	(0.074)	(0.060)	(0.066)	(0.024)
Final uncompensated elasticities				
	Con. dairy	Org. dairy	Lactose-free	
Con. dairy	**-0.804**	0.283	0.201	
Org. dairy	0.449	**-0.901**	0.065	
Lactose-free	0.371	0.084	**-0.804**	

Source: Calculated based on data from ICA Maxi.
Notes: Standard errors in parenthesis, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5. Third stage elasticities, plant-based drinks

Compensated elasticities, within group				
	Oat drinks	Soy drinks	Other	Income
Oat drinks	**-0.972*****	0.018	-0.026	0.979***
	(0.075)	(0.042)	(0.051)	(0.012)
Soy drinks	0.181	**-1.412*****	0.131	1.100***
	(0.636)	(0.509)	(0.384)	(0.099)
Other	-0.232	0.051	**-0.901*****	1.082***
	(0.296)	(0.146)	(0.264)	(0.060)
Final uncompensated elasticities				
	Oat drinks	Soy drinks	Other	
Oat drinks	**-0.991**	0.017	-0.029	
Soy drinks	0.159	**-1.413**	0.128	
Other	-0.254	0.050	**-0.904**	

Source: Calculated based on data from ICA Maxi.
Notes: Standard errors in parenthesis, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

As seen in Table 4 and 5, all own-price elasticities are negative in accordance with theory. Organic dairy has the highest income elasticity (1.121) of the dairy variants which is reasonable due to the price premium associated with organic products. All dairy variants are viewed as substitutes when allowing expenditure to flow between groups as seen by the non-negative final cross-price elasticities. Consumers' propensity to shift away from conventional dairy is lower than the propensity to shift towards conventional dairy. Furthermore, the relatively low cross-price elasticities of organic and lactose-free dairy suggests that consumers choose between either organic dairy and conventional dairy, or lactose-free dairy or conventional dairy. This result is reasonable as the average price of conventional dairy is lower than that of organic- or lactose-free dairy and is also the most purchased dairy on average per day.

Regarding the various plant-based drinks, the own-price elasticities are all negative in accordance with theory and are furthermore close to unitary elasticity, except for soy drinks which is more elastic. The income elasticities show that oat drinks are classified as a normal good, whilst the more exotic soy and other plant-based drinks are perceived as relatively more luxurious. However, these results are reasonable considering higher average prices and that neither soy drinks nor other plant-based drinks are domestically produced. Final cross-price elasticities are low overall and vary across the commodities. Regarding oat drinks, an increase in the price of soy drinks will increase the demand for oat drinks, whilst an increase in the price of other plant-based drinks will decrease the demand. The latter is undesirable given that we want consumers to shift into oat drinks as it is the least emission-intensive food group.

Considering the lack of previously conducted studies on the demand for plant-based drinks, it is not possible to evaluate the magnitude of the elasticities relative to the literature. The compensated own-price elasticities of the dairy variants, however, are somewhat similar to the results found by Säll & Gren (2015), albeit larger in magnitude. Säll & Gren (2015) find the own-price elasticity for dairy to be -0.709 which is less elastic in comparison to conventional dairy (-1.090), organic dairy (-1.106), and lactose-free dairy (-0.968). However, the fact that Säll & Gren (2015) use yearly data on per capita consumption and have another demand system structure can explain the difference in magnitude.

In summary, the second stage final uncompensated elasticities suggest that a CO_2e weighted tax scheme has the potential to shift consumption towards plant-based drinks away from the dairy variants. However, putting plant-based drinks under taxation may potentially increase GHG emissions due to the high cross-price elasticity with dairy. It is less clear how consumers will shift their consumption within the plant-based drinks group when price changes across all commodities are implemented simultaneously given the mixed positive and negative final cross-price elasticities.

6.2 The Impact of Consumption Taxes

The tax level is calibrated using the average daily price per kg and quantity sold over the whole period for each commodity group to avoid potential daily variation affecting the outcome. The results of the CO_2e weighted consumption taxation scheme on demand and GHG emissions are presented in Table 6.

