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The Importance of Retail Trade Margins for Calculating the Carbon Footprint of Consumer Expenditures: A Sensitivity Analysis*

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Abstract:
If environmental footprint attributable to various consumption patterns are evaluated, monetary transactions in the environmentally-extended input-output analysis need to be linked to household-specific expenditures. However, while the former are recorded in basic prices, the latter is typically recorded in purchaser's prices, adding a commodity tax and margins to basic prices. Product homogeneity assumption —inherent to input-output analysis — implies that two identical products sold to consumers with different retail trade margins are responsible for different footprints. In this paper we investigate how footprint attributable to Food and Goods is affected across household income classes if we relax the homogeneity assumption and assume different allocations of retail trade margins across the income classes. While different allocations affect footprints of the two Consumption groups significantly, in particular in the highest deciles, the effect on total footprint is very small, up to 10% even for two extreme cases of margins allocation.

JEL: C67, R15, Q56, Q57
Keywords: Environmentally extended input–output analysis, carbon footprint, GHG emissions, retail trade margins, product homogeneity assumption, sensitivity analysis

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INTRODUCTION

The analysis of environmental impact of overall household consumption has become a popular research topic in recent decades. Emissions, energy or environmental footprints associated with final consumption have been calculated using either life cycle assessment or environmentally extended input-output analysis (EE-IOA). The source data for the latter approach are usually gained from consumer expenditure surveys (CES) or final demand of households in input-output tables (IOT). They are combined with intermediate matrix of input-output tables extended with sector specific environmental variables, such as emissions or resource use. The expenditure surveys provide data on product specific consumption volume, while EE-IOA provides the emission intensities of the consumed products. An extensive overview of papers dealing with this subject was gathered by several authors (Di Donato et al., 2015; Hertwich, 2005; Mach et al., 2018; Tukker et al., 2010).

In general, these studies find a correlation between household total income (or total expenditures) and emissions attributable to final consumption, e.g. (Mach et al., 2018). This seems logical, since emissions are a product of expenditures and of emission intensities of the product groups in which households spend their income. Some of these studies note that higher expenditures in the same product group do not necessarily cause higher emissions due to inhomogeneity of sectors and product groups. Different consumption items of the same product group may differ in production technology resulting in different emission intensity (Kerkhof et al., 2009), or households can pay different margins for equivalent products (Peters and Hertwich, 2006).

The combination of household expenditure surveys and input-output data is related to different pricing systems. While expenditures gathered through consumer expenditure surveys are reported in purchasers' prices (the price a household pays), the financial flows, recorded in input-output tables, are commonly reported in basic prices[1]. The difference between the purchasers' prices and basic prices is comprised of trade and transport margins, subsidies and taxes. Trade margins are expenditures paid to services of wholesale and retail sale. Transport margins are charged separately for the transportation of a product between a producer and final consumer (Eurostat, 2008).

In this paper we focus specifically on retail trade margins, as here we expect the largest variations among different household expenditure deciles. The differences in taxes and wholesale trade margins should be minor, as the same taxes should apply for all households and it is expected that the majority of household purchases are realized through retail trade with similar wholesale trade margins. Furthermore, transport margins represent only 3% of the total margins.

[1] There are several national statistical offices which report IO data in producer prices, such the US National Bureau of Statistics.

Retail trade margins within one product group might be influenced by several factors, such as product characteristics (durability, stage of product life-cycle and business-cycle, brand (Peters and Hertwich, 2006) and shop-type, since larger shops or supermarkets may benefit from economies of scale (Notenboom, 1985). Simonovska (2015) shows that identical wearing apparel items are sold with different prices that are proportional to the average income of a country.

It is a reasonable hypothesis that household income (and expenditure) determines the type of shops in which particular goods are typically purchased, and therefore influences retail trade margins. Richer people may afford to shop in more luxurious or branded shops. On the contrary, poorer consumers are likely to spend their incomes in discount shops or outlets offering seasonal sales and clearances where goods are typically sold with lower retail trade margins. In turn, the expenditure on even similar items (e.g. a T-shirt) can differ in the retail trade margin for different households.

Differences in retail trade margins that are natural on the real market are not existent when the homogeneity assumption in the EE-IOA is followed. This motivates us to investigate how emissions attributable to consumption across households with various levels of total income are affected by different assumptions on retail trade margins. Specifically, we investigate how carbon footprint changes if we relax the homogeneity assumption in quantification of retail trade margins associated with consumption of goods by different households. Therefore, we analyze just one type of inhomogeneity leaving out of scope of our paper the inhomogeneity of sector and product groups within the IO table.

In this particular case, we investigate carbon footprint for household segments defined by ten deciles ranked by total annual expenditures of households. For this purpose, we perform a sensitivity analysis assuming different levels of retail trade margins for different household deciles (defined by their overall consumption expenditures). More specifically, we assume that richer households pay higher retail trade margins, whilst households with lower total expenditures buy products that are sold with lower retail trade margins. Assuming different distributions of retail trade margins across expenditure deciles, we then quantify total greenhouse gas emissions attributable to their expenditures, including expenditures spent to cover these retail trade margins. Our study follows our previous work in which we derived direct and embodied emissions of total consumption expenditures, using multi-regional environmentally-extended input-output tables linked to household-level expenditures from a consumer budget survey (Mach et al., 2018). In this paper, we focus specifically on retail trade margins for food and goods, for which we expect a considerable variation in the real market.

