Levying carbon footprint taxes on animal-sourced foods. A case study in Spain

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Abstract

The consumption of some kinds of meat contributes significantly to global warming. Hence, dietary changes towards a decreased consumption of these products might lead to reductions in greenhouse gas emissions. Information campaigns can induce a reduction in meat consumption, but they need time since meat is deeply rooted in our diets. Instruments based on changing prices, such as the levying of taxes, stand out as an effective option. This study aims to estimate the greenhouse gas mitigation potential of implementing consumption taxes on some protein-rich foods in Spain. Data from the Spanish panel of household food consumption for the period 2004–2015 and literature data on the carbon footprint of animal sourced foods were used. An almost ideal demand system with the moving blocks bootstrap method was applied to estimate the elasticities and calculate the consequences for the carbon footprint associated with the consumption of seven animal-sourced foods. The results show that taxes on fish can be the most effective at reducing the total carbon footprint and those applied on pork are the least. The results also suggest that high tax rates on the most polluting products do not always lead to the greatest carbon footprint reduction. Further research should incorporate combinations of taxes on different products together with an analysis of potential regressive effects on other socio-economic issues. However, reducing meat GHG emissions is a global challenge which requires inter-disciplinary collaboration together with political actions.

Keywords

Life cycle assessment, greenhouse gas emissions, carbon based food tax, meat consumption, sustainability

1. Introduction

The agricultural sector is giving cause for concern due to its greenhouse gas (GHG) emissions, which represent between 25% and 30% of the global GHG emissions (McMichael et al., 2007; Clark and Tilman, 2017), of which three quarters are associated with meat (Springmann et al., 2016; Macdiarmid et al., 2016). Furthermore, the production of animal-sourced foods (ASF) has other negative consequences, such as biodiversity loss, reduction in available arable land, or higher food prices (Bailey et al., 2014; Liu, 2017). In addition, it has been claimed that meat consumption exerts negative impacts on health (Micha et al., 2010; McAfee et al., 2010). These issues should be contextualized bearing in mind future meat consumption growth, with projections from 88 to 100 kg·capita^{-1} between 1999 and 2030 in high-income countries, and from 25.5 to 37 kg·capita^{-1} in middle and low income countries (Walker et al., 2005; Bruinsma, 2003).

Different strategies can help reduce GHG emissions from ASF, e.g., technological improvements, or food waste reduction (Hedenus et al., 2014; World Resources Institute, 2013). Considering the above-mentioned negative impacts associated with meat and the expected increase in consumption, many studies point to dietary changes towards a reduced consumption of ASF, and of red meat in particular, as an additional optional means to achieve this goal (World Resources Institute, 2016). Specifically, McMichael et al (2007) recommend a substantial reduction in meat consumption in industrialized countries and a constrained growth in developing ones.

In spite of the increase in available information regarding the environmental impacts of the consumption of ASFs, voluntary changes towards more balanced diets are not easy to implement. There are deeply entrenched tastes which are hard to alter, and most individuals underestimate the environmental impacts associated with their consumption since they consider that it will take a long time for these impacts to happen (de Boer et al., 2016; Laestadius et al., 2014). Different policies and actions have been proposed for the purposes of shifting eating patterns, namely (Garnett et al., 2015): implementing fiscal measures; inducing changes in the governance of production or consumption; encouraging collaboration and shared agreements (e.g. certification eschemes); changing the context, defaults and norms of production or consumption through nudges or store layouts, and informing and educating consumers. To date, there is no evidence of the effectivity of these measures, since political discussion along these lines is just beginning and examples of policy actions are scarce (Bähr, 2015; Watts et al 2015). In any case, there is inevitable overlap between these actions (Garnett et al., 2015), whose interaction should be considered when designing effective strategies, as should the incorporation of a dialogue between consumers and political authorities (de Bakker and Dagevos, 2012).

As to taxes, the basic idea of their implementation to minimize negative externalities, such as GHG emissions associated with the consumption of some goods, is credited to Pigou (1920), and they are thus known as Pigovian taxes (Hubbard and O´Brien, 2013). Imposing a tax based on the estimate of the marginal damage on the externality-generating good can correct it, ensuring that the market produces the efficient level of the good (Williams III, 2017); this means that, in the case of an environmental tax, a product should be taxed according to its GHG emissions and its marginal damage cost (Gren et al., 2019).

However, the implementation of a tax on consumption may imply unpopularity for politicians, and can have negative impacts on income and nutrition (García Muros et al., 2017). Previous studies remark that a well-designed tax emerges as a good alternative means to changing consumer behaviour towards more environmentally-friendly consumption paths (Hunter and Röös, 2016; Abadie et al., 2016). In any case, the main principle underpinning the decision-making process is consequentialism (Yang and Heijungs, 2018). This means that, before establishing a tax on an ASF, an *ex ante* evaluation of the environmental consequences induced by the tax is needed (Säll and Gren, 2015).

Life cycle assessment (LCA), and hence carbon footprint (CFP), have been widely applied to assess the environmental impact of diets with and without animal protein (Scarborough et al., 2014; Ribal et al., 2016). However, in those studies, an attributional LCA perspective has been applied, without taking market forces into account. Consequential life cycle assessment (CLCA) has, thus, been proposed for modelling the system-wide change in environmental impacts in response to changes with (marginal or structural) market implications beyond the foreground system of the production system analyzed (Ekvall and Weidema, 2004).

Different strategies for CLCA have been proposed; most of them are intended to establish changes in the physical level of a product that could arise as a consequence of an alteration in the demand for products in the system (Earles and Halog, 2011; Brander et al., 2008). As Yang and Heijungs

(2018) point out, both ALCA and CLCA have strengths and limitations. A decisive aspect of CLCA is the substitution ratio between the product systems being compared. Chalmers et al. (2015) highlight the importance of modelling the actual substitution ratio based on empirical data and propose calculating this ratio from the crossprice elasticities of demand for possible competitor products.

As a first step to assessing the environmental consequences of meat taxation, this study aims to determine how a Pigovian tax on different ASFs would modify the CFP associated with their consumption in Spain. The main contribution of the study is that it analyzes different scenarios related to the direct impact of the tax on the CFP of the product being taxed, together with the indirect impacts on the CFP of other ASFs, emphasizing the effects of substitutability and complementarity between the analyzed products.

2. Literature review on meat taxes

There is an increasing body of research into the potential environmental and health benefits of the so-called sustainable diets, mainly in high-income countries. From a thorough review, Aleksandrowicz et al (2016) conclude that shifting current diets to a variety of more sustainable patterns can provide environmental benefits proportional to the magnitude of the reduction in meat (particularly from ruminants) and dairy products. Taxes on meat consumption arise as a means of promoting shifts towards sustainable diets in accordance with the "polluter pays" principle. Although there are many studies dealing with taxes on different foods (fat, sugar-drinks, etc) focusing on health-related effects (e.g. Maniadakis et al. 2013; Thow et al., 2010), studies related to meat taxation are newer and scant.

Literature provides several issues related to ASF taxation. A key methodological one is how to impose a Pigovian tax on ASFs. There are basically two ways: ad-valorem and as a specific or unit tax. The first one consists of collecting a tax rate for every monetary unit that a consumer spends; in the second one, a specified amount of money is collected per unit of output (Perloff, 2018). Generally speaking, in a scenario of competitive markets with demand uncertainty, ad valorem taxes are prefered and only in the case of monopoly and competitive markets would it be more efficient to implement specific taxes (Dickie and Trandel, 1996). Furthermore, the administrative cost of tax collection and the cost of monitoring emissions can alter the results of the tax (Nechyba, 2015). The imposed taxes are, thus, mostly based on the average emission levels for each food category representing all food producers in the entire market rather than individual producers' specific emission levels. In this way, the bias is minor since the CFP variation between individual food producers of the same product is generally much smaller than the difference between food categories (Wirsenius et al., 2010). Along these lines, implementing a tax on the consumption side is a better option than doing so on the production side (Slemrod, 1990; Säll and Gren, 2015), because then all the emissions throughout the product's life cycle are considered. Furthermore, taxes on consumption can reduce emissions from both imported and internally produced goods (Gren et al., 2019; Säll and Gren, 2015), avoiding "carbon leakage", that is, an increase in GHG emissions in a country as a consequence of another country's effort to reduce its emissions (Edjabou and Smed, 2013). Taxes might affect meat sales not only within a region (e.g. EU) but also in developing countries, placing a disproportionate burden on them. Consequently, differentiated responsibilities should be achieved by other means, for instance, by transferring tax revenue to the developing countries (Bähr, 2015).

