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Demand elasticities for fresh meat and welfare effects of meat taxes in Germany

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ABSTRACT

This paper assesses the effect of different meat tax designs in Germany including increasing the value-added tax as well as two climate-gas-emission-sensitive excise tax scenarios. For the simulation study, we first estimate price and expenditure elasticities for fresh meat for different household types using data from the GfK ConsumerScan FreshFood panel over the period 2012–14. The estimated elasticities are used to derive budget and welfare effects for the tax scenarios. A general rise in the value-added tax from 7% to 19% leads to a welfare loss of 0.83 euros per household per month. Disentangling the effect by household group according to income and age shows that low-income and older households experience a higher welfare loss and bear a larger tax burden relative to their income compared to low-income and younger households, respectively. Comparing the different taxation scenarios highlights the comparative efficiency of excise taxes and the importance to consider effects on older households.

1. Introduction

The role of lowering meat consumption has been discussed in recent literature on healthy and sustainable diets. It is estimated that the agricultural sector and food production globally emit 21–37% of all greenhouse gases (IPCC, 2019). Animal products in particular contribute to these emissions, independent of whether considered on a per kcal, gram protein, or food serving basis (Tilman and Clark, 2014). Additionally, the consumption of meat is related to a range of adverse health outcomes (Bonnet et al., 2020). In its report from 2019 the IPCC therefore recommends a shift towards balanced diets, featuring plant-based food as a major opportunity for climate change adaption and mitigation (IPCC, 2019). It remains unclear, though, how a change towards healthy and sustainable food consumption can be achieved. Besides information campaigns, nudges or changes in social norms, fiscal approaches using taxes are frequently discussed (Katare et al., 2020; Bonnet et al., 2020). However, understanding the potential of fiscal policies that aim at making diets more sustainable requires knowledge of consumer reactions to price interventions, in particular the elasticities of demand, as well as precise insights into the effects of alternative tax designs.

The present study deals with fresh meat demand in Germany. German meat consumption averages at around 60 kg per capita per year and is therefore slightly lower than the European average (Federal Office for Agriculture and Food, 2020). Given the size of the population, Germany is the largest meat consumer in the EU. As in Germany across the counter purchases are significant and make up about half the volume of consumer demand (AMI, 2020) and because fresh meat and processed meat (e.g., sausage) are not available in a unified data set, we focus here on fresh meat purchases. Reports by scientific advisory boards to federal government institutions in Germany have discussed potential market interventions that directly or indirectly affect prices on meat markets, and thus, trigger changes in demand (SRU, 2012; Weingarten et al., 2016; SAB, 2020). The SRU argued that high price elasticities for meat and dairy products make taxes a favourable option to increase prices and reduce consumption. Similarly, the Scientific Advisory Board on Agricultural Policy, Food and Consumer Health Protection at the Federal Ministry of Nutrition and Agriculture suggests removing the reduction in the value-added tax (VAT) as a simple means to curb consumption (SAB, 2020). At the same time, both reports discuss the potentially regressive nature of such a tax, calling for policy designs that do not leave low-income households worse off.

Abbreviations: AIDS, Almost Ideal Demand System.

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Despite the frequent discussions on the potential effects of fiscal measures, scientific studies of the parameters of meat demand and the potential impact of a carbon tax are surprisingly rare. A few studies have simulated the impact of a carbon tax on food. Säll and Gren (2015) and Säll (2018) have analysed the effect of an environmental tax on meat and dairy products in Sweden. Consumer response to the tax was derived through elasticity estimates obtained from an Almost Ideal Demand System (AIDS) based on per capita consumption and price data for the period 1980 to 2012. Säll (2018) has used this data to assess the impact on different household income groups despite not being able to estimate household-specific elasticities. Other studies use elasticities from a linear AIDS to predict changes in consumption at the product and nutrient level for Denmark (Edjabou and Smed, 2013) and Norway (Abadie et al., 2016). An environmental tax on animal products was also analysed for France by Bonnet et al. (2018) and by Caillavet et al. (2016) and for Spain by Dogbe and Gil (2018). Bonnet et al. (2018) estimate a random coefficients logit model on household purchase data for 2010 from a French household panel. The authors analyse consumption and related emission changes, and show that a tax levied exclusively on beef would yield the most efficient reduction in carbon dioxide equivalents (CO_{2e}) when considering emissions and household surplus. Caillavet et al. (2016) estimate the effect of an ad valorem tax on all or specific animal products based on an Exact Affine Stone Index demand system (EASI). They simulate changes in emissions, nutrients and welfare for households differentiated by income and age. Dogbe and Gil (2018) also use an EASI demand model and calculate consumption, diet quality and emission changes as well as the welfare effects for four excise tax scenarios where tax rates are based on carbon emissions. Yokessa and Marette (2019) use experimental data to estimate the effect of a carbon tax on milk.

In our analysis we follow Säll and Gren (2015) and Edjabou and Smed (2013) and aggregate goods at the category/species level, i.e. for the commonly consumed meat categories poultry, pork, and beef & veal rather than focusing on individual cuts as done in Bonnet et al. (2018). However, rather than using time series data at the national level as done in those papers, we use household scanner data to estimate demand elasticities and simulate the impact of different carbon tax scenarios. In considering the discussion of different tax designs (Bonnet et al., 2020), this paper assesses the potential effect of four tax scenarios including two ad valorem taxes, increasing the VAT on meat from 7% to 14% or the general level of 19%, and two excise tax scenarios based on carbon emissions by meat category. To prepare for the simulation, we first estimate an Almost Ideal Demand System in its linear approximation (LA-AIDS) to obtain demand elasticities for Germany as a whole and specific household groups. The elasticities are used to simulate the impact of the different tax scenarios on fresh meat consumption, household expenditures, household welfare, tax revenue, and carbon emissions.

We employ a rich household scanner data set from the market research company GfK, which provides detailed information regarding the quantity of and expenditure on fresh meat purchases for 21,656 German households from 2012 to 2014. Data availability restricts us to focus on fresh meat only, excluding processed meat (e.g., sausages and cured meat products) and out-of-home consumption. Fresh meat demand is aggregated into the categories poultry, pork, beef & veal, and meat mixtures. These data also include relevant socio-economic variables as well as measures of attitudes towards food, e.g., regarding price and quality. We account for the censoring of the purchase data using the approach proposed by Shonkwiler and Yen (1999) and derive quality-adjusted prices according to Cox and Wohlgenant (1986). Employing these established and widely used approaches, we provide new and insightful elasticity estimates based on recent data to inform current policy debates. In particular, we estimate the demand system separately for households that differ according to their income and age. We can thus overcome a limitation in the study by Säll (2018) who did not have group-specific elasticities. Thiele (2008) was able to show that elasticities differ by household group using data from the German Income and Consumption Survey for 2003. Lee et al. (2020) also underline the importance of accounting for cohort and age effects when estimating meat demand elasticities in the United States. The results from these detailed analyses allow us to shed more light on heterogeneous behaviour across different consumer segments since households arguably differ both in their baseline consumption and in their price reaction. Furthermore, the results depict the distribution in welfare impacts and underline the regressive nature of food taxes.