METHODOLOGY

Calculation of total emissions of household consumption

Household consumption is derived from the 2010 Czech Consumer Expenditure Survey (CES) for 1,682 consumption items for 2,930 individual households. Total emissions attributable to households present the sum of direct emissions and indirect emissions associated with consumption of all of these items. The direct emissions are emissions arising from combustion of fuels directly in a dwelling or in a passenger car owned by a household. They are quantified by converting expenditures of relevant products into physical units and applying emission factors for their combustion. Indirect emissions are calculated through environmentally extended input-output analysis. In our approach we connect domestic and multiregional input-output tables that benefits our analysis by 1) allowing the finer division of product groups from domestic or multiregional tables to domestic production chain, 2) capturing the full foreign production chain from multiregional tables for imports (Mach et al., 2018).

GHG emissions are calculated by multiplying expenditures in basic price and expenditures on margins by corresponding emission intensities obtained from the environmentally extended input-output analysis as described by Mach et al. (2018). However, contrary to Mach et al. (2018), who performed the calculation on the level of individual households, we perform our analysis and simulations on the level of household deciles ranked by their total expenditures. The rest of the calculation of the resulting emissions attributable to household consumption is done according to Mach et al. (2018), including the assumption that other margins and taxes are homogeneous across the household deciles and reporting emissions by seven consumption groups: Food, Goods, Services, Transport, Heating, Electricity, and Housing. The sensitivity analysis is performed for Food and Goods consumption groups.[2]

Transformation of household expenditures from purchaser's to basic prices

As mentioned in the introduction, the differences between the purchasers' prices and basic prices are due to trade and transport margins, subsidies and taxes. When household expenditures, reported in purchasers' prices, are converted to basic prices, for the purpose of calculation of upstream emissions through EE-IOA, the taxes are subtracted, transport and trade margins are subtracted and assigned to the product group providing the particular margin, as these product groups have non-zero emission intensity and therefore contribute to emissions attributable to household consumption.

The particular ratios for the transformation can be derived from the national accounts supply and use tables (SUT) (CZSO, 2012), which report household expenditures in basic prices, purchasers' prices and the margins for each product group. This procedure is described in detail in Appendix B.

In the presented sensitivity analysis, we do not address net taxes, since differences among taxes paid by different households are not large, as the taxes are determined by law and

[2] Food consumption group covers all groceries, drinks including meals in restaurants and canteens. Goods consist of all varieties of material goods, tobacco, pharmaceuticals and water and its treatment.

respective tax rebates and exemptions are typically provided per specific purpose or use, rather than to specific households groups.

Trade margins are reported as individual margin product groups: wholesale trade services, retail trade services, motor fuels production and sale, and wholesale and retail trade and repair services of motor vehicles product groups. The transport margins represent about 3% of the total margins[3].

There are several issues worth mentioning with respect to these margins. First, there are no margins for most items that are provided to households directly – by utilities[4], the public sector or as services. This applies, for instance, to electricity (CPA 35.1), centrally supplied heat (CPA 35.3) and natural gas (CPA 35.2), public transportation (CPA 49.1 and 49.3), and all services (CPA 55 –99). Second, we expect only minor differences in the margins of motor fuels among different households, since motor fuels (petrol, diesel, and LPG) form a uniform commodity and their price vary rather across regions, urban-rural-highway areas, and season. For this reason, we exclude retail trade margins for motor fuels from the sensitivity analysis. Third, we presume approximately an equal margin of vehicle sales, because car purchases are under-reported in CES and all but one of the purchases were within the price category of under 15.000 Eur attributable to lower class automobiles. For this reason, we exclude the margins of motor vehicles sale and maintenance from the sensitivity analysis. Fourth, it is reasonable to assume that differences in the wholesale trade margins as paid by different segments of households are low or negligible, since most consumer products are purchased by households in retail. Fifth, we do not modify taxes and subsidies in the sensitivity analysis.

For the reasons above, we focus the sensitivity analysis solely on the retail trade margins, which is relevant only for two consumption groups: Food (CPA 01 – 03, 10 – 11, 56) and Goods (CPA 12 – 23.1, 25.4 – 28.9, 31 – 32.9, 36). It is reasonable to expect that there is a large variability in retail trade margins paid by individual household deciles for products included in Food and Goods. For the rest of the margins and taxes, as for all non-margins product groups we keep the homogeneity assumption.

Assumptions on shares of retail trade margins on total expenditure value across household deciles

Most, if not all, previous studies have followed the homogeneity assumption for household expenditures and margins across all households, i.e. it has been assumed that there is an even ratio of net taxes and purchase price, margins and purchase price, and the product basic price and its purchaser price for each product group and across all households. In other words, if margins comprised 15% of purchase price for a certain product group for a poorer household,

[3] One of the reasons for such a low contribution is that transport services are often not accounted for separately.

[4] The price of one unit may still differ by the pricing scheme. The analysis of these pricing differences is beyond the scope of this paper.

these margins also contributed by 15% to the purchaser price of that product group for any other household segment.

In order to perform the sensitivity analysis of retail trade margins, we relax the homogeneity assumption of input-output analysis and assume that richer households with higher expenditures pay higher retail trade margins[5].