When reviewing specific case studies on the application of taxes on ASFs, it may be seen that this is carried out in different ways. For instance, Edjabou and Smed (2013) compare the effect of a tax imposed on all foods (uncompensated scenarios), with scenarios designed so that the total tax revenue derived from food taxation is unaltered (compensated). Gren et al. (2019) suggest that existing taxes on GHG should be considered to avoid double taxation, and assign differentiated taxes for each GHG. Abadie et al. (2016) estimate the optimal combination of ad-valorem taxes and subsidies that minimize the deadweight loss for certain GHG emission reduction targets.

Assessing the changes in food consumption is another methodological issue tackled in the literature. The studies reviewed use economic tools to evaluate those changes in consumption as a consequence of levying taxes and they determine potential substitution among food groups to elucidate how taxes can decrease GHG emissions. Many studies calculate demand, expenditure and income elasticities by using different variations of the Almost Ideal Demand System (AIDS) model (Edjabou and Smed, 2013; Säll and Gren, 2015; Chalmers et al., 2015; Säll, 2018), whereas the Exact Affine Stone Index (EASI) demand system was used by Caillavet et al (2016).

As to the nutritional effects, Bonnet et al. (2018) found that a tax on the consumption of all animal products leads to a decrease in all nutritional indicators. However, when only the consumption of ruminant meats is taxed, the impact on nutrition is mitigated because the reduction in the market share of those meats generates a smaller degree of substitution with the vegetable-based food, but greater substitution with other ASFs. Caillavet et al. (2019) also detect a decrease in the nutritional score when all ASFs are taxed, obtaining the best nutritional score in the revenue neutral scenario, which subsidizes healthier and more environmentally- friendly vegetable foods. On the other hand, Caillavet et al. (2016) found that nutritional quality worsens when taxing all ASFs whereas it improves when only ASFs rich in fat are levied.

The distributional effects represent another critical issue, one which is less treated in the literature. A major disadvantage to food taxation policies is their regressivity because lower-income households spend a higher proportion of their budget on food (Caillavet et al., 2019). In a case study in Spain, García-Muros et al. (2017) found that, in terms of welfare, taxes are regressive; it is the low-expenditure and single parent households which are the most affected, while those least affected are the ones made up of the youngest individuals and adults living alone. Säll (2018) analyzes the distributional effect of a meat tax in Sweden. From the perspective of expenditure, they found a regressive impact in all income groups, the middle-income group being the most affected; while from the point of view of income, the lowest income households would need the highest compensation. Caillavet et al (2016) found a regressive impact of ASF taxation on welfare, with losses depending on the taxation scenario. The results of Caillavet et al (2019) show that carbon pricing needs to be high to obtain substantial reductions. Although regressivity would then be higher, those authors remark that the decision over the use of revenues is key for the tax acceptability.

Previous analyses have focused on specific regions, in particular in high-income countries, and global studies are scarce. Springman et al. (2016) analyzed the impact of taxes on food consumption and food security in 150 world regions. Results suggest that levying GHG taxes on food commodities could be a health-promoting climate change-mitigation policy in high-income, middle-income, and most low-income countries and propose that the most affected groups be compensated using a portion of tax revenues. Zech and Schneider (2019) analyze how international trade would be affected, and therefore GHG emissions, by a carbon tax in the EU on all food products. The study shows that the tax may be less effective than suggested by previous studies. They found a 43% carbon leakage due to a drop in domestic demand, which is offset by increased net-exports.

3. Data and methods

3.1 Data

Detailed data on the quarterly purchases of meat, eggs and fish, were obtained from the Spanish *National Statistics Institute* (INE) corresponding to the *Panel of household food consumption in*

Spain over forty-six Quarterly periods, since the first quarter of 2004 to the second quarter of 2015 (2004Q1-2015Q2). The panel gathers information on total volume and total expenditure, average price, per capita expenditure and per capita volume. The consumption is given in thousands of kilograms, and the prices in Euro (€) per kilogram.

Panel data include quarterly information for five kinds of meat (pork, beef, chicken, turkey, lamb), which were considered together with eggs and fish. The meat products can be either fresh, frozen or processed. The fish group includes forty-six products, classified as frozen, fresh or smoked. Since the fish group incorporates all types of fish and seafood, a volume-weighted price was built. Eggs were included given their possible substitutability with meat; however, only hen´s eggs were used, since quail's eggs did not reach 0.5% of the total egg consumption.

Table 1. Average carbon footprint of the analyzed products

Product	Carbon footprint (kg CO_2 eq · kg product^{-1})	Std deviation	Observations
Beef	18.21	0.59	86
Chicken	4.02	0.25	43
Eggs	3.02	0.19	26
Fish	2.83	0.24	65
Pork	4.97	0.22	67
Lamb	22.96	1.17	41
Turkey	5.56	0.27	8

For the CFP, a database was built from a literature review on LCA and CFP studies considering diverse farming and processing systems (see Supplementary Material). The database consists of more than 300 items, mainly from scientific journals and reports from institutions, such as FAO. In Table 1, the number of items included in each ASF group is shown. In addition to the CFP value, other data related to the LCA method have been included, namely, the year of study, literature reference, geographic location, system boundaries, original functional unit and other descriptors, such as species, feed type, farming methods, etc. Different functional units have been used in meat LCA studies, e.g. carcass weight, bone-free meat, etc. Hence, to enable comparison, the GWP values for meat studies were converted to a common functional unit of kg CO_2-eq/kg carcass weight by using, when needed, the conversion ratios given by the authors of the study itself or, when not available, the ones from Clune et al. (2017).

Since the system boundaries in the reviewed studies also varied, a common system boundary was set at the processor gate. The rationale is that emissions from processing, transport, packaging, retail, consumption and waste, usually make up about 10–20% of total emissions (Weiss and Leip, 2012) or even less. In this way, the variability in the transport distances to the distribution center was omitted. Nonetheless, those literature sources in which the emissions from processing or packaging were not taken into account were also considered in the present study according to Pernollet et al (2017) recommendations. For each product, the average CFP of the selected literature sources was used for the calculations (Table 1). Information about the data and sources used can be found in the Supplementary Material.

3.2. Methods

Measuring how a change in the price of a food affects the consumption of ASFs, and therefore their CFP, implies calculating an elasticity. To this end, an estimation of the price and expenditure elasticities (cross, own-price and expenditure) using an AIDS Model applying the moving block bootstrap method was firstly developed for the above-described products in the period 2004-2015.

3.2.1. The Almost Ideal Demand System

Demand models have been widely used to analyze some characteristics of the tastes and preferences of the consumer, and play an important role in the analysis of variables linked to them, such as prices and quantities on the market (Dubé, 2018). The AIDS model (Deaton and Muellbauer, 1980) is one of the most commonly-used demand models because it has many desirable properties and allows flexible demand specifications to be estimated (Alston et al., 1994). The model allows preferences to be separated and the sub-utilities from consuming individual commodities in a group to be aggregated in order to give the total utility for the group (Chambwera and Folmer, 2007). The AIDS model is easier to estimate than other models, such as Rotterdam and translog, and it offers a comparatively parsimoniously parameterized model relative to other general models (Alley et al., 1992).