The paper proceeds as follows. The next section presents our methodological approach. First, we introduce the AIDS framework as well as our estimation and simulation approach. This section is followed by a description of the underlying dataset and descriptive statistics on purchase characteristics and socio-demographics in Section 3. Section 4 presents estimation results and discusses elasticities in addition to the demand and welfare effects of alternative tax scenarios. Section 5 discusses implications for policymaking, limitations, and concludes.

2. Empirical approach

We approach the assessment of the impact of taxes on fresh meat demand in three steps. In the following we first describe the theoretical specification of the AIDS in 2.1, followed by the specification of unit values and the two-step estimation according to Shonkwiler and Yen (1999) in 2.2. Finally, the simulation approach based on the estimated price elasticities is described in 2.3.

2.1. Specification of the basic Almost Ideal Demand System

We model demand for four subgroups of fresh meat in Germany based on Deaton and Muellbauer's (1980) AIDS, as applied in Säll (2018), Säll and Gren (2015), Thiele (2008), Jensen et al. (2016), and Edjabou and Smed (2013). Household expenditure shares result from cost minimisation as:

$$w_{iht} = \alpha_i + \sum_j \gamma_{ij} \ln p_{jht} + \beta_i \ln(M_{ht}/P_{ht}) + \upsilon_{iht} \quad \text{for } i = 1, \cdots, 4 \tag{1}$$

where w_{iht} is the expenditure share of meat group $i = 1$ (poultry), 2 (pork), 3 (beef&veal), 4 (mixtures), for household h in period t; p_{jht} is the price of product group j, M_{ht} a household's total meat expenditure, α_i, γ_{ij}, and β_i are parameters to be estimated, and υ_{iht} denotes the error term. P_{ht} is the price index and we used a linear approximation of the AIDS by employing the corrected Stone-Laspeyres-type price index suggested by Moschini (1995), which is given by

$$\ln P^S_{ht} = \sum_{i=1}^{n} \overline{w}_i p_{iht} \tag{2}$$

We impose the theoretical properties of demand by:

$$\sum_i \alpha_i = 1, \sum_i \beta_i = 0, \sum_i \gamma_{ij} = 0 \quad \text{(adding-up)} \tag{3a}$$

$$\sum_j \gamma_{ij} = 0 \quad \text{(homogeneity)} \tag{3b}$$

$$\gamma_{ij} = \gamma_{ji} \quad \text{(symmetry)} \tag{3c}$$

2.2. Two-step estimation accounting for censoring

Since our data contain a large number of zero observations, where households did not purchase any products from a specific category, estimating the standard system outlined by Eqs. (1) and (2) will result in biased coefficients due to censoring. There are a number of alternative procedures to circumvent this problem (e.g. Shonkwiler and Yen, 1999; Dong et al., 2015; Dong et al., 2004; Meyerhoefer et al., 2005; Perali and Chavas, 2000). We have adopted the two-step approach from Shonkwiler and Yen (1999) to obtain consistent estimates of demand parameters.

In the first step of the estimation, we derive estimates of the probability that a household will purchase products from a specific meat category in a given month based on probit models for each category. The dependent variable is a binary indicator of a positive quantity in a meat category which we model as a function of relative average regional prices of meat types, household characteristics, attitudes towards price and quality, as well as time and geographic variables. Based on the estimates, we derive the values of the probability density function ϕ_{iht} and the cumulative distribution function Φ_{iht}, for a purchase in each product group per household and time period.

In the second step, we estimate budget shares based on Eq. (4), which corrects for censoring by including ϕ_{iht} and Φ_{iht}:

$$w_{iht} = \Phi_{iht} \times \left[\alpha_i + \sum_j \gamma_{ij} \ln p_{jht} + \beta_i \ln(M_{ht}/P_{ht})\right] + \theta_i \phi_{iht} + \varepsilon_{iht} \quad (4)$$

We estimate the system as described by Eqs. (4) and (2) using a seemingly unrelated regression procedure for three product categories (poultry, pork, beef & veal) and retrieve parameters for the fourth group (mixtures) from the restrictions (3a)–(3c). It is a common approach in demand system estimation to drop one equation to avoid singularity and to retrieve the parameters of the omitted equation based on the theoretical restrictions afterwards. The stability of the model results is assured by robustness checks dropping various meat types from the estimation. We also include a set of binary indicators for months to control for seasonality effects in meat demand as well as sociodemographic characteristics including age category, occupation, household net income, and sex.

We compute the conditional expenditure elasticities $\eta_{(r)i}$, uncompensated price elasticities $\varepsilon_{(r)ij}$, and compensated price elasticities $\varepsilon^*_{(r)ij}$ at means within the commodity group of fresh meat indicated by (r) following Green and Alston (1990) using the estimated parameters, the mean budget shares, $\overline{w}$, and purchase likelihoods, $\overline{\Phi}$, coming from the predictions of the first-step probit models:

Expenditure elasticities:

$$\eta_{(r)i} = \overline{\Phi}_i \cdot \frac{\widehat{\beta}_i}{\overline{w}_i} + 1 \quad (5a)$$

Uncompensated price-elasticities:

$$\varepsilon_{(r)ii} = \overline{\Phi}_i \cdot \left(\frac{\widehat{\gamma}_{ii}}{\overline{w}_i} - \widehat{\beta}_i\right) - 1 \quad (5b)$$

$$\varepsilon_{(r)ij} = \overline{\Phi}_i \cdot \left(\frac{\widehat{\gamma}_{ij} - \widehat{\beta}_i \overline{w}_j}{\overline{w}_i}\right), \quad \text{with } k \neq j \quad (5c)$$

Compensated price-elasticities:

$$\varepsilon^*_{(r)ij} = \varepsilon_{(r)ij} + \overline{w}_j \cdot \eta_{(r)i} \quad (5d)$$

In the next step, we calculate the unconditional elasticities using elasticity estimates for the commodity group (r), fresh meat, following Edgerton (1997) as follows:

Expenditure elasticities:

$$\eta_i = \eta_{(r)i} \eta_{(r)} \quad (6a)$$

Uncompensated price-elasticities:

$$\varepsilon_{ii} = \varepsilon_{(r)ii} + \eta_{(r)i} w_i \left(1 + \varepsilon_{(r)}\right) \quad (6b)$$

$$\varepsilon_{ij} = \varepsilon_{(r)ij} + \eta_{(r)i} w_j \left(1 + \varepsilon_{(r)}\right) \quad (6c)$$

Compensated price-elasticities:

$$\varepsilon^*_{ij} = \varepsilon^*_{(r)ij} + \overline{w}_j \cdot \eta_{(r)i} \varepsilon^*_{(r)} \quad (6d)$$

The elasticities for the commodity group meat and meat products are

Table 1
Product-based CO_{2e}-emission and simulated tax rates by type of meat.