First, we reproduce the calculation of total emission following Mach et al. (2018) assuming product homogeneity with respect to retail trade margins. See appendix A for details. We convert expenditures reported in CES to basic prices assuming equal shares of taxes and margins on the total value of the product in purchasers' prices for all households. This implies the equal emission intensity of one product group (related to its purchaser price) for all households. This case is labelled as *"Reference."*

Second, we assume two extreme cases for retail trade margin magnitude – in the first case we set the retail trade margins to 0%, and in the second case to 100% of the retail trade margin plus the basic price of the consumed product[6]. These cases are hereinafter labelled as *"Extreme 0%"* and *"Extreme 100%"*, respectively. It is obvious that those two assumptions are extremes which cannot happen in real life (especially the latter), still, these two cases provide a range for emissions attributable to a given product group, regardless of which assumption on retail trade margin is used. Note that for these two extremes and the linear scenario below the sum of the total retail trade margins paid by all households (or by all ten deciles in our case) is not equal to the original sum of the total retail trade margins.

Third, a scenario denoted as *"Linear"* assumes retail trade margins are modified in such a way to represent a certain share of expenditures in basic prices which linearly increase with household income (along the deciles). In our case, we assume retail trade margins represents 5% of the value of expenditures in basic prices plus a value of unmodified retail margins for the first decile, they are 15% in the second decile, 25% in the third, and 95% in the last tenth decile. Increasing margins for richer households reflect the fact that richer households are more likely to buy luxury and branded products with higher share of retail trade margin.

Fourth, we assume different distributions of increasing retail trade margins across deciles, while keeping the sum of retail trade margins paid by all households unchanged and hence corresponding to the underlying data in its aggregate. The expenditures are then scaled to keep the aggregate of expenditures in basic prices and retail margins for each decile unchanged. The retail trade margins are assumed to increase exponentially, with respect to the original margins, as follows:

$$m_{ij} = r_{ij} x^{(j-1)} \frac{\sum_{j=1}^{10} r_{ij}}{\sum_{j=1}^{10} r_{ij} x^{(j-1)}}$$

[5] We do not assume the opposite, as our aim is to verify the validity of the general result of most studies that richer households have higher footprints.

[6] The expenditure in basic prices is obtained by subtracting taxes and all three types of margins, including the value of retail trade margins.

where $\sum_{j=1}^{10} r_{ij}$ is the original aggregate of retail trade margins of product *i* paid by all households, r_{ij} is the original retail trade margin paid by decile *j* for product *i*, *x* is a parameter which determines how steep the exponential function is, and we set x = {1.1, 1.2, 1.5, 2.0), and $\sum_{j=1}^{10} r_{ij} x^{(j-1)}$ is the aggregate of multiplied retail trade margins, in order to normalize household expenditures to keep its aggregate unchanged compared to the original aggregate. These scenarios are labelled as *"Exponential-x."*

The resulting retail trade margins for the two relevant consumption categories – Food and Goods – are displayed in the two panels in Figure 1. The two extreme distributions (bold gray lines) define the possible range, the Reference (bold line), Linear[7] (dashed with circles), and Exponential (dashed line) scenarios are within their range.

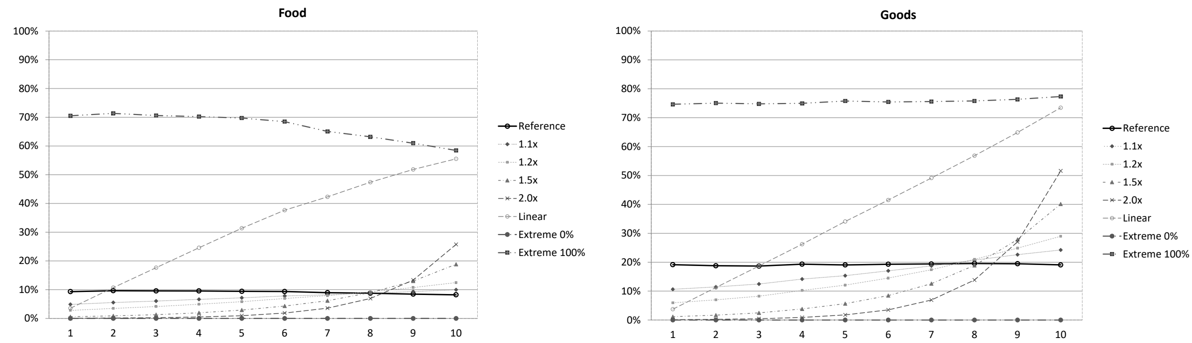

Figure 1: Retail trade margin as percentage of expenditures in final prices for Food (left panel) and Goods (right panel), by household deciles (weighted averages)

Figure 1 displays the contribution of the retail trade margins to the value of products in purchase prices, while the remaining part consists of products value in basic prices plus product taxes plus margins other than retail trade. In the case of Extreme 100% scenario, the taxes on products and other margins still cover the remaining part.

The total emissions attributable to consumption for an average household has been changed mainly for Linear and Extreme scenarios as shown in Figure 2. Margins that are exponentially increasing (1.5x) lead to emissions levels that are slightly larger than the reference level in lower deciles and smaller in higher deciles. The average emissions of this scenario are equal to the original, since the total of expenditures and margins are the same and distribution among deciles differ. Linearly increased margins, and to an even greater extent in the Extreme 100% scenario result in lower emissions, by about 5.4 %. In the case of there being no retail trade margin at all (Extreme 0% scenario) this leads to emissions that are 10.5 % larger than in the Reference case.

[7] Retail margin in „Linear" does not perfectly (linearly) increase along expenditures since expenditures on the „Restaurants and canteens" production group – that is a part of Food – do not include retail margins, which consequently leads to slightly lower margins visible in higher deciles.