In its base form, the AIDS is specified as:

$$w_i = \alpha_i + \sum_j \gamma_{ij} \ln p_j + \beta_i \ln\left(\frac{x}{P}\right) \quad (1)$$

Where w_i is the expenditure share of the *ith* good with respect to the total expenditure, p_j denotes the prices of the goods, x is the total expenditure, and P is a translog price index defined by:

$$\ln(P) = \alpha_0 + \sum_j \alpha_j \ln p_j + \frac{1}{2}\sum_j \sum_i \ln P_i \ln P_j \quad (2)$$

In equation (1), the intercept α_i is the individual effects, β_i the expenditure elasticities and γ_{ij} the price elasticities. This model is considered as a good first order approximation to a general relationship between w_i, ln(x) and ln(P_j), and it has some constraint conditions (Bilgic and Yen, 2013):

i. Symmetry. $\gamma_{ij} = \gamma_{ji}\ \forall\ i \neq j$
ii. Homogeneity. $\sum_{i=1}^{n} \gamma_{ij} = 0$
iii. Additivity. $\sum_{i=1}^{n} \alpha_i = 1, \sum_{i=1}^{n} \beta_i = 0$
iv. Negativity. The substitution matrix is negative semidefinite.

Some empirical problems are found in the estimation of P from equation (2) (Green and Alston 1990). To solve this issue, the Stone price index is used to obtain a linear demand system, obtaining the so-called LAIDS model:

$$\ln(P) = \sum_{i=1}^{n} w_i \ln(p_i) \quad (3)$$

This index is not invariant to changes in the units of price measurement, but this problem can be solved using the Paasche price index and the loglinear analogue of the Laspeyres price index (Moschini, 1995):

$$\ln(P^S) = \sum_{i=1}^{n} w_i \ln\left(\frac{p_i}{p_i^0}\right) \quad (4)$$

where the upper case 0 for P_i represents the base period.

3.2.2. The Moving Block Bootstrap

When using the AIDS model, problems related to the type of data and the sample size can arise, because, in such models that use time series, the error terms can be correlated, and a small sample size can cause estimation and inference problems from the applied model (Baltagi, 2008; Greene, 2012). To solve both problems, the Moving Block Bootstrap (MBB) technique, which is an application of the bootstrap method, was used to obtain an empirical probability distribution of the total CFP associated with the required quantities of each ASF without and with the application of different tax rates. The bootstrap takes the sample as an embodiment of the population and resamples it to produce a so-called bootstrapped sample (Lahiri, 2003). When the data of the analyzed phenomenon are collected over discrete intervals of time, it is likely that successive observations are correlated, and the classic bootstrap omits this correlation structure. MBB resamples blocks of consecutive observations that preserve the structure of the original observations in each block, this being an efficient method when the error terms are serially correlated (Mizobuchi and Tanizaki, 2013).

An outline of the MBB implemented in this study is shown in Fig. 1, and can be described as follows. Suppose that $r \equiv r \in [1,T]$ is an integer. Let $\chi = (X_1, \ldots, X_T)$ be the set of observations, where each $X_t \equiv (w_t, p_t)$ is the data vector at time t for $t = 1, 2, \ldots, T$. Let $\beta_i = (X_i, \ldots, X_{i+r-1})$ denote a data block of length r starting with X_i, $1 \leq i \leq N$, where $N = T - r + 1$.

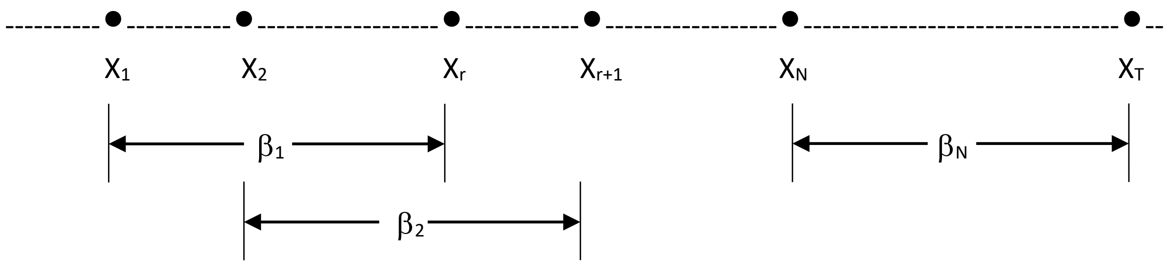

Figure 1. Collection of overlapping blocks under the MBB (adapted from Lahiri, 2003)

According to this, it is possible to select a number of blocks randomly from the collection $\{\beta_1, \ldots, \beta_N\}$ to derive the *m* MBB samples. Then a simple random sample $\{\beta_1^*, \ldots, \beta_m^*\}$ is drawn with replacement from $\{\beta_1, \ldots, \beta_N\}$. Each block β_j^*, j =1…m., has r consecutive observations; thus, the MBB sample has $k \equiv mr$ size. The MBB sample is used to estimate the elasticities and quantities required from the AIDS model using the micEconAids package (Henningsen, 2015) for R (R Core Team, 2018). Subsequently, the total CFP associated with each product is calculated using the individual CFP (Table 1) and the estimation of the demanded quantities. The sampling and estimation procedures are repeated *n=1,000* times to obtain an empirical distribution of the total CFP.

The CFP distribution has been obtained for two scenarios: (i) considering the original price, that is, without tax, and (ii) using a modified price with tax rates ranging from 10% to 20%. The Locally Estimated Scatterplot Smoothing (LOESS) procedure was used to smooth the CFP curves with and without tax and compare them enhancing the visual information (Cleveland, 1979).

4. **Results and discussion**

4.1 Consumption

As to ASF consumption (Fig. 2), it is noted that eggs exhibit a persistent fall. For beef and lamb, a steady consumption is observed until 2008, and from that year on, a gradual decrease may be seen. Although fish consumption increased during the first few years of the studied period, it then decreased gradually and, in 2015, it was similar to what it was at the beginning of the period. The opposite is observed for turkey, since its consumption fell until 2008, and from then on, it began to grow. This could be explained by the beginning, in that very year, of the economic recession. Although it did not affect the consumption of products, such as pork and chicken, it is appealing to analyze the consumption of expensive meats (Fig. 3). As to beef, a correlation is found between the growth rate of its consumption and the Gross Domestic Product (GDP) during the recession period, with a drop in consumption below the economy´s growth. On the contrary, lamb consumption grew despite the fall in GDP and, apparently, it was not affected by the recession.

