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Demand for plant-based milk and effects of a carbon tax on fresh milk consumption in Sweden ☆

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ABSTRACT

A hypothetical carbon tax on the carbon footprint of fresh milk products from animals (cow's milk) and plant-based substitutes (rice milk, oat milk, soy milk, almond milk) was applied to estimated price and income elasticities for Swedish household expenditure on these products. Overall aims were to (i) to estimate fresh milk consumption patterns in Swedish households and (ii) simulate the direct distributed effects of a carbon tax on fresh milk. The results indicated that fresh milk consumption in Swedish households is affected mainly by price and income, rather than by sociodemographic characteristics of the household. The estimates revealed a substitutional relationship between plant-based milk on one hand and low-fat and standard milk on the other, while there was a complementary relationship between plant-based and reduced-fat milk. The effects of a carbon tax were simulated based on damage cost and price. The results indicated that introduction of a carbon tax would decrease the carbon footprint of dairy fresh milk, but would increase the carbon footprint of plant-based milk because of the institutional and complementary relationship between the different categories of fresh milk. Thus levying a carbon tax on fresh dairy milk, rather than on plant-based milk, would be more likely to promote climate-friendly fresh milk consumption.

1. Introduction

The introduction of taxes on carbon emissions as a strategy for combating climate change is a recurring topic within political discussions in many countries. Sweden has been at the forefront of such attempts, introducing low levels of carbon taxes within the scope of energy taxation back in the early 1990s. Since then, Sweden has continuously reformed its carbon tax system towards higher and more specific taxation of climate-relevant emissions, including taxing energy emissions from transport, buildings (heating), industry and agriculture. This gives it one of the oldest and strongest carbon price signals, with the largest sector coverage in the world (currently at about SEK[1] 0.12/kg CO_2-equivalents) (The World Bank, 2017). The Swedish carbon tax experience provides confirmation that high carbon prices are extremely effective and efficient instruments for driving down emissions (Baranzini et al., 2017; Martin et al., 2014; Murray and Rivers, 2015).

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[1] SEK is the abbreviation for Swedish krona. Rate 1 SEK = 0.11 USD.

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The negative environmental impacts of dairy farming in terms of high greenhouse gas (GHG) emissions are well-understood and have been the subject of extensive research (Foley et al., 2011). Plant-based alternatives, such as "milk" from soybeans, almonds or oats, can contribute to lower GHG emissions, due to a generally much lower carbon footprint[2] (Poore and Nemecek, 2018). Previous studies on consumption of plant-based milk products have tended to evaluate stated willingness to pay (McCarthy et al., 2017) or have focused on consumers' motives, attitudes and observed dietary patterns (Waldmann et al., 2003, Dyett et al., 2013, Radnitz et al., 2015). It is therefore not yet clear whether, and to what extent, the observed trends would be affected by a potential tax on the carbon footprint of raw milk or a carbon tax on agricultural raw materials in general. In previous studies, Nordström and Thunström (2009) simulated the effects of tax reforms aimed at encouraging healthier grain consumption in Sweden, while Edjabou and Smed (2013) assessed application of consumption taxes on foods to promote climate-friendly diets in Denmark. Wirsenius et al. (2011) examined the emission mitigation potential of GHG-weighted consumption taxes on animal food products in the EU and found that the effect of a GHG-weighted tax on animal food can be captured by taxing consumption of ruminant meat, while Säll investigated the effect of an environmental tax on meat consumption in Sweden (Säll, 2018; Säll and Gren, 2015). However, to my knowledge no previous study has simulated the effect of a carbon tax on consumption of dairy and non-dairy (plant-based) milk alternatives.

Previous studies analysing the set of price and income elasticities of European households (Thiele, 2008) seem to ignore the disaggregated demand for animal and plant-based dairy products. In recent years, several studies have reported the demand in European countries for different brands of fluid milk, distinguishing between organic and conventional milk (De Boer, 2003; Bouamra-Mechemache et al., 2008; Jonas and Roosen, 2008; Wier et al., 2008; Bernard and Bernard, 2009). With the exception of contributions by Dharmasena and Oral Capps (2014), Copeland and Dharmasena (2016) and Li and Dharmasena (2016), there have been no empirical works focusing on the demand for non-dairy milk alternatives, e.g. soya milk, almond milk, rice milk and oat milk, using data from European Union (EU) countries.

The present study is the first to seek to simulate the potential effect of a hypothetical carbon footprint tax on consumption of plant-based milk and dairy milk in Sweden using the Exact Affine Stone Index (EASI) demand system. The aim was to contribute novel information on the consumption level and changing trends in plant-based milk and dairy milk products. Specifically, the study sought to answer the following three research questions: How sensitive to price changes is the demand of Swedish households for animal-based and plant-based fresh milk products? What are the self- and cross-price elasticities between dairy milk and plant-based fresh milk products? and How would a tax on carbon emissions of plant-based products and animal-based raw milk affect Swedish households' preferences and what would this mean for the total household carbon footprint from combined (animal and plant-based) fresh milk consumption?

The remainder of the paper is structured as follows: Section 2 presents the data used in the analysis, Section 3 outlines the theoretical framework and estimation strategy, Section 4 presents the results of the empirical analysis and Section 5 provides a discussion on the policy implications of the results.

2. Data description

Home-scanner data from the GFK consumer panel were used for the analysis of fresh milk consumption in Sweden. These scanner data were collected by date of purchase and included records of whether the purchase took place at a supermarket, grocery store or other type of store during 2013. The dataset included all Swedish regions and the total number of households for which data were available was 1220, with representative numbers of households from urban regions (83.77%) and rural areas (16.23%).

The dataset included purchase information for five subgroups of fresh milk defined as: (i) reduced-fat (semi-skimmed, Sw. *mellan*) milk containing 1.5% fat, (ii) standard milk, containing 3.0% fat, (iii) low-fat (skimmed, Sw. *lätt*) milk, containing 0.5% fat, (iv) plant-based milk, including rice milk, soya milk, almond milk and oat milk, and (v) other fresh milk, including mini-fat milk, old-fashioned milk, country (*lant*) milk, protein milk, *latte del barista* milk and high-calcium milk. In addition, information on unit price and quantities of fresh milk purchased was available for each transaction. Using these variables, it was possible to compute total expenditure on each transaction and the expenditure share for each subgroup of fresh milk. During the observation period (2013), 86% of households consumed reduced-fat milk, 71% consumed standard milk, 36% consumed low-fat milk, 15% consumed plant-based milk and 22% consumed other fresh milk. Within the sample of 1220 households, 177 purchased plant-based milk on at least one occasion and only four households purchased plant-based milk exclusively during 2013.