Table 6. Baseline scenario: Impact of the CO_2e weighted consumption tax scheme

Second stage							
Food group	**ΔP**	**ΔP (%)**	**ΔQ**	**ΔQ (%)**	**ΔGHG (%)**	**%-share of GHG reduction**	**%-share of GHG increase**
Dairy	1.68	15.12	-146.66	-5.00	-5.00	100.00	0.00
Plant-based	0.46	2.45	47.26	9.64	9.26	0.00	100.00
Total					*-4.27*	*100.00*	*100.00*
Third stage - Dairy							
Con. dairy	1.68	17.83	-104.20	-7.52	-7.52	71.05	0.00
Org. dairy	1.68	13.85	-27.27	-3.32	-3.32	18.60	0.00
Lactose-free	1.68	12.69	-15.18	-2.09	-2.09	10.35	0.00
Total					*-5.00*	*100.00*	*0.00*
Third stage - Plant							
Oat drinks	0.36	2.00	39.82	10.07	10.07	0.00	68.72
Soy drinks	0.84	4.55	1.68	6.38	6.38	0.00	6.76
Other	0.89	3.80	5.76	8.40	8.40	0.00	24.52
Total					*9.26*	*0.00*	*100.00*

Source: Calculated based on data from ICA Maxi, CarbonCloud (2022), and Karlsson Potter et al., (2020).
Notes: Prices are expressed in SEK per kg, quantities in kg, and GHG emissions in CO_2e.

First off, the relatively higher CFs of the dairy variants in combination with lower average prices per kg leads to substantially higher price changes measured in percent compared to plant-based drinks. The change in prices induced by taxes vary between 17.83 percent and 2.00 percent where the price of conventional dairy increases the most and oat drinks the least. As expected, the change in prices of the commodities within the plant-based drinks group are much smaller due to the relatively lower emission intensity. The price increase of oat drinks, soy drinks, and other plant-based drinks amount to 2.00 percent, 4.55 percent, and 3.80 percent respectively. Although soy drinks have a marginally lower CF relative to other plant-based drinks, the lower average price of soy drinks results in a higher percentage change.

The tax scheme decreases the demand for dairy by 5.00 percent and increases the demand for plant-based drinks by 9.64 percent. Focusing on the third stage of the demand system, the tax implementation reduces the demand for conventional dairy, organic dairy, and lactose-free dairy by 7.25, 3.32, and 2.09 percent respectively. Consumers shift away from conventional dairy to a higher extent than organic and lactose-free dairy, which is reasonable given the higher relative price increase. Furthermore, the change in demand for oat drinks, soy drinks, and other plant-based drinks measured in percent is relatively similar. However, the absolute changes show that consumers substitute most heavily into oat drinks, relative to soy and other plant-based drinks. Consistent with the cross-price elasticities found in the second stage, the tax scheme causes a shift away from dairy towards plant-based substitutes which is in line with expectations outlined the literature on dietary change (e.g., Springmann et al., 2016; Willett et al., 2019).

The tax implementation causes a total reduction of GHG emissions by 4.27 percent relative to the initial consumption levels, where 100 percent of the reduction stems from reduced demand for dairy. The reduction in GHG emissions for dairy variants, without considering the increase stemming from plant-based drinks, is 5.00 percent. Furthermore, 71.05 percent of the total reduction stems from reduced demand for conventional dairy, 18.60 percent from organic dairy, and 10.35 percent from lactose-free dairy. Additionally, 100 percent of the increase in GHG emissions are attributable to the increased demand for plant-based drinks. Within the plant-based drinks group, 68.72 percent of the increase stems from oat drinks, 6.76 percent from soy drinks, and 24.52 from other plant-based drinks. This result is promising as the consumers shift most heavily into oat drinks which is the least emission-intensive commodity. However, best case scenario is that this share is 100 percent due to the lower impact it would have on the climate. Given the cross-price elasticity of plant-based drinks and dairy it may be possible to increase oat drinks' share of GHG increases by increasing the financial incentive to shift into oat drinks.

To compare the total impact of the taxation to results of previous studies we need to make some assumptions. Assuming that these results are representative for the whole Swedish population, a CO_2e weighted tax scheme has the potential to lower GHG emissions through reduced dairy consumption by 5.12 percent. By using the total dairy consumption per capita and year in Sweden for the year 2020 as the initial consumption level (see Swedish Board of Agriculture, 2022), it is possible to obtain the per capita reduction in GHG emissions since all dairy variants have the same climate footprint. However, any results need to be interpreted cautiously as this operation is set up to reflect the behavior of a representative Swedish consumer, whilst using data from a store located in a high-income area of Sweden.