	Poultry	Pork	Beef & veal	Mixtures
CO_{2e} –emissions in kg per kg meat based on Meier (2013)	5.85	7.94	18.58	13.26
	Tax in euros per kg			
Increase in value added tax				
(a) Ad valorem tax 19% (mean)	0.69	0.64	0.91	0.51
(b) Ad valorem tax 14% (mean)	0.41	0.37	0.53	0.30
Excise tax on carbon emissions				
(c) US-$ 40 (37 euros) per ton CO_{2e}	0.22	0.29	0.69	0.49
(d) US-$ 100 (93 euros) per ton CO_{2e}	0.54	0.74	1.72	1.22

Note: Emissions based on carcass weight. Mixtures calculated for an equal share of pork and beef.

taken from Thiele (2008) with $\eta_{(r)} = 1.19$, $\varepsilon_{(r)} = -1.02$, and $\varepsilon^*_{(r)} = -0.63$.

As literature has shown that demand elasticities can differ by sociodemographic groups, we estimate the model for specific subgroups defined by income and age of the household reference person. This approach has also been used in Park et al. (1996) and Thiele (2010).

2.3. *Welfare effects of meat taxes*

2.3.1. *Procedures*

We follow Säll and Gren (2015) and Säll (2018) and use the elasticities from the demand system estimation to derive demand, budget, and welfare effects. First, we use the uncompensated price elasticities to simulate the demand effects of an increase in the price of meat using market-level median prices per district (d) and month (t). When doing so, we assume a tax at the consumer level, where tax equals the difference in price before and after the tax introduction indicated as a superscript of the price variable, i.e., $t = p^1_{idt} - p^0_{idt}$.

The percentage change in quantity demanded for product group i results from the own-price and cross-price effects

$$\%\Delta x_{iht} = \sum_{j=1}^{4} \varepsilon_{ij} \%\Delta p_{jdt}. \quad (7)$$

Hence, the new consumption level for meat group i by household h in period t, x^1_{iht}, can be calculated depending on baseline consumption, x^0_{iht}. The change in household expenditures (ΔExp) accounting for demand adjustments from x^0_{iht} to x^1_{iht} can then be calculated as

$$\Delta Exp_{ht} = \sum_{i=1}^{4} \left[\left(p^1_{idt} * x^1_{iht}\right) - \left(p^0_{idt} * x^0_{iht}\right)\right]. \quad (8)$$

Furthermore, the tax revenue (TR) per household and month is calculated as the product of the price change and the new quantity demanded:

$$TR_{ht} = \sum_{i=1}^{4} \left[\left(p^1_{idt} - p^0_{idt}\right) * x^1_{iht}\right] \quad (9)$$

Finally, consumer welfare effects can be calculated as the compensating variation (CV) of a price change. It is defined as the change in the consumer cost (expenditure) function resulting from the price change, keeping utility constant. It corresponds to the willingness to accept, that is the monetary transfer at which the consumer is indifferent between the prices with and without the tax. Following Azzam and Rettab (2012) we calculate

$$CV = \sum_{i=1}^{4} p^0_i x^0_i \left(\frac{dp_i}{p^0_i} + \frac{dx^*_i}{p^0_i} + \frac{dp_i}{p^0_i} \cdot \frac{dx^*_i}{p^0_i}\right) \quad (10)$$

where p^0_i and x^0_i correspond to prices and quantities before the tax and

dx_i^* is the compensated quantity change in demand following the tax calculated using the compensated elasticities.

2.4. Tax scenarios

We consider four tax scenarios summarised in the lower part of Table 1: (a) an ad valorem tax in the form of an increase in the VAT for all meat types from 7% to 19%, (b) a smaller increase in the VAT for all meat types from 7% to 14%, (c) an excise tax according to the CO_{2e} emissions by meat type using the low carbon tax discussed by the Intergovernmental Panel on Climate Change (IPCC, 2014) of 40 US-$ per t CO_{2e} and (d) a high excise tax, charging 100 US-$ per t CO_{2e}. Amounts in US-$ were converted into euros at a rate of 1.08 $ per euro so that the scenario translates into 37 and 93 euros per t CO_{2e}, respectively. These tax values are lower than those considered in Bonnet et al. (2018) who use tax rates of 56 and 200 euros per t CO_{2e} according to Quinet (2009). The SAB (2020) of the German Ministry of Food and Agriculture gives a reference damage cost of 180 euros per t CO_{2e} based on the report by the SRU (2012). However, together with a number of German economic institutes, it suggests an entry level of 35 euros per t CO_{2e}, which corresponds approximately to the low excise tax scenario in this paper. The generic increasing of the VAT to the general level of 19% was chosen owing to ongoing German discussions to consider this as an option (SAB, 2020). To make the results between the ad valorem and excise tax more comparable, we also consider an increase in the VAT to 14% as this tax rate yields a reduction in carbon emission of comparable size as the low excise tax scenario.

The calculation of a carbon tax per meat category requires knowledge of the carbon emissions per meat category, which are taken from Meier (2013). The author combines aspects of a Life Cycle Analysis (LCA) according to ISO norms with those of an input–output analysis of national accounts. The numbers are reported in Table 1. A comparison to other studies reveals differences that can in part be explained by e.g., feeding conditions (concentrates versus pasture access) and transportation needs. While the exact emission quantity varies by country and type of analysis, the relative impact by meat category is robust. A number of meta-analyses exist now (e.g., Clune et al., 2017; Poore and Nemecek, 2018), but we chose to consider country-specific estimates that reflect German production conditions. For the product group 'meat mixtures', we use a 50–50 combination of CO_{2e} emissions for beef and pork, as mixtures are mostly composed of minced and diced beef-pork combinations.