Sociodemographic characteristics in the dataset included household expenditure on fresh milk, household head age, household size, number of children in the household, a dummy variable for the education status of the household

[2] It is worth stressing that although plant-based milk substitutes are lactose-free and most are low in saturated fat and cholesterol, and thus could offer an alternative to allergy problems pertaining to cow's milk, they cannot be considered equivalent to the latter in terms of nutritional content and health effects (Thorning, 2016). In fact, their nutritional properties vary greatly depending on raw material, processing, fortification and presence of other ingredients such as sweeteners and oil (Mäkinen et al., 2016a,b p.343). With the exception of soya milk, they have a low protein content, which has raised concerns in relation to children consuming such low-protein drinks. In addition, plant-based milk substitutes tend to have poorer attributes than cow's milk in terms of dietary calcium, iodine, vitamin B12 and riboflavin (Millward and Garnett, 2010), so some need to be fortified with calcium and vitamin B (Mäkinen et al., 2016a,b). Against this background, health authorities currently tend to be cautious and even reluctant to fully consider plant-based drinks as an alternative to cow's milk, leading Thorning (2016, p.6) to conclude that "further evidence-based assessment of the nutritional and health value of the plant-based drinks must await more studies in humans".

Table 1
Summary of descriptive statistics on expenditure, prices, costs, budget share and sociodemographic variables.

Variables		Sym.	Obs. no.	Mean	Std. dev.	Min.	Max.
Expenditure	Plant-based milk	e_1	152	102.850	150.810	5.900	1096.070
	Low-fat milk	e_2	392	111.800	114.810	4.400	833.400
	Reduced-fat milk	e_3	944	142.320	129.720	3.700	1341.000
	Standard milk	e_4	774	90.070	98.750	3.800	786.800
	Other fresh milk	e_5	232	66.730	113.230	4.280	992.100
Prices	Plant-based milk	p_1	152	18.270	6.940	10.000	54.270
	Low-fat milk	p_2	392	9.670	4.150	2.930	43.600
	Reduced-fat milk	p_3	944	10.110	3.960	3.700	57.140
	Standard milk	p_4	774	9.970	2.670	3.330	21.000
	Other fresh milk	p_5	232	15.690	18.120	3.340	154.320
Budget share	Plant-based milk	s_1	152	0.310	0.280	0.010	1.000
	Low-fat milk	s_2	392	0.410	0.310	0.010	1.000
	Reduced-fat milk	s_3	944	0.580	0.330	0.010	1.000
	Standard milk	s_4	774	0.380	0.330	0.010	1.000
	Other fresh milk	s_5	232	0.190	0.200	0.010	0.980

Sociodemographic variables–Continuous variables (n = 1093)

Variable name	Sym.	Obs. no.	Mean	Std. dev.	Min.	Max.
Expenditure on fresh milk	x	1093	255.2649	183.8276	5	1883.85
Age	z_2	1093	53.496	13	22	82
Household size	z_3	1093	2.080	1	1	6
Household annual income	*inc*	1093	423 911.300	199 376	5000	800 000

Sociodemographic variables–Dummy variables (n = 1093)

Variable name	Sym.	Mean	No. of '1' obs.	No. of '0' obs.
Children dummy: 1 = child in household	z1	0.195	213	880
Education dummy: 1 = university or higher level of education	z4	0.399	436	657
Urban dummy: 1 = living in urban region, 0 = living in rural region	z5	0.846	925	168
Cross-term of education dummy and urban dummy	z6	0.027	29	1064
Employment status: part-time job	z7	0.146	160	933
Employment status: full-time job	z8	0.464	586	507
Employment status: retired	z9	0.288	778	315

Notes: Obs. = observations; Std dev. = standard deviation; Min. = minimum, Max. = maximum. Values in brackets in the lower part of the table indicate number of households taking a value 0 or 1 for each dummy variable. SEK = Swedish kronor. Household income, age and household size were initially reported as categorical data with several levels; reported means refer to the average of the midpoints for each range of these categories.

head, a dummy variable for whether the household was located in an urban or rural area, and categorical variables defining employment status, such as full-time employment, part-time employment, retired person, student or hourly-paid employment. The households were divided into four groups based on income. Household group 1 (250 households, 22.87% of the whole sample) had annual income below 259 999 SEK, household group 2 had annual income of 259 999 SEK to less than 399 999 SEK (293 households, or 26.81% of the whole sample), household group 3 had annual income of 399 999 SEK to less than 599 999 SEK (313 households — 28.64% of the whole sample), and household group 4 had annual income of 599 999 SEK or above (237 households, or 21.68% of the whole sample). Descriptive statistics on expenditure and sociodemographic variables are summarised in Table 1. For those households not purchasing a particular category of fresh milk during the observation period, the corresponding price was not observed. In order to obtain estimates for the EASI demand system, unobserved prices were replaced by an average value obtained by considering the price paid for the same category of milk by households (Dong et al., 2004).

3. Methodology and model specification

In order to answer the research questions, the study proceeded with: (i) estimation of demand system for various fresh milk product categories in Swedish households, (ii) analysis of own-price and cross-price elasticity between various fresh milk categories, and (iii) simulation of the effects of a hypothetical carbon emissions tax on fresh milk product quantity demand and total carbon emissions for an average Swedish household. However, when modelling the consumption preferences of households for different subgroups of fresh milk, several assumptions had to be made and household preferences were modelled according to a multi-stage expenditure allocation. In the first upper stage, a household allocates expenditure between fresh milk and other (food-related) consumer goods. In the lower stage of the decision process, a household makes purchasing decisions about different categories of fresh milk conditional upon their total fresh milk expenditure (Edgerton, 1997, Carpentier and Guyomard, 2001). Thus, weak separability was assumed between categories of fresh milk and other consumer products, including other food products and consumer goods.

3.1. Modelling demand for fresh milk based on the EASI demand system

The EASI demand system was developed by substituting the utility level in the Hicksian budget shares with an affine transformation of Stone-index deflated log nominal expenditures to yield implicit Marshallian budget shares. According to Lewbel and Pendakur (2009), Marshallian budget shares are considered "implicit" firstly due to the construct employed to substitute real expenditure for the utility level in the EASI Hicksian budget shares, and secondly due to the fact that the budget shares are also endogenous regressors in the EASI demand model. In the present study, the demand system for the different categories of fresh milk was estimated using the exact EASI model specification with endogenous budget shares and a three-stage least-squares regression (3SLS) procedure (Yen et al., 2011).