The results found in Table A8 in the Appendix show that the CO_2e weighted tax scheme reduces the dairy consumption by 3.29 kg per person and year which corresponds to a reduction in GHG emissions by 4.61 kg CO_2e per person and year. The reduction in GHG emissions from lower dairy consumption is approximately

43 percent of the reductions presented in Säll et al., (2020). The relatively large difference could stem from the fact that the consumers visiting the ICA Maxi store in Nacka are less price sensitive in comparison to consumers from rural areas of Sweden due higher average income-levels. Substantial increases in the prices for the dairy variants, could affect low-income households more than high-income households, which would explain why the per capita reduction in Säll et al., (2020) is higher. Säll et al., (2020) also implement their tax scheme over 52 commodity groups, meaning that there are more cross effects from taxation influencing expenditure allocation which could explain the difference. Furthermore, given that Swedish per capita dairy consumption in 2015 was higher on average and Säll et al., (2020) use 2015 as a baseline for initial consumption, a difference is expected. Thus, the yearly per capita reductions in GHG stemming from reduced dairy consumption found in this paper are reasonable even though there is a difference in magnitude relative to prior studies.

The GHG mitigation potential of decreased dairy consumption is small relative to other animal products, beef especially, which is in accordance with what studies in the literature has found (e.g., Edjabou & Smed, 2013; Säll & Gren 2015; Säll et al., 2020). As shown by Säll et al., (2020), a CO_2e weighted consumption tax has the potential to decrease CO_2e emissions from reduced beef and cheese consumption by approximately 96 and 24 kg per person and year respectively. Consequently, as the global effort is to limit global warming, reductions in GHG emissions stemming from beef should be prioritized. However, although the potential GHG reductions per capita and year found in our study are small in contrast, the findings confirm that it is possible to get consumers to shift towards plant-based dairy substitutes through implementation of a CO_2e weighted consumption tax scheme.

In summary, a CO_2e weighted tax scheme implemented on all commodities reduces the demand for dairy variants, increases the demand for plant-based drinks and therethrough reduces GHG emissions, which is congruent with expectations based on the literature on dietary change (e.g., Springmann et al., 2016; Willett et al., 2019). Furthermore, consumers shift into oat drinks the most out of all the plant-based drinks. Although no directly comparable studies using in-store data exist, the results concerning reduced dairy consumption follow the same direction as in Säll et al., (2020), but are smaller in magnitude.

6.3 Sensitivity Analysis

The results in baseline scenario suggest that there is a potential to increase the shift into the least emission-intensive food group oat drinks. Therefore, the sensitivity analysis aims to determine the marginal effects of a 1 SEK tax on GHG emissions by implementing the tax on a one-at-a-time basis to evaluate how to best steer consumers towards oat drinks. Figure 4 shows the marginal effect of a 1 SEK unit tax on GHG emissions relative to the total effect when all taxes are introduced simultaneously.