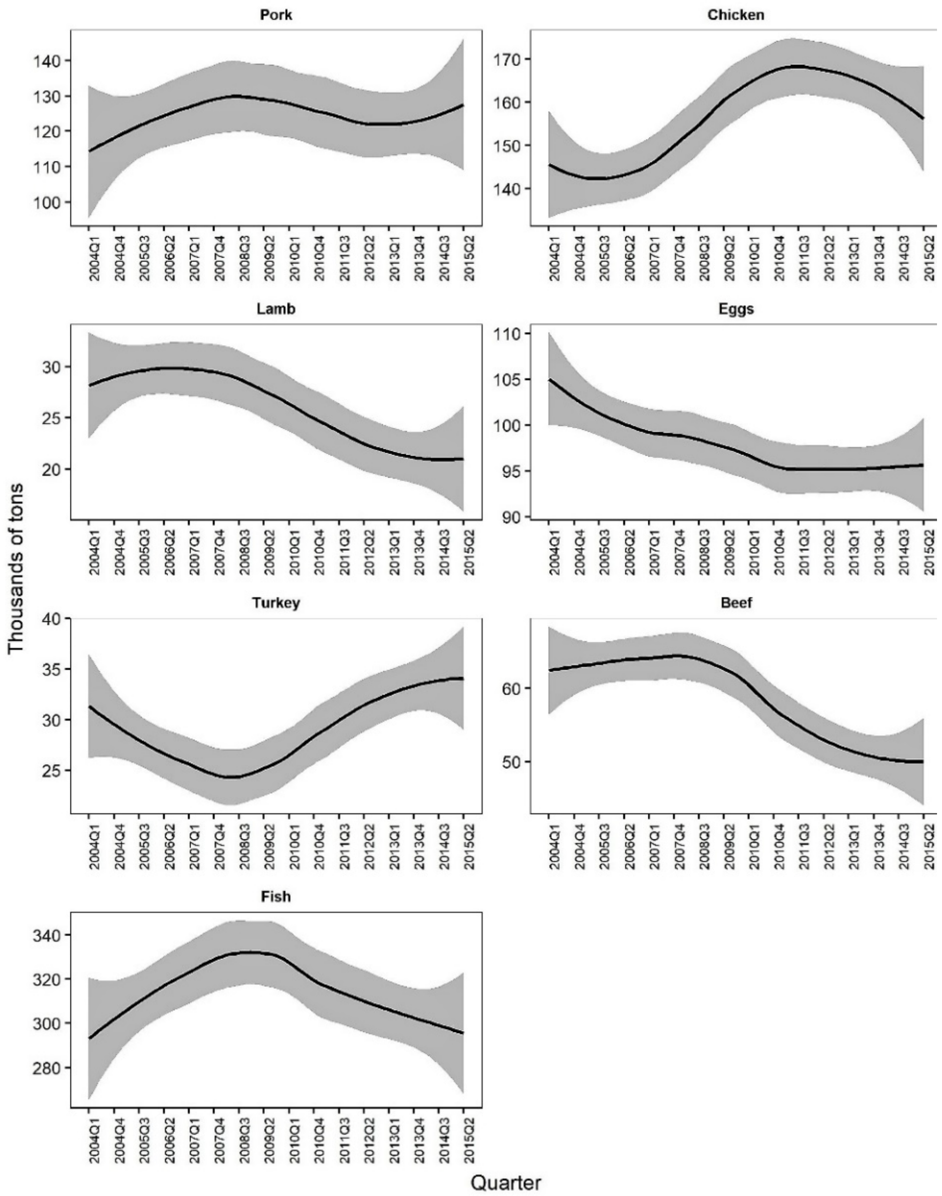

Figure 2. Consumption of some animal-sourced foods in Spain and confidence interval (2004Q1-2015Q2)

There are significant differences in the percentage share as regards the consumption of the products (Fig. 4). A gradual decrease in the consumption share of lamb, eggs, and beef is observed, although it seems to have been steady in the last few years; chicken, on the other hand, shows a slight increase. Despite the changes in consumption tendencies over the studied period, the consumption of pork, chicken and turkey in 2015 increased with respect to 2004. In general, fish presents the major average consumption share (39%) compared with the other ASFs for the 2004-2015 period. It is followed by chicken (19%), pork (16%), eggs (12%) and beef (7%), with the remaining 7% corresponding to lamb and turkey. The high values for fish consumption are explained by the grouping of all sea products, which is necessary for the AIDS to be computationally consistent and to preserve the principle of parsimony (Gujarati and Porter, 2009).

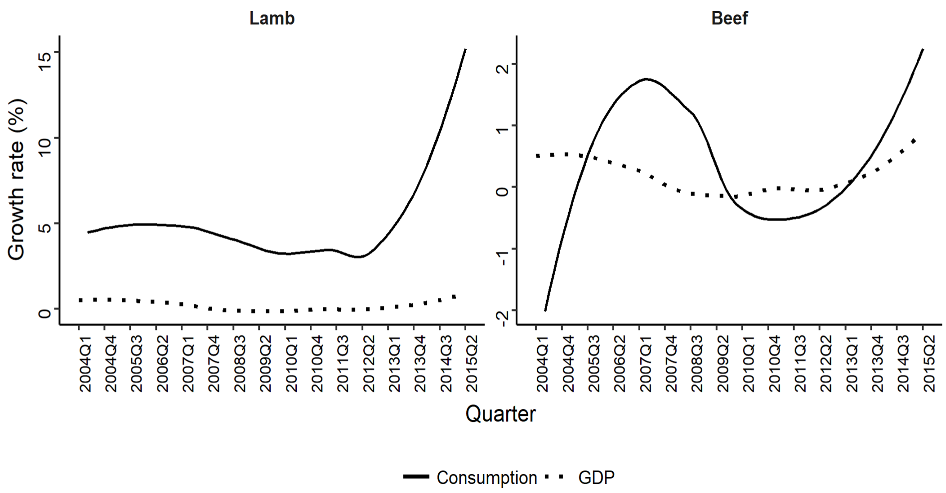

Figure 3. Evolution of growth rate of GDP and the consumption of lamb and beef in Spain (2004Q1-2015Q2)

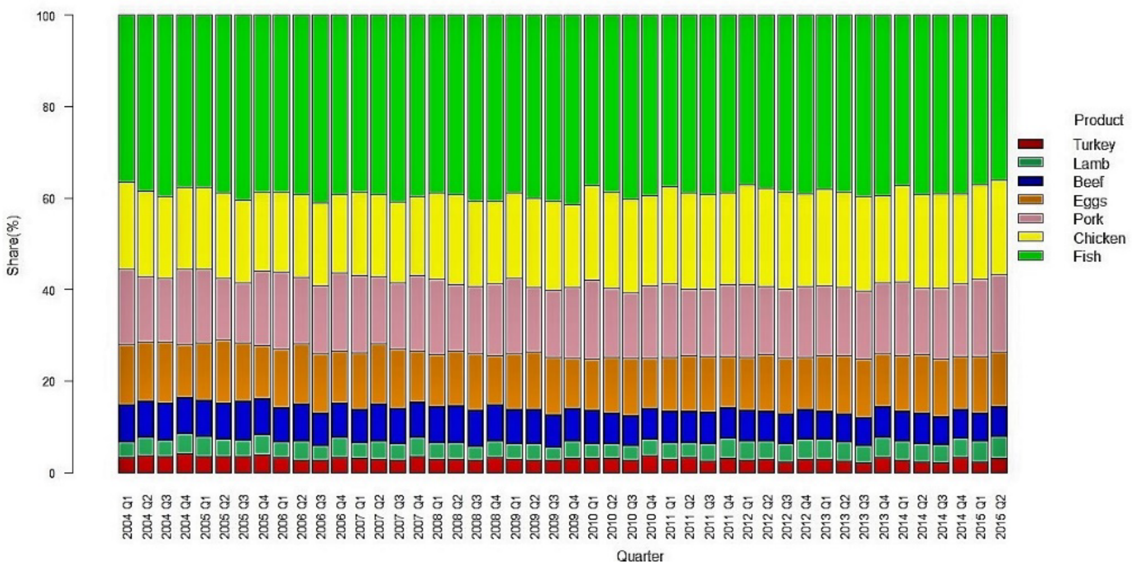

Figure 4. Share percentage in consumption of animal-sourced foods in Spain (2004Q1-2015Q2)

Table 2. Mean value of own-price and cross-price elasticities together with expenditure elasticities from 1000 iterations of the resampling procedure

	Pork	Chicken	Sheep	Eggs	Turkey	Fish	Beef	Expenditure
Pork	**-0.399**	-0.688	0.495	0.100	-0.429	0.231	0.690	1.002
Chicken	-0.826	**-0.028**	0.193	0.158	0.011	0.210	0.281	0.568
Sheep	1.435	0.465	**-0.966**	-0.535	-0.033	0.374	-0.741	2.210
Eggs	0.371	0.488	-0.686	**0.010**	0.104	-0.019	-0.268	0.731
Turkey	-1.940	0.039	-0.050	0.123	**-0.856**	2.567	0.116	0.689
Fish	0.075	0.057	0.042	-0.002	0.184	**-0.111**	-0.244	0.915
Beef	0.970	0.334	-0.361	-0.102	0.031	-1.066	**0.194**	1.489

4.2 Elasticities

For each particular MBB sample, the 56 elasticities were estimated. Table 2 shows the mean elasticities for 1000 iterations of the resampling procedure. For pork, chicken, eggs, and fish, some similarities are found with other studies in Spain (García-Muros et al, 2017; Lasarte et al, 2014), mainly in the sign of the own-price elasticities (in bold) and expenditure elasticities (last column). From the expenditure elasticities, it can be inferred that beef and lamb are luxury goods (expenditure elasticity > 1), and the rest of the products behave as normal goods (expenditure elasticity in the (0,1] interval). Initially, the property of symmetry was not fulfilled in the beef-turkey case; this is because, when the Marshallian demand is implemented, in some cases the cross-price effect cannot be symmetrical because the income effects caused by some products can be very different (Nicholson and Snyder, 2008); for that reason, the Hicksian demand was used to fulfill the property of symmetry.