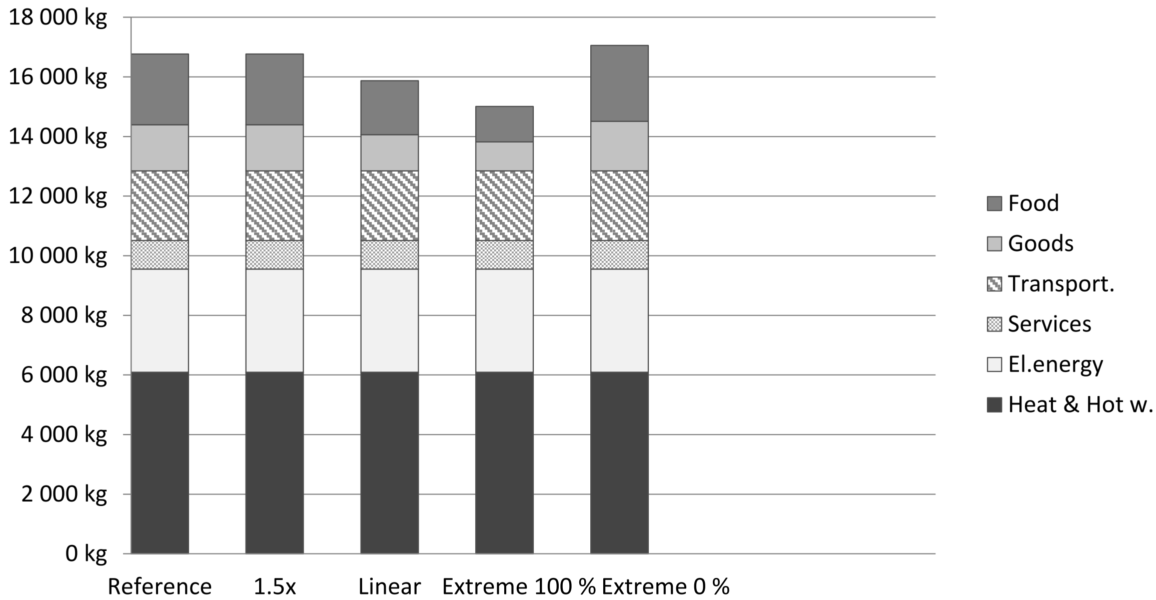

Figure 2. Average GHG emissions (CO_{2eq}) attributable to household consumption by different retail trade margins, averaged across deciles (each decile has 293 household)

RESULTS

Retail trade margins

For an average Czech household, the consumption expenditures were 9,008 EUR in 2010[8]. Out of these expenditures, 81% is attributed to the product's value in basic prices, 11.7% to taxes on products, 7.1% to wholesale trade margins, altogether only 1.4% to transport margins, fuel margins and vehicle sale margins and maintenance, with the remaining 6.9% devoted to retail trade margins. These shares vary considerably across the Consumption Groups.

Average household expenditures and GHG emissions for the six consumption groups and all trade margins associated with Food and Goods combined are displayed in Figure 3. Household consumption of food products and goods requires more than half of the household budget. Specifically, expenditures on Food and Goods represent 31% and 27.4% of the total household expenditures (in purchasers' prices), respectively.[9] Retail trade margins represent 8.1% (Food) and 15.9% (Goods) of the total value of expenditures on respective consumption group. Overall, the two retail trade margins represent a small fraction of household expenditures spent on all consumption products, 2.5% are retail trade margins for Food and 4.4% are margins attributable to Goods.

[8] Excluding 756 EUR spent on housing, accounted for capital non-consumption expenditures.

[9] Expenditures (in purchasers' prices) on other consumption categories represent 16.4% (Services), 11.3% (Transport), 8.9% (Heat), and 5.1% (Electricity). Retail trade margins associated with consumption of the products belonging to these five consumption groups are negligible, less than 0.2% of final expenditures.

Although expenditures on Food and Goods represent almost 60% of households' budget, due to lower carbon emission intensity of their items, total emissions attributable to all products belonging to the two consumption groups contribute to total household emissions only by about 20%, see Figure 3, on the left-hand side.

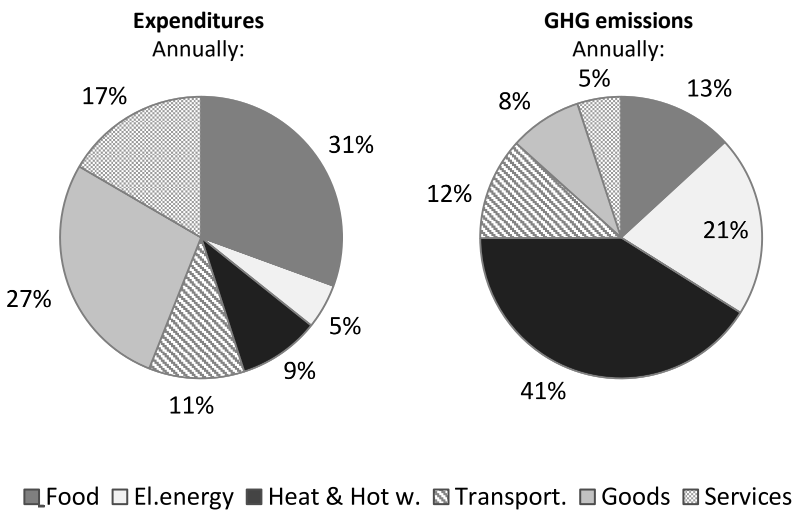

Figure 3: Average household annual expenditures and GHG emissions

The average carbon intensity is 1.033 kg CO_{2eq} (for Food) and 0.919 kg CO_{2eq} (for Goods) per 1 Euro of expenditures in basic prices (see Table 1). Retail trade is less carbon intensive, with 0.456 kg CO_{2eq} per 1 Euro, and is the same across all consumption groups. In other words, the GHG intensity of the retail trade is approximately 55% lower than the emission intensity of Food products (in basic prices) and 50% lower than the emission intensity of Goods.