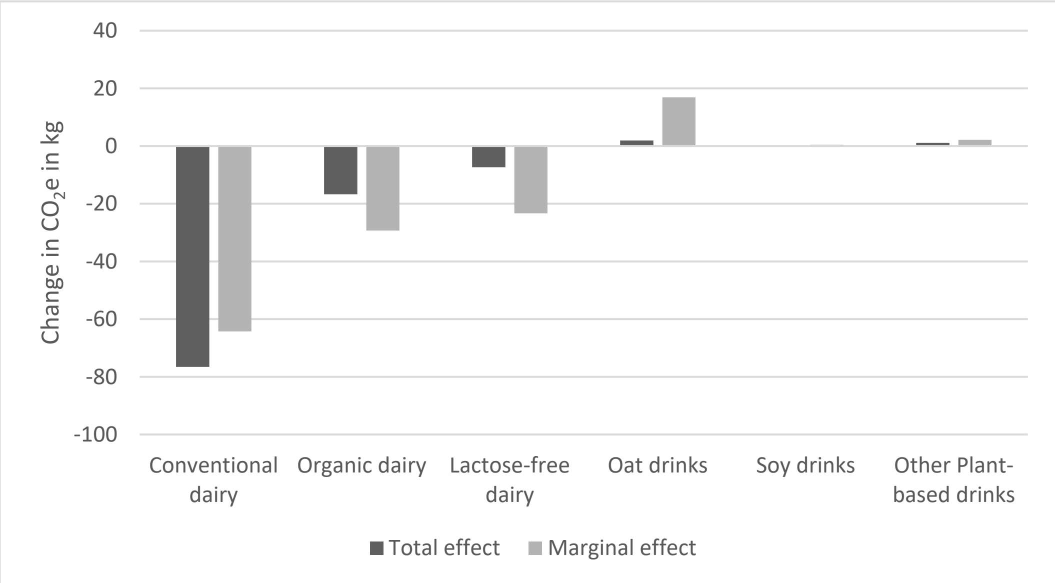

Figure 4. Total and marginal effects of 1 SEK taxes
Source: Own illustration based on data from ICA Maxi.

The difference between the total and marginal effect for each food group *i* is the sum of all cross effects due to taxation on the other groups *j*. Putting plant-based drinks under taxation (oat drinks in particular) is counterproductive as the net GHG emissions would increase. On the other hand, the tax is effective in reducing GHG emissions induced on any of the dairy variants, where conventional dairy is the most valuable to tax as this results in the highest net GHG reduction. Arguably it is therefore unsensible to place oat drinks under taxation given that the purpose of the tax is to reduce net GHG emissions.

Considering that we want consumers to shift into plant-based drinks and oat drinks specifically, it is therefore reasonable to exclude oat drinks from the tax scheme to increase the financial incentive to buy oat drinks. Since the tax scheme is consumption-sided, this would also be politically feasible as it would not violate any trade agreements or other regulatory barriers. Given this, oat drinks percentage share of GHG increases should go up due to its environmental superiority and total GHG reductions should increase. The results are presented in Table 7.

Table 7. Sensitivity analysis: Impact of the CO_2e weighted consumption tax scheme

Second stage							
Food group	**ΔP**	**ΔP (%)**	**ΔQ**	**ΔQ (%)**	**ΔGHG (%)**	**%-share of GHG reduction**	**%-share of GHG increase**
Dairy	1.68	15.12	-152.83	-5.21	-5.21	100.00	0.00
Plant-based	0.17	0.90	55.38	11.30	10.62	0.00	100.00
Total					*-4.40*	*100.00*	*100.00*
Third stage - Dairy							
Con. dairy	1.68	17.83	-107.12	-7.73	-7.73	70.10	0.00
Org. dairy	1.68	13.85	-28.99	-3.53	-3.53	18.97	0.00
Lactose-free	1.68	12.69	-16.71	-2.30	-2.30	10.93	0.00
Total					*-5.21*	*100.00*	*0.00*
Third stage - Plant							
Oat drinks	0.00	0.00	47.68	12.06	12.06	0.00	71.73
Soy drinks	0.84	4.55	1.60	6.07	6.07	0.00	5.60
Other	0.89	3.80	6.11	8.91	8.91	0.00	22.67
Total					*10.62*	*0.00*	*100.00*

Source: Calculated based on data from ICA Maxi, CarbonCloud (2022), and Karlsson Potter et al., (2020).
Notes: Prices are expressed in SEK per kg, quantities in kg, and GHG emissions in CO_2e.

As seen in Table 7, the percentage share of GHG increases regarding oat drinks increases from 68.72 percent to 71.05 percent which is in line with the expectations. However, the change is marginal and only reduce total GHG emissions by an additional 0.13 percent even though the difference in ΔQ between the scenarios is 7.85 kg. The small impact in total GHG emissions can likely be explained by the fact that the change in price for oat drinks was small in the baseline scenario. Consequently, it is reasonable that by lowering the price 0.36 SEK does not have a substantial effect on the outcome. A possible way to further increase the financial incentive is to subsidize oat drinks through e.g., lowered VAT. However, this is beyond the scope of this paper.