The implicit Marshallian demands with budget shares are obtained as:

$$w = m(y, z) + v \tag{1}$$

where $m(y, \boldsymbol{z})$ is a J-vector valued function with $1'_J m(y, \boldsymbol{z}) = 1$, the implicit utility $y = g(\boldsymbol{w}, \boldsymbol{p}, \boldsymbol{z}, x) = x - \boldsymbol{p}'\boldsymbol{w}$, which equals the log of nominal expenditures x deflated by the log Stone price index, $\boldsymbol{p}'\boldsymbol{w}$, $\boldsymbol{z}$ is a vector of demographic characteristics, and $\boldsymbol{p}$ is the price of each consumer good. An empirical EASI demand model for estimation is defined as a set of $i = 1,\ldots,I$ budget shares w that are explained as a function of price, real expenditure and sociodemographic characteristics, as written in Eq. (2):

$$w_i = \sigma_i + \sum_{r=0}^{R} \beta_{ir} y^r + \sum_{j=1}^{n} \alpha_{ij} logp_j + \sum_{k=1}^{m} \gamma_{ik} z_{ik} \tag{2}$$

where r is the polynomial order in y, σ is a constant term, β, α, γ are parameters to be estimated $y = logx - \sum_{j=1}^{J} w_j lnp_j$, $x = \sum_{j=1}^{J} p_j q_j$, and q is the corresponding purchase quantity. Theoretical constraints on parameters are imposed to satisfy the homogeneity, symmetry and adding-up conditions in the exact EASI demand system. First, the homogeneity condition requires $\sum_{j=1}^{J} \alpha_{ij} = 0$, and thus the price coefficients add up to zero in each share equation. Second, the symmetry condition implies $\alpha_{ij} = \alpha_{ji}$ for all i and j. Third, the adding-up condition implies that the sum of the j coefficients associated with the constant term of each share equation is equal to unity, and the j coefficients associated with other variables add up to zero: $\sum_{j=1}^{J} \alpha_{ij} = 0$; $\sum_{j=1}^{J} \beta_{jr} = 0$, $r = 1$ and 2; $\sum_{j=1}^{J} \gamma_{jk} = 0$, $k = 1, \ldots, K$.

3.2. Consistent two-stage estimation of a censored EASI system

Use of home scanner data for fresh milk consumption is complicated by the existence of zero consumption observations, whereby some households do not purchase a subgroup of fresh milk during the study period, leading to zero values in the dependent variables. This feature of zero-censored dependent variables is particularly notable in modelling demand in the lowest stage of a multi-stage budgeting allocation (Deaton and Muellbauer, 1980; Copeland and Dharmasena, 2016). Applying ordinary least squares (OLS) regression analysis in order to estimate a regression with zero purchases or removing all zero consumption observations from the dataset before estimating regression functions for non-zero purchases would create biased and inconsistent estimates. Therefore, in order to obtain a consistent estimate for censored consumption observations, a two-step estimation approach proposed by Shonkwiler and Yen (1999) (S-Y) was employed. The true EASI demand system was estimated using the S-Y two-stage estimation procedure: first, a multivariate probit model was used to express the household decision to purchase a given category of fresh milk and then the selectivity-augmented equation system was estimated using 3SLS (Tauchmann, 2005).

The S-Y estimation procedure features the following structure for the censoring variables:

$$\mathrm{d}_i = \begin{cases} 1 & if\ d_i^* > 0 \\ 0 & if\ d_i^* \le 0, \end{cases} \qquad d_i^* = \tau_i z_i + v_i \tag{3}$$

$$\mathrm{w}_i(\theta) = \begin{cases} w_i^*(\theta) + \varepsilon_i & if\ d_i = 1 \\ 0 & if\ d_i = 0 \end{cases} \tag{4}$$

where d_i is the observed variable of purchase behaviour ($\mathrm{d}_i = 1$ if the household purchases the specific group of food products during the observed time window, otherwise $\mathrm{d}_i = 0$), d_i^* is the latent variable of d_i, z is a vector of exogenous variables that represent the socioeconomic characteristics of the households, τ is a vector of parameters to be estimated, w_i is observed budget share, $w_i^*(\theta)$ is the latent demand function and v is random error. The error terms are assumed to follow a multivariate normal distribution with zero means, variances normalised to unity and a contemporaneous covariance matrix $\sum$. The S-Y procedure was applied as follows:

(1) $\widehat{\tau_i}$ was obtained for all households i using a multivariate probit estimation.

(2) For each household, the cumulative normal distribution function $\Phi(\widehat{\tau_i} z_i)$ and the normal probability density $\phi(\widehat{\tau_i} z_i)$ were calculated for each category of fresh milk.

(3) The parameters θ and δ were estimated in the augmented EASI demand system, using the following expression:

$$\omega_i = \Phi(\widehat{\tau_i} z_i)\, w_i(\theta) + \delta_i \varphi(\widehat{\tau_i} z_i) + \eta_i \tag{5}$$

where ω_i is the budget share of household i, δ is a parameter to be estimated and η is a heteroscedastic error term. As suggested by S-Y, to handle the heteroscedastic structure of the error terms in (5), the standard errors of the estimated parameters were obtained using a bootstrapping procedure.

3.3. Empirical model specification and estimation

In the empirical model specification, Eq. (6) was estimated combining the EASI demand system and S-Y approach for different categories of fresh milk in Sweden:

$$\omega_i = \Phi\left(\widehat{\tau_i} z_i\right)\left(\sum_{r=0}^{3} \beta_{ir} y^r + \sum_{j=1}^{5} \alpha_{ij} \log p_j + \sum_{k=1}^{9} \gamma_{ik} z_{ik}\right) + \delta_i \varphi\left(\widehat{\tau_i} z_i\right) + v_i \tag{6}$$

where y is treated as an implicit utility that is approximated by the total value of expenditure deflated by a Stone price index, $y = logx - \sum_{j=1}^{5} \overline{\omega_j} logp_j$, x is the total value of expenditure $x = \sum_{j=1}^{5} p_j q_j$, $\overline{\omega_j}$ is the average budget share of consumer good, p is the price of each consumer good, q is the corresponding purchase quantity, r is the polynomial order in y, and z is a vector of demographic characteristics. $j = 1, \ldots, 5$ for five subgroups of fresh milk, whereby $j = 1$ denotes reduced-fat milk, $j = 2$ denotes standard milk, $j = 3$ denotes low-fat milk, $j = 4$ denotes plant-based milk and $j = 5$ denotes other fresh milk; and $k = 1, \ldots, 9$ denotes the sociodemographic variables of each household. β, α, γ, δ are parameters to be estimated and v is the error term. The estimated cumulative distribution functions $\Phi(\widehat{\tau_i} z_i)$ and the estimated density functions $\phi\left(\widehat{\tau_i} z_i\right)$ were derived from the estimated multivariate probit model described in Eq. (4).