CZ-CPA (Consumption Group)	Kg CO2eq per Eur
Retail trade	0.456
Food in basic prices	1.033
Goods in basic prices	0.919

Table 1. GHG emission intensity for Food, Goods, and retail trade, weighted average.

Table 1 displays GHG emissions intensity of an average Czech household, calculated from average emissions and average household expenditures on respective consumption group.

Total GHG emissions attributable to Food and Goods when retail trade margins vary

The results of the sensitivity analysis of GHG emissions attributable to Foods and Goods is displayed in Figure 4. The area given by two extreme margin allocations, i.e. the whole sum of the retail trade margin and the basic price is the entire retail trade margin, or there is no retail trade margin at all (Extreme 100% and Extreme 0%) also defines the band for all possible values of emissions. The reference value (not modified allocation) is described in Figure 4 by the bold line, while all potential emissions attributable to Food and Goods given by all our defined distributions of retail trade margins are displayed by dashed lines.

In the case of Food, if all product value is replaced by retail trade margins (i.e. Extreme 100%) total emissions attributable to Food are about 50% smaller than in the Reference case (i.e. homogeneity product assumption). On the other hand, replacing these margins with the product value (Extreme 0% assumption) results in higher emissions attributable to Food. Emissions increase evenly along the deciles, since the two lines, for Reference and Extreme-0%, are almost parallel. If these margins increase exponentially along expenditure deciles, then Food emissions are very similar to the Reference case, with an exception for the 10th decile for which emissions are 20% smaller compared to the Reference level. This difference may be explained by consumption of product items sold with larger retail trade margins. For linearly increasing margins, emissions attributable to Food deviate significantly from the Reference levels and this deviation is increasing with increasing expenditures (along deciles). In fact, in the case of linearly increasing margins, emissions are approaching the levels for the scenario that completely replaces the basic price of products by retail trade margins (Extreme 100%) and they are approximately 49% lower in relative terms than in the Reference level for the 10th decile.

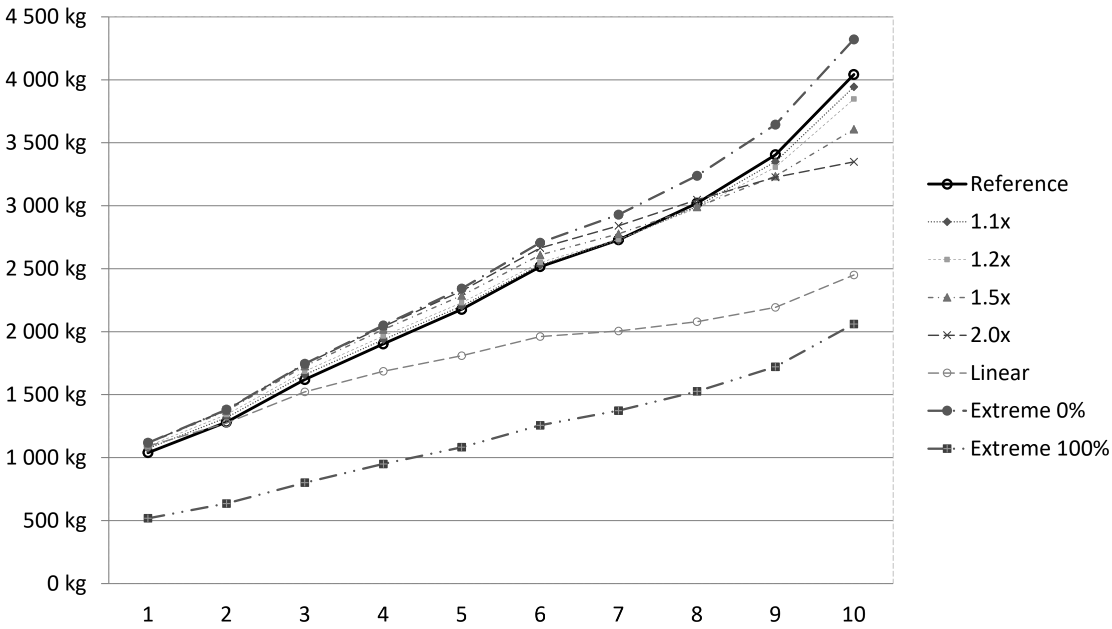

Figure 4. Total emissions attributable to Food assuming different distributions of retail margins, by deciles (in kg CO_{2eq} a year and per household)

Emissions attributable to Goods are less sensitive to changes in allocation of margins across household deciles, see Figure 5, even though the share of retail trade margin on total value of goods is higher than in the case of food products. This is because the emission intensity of Goods (0.919 kg GHG per Euro) is closer to the emission intensity of the retail trade (0.456 kg GHG per Euro). A smaller difference in the two emission intensities also makes the width within emissions lines in the graph may appear closer than in the case of Food.