The per-unit taxes translate to surcharges of 8% and 21% for beef & veal in the US-$40 and US-$100 scenarios, respectively. Pork is taxed at lower rates with 5% and 13% as is chicken with 4% and 9%, respectively. Given that only climate gas emissions are accounted for, the tax rates are lower compared to Säll and Gren (2015), where taxes are designed to also correct for other environmental externalities coming from nitrogen and phosphorus emissions. Their excise tax rates range between 9% (chicken) and 33% (beef) of the product price. Relative tax rates at the lower tax scenario are comparable to Bonnet et al. (2018).

3. Meat demand data, descriptive statistics and adjustments

3.1. Sample

Our analysis is based on household scanner data from the *ConsumerScan FreshFood* panel provided by the GfK in Nuremberg, Germany. This panel consists of a nationally representative set of households in Germany, which scan all their purchases and forward the collected data to the GfK. Additionally, the GfK surveys participating households once a year, collecting information on socio-demographic characteristics, consumption behaviour, as well as attitudes towards various aspects of consumption.

For this study, we use data on purchased quantities and expenditures for fresh meat reported by a total of 21,656 households over the years 2012 to 2014. We aggregate the raw data on single purchases into expenditures on a monthly basis for four different categories of fresh meat: poultry, pork, beef & veal, as well as meat mixtures. The *poultry* category combines chicken, turkey, goose, and other poultry meat. *Pork* contains all pure pork. We merged *beef & veal* into one category as both originate from the same species and are located in the upper price range. *Meat mixtures* include for example mixed diced meat, shashlik, goulash, and minced meat. The resulting monthly data span from January 2012 to December 2014, where a household can reach a maximum of 36 observations. In all of the following analyses, we adjust for survey weights, yielding a final unbalanced panel data set with a stable number of around 7000 household observations each month and a total of 251,099 effective household-month observations.

The purchasing households also recorded several sociodemographic characteristics such as the administrative district, income and size of the household, as well as the age, gender, and occupational group of the household's reference person. Additionally, variables reflecting households' attitude statements regarding quality and price are included. We divide households into different income and age groups. As the exact household composition is not recorded in the data, partitioning based on equivalent income was not possible and we use an auxiliary definition for assigning households to the low- or high-income group. A *low-income* household is defined as single households with a monthly net income $<$1000 euros and multi-person households with a monthly net income of under 500 euros per additional household member (that is, below 1500 euros per month for a two-person household, below 2000 euros per month for a three-person household etc.). A *high-income* household is a single household having more than 2499 euros per month at its disposal, and for multi-person households, we allowed 999 euros more per additional household member and month. We regard households as belonging to the *young* group when the person in charge of food purchases is 39 years old or younger. On the other hand, we define *old* households as those where the household's reference person is 60 years old or over.

Descriptive statistics of the corresponding variables provided in the appendix in Table A1 show that 29% of households in the sample are single households, 41% are two-person households and the rest (30%) has three or more persons. This compares to 40.8% for single households and 34% for two-person households in Germany in 2014 (Federal Statistical Office, 2020). The sample's age structure mirrors the general demographic trend in society, with 20% younger and 40% older household reference persons. This compares to a share of 31% and 32% of younger and older persons in the German population in general. According to our defined income categories, we have 22% low-income, 58% middle-income, and 20% high-income households. The cross-classification by income and age group is given in Table A2. A man serves as the household's reference person in only 20% of the sample households. In 40% of our households, the person responding to the survey is not actively engaged in the labour market[1], while 36% are employees and 14% are workers. The majority of our households are located in towns or smaller cities. With respect to statements about their attitudes towards food consumption and purchases, we observe that sample households care about food quality with an average rating of 3.16 on a scale from 1 (low) to 5 (high). At the same time, the average price consciousness is rated at 3.45.

3.2. Unit values

Since the demand estimation is based on monthly aggregates of household purchases, this analysis relies on unit values (UVs). A well-

[1] The share seems comparatively high; however, average labour participation rate in Germany is 73 % among 15–65-year-olds in 2014 and 38 % of our respondents are over 59.

Table 2
Prices, adjusted unit values and quantities by sociodemographic group (mean and coefficient of variation).

Household Group	Poultry		Pork		Beef & veal		Mixtures	
	mean	coeff var	mean	coeff var	mean	coeff var	mean	coeff var
	Month-district retail prices (euros per kg - unadjusted)							
All households	6.199	0.066	5.736	0.081	8.138	0.097	4.613	0.082
Low Income	6.175	0.067	5.679	0.083	8.086	0.095	4.603	0.081
High Income	6.228	0.064	5.807	0.077	8.196	0.097	4.625	0.081
Age $\leq$ 39 years	6.214	0.065	5.742	0.083	8.156	0.099	4.617	0.081
Age $\geq$ 60 years	6.189	0.067	5.726	0.082	8.126	0.096	4.609	0.082
	Adjusted Unit Values (euros per kg - adjusted)							
All households	6.877	0.300	5.739	0.332	7.505	0.424	4.020	0.563
Low Income	6.894	0.257	5.780	0.287	7.445	0.336	4.074	0.407
High Income	6.917	0.350	5.816	0.384	7.674	0.538	4.056	0.747
Age $\leq$ 39 years	6.884	0.288	5.701	0.286	7.420	0.378	4.071	0.453
Age $\geq$ 60 years	6.863	0.310	5.753	0.365	7.563	0.452	3.977	0.626
	Quantities (kg per month)							
All households	0.722	1.683	1.457	1.349	0.442	2.119	0.377	2.052
Low Income	0.753	1.679	1.585	1.360	0.356	2.469	0.417	1.925
High Income	0.676	1.762	1.183	1.421	0.528	1.958	0.332	2.273
Age $\leq$ 39 years	0.658	1.612	1.024	1.488	0.280	2.525	0.417	1.713
Age $\geq$ 60 years	0.647	1.820	1.501	1.306	0.522	1.914	0.298	2.294
	Expenditures (euros per month)							
All households	4.071	1.684	8.257	1.283	4.059	2.283	2.169	2.386
Low Income	3.860	1.626	8.257	1.293	2.846	2.563	2.117	2.148
High Income	4.280	1.750	7.621	0.1372	5.628	2.135	2.289	2.744
Age $\leq$ 39 years	3.864	1.514	5.772	1.443	2.363	2.599	2.077	1.851
Age $\geq$ 60 years	3.529	1.914	8.512	1.217	4.920	2.087	1.985	2.762

Note: Age $\leq$ 39 years: n = 67,149; Age $\geq$ 60 years: n = 126,634; Low income: n = 83,295; High income: n = 59,234. n refers to household-month observations.

known drawback of using UVs in demand analyses is that they do not only represent exogenous price variation but also depend on households' choices over the composition of shopping baskets with respect to products of different quality. Therefore, UVs need to be adjusted for quality effects. We have adopted the approach of Cox and Wohlgenant (1986) for this purpose and model the variation in UVs as a function of a constant, different quality characteristics C_{ic}, and an error term:

$$UV_i = \delta_i + \sum_c \kappa_{ic} C_{ic} + e_i \tag{11}$$

As the quality characteristics (C_{ic}) of purchased meat types are not available in the data, we employ sociodemographic and socioeconomic household characteristics, specifically the number of household members, net income, household size, as well as occupation, gender, and the age of the reported reference person of the household as proxy variables (Cox and Wohlgenant, 1986). We also include the households' statements on price consciousness and quality orientation as additional variables, which are likely to affect average prices paid.