The budget shares are endogenous regressors in the EASI demand model because total expenditure might be jointly determined with the budget shares of the specific commodities in the demand system. However, EASI budget shares are linear parameters and conditional on log real expenditures, log prices and sociodemographic characteristics. The two-step approach with implicit Marshallian demand system developed by Lewbel and Pendakur (2009) can avoid the endogeneity problem using the simultaneous equation estimator (3SLS).

Under the assumption of weak separability of fresh milk consumption relative to consumption of other consumer goods, the conditional Marshallian price elasticity ($\eta_{ij}{}^M$) and conditional expenditure elasticity (ε_i) were calculated using the expressions found in the online appendix to the paper by Lewbel and Pendakur (2009). Based on the conditional Marshallian price elasticities, expenditure elasticities and the Slutsky equation, conditional Hicksian price elasticities ($\eta_{ij}{}^H$) were derived according to Eq. (6), where $\widehat{w_i}$ is the expected budget share. The Hicksian and Marshallian price elasticities provided a partial picture of the demand responses of Swedish households to changes in the price of each category of fresh milk, with household expenditure not just conditional upon price, but also upon expenditure on fresh milk.

3.4. Carbon tax simulation

The basic concept with setting a carbon tax is that consumers should pay for the damage cost of the carbon footprint generated by the products (Säll and Gren, 2015; Zechter et al., 2017). The simulation process consisted of four steps: (1) Estimate the carbon dioxide equivalents (CO_2-eq) contained in one litre of fresh milk, (2) calculate the price (or cost) of CO_2-eq contained in one litre of fresh milk, (3) calculate the carbon tax that should be implemented, and (4) simulate implementation of a carbon tax in order to compare the carbon footprint change under different scenarios. The other fresh milk product examined in this study was a combination of mini-fat milk, old-fashioned milk, country (*lant*) milk, protein milk, *latte del barista* milk and high-calcium milk, which contain different percentages of fat and have a different impact on the carbon footprint. It was therefore decided to exclude this other fresh milk product from the scenario analysis.

Carbon taxes for each commodity i were calculated according to the damage cost from CO_2-eq, which means that customers pay for the damage cost from CO_2-eq contained in the product they consume. The damage cost of CO_2-eq is the cost incurred by impacts of CO_2-eq. In environmental accounting, it is part of the costs borne by economic agents (Andersson, 2019). The damage cost of CO_2-eq. was computed as:

$$\text{Carbon tax} = \text{Damage cost} = \frac{\text{Price of } CO_2\text{eq}}{\text{Price of purchased fresh milk}} \times 100\ \% \tag{7}$$

where

$$\text{Price of } CO_2 - \text{eq per litre milk (SEK)} = \text{kg } CO_2 - \text{eq per litre milk} \times \text{damage cost (SEK) per kg } CO_2 - \text{eq} \tag{8}$$

Change in demand quantity i from the price change of product j owing to the carbon tax implemented on j was calculated as: $\frac{\Delta q_i}{q_i} = \frac{\Delta p_j}{p_j} \times \widetilde{\eta_{ij}{}^H} = \text{carbon tax} \times \widetilde{\eta_{ij}{}^H}$, where $\frac{\Delta q_i}{q_i}$ is the percentage change in demand for each subgroup of fresh milk and $\frac{\Delta p_j}{p_j}$ is the percentage change in price of each product because of the carbon tax, which is equal to the carbon tax from Eq. (7). Finally, the corresponding percentage change in the carbon footprint is the sum of the carbon footprint change over all subgroups of fresh milk:

$$\Delta \text{carbon footprint}_i = \sum_{i=1}^{I} \text{carbon footprint}_{ij} \times \Delta q_i = \sum_{i=1}^{I} CO_2\text{eq per litre milk} \times \Delta q_i \tag{9}$$

4. Empirical results

The first-step model consisting of five probit equations pertaining to the decision of whether or not to purchase the five categories of fresh milk depended solely on household sociodemographic variables. It was estimated using a multivariate simulated maximum likelihood (ML) procedure. The cross-correlation coefficients of the estimated error terms in the equations and a likelihood ratio test rejected the null hypothesis of independence among the estimated residuals, indicating that it was reasonable to adopt a multivariate probit model[3] in the first step.

4.1. Econometric estimates of the EASI demand system

Relatively strong price effects occurred on the budget shares for all fresh milk subgroups. First, all the estimated coefficients associated with own prices were estimated to be negative and statistically significant. Second, cross-price effects were found to be significant in most cases. Since homogeneity and symmetry conditions were imposed and were satisfied by the estimated EASI demand system, only ten free cross-price coefficients were freely estimated. The information contained in Table 2 indicates that five of these ten estimated cross-price coefficients were statistically significant. It is important to note the sign of some of these significant cross-price effects: the estimated coefficients associated with the price of plant-based milk in the reduced-fat milk budget share were significantly negative, but those in the standard milk budget share equation were significantly positive. The estimated coefficients associated with the price of low-fat milk in the reduced-fat milk budget share equation and those associated with the price of reduced-fat milk in the low-fat and standard milk budget share equations were also significantly positive. However, the estimated coefficients in the plant-based milk budget share equation were significantly negative. Finally, the estimated coefficients associated with the price of standard milk in the plant-based milk budget share equation and reduced-fat milk budget share equation were significantly positive.

To determine the proper degree of expenditure polynomials, likelihood ratio tests were used,[4] starting from R = 2 to R = 5. Finally, the polynomial was set at R = 2 on total real expenditure y. In terms of expenditure effects, the linear effects of real expenditure (y_1) were significantly positive for the budget shares of low-fat milk and the other fresh milk, but significantly negative for the budget share of standard milk. The quadratic orders of total expenditure (y_2) were only significantly negative for the budget share of reduced-fat milk, but significantly positive for the budget share of standard milk.

Sociodemographic characteristics also had effects on the budget shares of some groups of fresh milk consumption, with presence of children in a household (z_1) likely to decrease consumption of plant-based milk significantly. Dharmasena and Oral Capps (2014) also found that household composition and demographic characteristics can play an important role in the demand for plant-based milk, e.g. soya milk and almond milk. Unfortunately, no other significant effects of socioeconomic characteristics on budgets shares were found. In summary, the estimation results from the EASI demand system in Table 2 show that out of twenty-five coefficients estimated on prices, fifteen were found to be significant. This suggests that overall economic factors such as price, rather than socioeconomic characteristics, explained households' purchasing decisions of fresh milk products in this dataset.