From the cross-price elasticities (CPE), it is possible to establish the complementarity and substitutability relationships between each pair of goods. If the CPE is negative, the increase in the price of one good will lead to a fall in the demand for the other and both will be complementary foods. On the contrary, a positive CPE means that an increase in the price of one good will raise the demand for the other one and they are substitutes. For example, as can be observed in Table 2, an increase in the price for beef will result in an increase in demand for pork, and a reduction in fish consumption; that is, beef and pork are substitutes while beef and fish are complements. The other products can be analyzed in a similar way, as summarized in Table 3.

Table 3. Complementarity and substitutability relationships between the analyzed animal-sourced foods

	Pork	Chicken	Lamb	Eggs	Turkey	Fish	Beef
Pork		C	S	S	C	S	S
Chicken	C		S	S	S	S	S
Lamb	S	S		C	C	S	C
Eggs	S	S	C		S	C	C
Turkey	C	S	C	S		S	S
Fish	S	S	S	C	S		C
Beef	S	S	C	C	S	C	

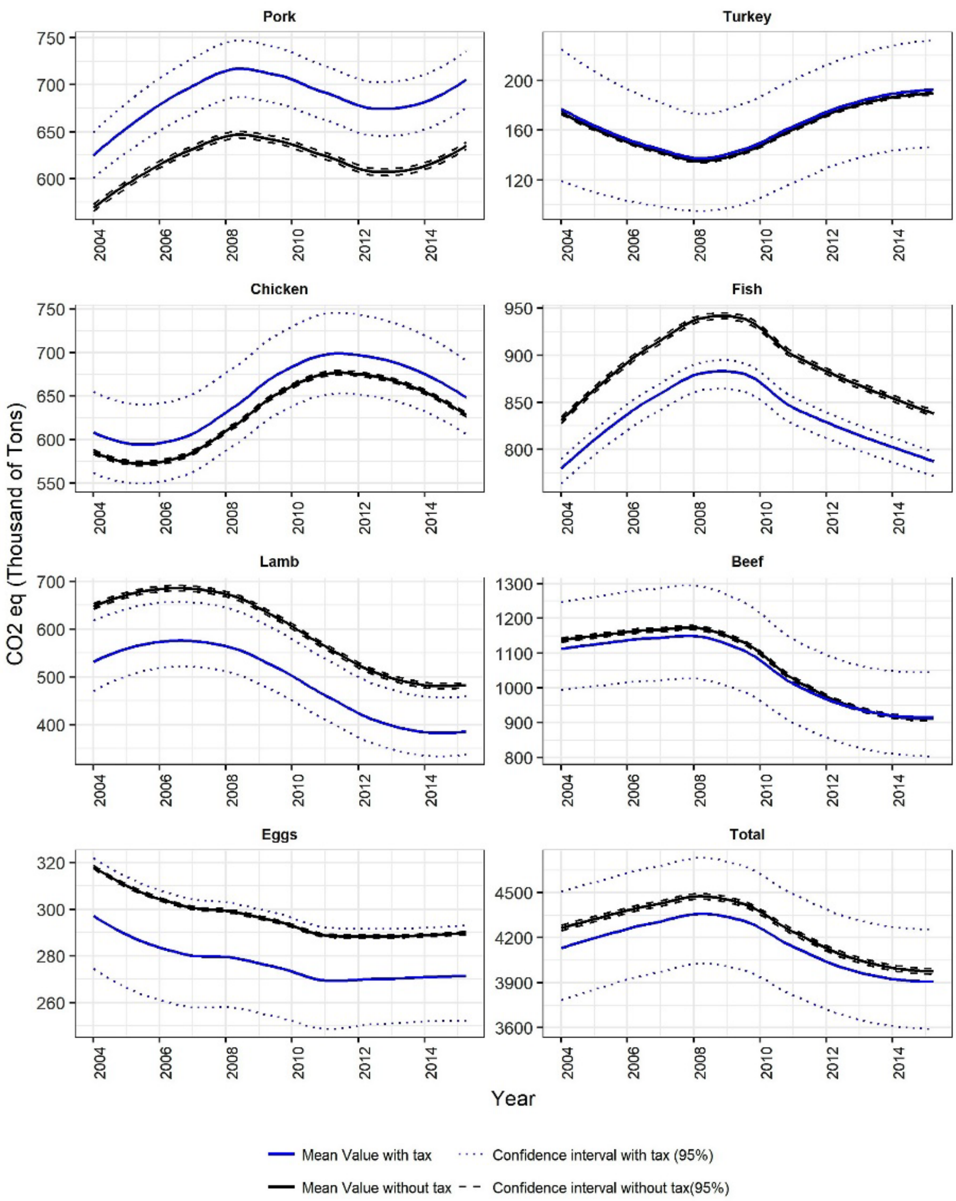

Figure 5. Evolution of the carbon footprint by product and total ASF consumption considering both a 20% tax on beef and without tax.

4.3. Carbon footprint

Fig. 5 shows the CFP results expressed as kg CO_2 equivalents for each ASF without and with a 20% tax on beef, which is the product with the highest CFP of the analyzed foods, while Fig. 6 shows the change generated in the CFP for the same tax. In both cases, the bootstrap confidence intervals are shown. For pork, lamb and fish, the confidence intervals with and without the tax on beef are not overlapped (Fig. 5), which can be interpreted as statistically significantly different. For the remaining products, the confidence interval curves are overlapped, presenting statistical similarity; however, it does not imply that the tax effect on the CFP be null (Ellis and Steyn, 2003; Nakagawa and Cuthill, 2007).