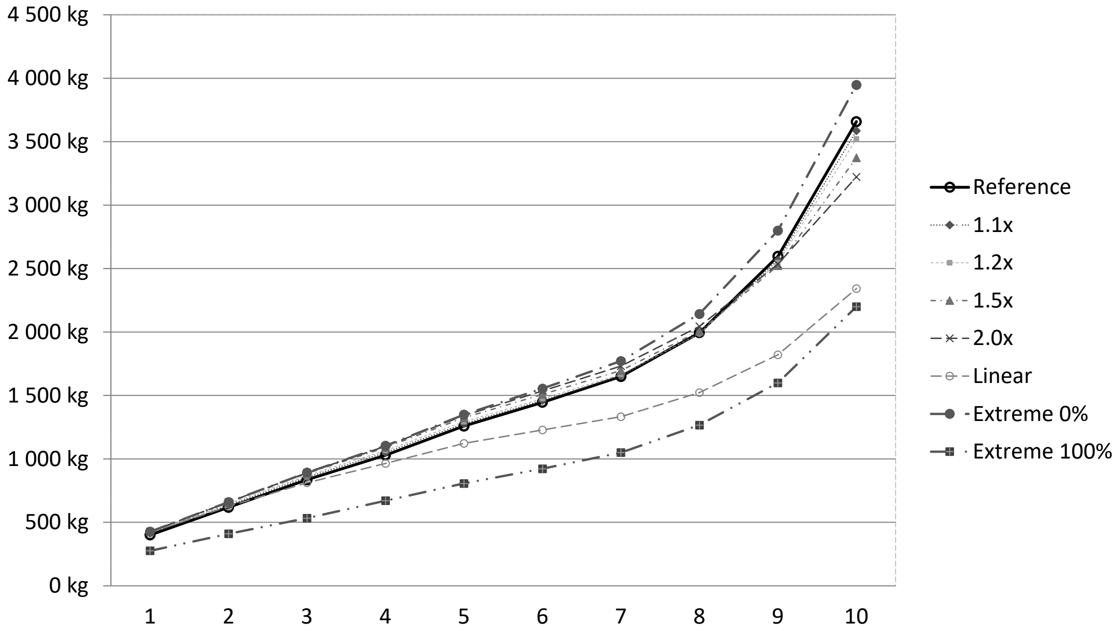

Figure 5. Total emissions attributable to Goods assuming different distributions of retail margins by deciles (in kg CO_{2eq} a year and per household)

Sensitivity analysis of the total emissions attributable to household consumption

Since consumption of Foods and Goods is responsible for only one fifth of the total emissions attributable to household consumption, the overall effect of different assumptions is relatively small even for the Extreme 100% case, see Figure 6. Even completely replacing margins by product value would have a negligible effect on total emissions. More realistic assumptions, such as exponentially increasing allocation of margins, would result in negligible deviation in total emissions as well. Linearly increased margins result in lower emissions, this difference being negligible in the first three deciles and is increasing thereafter. Changing the margin allocation in this way would reduce the total emissions by 5% for the deciles 6 and 7, up to 10% for the deciles 8 to 10. Extreme 100% results in lower emissions as well, with a difference that is relatively the same across the deciles.

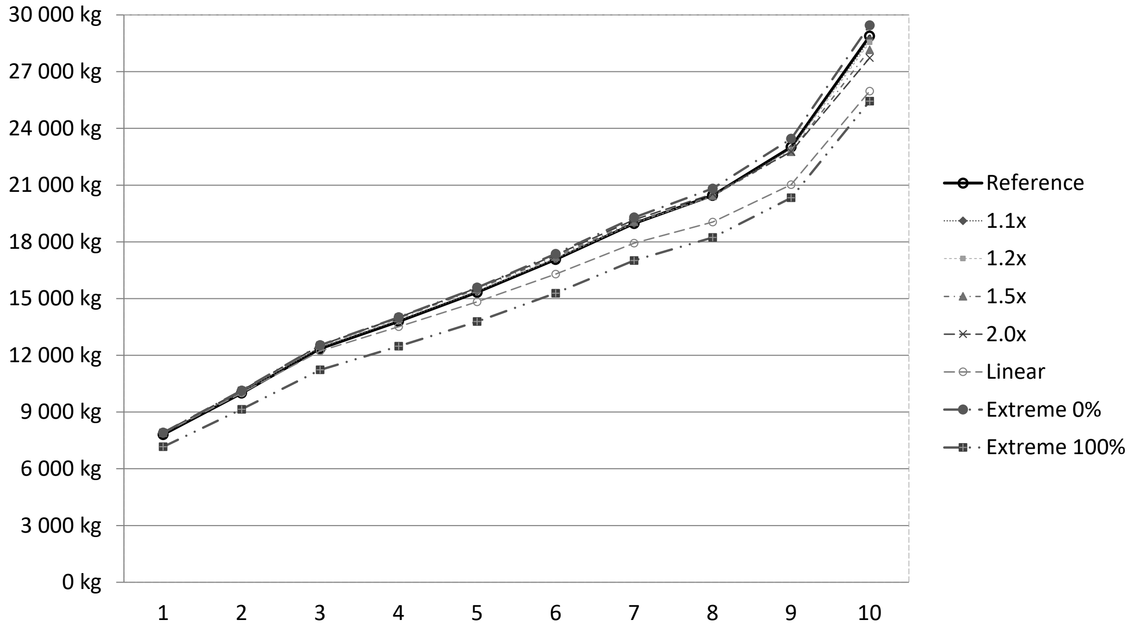

Figure 6. Total emissions of household consumption, by different retail margin allocation and by deciles (in kg CO_{2eq} a year per household)

DISCUSSION AND CONCLUSIONS

Linking of the IO aggregated data with household consumer expenditure survey (CES) data often requires conversion of household expenditures from purchaser prices (in CES) to basic prices (in IOT). For this transformation, the homogeneity of margins and taxes is usually applied, assuming the same share of margins and taxes on product value (in basic prices) for all households, regardless of whether the given household bought and consumed a good with a higher margin (typically luxury and branded goods) or lower margin (typically sales and clearances). In this paper, we investigate to what extend different distribution of retail trade margins among households (by expenditure deciles) may influence the total emissions attributable to household consumption.