4.2. Elasticity results

Based on estimates from the EASI demand system, conditional Marshallian price elasticities, total milk expenditure elasticities and Hicksian price elasticities were calculated (Table 3).

All own-price elasticities were negative in this study, which is consistent with general economic theory. The average conditional Marshallian own-price elasticity of plant-based milk, low-fat milk, reduced-fat milk and standard milk was −4.546, −2.075, −1.361, 2.244 and −2.082, respectively. The expenditure elasticity was estimated to range between 0.638 and 1.533, indicating that no type of fresh milk would be an inferior good in Swedish households. There were consistent signs and magnitudes between Marshallian own-price elasticities and Hicksian own-price elasticities. The average unconditional Hicksian own-price elasticity of plant-based milk, low-fat milk, reduced-fat milk and standard milk was −4.411, −1.982, −0.831, −2.073 and −1.952, respectively. On comparing the own-price elasticities of the five subgroups of fresh milk, plant-based milk was found to be the most price-sensitive. The self-price elasticity of plant-based milk was estimated to be high, which is consistent with findings by Dharmasena and Oral Capps (2014) of a price-elastic response to demand for soya milk in the US. Those authors found an own-price elasticity for soya milk of −1.68, while Copeland and Dharmasena (2016) estimated the unconditional own-price elasticity for demand for almond milk to be −2.72. Given the new premium property of plant-based milk, it is reasonable to deduce that consumers are very reactive to price changes. The sign and magnitude of unconditional Hicksian cross-price elasticities and unconditional Marshallian cross-price elasticities were consistent with one other. Positive (negative) cross-price elasticity indicated substitution (complementarity) between pairs of fresh milk categories. There was a substitutional relationship between plant-based milk and low-fat milk, standard milk and other milk, but a complementary relationship between plant-based milk and

[3] The multivariate probit model estimates can be supplied upon request.

[4] Details of these tests are available from the author upon request.

Table 2
Estimated coefficients of the Exact EASI demand system (5-equation).

Variables	Plant-based milk ($j = 1$)		Low-fat milk ($j = 2$)		Reduced-fat milk ($j = 3$)		Standard milk ($j = 4$)		Other fresh milk ($j = 5$)	
	coef.	s.e.	coef.	s.e.	coef.	s.e.	coef.	s.e.	coef.	s.e.
Constant	−0.178	(0.197)	0.035	(0.0252)	0.521***	(0.131)	0.588***	(0.193)	0.0339	(0.0279)
$\Phi\left(\widehat{\tau}_j z_j\right) \times y_1$	−0.00622	(0.0435)	0.0914**	(0.0428)	0.0383	(0.0337)	−0.230***	(0.0519)	0.107***	(0.0374)
$\Phi\left(\widehat{\tau}_j z_j\right) \times y_2$	0.00661	(0.00561)	−0.015	(0.0125)	−0.00645*	(0.00390)	0.0330***	(0.0127)	−0.0182	(0.0114)
$\Phi\left(\widehat{\tau}_j z_j\right) \times lp_1$	0.0331	(0.0383)	−0.446***	(0.0719)	−0.0949***	(0.0359)	0.336***	(0.0762)	0.172***	(0.0438)
$\Phi\left(\widehat{\tau}_j z_j\right) \times lp_2$	−0.186***	(0.0433)	0.0331	(0.0383)	0.146***	(0.0328)	−0.0203	(0.0454)	0.0273	(0.0292)
$\Phi\left(\widehat{\tau}_j z_j\right) \times lp_3$	0.146***	(0.0328)	−0.0949***	(0.0359)	−0.165***	(0.0325)	0.0902**	(0.0426)	0.0241	(0.0249)
$\Phi\left(\widehat{\tau}_j z_j\right) \times lp_4$	−0.0203	(0.0454)	0.336***	(0.0762)	0.0902**	(0.0426)	−0.366***	(0.109)	−0.0396	(0.0495)
$\Phi\left(\widehat{\tau}_j z_j\right) \times lp_5$	0.0273	(0.0292)	0.172***	(0.0438)	0.0241	(0.0249)	−0.0396	(0.0495)	−0.184***	(0.0425)
$\Phi\left(\widehat{\tau}_j z_j\right) \times z_1$	−0.0912**	(0.0450)	−0.0196	(0.0761)	−0.015	(0.0404)	0.0814	(0.0889)	0.0444	(0.0580)
$\Phi\left(\widehat{\tau}_j z_j\right) \times z_2$	−0.0051	(0.00661)	−0.00455	(0.0114)	−0.00762	(0.00554)	0.0154	(0.0126)	0.00183	(0.00796)
$\Phi\left(\widehat{\tau}_j z_j\right) \times z_3$	0.00368	(0.0164)	−0.022	(0.0295)	0.00726	(0.0154)	0.0151	(0.0320)	−0.00402	(0.0251)
$\Phi\left(\widehat{\tau}_j z_j\right) \times z_4$	−0.00472	(0.0258)	0.0599	(0.0418)	0.012	(0.0241)	−0.0587	(0.0498)	−0.00859	(0.0360)
$\Phi\left(\widehat{\tau}_j z_j\right) \times z_5$	0.0034	(0.0300)	0.0132	(0.0530)	0.0135	(0.0275)	−0.0403	(0.0636)	0.0102	(0.0420)
$\Phi\left(\widehat{\tau}_j z_j\right) \times z_6$	0.018	(0.0809)	−0.213	(0.137)	−0.0726	(0.0797)	0.148	(0.164)	0.119	(0.114)
$\Phi\left(\widehat{\tau}_j z_j\right) \times z_7$	0.0428	(0.0472)	−0.00681	(0.0831)	−0.0167	(0.0456)	−0.00208	(0.102)	−0.0173	(0.0662)
$\Phi\left(\widehat{\tau}_j z_j\right) \times z_8$	0.0421	(0.0424)	−0.00956	(0.0734)	−0.000583	(0.0431)	−0.0442	(0.0859)	0.0123	(0.0592)
$\Phi\left(\widehat{\tau}_j z_j\right) \times z_9$	0.0597	(0.0484)	−0.0137	(0.0876)	0.0031	(0.0491)	−0.000774	(0.101)	−0.0484	(0.0718)
$\phi\left(\widehat{\tau}_j z_j\right)$	0.751*	(0.432)	−0.196	(0.213)	−0.134	(0.191)	−0.0991	(0.529)	−0.322	(0.198)
Statistics										
No. of obs.	1093		1093		1093		1093		1093	
p-value	0.0000		0.0002		0.0002		0.0000		0.0000	
RMSE	0.1446		0.2673		0.3577		0.3190		0.1176	

Note: coef = estimated coefficient; s.e. = standard error.
*Significant at 10 % level ($P < 0.10$).
**Significant at 5 % level ($P < 0.05$).
***Significant at 1 % level ($P < 0.01$).