Table A3 in the appendix depicts the results of the UV regressions. Based on these regressions, we purge the quality effects and define adjusted prices (p_i^*) as the sum of the constant ($\widehat{\delta}_i$) and predicted residuals ($\widehat{e}_i$) from (11). These represent variation in UVs due to supply-side factors.

Given the presence of missing values due to the non-purchase of a product group by a household in a certain month, we replace observations with missing price data with the median values of the respective household's district in the given month. Thus, we obtain a complete set of prices for the subsequent demand analyses.

3.3. Demand variables

Table 2 depicts summary statistics of month-district retail prices, adjusted UVs, purchased quantities, and expenditures (including zero observations) for the four product groups included in the demand analysis. Looking at total quantities for all households, we observe that the average quantity of pork purchased is the largest at 1.46 kg per month, followed by poultry (0.72 kg), beef (0.44 kg), and mixtures (0.38 kg). As illustrated in Table 3, this totals to a fresh meat demand of 3.0 kg per household per month or 36 kg per household per year. This seems low compared to German meat consumption which is about 60 kg per person per year. However, only fresh meat purchases are included (i.e. processed meat products such as ham or sausages, prepacked frozen meat, ready-to-eat meals, and out-of-home consumption are excluded).

Table 3
Average total fresh meat consumption and carbon-equivalent emissions.

Household Group	Quantity (kg/month)	Expenditures (euros/month)	CO_{2e} emissions (kg/month)
All households	3.00	18.56	28.99
Low Income	3.11	17.08	29.15
High Income	2.72	19.82	27.56
Age $\leq$ 39 years	2.38	14.08	22.72
Age $\geq$ 60 years	2.97	18.95	29.36

The numbers in Table 2 also show that month-district prices and adjusted unit values vary little by household type; purchased quantities show large differences for pork and beef & veal. Younger households and high-income households consume less pork compared to older households and low-income households, respectively. Younger households also consume less beef & veal compared to older households while high-income households consume more beef & veal than low-income households. Compensating behaviour is observed with mixtures that are consumed in larger quantities in low-income and younger households compared to their counterparts. Accordingly, high income households spend most on beef & veal.

Further aspects of meat demand by household type are depicted in Table 3. An average household spends 18.56 euros/month on fresh meat resulting in 28.99 kg CO_{2e} emissions per month. Younger households spent considerably less on fresh meat than older households, which leads to lower CO_{2e} emissions per month. High-income households consume less meat in total compared to low-income households, resulting in a slightly lower level of CO_{2e} emissions. At the same time, they consume more high-value cuts, notably beef & veal, spending more on average than low-income households.

Table 4
Estimated unconditional price and expenditure elasticities

Meat category	Price elasticities				Expenditure
	Poultry	Pork	Beef	Mixtures	
Uncompensated					
Poultry	**−0.861**	−0.022	−0.082	−0.024	1.154
Pork	−0.020	**−0.966**	−0.011	−0.003	1.167
Beef & Veal	−0.151	−0.142	**−0.960**	−0.026	1.492
Mixtures	0.022	0.096	0.052	**−0.948**	0.907
Compensated					
Poultry	**−0.771**	0.151	−0.019	0.027	
Pork	0.071	**−0.791**	0.054	0.048	
Beef & Veal	−0.034	0.082	**−0.878**	0.041	
Mixtures	0.093	0.232	0.102	**−0.908**	

Note: Price elasticities according to Eqs. (6b)–(6d) where *i* indicates the row and *j* indicates the column.

3.4. Probit regressions for purchase decisions

Table A4 in the appendix presents the average marginal effects from the probit regressions of prices and household characteristics on indicators of households' decisions to purchase a certain category in a certain month (=1) or not (=0). Older consumers are more likely to purchase pork and beef & veal, while younger consumers have a higher probability of purchasing mixtures. Household size increases the probability of purchase for all meat types. Increasing incomes go hand in hand with a higher rate of purchases with respect to poultry and beef. Households with male reference persons are more likely to purchase pork and less likely to purchase all other types of meat. Higher price sensitivity increases the likelihood of purchasing pork, poultry, and mixtures, and decreases that of beef. We find exactly the opposite effects for quality consciousness.

4. Results

4.1. Demand elasticity estimates for the total sample

The estimation of the demand system using the data from all households yields highly significant parameters (see Appendix Table A5). These are used to derive unconditional elasticities as in Eqs. (6a)–(6d). Table 4 shows the unconditional uncompensated and compensated price elasticities as well as expenditure elasticities computed at sample means for the entire sample. Conditional elasticities are reported in Table A6 in the appendix. Standard errors are obtained via Krinsky and Robb (1986) bootstrap. Expenditure elasticities for the meat categories fit common perceptions of each meat type regarding quality and exclusivity. Unconditional expenditure elasticities for poultry and pork result as 1.154 and 1.167, while the demand for beef & veal reacts very strongly to changes in expenditures, with an elasticity of 1.492, supporting the notion of beef as the luxury meat (Verbeke and Ward, 2001). The expenditure elasticity of meat mixtures is below unity with a value of 0.907, indicating that this category includes many standard and cheap meat products such as minced meat. Uncompensated own-price elasticities are all very similar across the meat categories with values around 0.9. Cross-price elasticities indicate that mixtures serve as substitutes for all other meat types. Compensated price elasticities are shown in the lower part of Table 4.

4.2. Elasticities across sociodemographic groups

We divide households along sociodemographic characteristics and re-estimate the demand model and elasticities to consider the equity effects of taxation. Key questions are the impact of meat taxes on different income and age groups. Accordingly, we derive and compare elasticity values for (1) low-income and high-income households as well as for (2) younger and older households. The classification into low-income and high-income, as well as younger and older households, follows the classification introduced in Section 3.