Our analysis aims at illustrating different patterns in retail trade margins and the effect of changing these patterns on carbon emissions attributable to Food and Goods consumption groups and on the total emissions of household consumption. We do not investigate other margins or taxes since their homogeneity seems a rational assumption (see the Methodology section).

In the performed analysis, we examine the effect of changing the allocation of the retail trade margins that we increase linearly and exponentially with household expenditures. We limit the sensitivity analysis to assuming that households with higher expenditures pay higher retail trade margins due to our underlying research question: Can the general result being found in many input-output studies that households with higher expenditures also have higher environmental footprints be questioned due to the heterogeneity of the retail trade margin? Therefore, our study does not analyse situations when higher margins are paid by low-income households. If we had assumed reverse allocation in margins (decreasing with expenditures), this assumption would just increase the difference in total emissions among household deciles. Still, these new emission scenarios would lie within the range given by our two extreme allocations.

We find that the effect of changing the allocation of retail trade margins among deciles on total emissions is relatively small. If the total household consumption and hence their total emissions is examined, changing the allocation of retail trade margin would not change the general pattern that richer households have a higher carbon footprint. This is due to two main reasons: first, the emission intensity of retail trade is close to the emission intensity of the two concerned consumption groups, Food and Goods; and second, Food and Goods combined contribute to only about 20% of total GHG emissions attributable to household consumption. Our results also indicate that changing allocation patterns in retail trade margins might be important for emissions attributable to specific product groups, particularly to food, and in a lesser extent to goods.

Relaxing the homogeneity assumption for the other margins and taxes alone may have only a negligible effect on the total footprint. In fact, taxes are imposed on products with rates that are not differentiated for different households (with a few exemptions for energy or water) and wholesale trade margins are similar for all households, as the majority of them buy goods in retail.

Our finding holds for the sensitivity analysis we perform for one specific case of relaxing product homogeneity assumption in the input-output analysis, i.e. the homogeneity of the retail trade margin. (Hertwich, 2005) argues that a very similar product supplied by different producers (such a passenger car made by Skoda or Audi) may be sold for a very different market price, while emissions induced in the whole production chain may be quite similar. Or seen from the other side, the same expenditures result in different quantities. Product homogeneity that is typically a key characteristic of any input-output table implies that the consumption of one good with a price of one million Euro is responsible for the same emissions as two goods that each cost a half million Euro (if both goods belong to the same product category). If richer households buy fewer goods with higher prices, then their footprint might be overestimated, while the footprint of poorer households might be underestimated. To investigate this problem, the data on physical consumption would be needed as well as from the monetary input-output table. We note that this issue is specific just when the EE-IOA with one representative household in final demand is linked to expenditures reported for more than one household such as in CES. Therefore general results found in most global EE-IOA analysis (e.g. Andrew et al., 2009; Hertwich, 2005; Hertwich and Peters, 2009; Schoer et al., 2013) that richer societies have higher environmental footprints is not questioned by our study.

Future research will focus more on the role of the key assumption in EE-IOA product homogeneity that implicitly leads to (basic) price homogeneity of these products that is not valid in real life. As pointed out by (Hertwich, 2005), it is unlikely that a physical product which costs twice as much is as a cheaper version has a footprint twice as large as that of the product which is half the price.

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Appendix A
Calculation of total emissions

Total emissions are the sum of direct emissions and indirect emissions. The direct emissions are emissions arising from combustion of fuels in households, are calculated for house and vehicle fuels. Their values are derived using household expenditures, fuel prices, physical properties, such as density or calorific value and emission intensities per physical mass or volume.

Indirect emissions are calculated using the multiregional environmentally extended input-output analysis (MR EE-IOA). We enhanced this method by the connection of domestic and multiregional input-output tables. Our approach facilitates capturing the finer division of product groups from domestic or multiregional tables for domestic production chain on one hand, and on the other it captures full foreign production chain from multi-regional tables for imports.

For the purpose of the MR EE-IOA, we prepare the data on domestic emissions in classification by products in two steps. First, we compile major emission sources, provided by the Czech NAMEA (CHMI, 2012), according to their NACE II code combined with disaggregated emissions of minor emission sources of 88 domestic industries to create a table of emissions for 184 industries corresponding to industries of the IOT. Second, we transform this dataset from industries to product groups using Almon's transformation with no negative values (see Mach et al., 2017).

Expenditures for 2,930 households are obtained for 1,682 detailed consumption items from the Consumer Expenditure Survey (CES) for the year 2010. These expenditures are then allocated to 232 product groups corresponding to 232 product groups in the MR EE-IOA. While the CES is collected in purchasers' prices for the year 2010, the CZ-IOT and EXIOBASE 2 are recorded in basic prices for the year 2010 and 2007, respectively, thus we make the appropriate transformations to merge these datasets consistently.