7. Concluding Remarks

In the light of global efforts of limiting GHG emissions, this paper has investigated the effect of a CO_2e weighted consumption tax scheme on change in demand and GHG emissions for dairy and plant-based drinks in the context of Sweden. The results of this paper support the evidence that a dietary transition towards plant-based substitutes from animal products has a positive mitigation effect on GHG releases (e.g., Springmann et al., 2016; Willett et al., 2019). Furthermore, the paper confirms that implementation of a CO_2e weighted tax levied on the consumers is an efficient policy in generating dietary change towards plant-based dairy substitutes. The baseline tax scheme may reduce GHG emissions by 4.27 percent, while the sensitivity analysis confirmed that exempting oat drinks from taxation resulted in marginally higher net reductions of 4.40 percent. Although consumers shift into plant-based drinks due to the taxation, most of the net GHG reductions stem from reduced dairy consumption.

The mitigation potential of decreased dairy consumption is small in magnitude relative to other animal products such as cheese of meat (e.g., Edjabou & Smed, 2013; Säll & Gren, 2015). Therefore, focus should arguably be on finding ways to limit consumption of more emission intensive food commodities given the urgent need to limit GHG emissions. However, there are still uncertainties regarding how consumers may switch from meat or dairy products towards plant-based substitutes as little research has been conducted. Although increased financial incentive of shifting into plant-based substituted nudges consumers in the right direction, consumption taxation alone will not be sufficient in causing the dietary transition needed due to the complexity of the global food system. There are multiple other environmental externalities, both positive and negative, stemming from the food system which influences the optimal diet which this paper does not account for. There is water usage, pesticide usage, and change in land use to name a few. However, this paper does not set out to provide the first best solution on how to minimize global GHG emissions, but rather to provide new insights regarding if dietary change towards plant-based substitutes can be achieved through taxation as hypothesized in the literature (e.g., Willett et al., 2019).

There are several potential issues related to implementation of this type of tax scheme. First off, given that the tax is weighted on CO_2e emissions the dairy variants will experience significant price increase relative to the plant-based drinks which might not be well accepted by the general public. Considering all food commodities being put under taxation, consumers most certainly will not be happy with having to pay several percent more for their food overnight. Furthermore, reduced long term dairy consumption may also have a negative impact on positive externalities associated with dairy production. As fewer calves will graze on natural pastures the positive effect on biodiversity will diminish. Although calves would be fewer in number most ruminants do not graze on natural pastures (Säll & Gren, 2015), and the potential loss of biodiversity could be counteracted by legislation enforcing a larger proportion of ruminants to graze on traditional fields.

There is still much to be done within the field and future research could provide additional insights by appending the demand system to include more animal products and respective plant-based substitutes. Furthermore, this study can be extended by gathering data from multiple stores located in all of Sweden to analyze the distributional effects of the tax scheme.

References

Arrieta, E. M., & González, A. D. (2018). Impact of current, National Dietary Guidelines and alternative diets on greenhouse gas emissions in Argentina. *Food Policy, 79,* 58–66.

Banks, J., Blundell, R., & Lewbel, A. (1997). Quadratic Engel curves and consumer demand. *Review of Economics and statistics, 79*(4), 527-539.

CarbonCloud (2022). *Technical Report – Climate Footprint of Rice drink 1L, Sweden.* https://apps.carboncloud.com/climatehub/product-reports/id/152938323851 (Accessed: 2022-02-28)

Christensen, L. R., Jorgenson, D. W., & Lau, L. J. (1975). Transcendental logarithmic utility functions. *The American Economic Review, 65*(3), 367-383.

Clune, S., Crossin, E., & Verghese, K. (2017). Systematic review of greenhouse gas emissions for different fresh food categories. *Journal of Cleaner Production, 140*, 766–783.

Dagevos, H., & Voordouw, J. (2013). Sustainability and meat consumption: is reduction realistic? *Sustainability: Science, Practice and Policy, 9*(2), 60-69.

Deaton, A., & Muellbauer, J. (1980). An Almost Ideal Demand System. *The American Economic Review 70*(3), 312–326.

Dekker, P. J., Koenders, D., & Bruins, M. J. (2019). Lactose-free dairy products: market developments, production, nutrition and health benefits. *Nutrients, 11*(3), 551.

Edgerton, D. (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.

Flysjö, A., Cederberg, C., Henriksson, M., & Ledgard, S. (2012). The interaction between milk and beef production and emissions from land use change–critical considerations in life cycle assessment and carbon footprint studies of milk. *Journal of Cleaner Production, 28*, 134-142.

Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falucci, 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), Rome.

Government Offices of Sweden. (2022). *Sweden's carbon tax*. https://www.government.se/government-policy/swedens-carbon-tax/swedens-carbon-tax/ (Accessed: 2021-02-08)

Gravelle, H., & Rees, R. (2004). *Microeconomics* (3rd ed.). Prentice Hall.

Hedenus, F., Wirsenius, S., & Johansson, D. J. (2014). The importance of reduced meat and dairy consumption for meeting stringent climate change targets. *Climatic change, 124*(1), 79-91.

IPCC, (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Jansson, T., & Säll, S. (2018). Environmental consumption taxes on animal food products to mitigate greenhouse gas emissions from the European Union. *Climate Change Economics, 9*(04), 1850009.

Karlsson Potter, H., Lundmark, L., & Röös, E. (2020). *Environmental impact of plant-based foods–data collection for the development of a consumer guide for plant-based foods*. Report / Swedish University of Agricultural Sciences, Department of Energy and Technology: 112. https://pub.epsilon.slu.se/17699/ (Accessed: 2022-02-22).

Kiff, L., Wilkes, A., & Tennigkeit, T. (2016). The technical mitigation potential of demand-side measures in the agri-food sector: a preliminary assessment of available measures. *CCAFS Report; 15*.

Mbow, C., C. Rosenzweig, L.G. Barioni, T.G. Benton, M. Herrero, M. Krishnapillai, E. Liwenga, P. Pradhan, M.G. Rivera-Ferre, T. Sapkota, F.N. Tubiello, & Y. Xu, (2019). *Food Security. In Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*, eds. P.R. Shukla, et al.

Moberg, E., Andersson, M. W., Säll, S., Hansson, P. A., & Röös, E. (2019). Determining the climate impact of food for use in a climate tax—design of a consistent and transparent model. *The International Journal of Life Cycle Assessment, 24*(9), 1715-1728.

Moberg, E., Säll, S., Hansson, P. A., & Röös, E. (2021). Taxing food consumption to reduce environmental impacts–Identification of synergies and goal conflicts. *Food Policy*, *101*, 102090.

Pigou, A.C. (1957). *A Study in Public Finance* (3rd ed.). Macmillan (1947).

Röös, E., Carlsson, G., Ferawati, F., Hefni, M., Stephan, A., Tidåker, P., & Witthöft, C. (2020). Less meat, more legumes: prospects and challenges in the transition toward sustainable diets in Sweden. *Renewable Agriculture and Food Systems, 35*(2), 192–205.

Röös, E., Larsson, J., Sahlin, K. R., Jonell, M., Lindahl, T., … André, E., & Persson, M. (2021*). Policy Options for Sustainable Food Consumption – Review and Recommendations for Sweden.* Mistra Sustainable Consumption Report 1:10.

Röös, E., Patel, M., & Spångberg, J. (2016). Producing oat drink or cow's milk on a Swedish farm—Environmental impacts considering the service of grazing, the opportunity cost of land and the demand for beef and protein. *Agricultural Systems, 142*, 23-32.

Rundgren, G. (2019). *Mjölkprodukter och vegetabiliska alternativ till mjölkprodukter – miljö, klimat och hälsa.* Rapport. MatLust. https://matlust.eu/wp-content/uploads/2019/02/MatLust-rapport-mjolk-final-webb.pdf (Accessed: 2022-02-26)

Säll, S., & Gren, M. (2015). Effects of an environmental tax on meat and dairy consumption in Sweden. *Food Policy 55*:41–53

Säll, S., Moberg, E., & Röös, E. (2020). *Modeling price sensitivity in food consumption – a foundation for consumption taxes as a GHG mitigation policy.* Working paper series / Swedish University of Agricultural Sciences, Department of Economics: 2020:01. https://pub.epsilon.slu.se/16931/ (Accessed: 2022-01-21)

Schmutzler, A., & Goulder, L. H. (1997). The choice between emission taxes and output taxes under imperfect monitoring. *Journal of Environmental Economics and Management*, *32*(1), 51-64.

Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B. L., Lassaletta, L., ... & Willett, W. (2018). Options for keeping the food system within environmental limits. *Nature*, *562*(7728), 519-525.