Table 5
Unconditional compensated own-price and expenditure elasticities across household groups

Meat type	Household groups				
	All	Income		Age	
	households	Low	High	≤ 39 years	≥ 60 years
	Compensated own-price elasticities				
Poultry	−0.771	−0.591	−0.814	−0.724	−0.792
Pork	−0.791	−0.654	−0.824	−0.732	−0.799
Beef & veal	−0.878	−0.438	−0.903	−0.843	−0.868
Mixtures	−0.908	−0.335	−0.996	−0.433	−0.986
	Expenditure elasticities				
Poultry	1.154	1.173	1.122	1.181	1.113
Pork	1.167	1.212	1.120	1.295	1.114
Beef & veal	1.492	1.469	1.507	1.455	1.520
Mixtures	0.907	0.868	0.970	0.780	0.981

Table 6
Relative consumption variation for alternative tax scenarios

	Relative quantity changes for alternative tax scenarios			
	Poultry	Pork	Beef & veal	Mixtures
(a) Ad valorem tax 19%				
All households	−0.113	−0.116	−0.112	−0.112
Low Income	−0.118	−0.125	−0.110	−0.101
High Income	−0.112	−0.114	−0.113	−0.115
Age ≤ 39 years	−0.116	−0.120	−0.113	−0.103
Age ≥ 60 years	−0.111	−0.115	−0.113	−0.115
(b) Ad valorem tax 14%				
All households	−0.066	−0.068	−0.065	−0.066
Low Income	−0.069	−0.073	−0.064	−0.059
High Income	−0.066	−0.066	−0.066	−0.067
Age ≤ 39 years	−0.068	−0.070	−0.066	−0.060
Age ≥ 60 years	−0.065	−0.067	−0.066	−0.067
(c) Low excise tax				
All households	−0.036	−0.053	−0.085	−0.107
Low Income	−0.037	−0.058	−0.084	−0.097
High Income	−0.035	−0.052	−0.085	−0.109
Age ≤ 39 years	−0.036	−0.055	−0.086	−0.099
Age ≥ 60 years	−0.035	−0.053	−0.086	−0.110
(d) High excise tax				
All households	−0.089	−0.133	−0.213	−0.268
Low Income	−0.093	−0.145	−0.210	−0.243
High Income	−0.088	−0.129	−0.213	−0.273
Age ≤ 39 years	−0.091	−0.138	−0.215	−0.247
Age ≥ 60 years	−0.087	−0.133	−0.216	−0.274

Table 5 presents unconditional compensated own-price and expenditure elasticities for the different socio-demographic household groups. Low-income households react less elastically to price changes than high-income households for all meat types. Looking at the meat categories, it becomes apparent that the differences in reaction to price changes for mixtures are particularly pronounced. This suggests that mixtures are considered a low-budget alternative, attractive to low-income and/or young consumers and purchased by the high-income and older consumers when promoted with specific price discounts. Turning to expenditure elasticities shows only small differences among household groups but for mixtures.

4.3. Effects of taxes on consumption, welfare, and emissions

Consumption levels and elasticities enter the estimation of demand and welfare effects of alternative meat tax scenarios. We start with the demand effects in Table 6, where average demand changes are shown as share of baseline consumption. In percentage terms, the variation in consumption is homogenous across households, hence we only report

Table 7
Expenditure, welfare, and emission effects of alternative tax scenarios

	Expenditures euros		Comp. Var. (CV) euros		Tax revenue euros		Tax share in income percent		CO_{2e} Reduction kg		$CV/\Delta CO_{2e}$ euros/kg
	mean	coeff var	mean	coeff var	mean	coeff var	mean	coeff var	mean	coeff var	mean
(a) Ad valorem tax (19%)											
All households	−0.27	−1.00	0.83	1.09	1.99	1.13	0.10	1.28	3.30	1.02	0.25
Low Income	−0.36	−1.11	0.82	1.10	1.92	1.17	0.17	1.19	3.38	1.03	0.24
High Income	−0.24	−1.04	0.73	1.10	1.96	1.19	0.05	1.17	3.13	1.09	0.23
Age ≤ 39 years	−0.23	−1.10	0.56	1.06	1.44	1.20	0.07	1.46	2.58	1.01	0.22
Age ≥ 60 years	−0.27	−0.99	0.89	1.09	2.09	1.10	0.12	1.21	3.35	1.03	0.27
(b) Ad valorem tax (14%)											
All households	−0.10	−1.01	0.52	1.08	1.22	1.13	0.06	1.28	1.93	1.02	0.27
Low Income	−0.15	−1.16	0.51	1.09	1.18	1.17	0.10	1.19	1.97	1.03	0.26
High Income	−0.09	−1.03	0.45	1.08	1.21	1.18	0.03	1.17	1.82	1.09	0.25
Age ≤ 39 years	−0.09	−1.15	0.35	1.05	0.89	1.20	0.05	1.46	1.51	1.01	0.23
Age ≥ 60 years	−0.10	−1.00	0.55	1.07	1.29	1.10	0.07	1.21	1.96	1.03	0.28
(c) Low excise tax											
All households	−0.09	−1.05	0.42	1.07	1.11	1.28	0.06	1.42	2.00	1.11	0.21
Low Income	−0.11	−1.14	0.42	1.06	1.05	1.32	0.09	1.35	1.99	1.10	0.21
High Income	−0.08	−1.17	0.38	1.09	1.14	1.33	0.03	1.31	1.94	1.19	0.19
Age ≤ 39 years	−0.07	−1.14	0.29	1.00	0.77	1.38	0.04	1.66	1.58	1.08	0.19
Age ≥ 60 years	−0.10	−1.09	0.45	1.07	1.21	1.23	0.07	1.32	2.04	1.12	0.22
(d) High excise tax											
All households	−0.50	−1.08	0.87	1.14	2.48	1.25	0.13	1.40	5.00	1.11	0.17
Low Income	−0.55	−1.06	0.89	1.12	2.34	1.30	0.20	1.33	4.97	1.10	0.18
High Income	−0.48	−1.18	0.77	1.15	2.52	1.31	0.07	1.29	4.85	1.19	0.16
Age ≤ 39 years	−0.40	−1.07	0.60	1.06	1.73	1.35	0.09	1.63	3.95	1.08	0.15
Age ≥ 60 years	−0.52	−1.11	0.96	1.13	2.69	1.21	0.15	1.31	5.09	1.12	0.19

Note: All values to be interpreted per household per month.

average effects. As expected, quantity effects are negative. The increase to a general VAT level of 19% yields an average reduction in purchase quantity of about 11% for all meat types and all households. There are small differences across household groups with low income and young households showing stronger reactions in the demand for poultry and pork and less reaction in beef & veal as well as mixtures. The increase to a VAT level 14% yields qualitatively similar, albeit smaller effects.