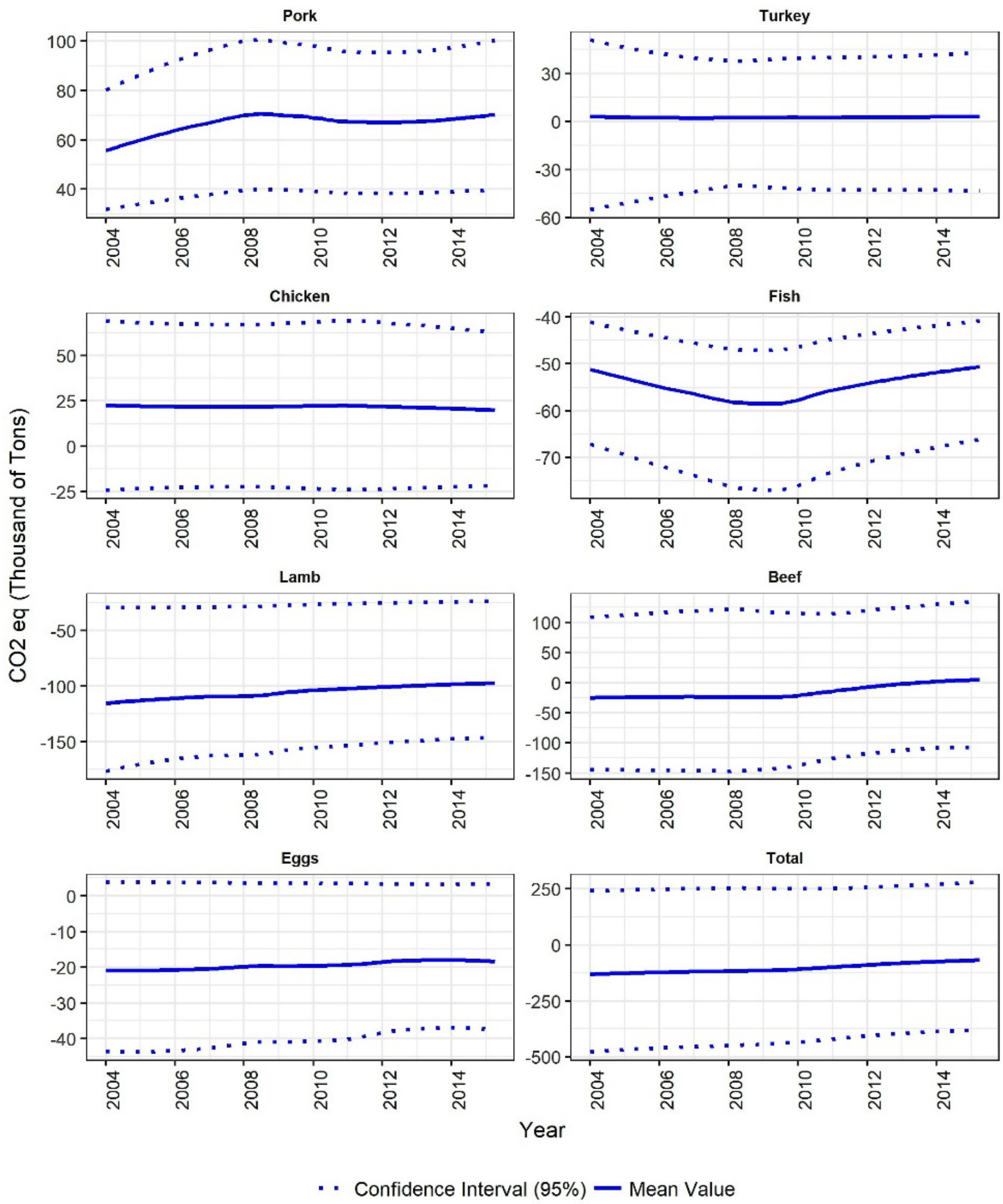

Figure 6. Change in the carbon footprint by product and total ASF consumption considering a 20% tax on beef

As a consequence of the 20% tax on beef, the total emissions during the analyzed period were not reduced as much as might be expected. From the results of the change in CFP (Fig. 6), it can be deduced that consumers apparently have strong preferences as regards beef consumption; this is because, although there is little reduction in its CFP up to 2010, after that year its value increases, and the change in the CFP is almost zero at the end of the period. The relationships of substitutability and complementarity among products explain the changes in the emissions associated with the consumption of the remaining ASFs as a response to the 20% tax on beef. Along these lines, a reduction in the emissions associated with the consumption of fish, eggs, and lamb is evident, which can be explained as a result of the complementarity between these products and beef. On the other hand, the substitutability relationships are clear for pork and chicken, since, in response to beef tax, consumers would seemingly substitute beef for these products, with the corresponding CFP increase. For turkey, the tax effect is null.

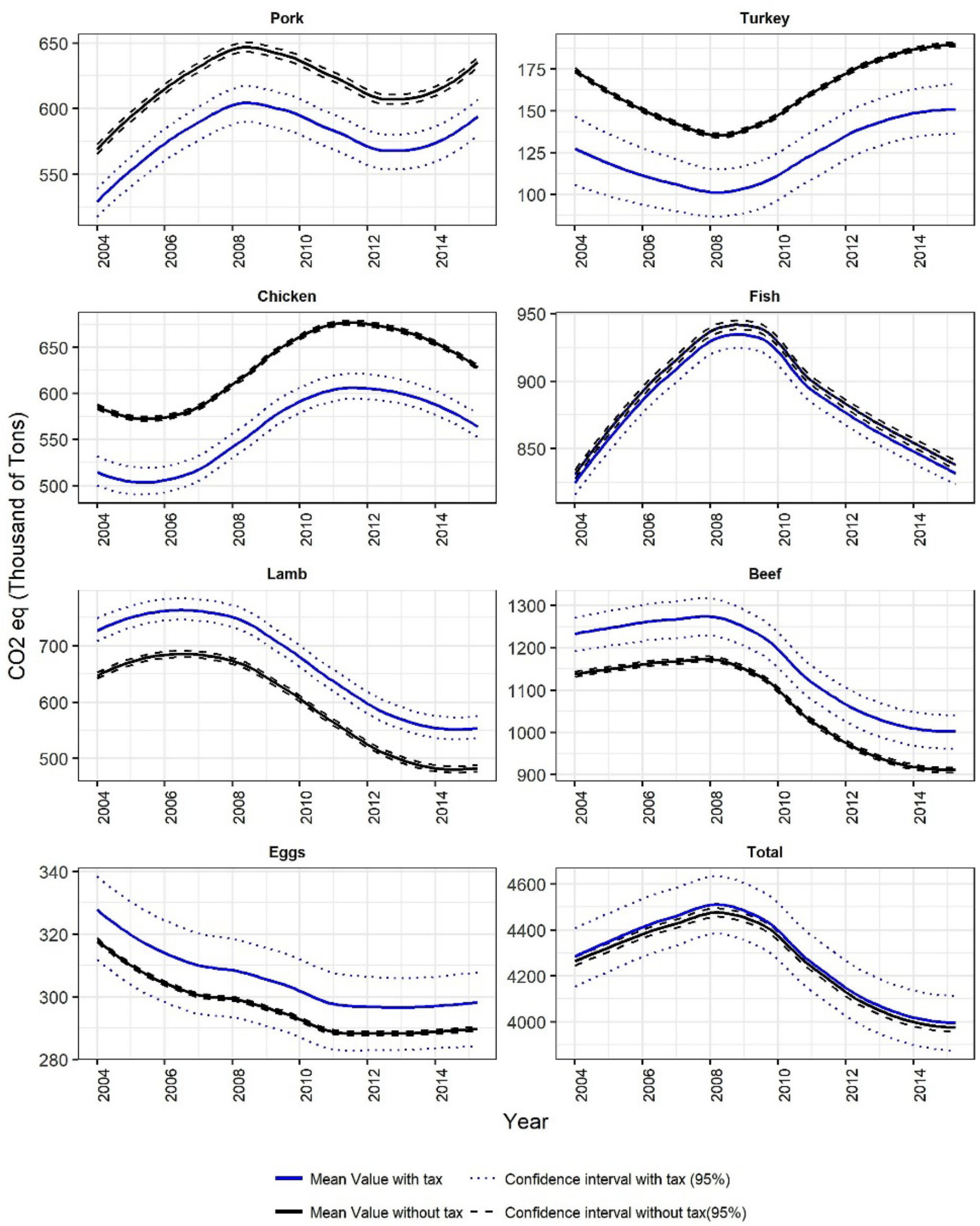

Figure 7. Evolution of the carbon footprint by product and total ASF consumption considering both a 12.5% tax on pork and without tax.

Analyzing the impact of a tax on the CFP change for a single product can lead to a misinterpretation of the overall results, as illustrated by the case of a 12.5% tax on pork (Figs. 7 and 8). This tax leads to a great reduction in pork associated emissions, and also a decrease in the CFP for turkey, chicken, and fish, explained by the effects of complementarity. On the other hand, given the effects of substitutability, a CFP increase for lamb, eggs and beef may be observed. As a result, the net change in the total CFP associated with the consumption of the ASFs is positive. Similar results can be observed when other tax rates are applied on pork; that is, in spite of reducing its own CFP, an increase in the total CFP is estimated. This highlights the fact that the application of a tax on the consumption of an individual product can reduce its emissions, but the overall reduction may not be as expected, since an increase in the total CFP may be obtained rather than a reduction. In the case of fish, which is a food with a lower CFP than beef, the impact on GHG emissions of a 10% tax was estimated (Figures 9 and 10). In six of the seven ASFs, a fall in the CFP is exhibited, and only turkey CFP showed an increase. It can be observed that the reduction in the total CFP for the tax on fish is higher than in the case of a tax on beef.