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.

Springmann, M., Mason-D'Croz, D., Robinson, S., Wiebe, K., Godfray, H. C. J., Rayner, M., & Scarborough, P. (2017). Mitigation potential and global health impacts from emissions pricing of food commodities. *Nature Climate Change*, *7*(1), 69–74.

Statistics Sweden (2022a). *Invånare per kvadratkilometer efter kön, region och år*. Statistical database. https://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__BE__BE0101__BE0101C/BefArealTathetKon/sortedtable/tableViewSorted/ (Accessed: 2022-03-02).

Statistics Sweden (2022b). *Inkomster för personer i Sverige.* Snabba fakta. https://www.scb.se/hitta-statistik/sverige-i-siffror/utbildning-jobb-och-pengar/inkomster-for-personer/ (Accessed: 2022-03-02).

Stock, J. H., & Watson, M. W. (2020). *Introduction to econometrics* (4^{th} global ed.). Pearson.

Swedish Board of Agriculture. (2016). *Mervärden i svensk mjölkproduktion.* På tal om jordbruk – fördjupning om aktuella frågor. https://www2.jordbruksverket.se/download/18.5f9a416f15572db9433db42c/1466672764501/ovr392_3.pdf (Accessed: 2022-01-26)

Swedish Board of Agriculture. (2022). *Totalkonsumtion efter vara.* https://statistik.sjv.se/PXWeb/pxweb/sv/Jordbruksverkets%20statistikdatabas/Jordbruksverkets%20statistikdatabas__Konsumtion%20av%20livsmedel/JO1301K2.px/table/tableViewLayout1/?rxid=5adf4929-f548-4f27-9bc9-78e127837625 (Accessed: 2022-03-21)

Theil, H. (1965). The Information Approach to Demand Analysis. *Econometrica*, *33*, 67-87.

Tietenberg, T. H., & Lewis, L. (2018). *Environmental and natural resource economics* (11th ed.). Routledge.

Unerman, J., Bebbington, J., & O'dwyer, B. (2018). Corporate reporting and accounting for externalities. *Accounting and Business Research, 48*(5), 497-522.

CCAC, U. (2021). Global Methane Assessment: Benefits and costs of mitigating methane emissions. *Climate and Clean Air Coalition (CCAC), United Nations Environment Programme (UNEP).*

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., ... & Murray, C. J. (2019). Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet, 393*(10170), 447-492.

Wirsenius, S., Hedenus, F., & Mohlin, K. (2010). Greenhouse gas taxes on animal food products: rationale, tax scheme and climate mitigation effects. *Climatic change, 108(1),* 159-184.

Acknowledgements

I would like to express my sincere gratitude to Sarah Säll and colleagues who have given me the opportunity to be a part their research project. Säll has been an invaluable supervisor in providing pointers and ways to improve my thesis for which I am very grateful. Furthermore, I want to thank Tobias Nilsson for his insightful input regarding this paper.

Appendix

Table A1. Sales weighted climate footprints.

Food group	**Total quantity sold**	**Fraction**	**CO_2e per kg**	**Weighted CO_2e per kg**
Coconut drink	1931.150	0.134	0.400	0.053
Rice drink	631.000	0.044	0.660	0.029
Almond drink	11900.717	0.823	0.800	0.658
Climate footprint: Other plant-based drinks				*0.740*

Source: Calculated based on data from ICA Maxi, CarbonCloud (2022), and Karlsson Potter et al., (2020).

Table A2. QUAIDS: Second stage test results.

Equation	**EQUAIDS1**
Dependent variable	**S1**
Mean of dep. var.	0.857
Std. dev. of dep. var.	0.016
Sum of squared residuals	0.055
Variance of residuals	0.000
Std. error of regression	0.015
R-squared	0.068
Adjusted R-Squared	0.056
LM het, test	0.018
LM sig.	[0.894]
Durbin-Watson	1.132

Source: Calculated based on data from ICA Maxi.
Notes: Last equation is dropped.