The low and high excise tax scenarios yield pronounced shifts in relative consumption levels as beef & veal and mixtures are more heavily taxed, in particular in comparison to poultry and to a lesser extent in comparison to pork. The excise tax scenarios differentiate between meat types so that the demand effect is strongest for beef & veal (−8.5% and −21.3% for all households in the low and high excise tax scenario respectively), and weakest for poultry (−3.6% and −8.9%). The quantity of pork demanded is reduced by 5.3% and 13.3%, respectively. The demand for meat mixtures is also strongly affected and decreases by 10.7% and 26.8%, respectively, as taxes are large relative to price. When households are compared according to sociodemographic group, the effects are stronger for low-income and younger households regarding poultry and pork and weaker for beef & mixtures compared to high-income and older households in the carbon tax scenarios.

The identified effects are quite strong. Säll and Gren (2015) find per capita demand effects of −19.0% for beef, −8.0% for pork and −4.7% for poultry in response to price increases similar to the high excise tax scenario for pork and chicken and higher for beef (33.3% for beef, 11.3% for pork and 8.9% for chicken)[2]. Bonnet et al. (2018) find market share reductions of −5.4% for chicken, −2.3% for other poultry, −0.5% for pork and −8.3% for beef in the low carbon tax scenario (56 euros per ton CO_{2e}).

Next, we consider the welfare effects in Table 7. We report the expenditure effect according to Eq. (8), the compensating variation (*CV*, Eq. (10)), and the tax revenue (Eq. (9)), all in euros per household per month. While expenditure effects are fairly similar across household types, the welfare effects vary. On average for all households, an increase in the VAT to 19% for all fresh meat leads to an average expenditure reduction of 0.27 euros per household per month and a welfare loss of 0.83 euros.

The welfare effect (*CV*) varies between 0.82 euros and 0.73 euros for low-income versus high-income households and 0.56 euros or 0.89 euros for younger versus older households, respectively. These differences carry over to the carbon tax scenarios, where differentiated tax rates encounter variations in elasticities and baseline consumption levels.

The tax incidence varies accordingly and charges older households more heavily. Calculating the share of tax incidence in household income (rather than expenditures) suggests that low-income households are more strongly affected by a meat tax than high-income households (for the high carbon tax scenarios it is 0.20% of income versus 0.07% of income). Hence, the carbon tax turns out to be regressive as expected for a food tax.

Fig. 1 shows the distribution of *CV* across household types for the 14% ad valorem tax scenario (b) and the low excise tax scenarios (c), which are comparable regarding the CO_{2e} reduction. Both tax scenarios show similar distributional impacts for low and high-income households. In contrast, comparing younger and older households demonstrates the impact of meat-eating habits and shows a distinct pattern of welfare losses across these household groups, where older households are much more often observed in higher classes of welfare incidence. The figure also illustrates the efficiency of the excise tax as it leads to lower welfare costs for all households.

Table 7 also shows the reduction in CO_{2e} emissions. The 19% ad valorem tax reduces emissions by an average of 3.30 kg CO_{2e} per month per household. The impact is lower for the low excise tax (2.00), which is comparable to the effect of an increase in VAT to 14% (1.93). The high excise tax leads to a reduction of 5.00 kg CO_{2e}. Calculating the welfare impact (*CV*) per kg the emission reduction shows that the excise scenarios yield a smaller cost per kg CO_{2e} avoided on private households for all household groups.

[2] The high excise tax scenario results in a price increase of 21 % for beef & veal, 13 % for pork, and 9 % for chicken.

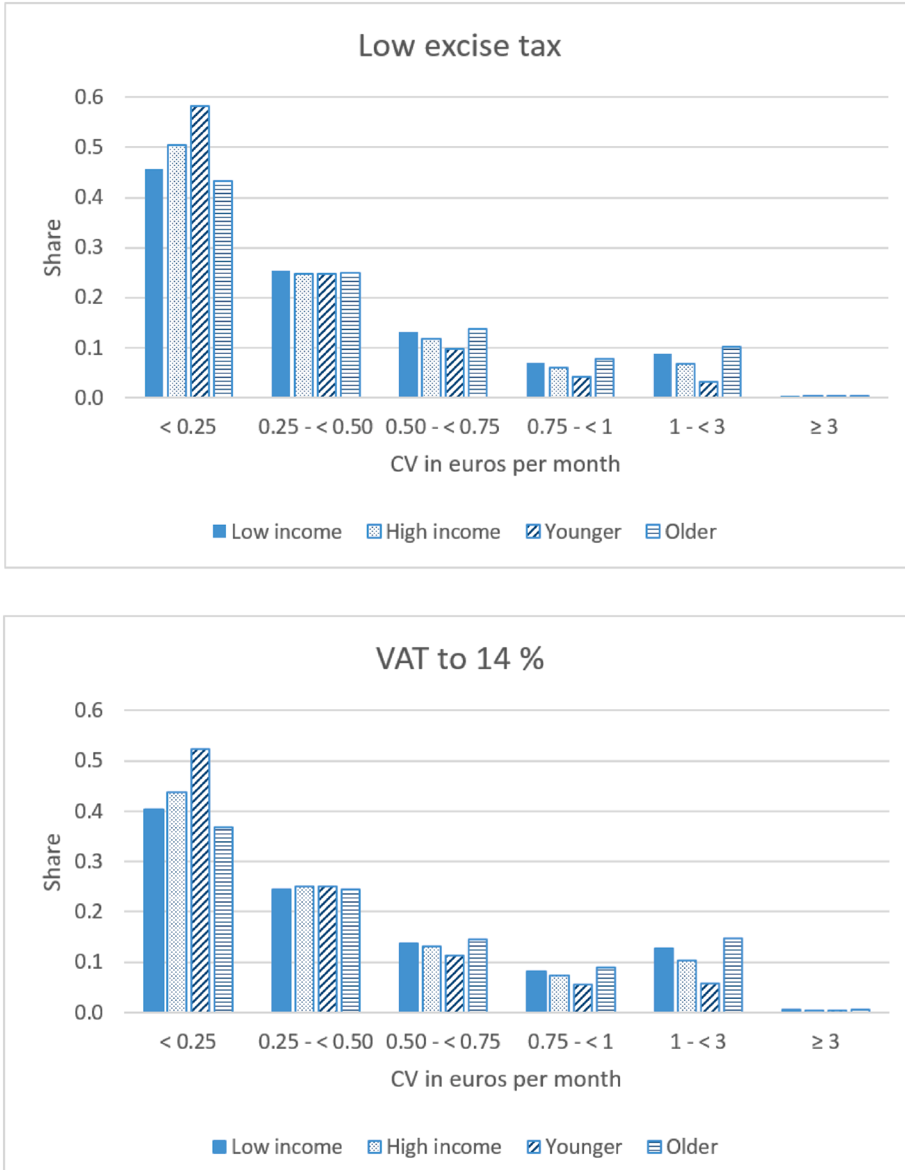

Fig. 1. Distribution of compensating variation for VAT 14% and low excise tax scenario.