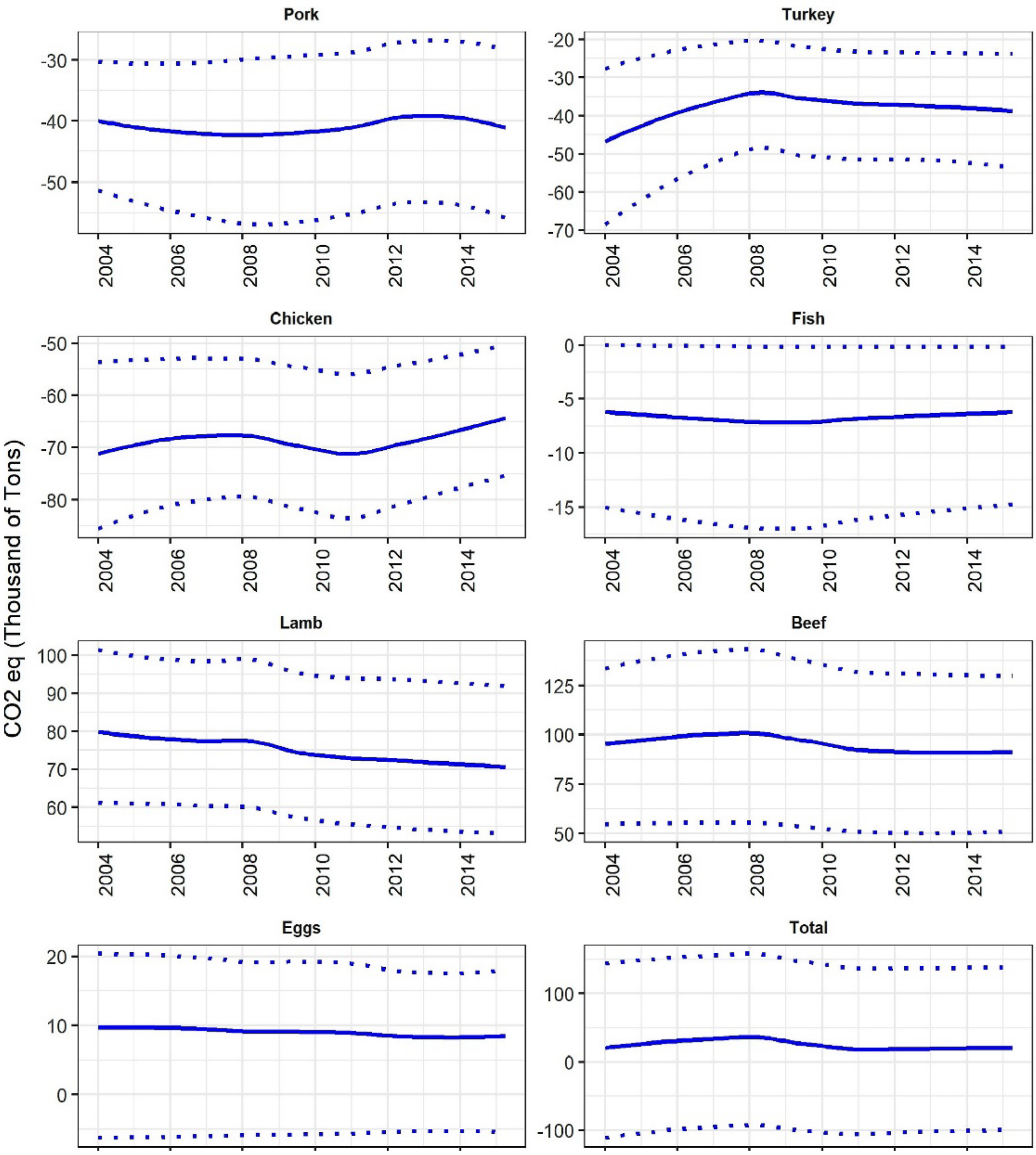

Figure 8. Change in the carbon footprint by product considering a 12.5% tax on pork

An assessment of the total CFP during the entire period of analysis (2004Q1-2015Q2) for the application of tax rates on each of the seven ASFs is summarized in Fig. 11. Each bar represents the total change in GHG emissions induced by a tax on a specific product. For example, a 15% tax on fish results in a total net reduction of 17.82 million tons of CO_2 eq. As expected, the higher the tax rate, the more likely a greater change in the total CFP. On the other hand, although taxes on products with a high consumption share could be expected to be more effective at reducing the total CFP, as in the case of fish, this cannot be considered to be a rule; this is because, in products such as chicken, the total CFP is similar or lower than products with a low share, such as lamb and turkey. Therefore, as to the kind of ASF to be taxed, the tax seems to contribute effectively to reducing the overall CFP when applied on fish, is mildly effective on beef, eggs and lamb, ineffective on chicken and turkey and may even be counterproductive on pork meat. Hence, the selection of the product on which the tax will be applied must be made with caution. Although the change in the individual results of CFP seems to be a good criterion, that perspective does not ensure a reduction in the CFP associated with the total consumption of ASFs. Another criterion for selecting the product to be levied could be the consumption level; however, this is not an effective strategy because, as seen for chicken, despite being a product with high consumption, the decrease in the total CFP is smaller than that of the taxes on eggs or beef.

Our study does not address the consequences induced by a specific product tax on health. However, a trade-off between tax effectiveness and healthy nutrition could arise, since although fish is healthier than beef, the tax that is most effective at reducing the emissions is the one on fish, and it is likely that its consumption would remain reduced in the long run, affecting the possibility of having a healthy diet. In subsequent studies, and related to the foregoing, it would be interesting to incorporate an analysis of the tax impact per consumer group, that is, classify the consumers according to income levels.

It is possible to develop different tax combinations on two or more products simultaneously. This can also be complemented with the inclusion of variability in the estimation of the ASFs' carbon footprint (Steinmann et al., 2014), because it can reflect important differences among alternative life cycles of equivalent products.

The paper focuses on the impact of a tax on the demanded quantities, but does not study the possible changes in the supply side. It would be thus interesting to analyze how food producers react to overcome the tax impact, because companies could change the composition of processed foods or incorporate new farming technologies (Llais et al., 2010). Food suppliers could also try to influence the tax implementation in some way, such as asking for the abolition of the tax or a reduction in the tax rate (Bødker al., 2015), thereby generating a change in the associated CFP.

5 Conclusions

Taxes on ASFs have been proposed as an economic policy instrument as a means of reducing the CFP associated with these products. This study proposes a counterfactual estimation of the potential individual and total CFP resulting from the implementation of different ad valorem tax rates on the consumption of some ASFs in Spain. Specifically, a tax has been applied on each individual product to examine their interactions, as well as the potential CFP change associated with ASF consumption.

The results of the case study show that the tax may be highly effective when applied on fish, moderately effective on beef, eggs and lamb, ineffective on chicken and turkey, and counterproductive on pork meat, evidencing that consumer preferences are difficult to predict. Results can change from country to country depending on consumer habits, e.g. fish consumption in Spain is higher than the EU average. Complementarity and substitutability effects, calculated through elasticity, can help to explain those preferences and to choose the foods to be levied. Although the results obtained from the AIDS model are a good representation of tastes and individual preferences, there are some habits that are not captured by the model, but which can change consumer reaction to the tax. Combinations of taxes on different products should be incorporated for the purposes of further research to improve the decisions on the selection of an optimal tax rate that not only reduces GHG emissions, but is also socially desirable.