Table 3
Overall price elasticity and expenditure elasticity.

Marshallian elasticities		Price of:					Expenditure elasticity
		Plant-based milk	Low-fat milk	Reduced-fat milk	Standard milk	Other fresh milk	
Quantity of:	Plant-based milk	−4.546 (1.232)	0.171 (0.059)	−1.022 (0.355)	2.486 (0.864)	1.301 (0.452)	1.552 (0.192)
	Low-fat milk	0.240 (0.056)	−2.075 (0.252)	1.109 (0.260)	−0.010 (0.002)	0.204 (0.048)	0.576 (0.099)
	Reduced-fat milk	−0.196 (0.001)	0.286 (0.001)	−1.361 (0.002)	0.167 (0.001)	0.044 (0.000)	1.054 (0.000)
	Standard milk	1.261 (0.202)	−0.016 (0.003)	0.512 (0.082)	−2.244 (0.199)	−0.114 (0.018)	0.638 (0.058)
	Other fresh milk	0.923 (0.159)	0.068 (0.012)	−0.132 (0.023)	−0.367 (0.063)	−2.082 (0.187)	1.533 (0.092)
Hicksian elasticities		Price of:					
		Plant-based milk	Low-fat milk	Reduced-fat milk	Standard milk	Other fresh milk	
Quantity of:	Plant-based milk	−4.411 (0.020)	0.421 (0.005)	−0.242 (0.003)	2.903 (0.006)	1.433 (0.012)	
	Low-fat milk	0.290 (0.007)	−1.982 (0.002)	1.399 (0.001)	0.144 (0.002)	0.253 (0.005)	
	Reduced-fat milk	−0.104 (0.014)	0.456 (0.004)	−0.831 (0.002)	0.451 (0.004)	0.134 (0.008)	
	Standard milk	1.317 (0.008)	0.087 (0.002)	0.833 (0.001)	−2.073 (0.002)	−0.060 (0.005)	
	Other fresh milk	1.057 (0.020)	0.316 (0.005)	0.638 (0.003)	0.045 (0.006)	−1.952 (0.012)	

Note: Values in brackets under elasticity indicate standard error of elasticity.

Table 4
Marshallian price elasticity and expenditure elasticity by household income group.

		Price of:					Expenditure elasticity
		Plant-based milk	Low-fat milk	Reduced-fat milk	Standard milk	Other fresh milk	
For household group 1							
	Plant-based milk	−4.455	0.167	−0.996	2.423	1.267	1.538
	Low-fat milk	0.203	−1.906	0.935	−0.009	0.172	0.643
Quantity of:	Reduced-fat milk	−0.200	0.292	−1.369	0.171	0.045	1.055
	Standard milk	1.323	−0.017	0.537	−2.304	−0.120	0.620
	other fresh milk	1.043	0.077	−0.149	−0.414	−2.222	1.603
For household group 2							
	Plant-based milk	−3.456	0.118	−0.708	1.722	0.901	1.382
	Low-fat milk	0.205	−1.918	0.947	−0.009	0.174	0.638
Quantity of:	Reduced-fat milk	−0.195	0.285	−1.360	0.167	0.044	1.054
	Standard milk	0.865	−0.011	0.351	−1.853	−0.078	0.752
	other fresh milk	0.983	0.073	−0.141	−0.390	−2.152	1.568
For household group 3							
	Plant-based milk	−3.582	0.125	−0.744	1.811	0.947	1.402
	Low-fat milk	0.311	−2.389	1.433	−0.014	0.263	0.452
Quantity of:	Reduced-fat milk	−0.197	0.287	−1.363	0.168	0.044	1.055
	Standard milk	1.431	−0.018	0.581	−2.411	−0.129	0.589
	other fresh milk	1.240	0.092	−0.177	−0.493	−2.454	1.717
For household group 4							
	Plant-based milk	−7.455	0.311	−1.860	4.526	2.368	2.005
	Low-fat milk	0.239	−2.069	1.104	−0.010	0.203	0.578
Quantity of:	Reduced-fat milk	−0.192	0.281	−1.354	0.164	0.043	1.053
	Standard milk	1.463	−0.018	0.594	−2.442	−0.132	0.580
	other fresh milk	0.441	0.033	−0.063	−0.175	−1.517	1.255

reduced-fat milk. This relationship strengthened somewhat on moving from Hicksian to Marshallian price elasticities. The substitution relationship between low-fat milk and plant-based milk was consistent with *a priori* expectations of a strong substitution relationship between low-fat milk and plant-based milk, e.g. assuming that the no-fat property of plant-based milk would potentially attract consumers who purchase low-fat milk.

Table 4 shows the Marshallian price elasticity and elasticity for household groups categorised by annual income, where household group 1 represented households with the lowest annual income and household group 4 represented the richest households with the highest annual income. On comparing the self-price elasticity of plant-based milk, the richest household group was most strongly price-elastic (−7.455), followed by the poorest household group (−4.455), although the price elasticity for groups 2 and 3 was also large: −3.456 for group 2 and −3.582 for group 3. The richer household groups 3 and 4 were more price-elastic than groups 1 and 2 when purchasing low-fat milk. All four household groups displayed similar price elastic patterns regarding the price change of reduced-fat milk, ranging from −1.369 to −1.354. There was also no significant difference in self-price elasticity for standard milk among the four household groups. In summary, the richest household group was the most price-elastic when purchasing plant-based milk and low-fat milk.