Table A3. QUAIDS: Third stage test results, dairy

Equation	EQUAIDS1	EQUAIDS2
Dependent variable	**S1**	**S2**
Mean of dep. var.	0.474	0.279
Std. dev. of dep. var.	0.021	0.018
Sum of squared residuals	0.098	0.071
Variance of residuals	0.000	0.000
Std. error of regression	0.020	0.017
R-squared	0.105	0.098
LM het. test	1.587	0.617
LM sig.	[0.208]	[0.432]
Durbin-Watson	1.704	1.759

Source: Calculated based on data from ICA Maxi.
Notes: Last equation is dropped.

Table A4. QUAIDS: Third stage test results, plant-based drinks

Equation	EQUAIDS1	EQUAIDS2
Dependent variable	**S1**	**S2**
Mean of dep. var.	0,806	0,053
Std. dev. of dep. var.	0,029	0,016
Sum of squared residuals	0,195	0,059
Variance of residuals	0,001	0,000
Std. error of regression	0,028	0,016
R-squared	0,011	0,007
LM het. test	2,314	0,020
LM sig.	0,128	0,887
Durbin-Watson	1,848	1,785

Source: Calculated based on data from ICA Maxi.
Notes: Last equation is dropped.

Table A5. Second stage parameter estimates

Number of observations	Log likelihood	Schwarz B.I.C.		
236	652.554	-641.626		
Parameter	**Estimate**	**Standard Error**	**t-statistic**	**P-value**
C11	-0.019	0.027	-0.723	0.470
B1	-0.009	0.006	-1.419	0.156
A1	0.855	0.001	782.846	0.000
D1	0.057	0.016	3.632	0.000

Source: Calculated based on data from ICA Maxi.

Table A6. Third stage parameter estimates, dairy

Number of observations	Log likelihood	Schwarz B.I.C.		
242	1315.510	-1287.690		
Parameter	**Estimate**	**Standard Error**	**t-statistic**	**P-value**
C11	-0.060	0.033	-1.802	0.072
C12	0.044	0.026	1.718	0.086
C22	-0.020	0.026	-0.775	0.439
B1	-0.036	0.008	-4.637	0.000
B2	0.034	0.007	5.065	0.000
A1	0.474	0.001	335.167	0.000
A2	0.280	0.001	231.908	0.000
D1	-0.022	0.020	-1.100	0.271
D2	0.000	0.017	-0.005	0.996

Source: Calculated based on data from ICA Maxi.

Table A7. Third stage parameter estimates, plant-based drinks

Number of observations	Log likelihood	Schwarz B.I.C.		
242	1215,490	-1187,670		
Parameter	**Estimate**	**Standard Error**	**t-statistic**	**P-value**
C11	0,009	0,060	0,156	0,876
C12	0,014	0,034	0,413	0,680
C22	-0,022	0,027	-0,799	0,424
B1	-0,017	0,010	-1,757	0,079
B2	0,005	0,005	1,010	0,312
A1	0,807	0,002	399,469	0,000
A2	0,054	0,001	48,331	0,000
D1	-0,013	0,021	-0,618	0,536
D2	-0,004	0,012	-0,330	0,742

Source: Calculated based on data from ICA Maxi.

Table A8. Baseline: Change in dairy consumption and GHG emissions per capita and year.

Per capita consumption (2020)	Per capita consumption (post tax)	ΔQ per person and year	ΔGHG per person and year
65.80	62.43	-3.37	-4.72

Source: Calculated based on data from ICA Maxi, CarbonCloud (2022), Karlsson Potter et al., (2020), and the Swedish Board of Agriculture (2022).
Notes: Per capita consumption, and ΔQ are expressed in kg. ΔGHG is expressed in kg CO_2e.

Publishing and archiving

Approved students' theses at SLU are published electronically. As a student, you have the copyright to your own work and need to approve the electronic publishing. If you check the box for **YES**, the full text (pdf file) and metadata will be visible and searchable online. If you check the box for **NO**, only the metadata and the abstract will be visible and searchable online. Nevertheless, when the document is uploaded it will still be archived as a digital file. If you are more than one author, the checked box will be applied to all authors. Read about SLU's publishing agreement here:

- https://www.slu.se/en/subweb/library/publish-and-analyse/register-and-publish/agreement-for-publishing/.

☒ YES, I/we hereby give permission to publish the present thesis in accordance with the SLU agreement regarding the transfer of the right to publish a work.

☐ NO, I/we do not give permission to publish the present work. The work will still be archived and its metadata and abstract will be visible and searchable.