We perform the MR EE-IOA with Czech product-by-product IOT and multiregional IOT taken from EXIOBASE 2. This MR EE-IOA provides indirect emission intensities for 232 items. Finally, we multiply the direct and indirect emission intensities with expenditures to obtain total emissions for each individual households as recorded in the CES and for each of 232 product items, see Mach et al., 2017; 2018 for the details.

To present the results of emissions, we define seven consumption groups: food, goods, services, transport, heating, electricity and housing which stems from COICOP. Merging and splitting consumption categories reflect the importance of COCIOP categories with respect to emissions. The food category covers all groceries, drinks including meals in restaurants and canteens. Goods consist of all varieties of material goods, tobacco and pharmaceuticals. Services cover all services including education and healthcare. Transportation consist of all modes of public transport, fuels for private transportation and purchases of personal vehicles. Heating includes heating and hot water, provided locally (by natural gas, coal, electricity) or centrally. Electricity includes electricity with a proportional portion deducted where heating or heating of hot water is installed. Finally, expenses of dwellings are omitted because they are considered a non-consumption expenditure. To retain consistency, rent expenditures are also excluded and the whole housing consumption groups is assumed to be zero.

Appendix B
Transformation from purchasers' to basic prices in detail

Only a few papers on EE-IOA mention the transformation of purchaser prices to basic prices of CES (Wiedmann et al., 2005), (Peters and Hertwich, 2006), (Steen-Olsen et al., 2016) and none of them describe their calculation. On account of this, we cover this topic within this paper in more detail.

The tables of CZ-IOT and EXIOBASE 2 are recorded in basic prices, in contrast to CES, which is collected in purchases' prices. For that reason, household expenditures are transformed so that taxes and subsidies are deducted, and transport and trade margins are deducted and redistributed to the product groups to which they belong. In general, the whole redistribution can be formulated mathematically as:

$$\mathbf{E_b} = \mathbf{E_p}\,\widehat{\mathbf{c^t}}\,(\widehat{\mathbf{c}^r} + \mathbf{C^m}) \qquad (1)$$

Where $\mathbf{E_p}$ and $\mathbf{E_b}$ stands for a matrix of household expenditures in purchasers' and basic prices respectively. Each row represents one household, each column one product group.

The diagonal matrix $\widehat{\mathbf{c^t}}$ subtracts the taxes, diagonal matrix $\widehat{\mathbf{c^r}}$ subtracts the margins and matrix $\mathbf{C^m}$ redistributes margins to margin product groups.

The vector entries of the first modifying matrix $\widehat{\mathbf{c^t}}$ are calculated as follows:

$$\{c_i^t\} = \{\frac{p_i + r_i}{p_i + r_i + t_i}\} \qquad (2)$$

where p_i is domestic production plus imports in basic prices, r_i are surcharges to production (margins of individual non-margin product groups) and t_i are taxes plus subsidies for each product group i. All are expressed in absolute monetary values obtained from use table (CZSO, 2012). For instances where the production and import total is p_i= 0, then also $\{c_i^t\} = 0$.

The second modifying diagonal matrix $\widehat{\mathbf{c^r}}$ represents consequently the production portion from price without taxes. Its vector entries are calculated as follows:

$$\{c_i^r\} = \{\frac{p_i}{p_i + r_i}\} \qquad (3)$$

To gain the expenditures only on products (without taxes and margins), where margin product groups has 0 values, the formula is simplified to:

$$\mathbf{E_b} = \mathbf{E_p}\,\widehat{\mathbf{c^t}}\,\widehat{\mathbf{c}^r} \qquad (3)$$

Conversely, to gain only the margins of the products the formula changes to:

$$\mathbf{E_b} = \mathbf{E_p}\,\widehat{\mathbf{c^t}}\,\mathbf{C^m} \tag{4}$$

The last modifying matrix $\mathbf{C^m}$ with c_{ij}^{m} entry is redistributing deducted margins to product groups that provides the margin:

$$\{c_{ij}^{m}\} = \{\frac{r_i}{p_i + r_i}\frac{m_j}{\sum_j m_j}\} \tag{5}$$

The first fraction represents the surcharge portion from the final price without taxes in each non-margin product group (e.g. a portion of all surcharges in Fruits and Vegetables product group). The second fraction represents the portion of the margin belonging to each type of margin m_j (e.g. a portion of margin on Retail trade compared to other types of margins). Please note that $r_i = 0$ for all product groups which have zero surcharges (any type of margin) and $m_j = 0$ for all non-margin product groups j.

Because the transport surcharges and trade margins are reported separately in SUT, the ratio between trade and transport varies for each non-margin product group. This means that the ratios expressed by m_j are not constant.

In addition to this, the sale margins for vehicles of fuel margin product groups are separated from wholesale and retail trade and their respective product groups must have separate ratios for the same reason. To express this, we had to combine $\mathbf{C^m}$ matrix from six matrices:

$$\mathbf{C^m} = \mathbf{C^{mOthTrade}} + \mathbf{C^{mOthTran}} + \mathbf{C^{mVehTrade}} + \mathbf{C^{mVehTran}} + \mathbf{C^{mFuelTrade}} + \mathbf{C^{mFuelTran}} \tag{4}$$

With e.g. first term on the right side:

$$\{c_{ij}^{mOthTrade}\} = \{\frac{r_i^{mOthTrade}}{p_i + r_i}\frac{m_j^{mOthTrade}}{\sum_j m_j^{mOthTrade}}\}$$

and others are calculated analogically. The matrices do not overlap in non-zero entries and the resulting matrix has its non-zero values on the same positions, as would the original plain $\mathbf{C^m}$ matrix.

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