5. Discussion and policy implications

In this paper, we report estimates of meat demand elasticities and assess the welfare impact of possible meat tax scenarios for Germany. Both, elasticities and the welfare impact are estimated for all households, and households grouped into low and high-income as well as younger and older households. The tax scenarios are motivated by ongoing policy discussions at the international level and in Germany. In Germany, a general "feeling" that meat is "too cheap" prevails as a narrative to explain the problem of unhealthy and unsustainable consumption choices (cf. SAB, 2020). Public discussions often circulate around the idea of removing meat from the goods qualifying for a reduced VAT of 7% (SAB, 2020), potentially recycling tax revenues into supporting farmers' investments in better animal welfare practices and to the meat industry to improve worker conditions. In addition, we simulate results for two levels of an excise tax, fixed at a rate of US-$ 40 and US-$ 100 per kg CO_{2e}. Compared to the tax scenario of 180 euros per CO_{2e} based on damage costs and proposed by the SAB (2020), these rates still appear low.

Unconditional own-price elasticities are around 0.9 in absolute values, with compensated elasticities being considerably smaller in absolute terms, indicating strong income effects, in particular for poultry and pork. Our estimates are higher than other estimates for Germany (Thiele, 2008) or Sweden (Säll and Gren, 2015), but similar to estimates for the US (Lee et al., 2020). Bonnet et al. (2018) obtain higher values for France when looking at market-share elasticities using a multinomial logit model. In comparison to other studies, we report price and expenditure elasticities by socio-economic group. Low-income households react less elastically to price changes compared to high-income households. This is different compared to the results by Thiele (2008) for Germany, Park et al. (1996) for the US and Mhurchu et al. (2013) for New Zealand who report higher own-price elasticities in low-income groups. However, Lopez and Lopez (2009) show that private label products are the least price elastic. Our result may therefore point to the effect discussed by Cotterill and Samson (2002) that low-income households may focus their purchases on the low price segment and then react little to price changes: low-income households may be already buying low-value meat (as indicated by the differences in the adjusted unit values across the meat categories). Inspecting the purchase location of low income households confirms that, for our data, low income households buy more often at discounters with low prices. In addition, the variation in budget shares shows that low-income households' budget shares do not vary much with price variation. We also obtain lower price elasticities for younger households compared to older households, although this difference is not as pronounced.

Based on meat expenditure averaging at 18.56 euros per household per month, the welfare effect of an increase in VAT to the general level of 19% totals to 0.83 euros per household per month. The low carbon tax scenario leads to a lower impact of 0.42 euros and the high carbon tax scenario to an effect of 0.87 euros. Given that the carbon tax penalises beef consumption in particular, consumption of beef & veal decreases by more than 20% as does the consumption of meat mixtures in the high excise tax scenario. The high excise tax leads to the largest welfare loss, at the same time, the consumer cost per kg CO_{2e} is lowest for households overall especially when compared to the ad valorem tax. The high excise tax also illustrates the social difficulty of introducing a carbon tax on meat. Beef & veal consumption is reduced by about 21%, but emissions are only reduced by about 17%. Imposing such a tax would likely be contentious. However, our results show that the contentiousness is more likely to be debated across generations than across income groups because the older population is affected most heavily.

In this paper, we address the effects of introducing higher taxes on meat exclusively within the fresh meat categories and find a reduction in meat expenditure. A more comprehensive model that also describes the dietary substitution of meat with other food categories and the differences in such substitution patterns across meat categories, would have certainly allowed for a more global assessment of tax effects (see Bonnet et al., 2018). However, owing to the nature of our data, we cannot assess a possible rebound effect and shifts to other climate-relevant products. Yet, since the change in fresh meat expenditure is small, large rebound effects are rather unlikely. In addition, consumers could also change the composition of their meat basket in terms of other quality dimensions (Bonnet et al., 2020).

Still our results provide valuable insights regarding tax design. The Pigouvian excise tax has the advantage in comparison with an ad valorem tax that it is neutral with regard to the quality differentiation of the meat product. In policy discussions, it is often assumed that the effects of an ad valorem tax would coincide with those of a Pigouvian tax because meat high in emissions (beef & veal) also demands higher prices. However, as shown in the results of this simulation study, this assessment is quite imprecise.

Theoretical work has assessed the use of per-unit taxes, minimum quality standards, or labels on polluting products. If consumers value the environmental quality of a product, a combination of per-unit taxes and labels is usually recommended. However, if consumers do not care about label information, a minimum quality standard may be preferable (Disdier and Marette, 2012). A quality standard is difficult to implement in the case of the climate externalities of meat consumption, as technical ways to reduce climate-gas emissions in livestock production are limited, if not achieved by a reduction in stocks (SRU, 2012). Hence investigating the effect of tax designs is quite important.

This paper is restricted to a demand impact assessment. In addition, producers and international trade will also be affected by the shift in demand. This is precisely the reason why the SRU (2012) or Bonnet et al. (2020) suggest taxing the consumer rather than the producer. Regulating the producer without changing demand would lead to a change in trade and would not fully address the externalities created by carbon emissions. Furthermore, the question arises as to how to use the tax revenues. The SAB (2020) in Germany suggest making it available to the producers to improve the sustainability of the production system. Alternatively, authors such as Dogbe and Gil (2018) provide scenarios of revenue-neutral carbon taxes that redirect tax revenues into subsidies for healthy products such as fruits and vegetables. As the earmarking of tax revenues is prohibited in Germany, we did not investigate these measures further.

Finally, carbon taxes may lead to changes in the social norms guiding meat consumption or de-bias consumer beliefs about the advantages and disadvantages of meat consumption (Friedrichsen and Gärtner, 2020; Hestermann et al., 2019). However, Ahn and Lusk (2021) recently showed that the non-pecuniary effects of food taxes are small compared to the price effects on demand. Nevertheless, as shown in this analysis the price effects of carbon taxes alone can lead to substantial shifts in consumption towards more sustainable levels.

CRediT authorship contribution statement

Jutta Roosen: Conceptualization, Funding acquisition, Methodology, Writing – original draft. **Matthias Staudigel:** Conceptualization, Data curation, Validation, Writing – review & editing. **Sebastian Rahbauer:** Data curation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodpol.2021.102194.

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