4.3. Simulating the demand effects of a carbon tax

The CO_2-eq per litre of fresh milk as estimated in step 1 is listed in column (2) of Table 5. Plant-based milk in this study included rice milk, soya milk, almond milk and oat milk, and thus an average CO_2-eq value for the plant-based milk group had to be used. According to Smedman et al. (2010), CO_2-eq emissions are around 0.21 per kg oat milk and around 0.31 per kg soya milk, although Dahllöv and Gustafsson (2008) reported 0.32 CO_2-eq per kg oat milk and Ho et al. (2016) reported 0.36 CO_2-eq per litre almond milk. Generally, however, estimated emissions expressed as kg CO_2-eq per capita and year are four to eight times higher for cow's milk compared with oat and soya milk (Mäkinen et al., 2016a,b). In addition, Röös et al. (2016) concluded that direct GHG emissions from animals, fertiliser and energy use were considerably lower (16%–41%) for all oat drink scenarios they analysed compared with a dairy scenario, due to lower methane emissions from ruminant enteric fermentation. Overall, the above results were summarised and 0.30 kg CO_2-eq per litre of plant-based milk was used as an approximate value (Dahllöv and Gustafsson, 2008; Mikkola and Risku-Norja, 2008, Smedman et al., 2010, Röös et al., 2016). A previous study by Flysjö et al. (2011) analysing the impact of various parameters on the carbon footprint of milk production in New Zealand and Sweden found a value of 1 kg CO_2-eq per litre for milk from outdoor pasture grazing systems in New Zealand and 1.16 kg CO_2-eq per litre for milk from indoor housing systems with high use of concentrate feed in Sweden. A value of 1.5 kg CO_2-eq per kg and year has been estimated for Irish dairy milk (Casey and Holden, 2005), while the value is reported to vary between 0.94 and 1.33 kg CO_2-eq per kg energy-corrected milk on Swedish dairy farms due to management differences (Henriksson et al., 2011). There is also a difference in CO_2-eq between organic dairy milk and conventional dairy milk, varying from 0.856 to 1.48 per kgin New Zealand, the Netherlands and

Table 5
Average carbon footprint level for fresh milk.

	Carbon dioxide equivalents (CO_2-eq) (kg/litre milk)	References	Price of CO_2-eq. (SEK/litre milk)[a]	Average price of purchased fresh milk (SEK/litre)	Carbon tax percentage (price of CO_2-eq/ average price of purchased fresh milk × 100%)
(1)	(2)	(3)	(4)	(5)	(6)
Plant-based milk	0.30	Dahllöv and Gustafsson (2008), Mikkola and Risku-Norja (2008), Smedman et al., 2010, Röös et al. (2016) and Ho et al., 2016	0.354	18.270	1.94%
Low-fat milk	1.17	Howden and Reyenga, 1999, Casey and Holden 2006, Flysjö et al., 2011, Henriksson 2011, Flysjö, 2011 and Mäkinen et al. (2016a,b)	1.381	9.670	14.28%
Reduced-fat milk	1.40		1.652	10.110	16.34%
Standard milk	1.23		1.451	9.970	14.56%
Other fresh milk	1.35		1.593	15.690	10.15%

[a]Price of CO_2-eq (SEK/litre milk) = kg CO_2-eq/litre milk x damage cost (SEK)/kg CO_2-eq.

Sweden (Basset-Mens et al., 2009). Since the other fresh milk analysed in the present study contained different fresh milk categories, a mean value of 1.35 kg CO_2-eq per litre of milk was generated to represent its CO_2-eq based on the literature cited above. The value per litre fresh milk was approximated to be 1.17, 1.40, 1.23 and 1.35 kg CO_2-eq for low-fat milk, reduced-fat milk, standard milk and other fresh milk, respectively (Flysjö, 2011).

In step 2, the price (or cost in SEK) of CO_2-eq contained in one litre fresh milk was calculated as kg CO_2-eq/litre milk multiplied by the damage cost (SEK) per kg CO_2-eq. The damage cost is a commonly employed metric of the expected economic cost from carbon dioxide emissions. Although there has been considerable research on pricing the carbon tax, there are vast differences in the reported damage cost of CO_2-eq for different products across countries. Tol (2005) assessed the marginal damage cost of carbon dioxide emissions by reviewing 28 published studies and found that the median was 0.13 SEK per kg carbon and the mean was 0.88 SEK per kg carbon. Säll (2018) used a damage cost of 1.29 SEK per kg carbon. In the present study, the damage cost was assumed to be 1.18 SEK per kg CO_2-eq according to the carbon tax set by The Government of Sweden (2019). Thus column (4) was obtained by multiplying column (2) by 1.18. As shown in column (4) in Table 5, the cost (SEK) of CO_2-eq per litre of fresh milk was 0.354, 1.381, 1.652, 1.451 and 1.593 for plant-based milk, low-fat milk, reduced-fat milk, standard milk and other fresh milk, respectively.

Step 3 involved calculating the carbon tax level, i.e. the percentage price of CO_2-eq in relation to the average price of purchased fresh milk, which is equal to the number in column (4) in Table 5 divided by that in column (5) multiplied by 100%. Column (5) in Table 5 shows the average initial price of purchased fresh milk, calculated from observed scan data. The percentages obtained in step 3, which are shown in the last column in Table 5, were set as the carbon tax level in Table 6. In summary, the carbon tax level was set at 1.88%, 14.20%, 16.38%, 14.62% and 10.15% for plant-based milk, low-fat milk, reduced-fat milk, standard milk and other fresh milk, respectively.

Step 4 simulated introduction of a carbon tax equal to the Marshallian elasticity (in Table 4) multiplied by the calculated carbon tax level (Table 5), which gave the percentage change in fresh milk demand (Table 6). The corresponding quantity change for fresh milk was then calculated and the corresponding change in carbon footprint after introduction of the carbon tax was determined (Table 7). This was equal to the simulated quantity change in fresh milk demand multiplied by CO_2-eq contained in one litre of fresh milk. In scenario 1, where a carbon tax on plant-based milk of 1.88% was simulated, the average carbon footprint per household and year increased by about 0.956 kg, with household group 3 making the largest contribution (0.389 kg). Scenario 2, featuring an increase in the price of low-fat milk of 14.20%, resulted in a 7.873 kg decrease in the carbon footprint per household and year, on average. Scenario 3, increasing the price of reduced-fat milk by 16.38%, decreased the carbon footprint by 14.316 kg per year, with household group 3 showing the highest percentage decrease. Scenario 4, involving an increase of 14.62% in the price of standard milk, resulted in a decrease in the carbon footprint of 11.726 kg per year. In scenario 5, where the carbon tax on other fresh milk resulted in a 10.15% price increase, the carbon footprint decreased by 4.890 kg. Thus according to the overall results, placing a carbon tax on dairy fresh milk products would lead to a decrease of between 4.890 and 14.316 kg in the annual carbon footprint. A carbon tax on reduced fat milk would give the greatest decrease in the carbon footprint from fresh milk consumption, followed by a tax on standard milk, but a carbon tax on plant-based milk would increase the corresponding carbon footprint because of the substitutional effects between plant-based milk and low-fat and standard milk. Generally, the results showed that levying a carbon tax on dairy fresh milk, rather than on plant-based milk, would be more likely to promote climate-friendly fresh milk consumption.

Table 6
Simulated percentage change in fresh milk demand quantity in scenarios 1-5.

	Scenario 1: carbon tax on Plant-based milk (1.88% increase in price)	Scenario 2: carbon tax on low-fat milk (14.2% increase in price)	Scenario 3: carbon tax on reduced-fat milk (16.38% increase in price)	Scenario 4: carbon tax on standard milk (14.62% increase in price)	Scenario 5: carbon tax on other fresh milk (10.15% increase in price)
For household group 1					
Plant-based milk	−8.63%	2.38%	−16.27%	35.27%	12.87%
Low-fat milk	0.39%	−27.22%	15.28%	−0.13%	1.74%
Reduced-fat milk	−0.39%	4.17%	−22.37%	2.49%	0.46%
Standard milk	2.56%	−0.24%	8.77%	−33.54%	−1.21%
Other fresh milk	2.02%	1.10%	−2.43%	−6.03%	−22.56%
For household group 2					
Plant-based milk	−6.70%	1.69%	−11.57%	25.07%	9.15%
Low-fat milk	0.40%	−27.38%	15.47%	−0.13%	1.77%
Reduced-fat milk	−0.38%	4.07%	−22.22%	2.43%	0.44%
Standard milk	1.68%	−0.15%	5.74%	−26.98%	−0.79%
Other fresh milk	1.90%	1.04%	−2.30%	−5.68%	−21.85%
For household group 3					
Plant-based milk	−6.94%	1.78%	−12.16%	26.36%	9.62%
Low-fat milk	0.60%	−34.11%	23.42%	−0.20%	2.67%
Reduced-fat milk	−0.38%	4.10%	−22.27%	2.45%	0.45%
Standard milk	2.77%	−0.26%	9.49%	−35.10%	−1.31%
Other fresh milk	2.40%	1.31%	−2.89%	−7.17%	−24.91%
For household group 4					
Plant-based milk	−14.44%	4.44%	−30.39%	65.89%	24.04%
Low-fat milk	0.46%	−29.54%	18.04%	−0.15%	2.06%
Reduced-fat milk	−0.37%	4.01%	−22.12%	2.39%	0.44%
Standard milk	2.83%	−0.26%	9.71%	−35.55%	−1.34%
Other fresh milk	0.85%	0.46%	−1.03%	−2.55%	−15.40%

Table 7
Corresponding change in carbon footprint after introduction of a carbon tax (kg) in scenarios 1-5.

	(1) Scenario 1: carbon tax on Plant-based milk (1.88% price increase)	(2) Scenario 2: carbon tax on low-fat milk (14.2% price increase)	(3) Scenario 3: carbon tax on reduced-fat milk (16.38% price increase)	(4) Scenario 4: carbon tax on standard milk (14.62% price increase)	(5) Scenario 5: carbon tax on other fresh milk (10.15% price increase)
For household group 1	0.267	−3.059	−2.081	−3.236	−1.325
For household group 2	0.194	−3.115	−2.276	−2.645	−1.291
For household group 3	0.389	1.755	−8.289	−3.232	−1.770
For household group 4	0.105	−3.455	−1.671	−2.613	−0.504
Total	0.956	−7.873	−14.316	−11.726	−4.890

5. Discussion and conclusions

Fresh milk contains products of animal origin, but also an increasing share of plant-based fresh milk substitutes, such as soya milk, almond milk and milk from oats. These plant-based substitutes typically have a substantially lower carbon footprint than milk from ruminants, but their retail price is currently approximately double that of animal-based milk. Based on the results and according to the preference structure found in this study, a carbon tax would decrease the relative price of plant-based fresh milk products and would be likely to induce a greater shift among households towards consumption of these products. However, rising household incomes, increased consumer awareness of climate-related sustainability issues and a potential carbon tax could also reduce the market share of cow's milk in Europe substantially and could potentially undermine ongoing attempts by policymakers to stabilise dairy farm incomes.

The results of the present analysis indicated that household milk expenditure significantly affects the demand for fresh cow's milk. The cross-price effects suggested a substitutional relationship between plant-based milk and low-fat, standard and other milk, but a complementary relationship between plant-based milk and reduced-fat milk. Regarding the effects of socioeconomic variables on the demand for fresh milk, the presence of children in a household is most likely to decrease consumption of low-fat milk. In terms of self-price elasticity and cross-price elasticity, the overall observed non-significance of socioeconomic variables showed that fresh milk products constitute a food product category that is widely consumed across different socioeconomic groups and that consumers are strongly price-elastic. This can be taken as an indication that future demand for plant-based milk, rather than cow's milk-based fresh milk products, is not solely a trend among subgroups of consumers who are easily identified by certain socioeconomic characteristics. For example, there was no evidence to support the hypothesis that demand for plant-based milk is primarily a trend among 'young and well-educated urban consumers'. Instead, the results suggested that plant-based milk is becoming widely established as a substitute for conventional fresh milk products, serving as a complement to low-fat milk. For the European dairy sector and dairy-related EU policies, this is potentially bad news as the results do not suggest that the demand for plant-based milk will remain limited to certain subgroups of consumers.

The results of this study indicate that applying a carbon tax to dairy fresh milk as part of future taxation policies to reduce the carbon footprint of private households' food consumption would decrease the carbon footprint, but applying a carbon tax to plant-based milk would increase the carbon footprint because of the institutional and complementary relationship between the different categories of fresh milk. Generally, the results show that levying a carbon tax on dairy fresh milk, rather than on plant-based milk, would be more likely to promote climate-friendly fresh milk consumption. However, substantially lower relative prices of plant-based milk or substitutes may amplify ongoing trends among consumers to consume more of these products for environmental and health reasons. Thus total carbon emissions may decline beyond the effect induced by the carbon tax.

The Swedish government is increasingly considering levying carbon taxes on the agriculture and food sectors, but taxation on food is still a hotly debated issue globally. This study assessed the distribution effects of a carbon tax on fresh milk based on estimates from the EASI demand system, but only the distributional effects on food were considered. Climate-friendly consumption requires consideration to be given also to other aspects, such as land use, water use, fertiliser use, pesticide use and technical innovations in agriculture.

There were limitations in this study, including e.g. weak separability among food subcategories. In reality, a potential effect of a carbon tax on fresh milk on consumption of other food products cannot be excluded. For instance, if the other products are not taxed, their consumption could increase, which could generate higher GHG emissions. In future work, the effectiveness of a carbon tax could be analysed in the context of a global food system. A wider analysis of the consequences of imposing a carbon tax on fresh milk would also be interesting, e.g. the consequences from a household welfare point of view or on diet quality. Those effects should be also considered when assessing the potential effectiveness of fiscal policies to promote more sustainable food consumption.

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