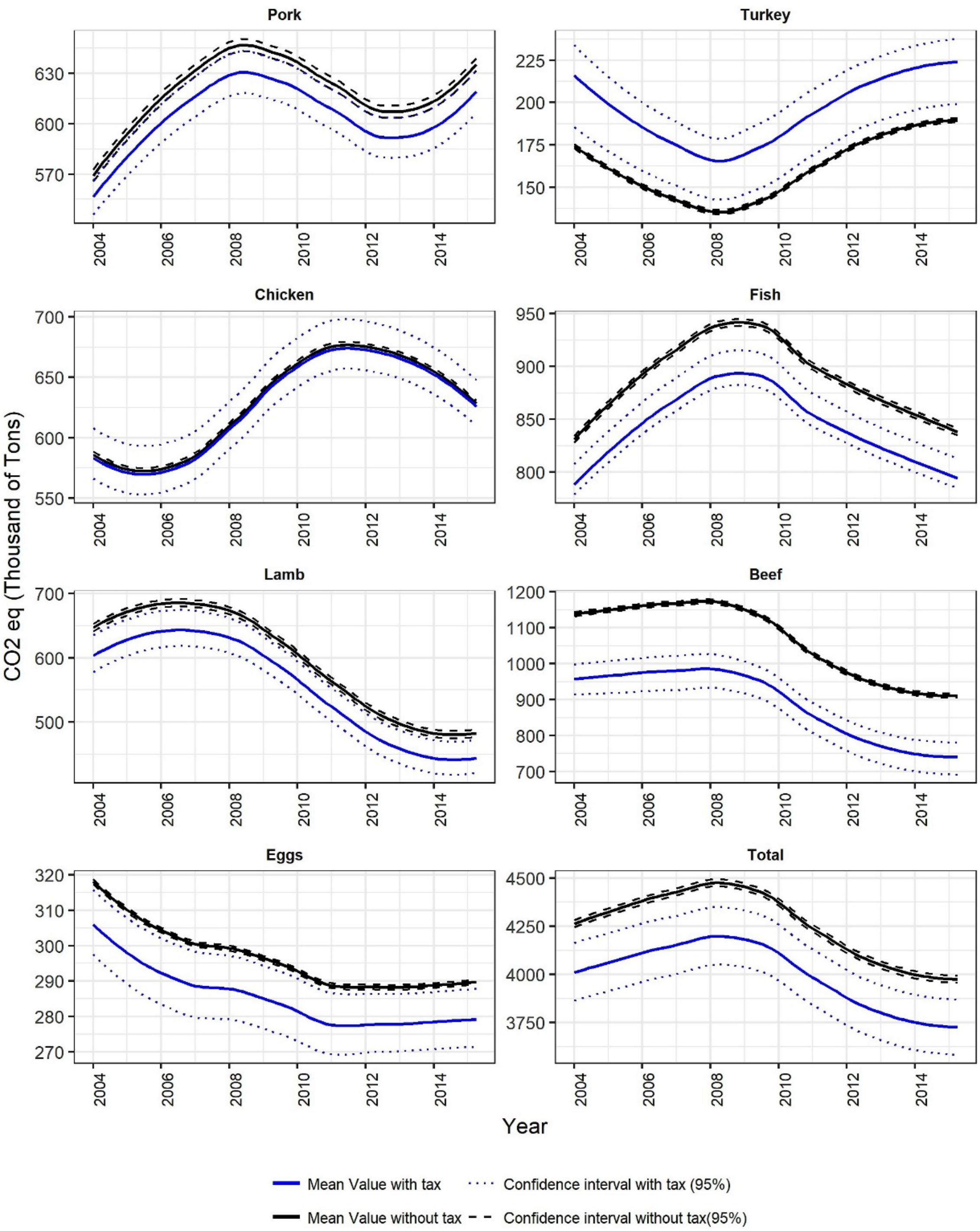

Figure 9. Evolution of the carbon footprint by product and total ASF consumption considering both a 10% tax on fish and without tax.

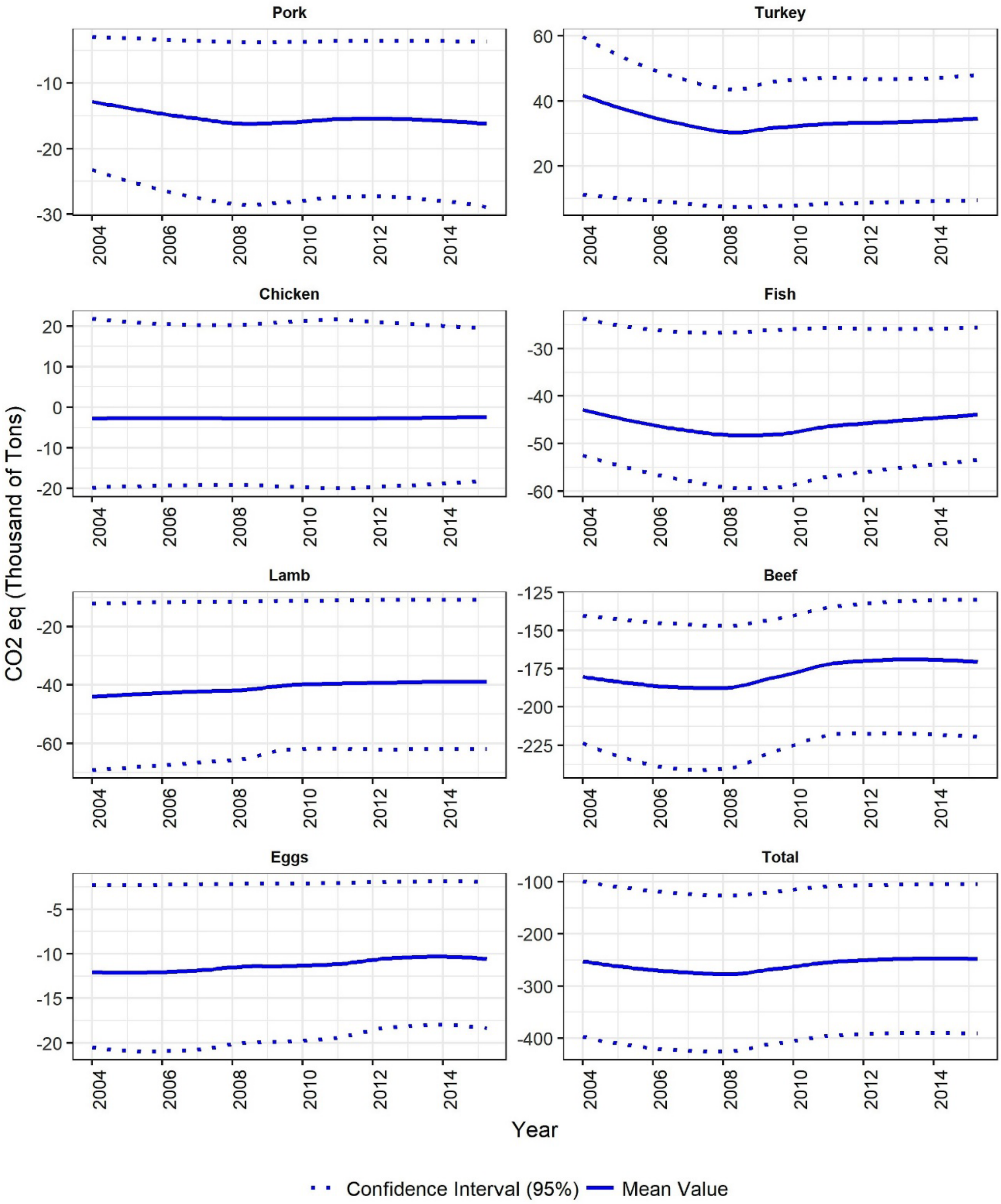

Figure 10. Change in the carbon footprint by product and total ASF consumption considering a 10% tax on fish.

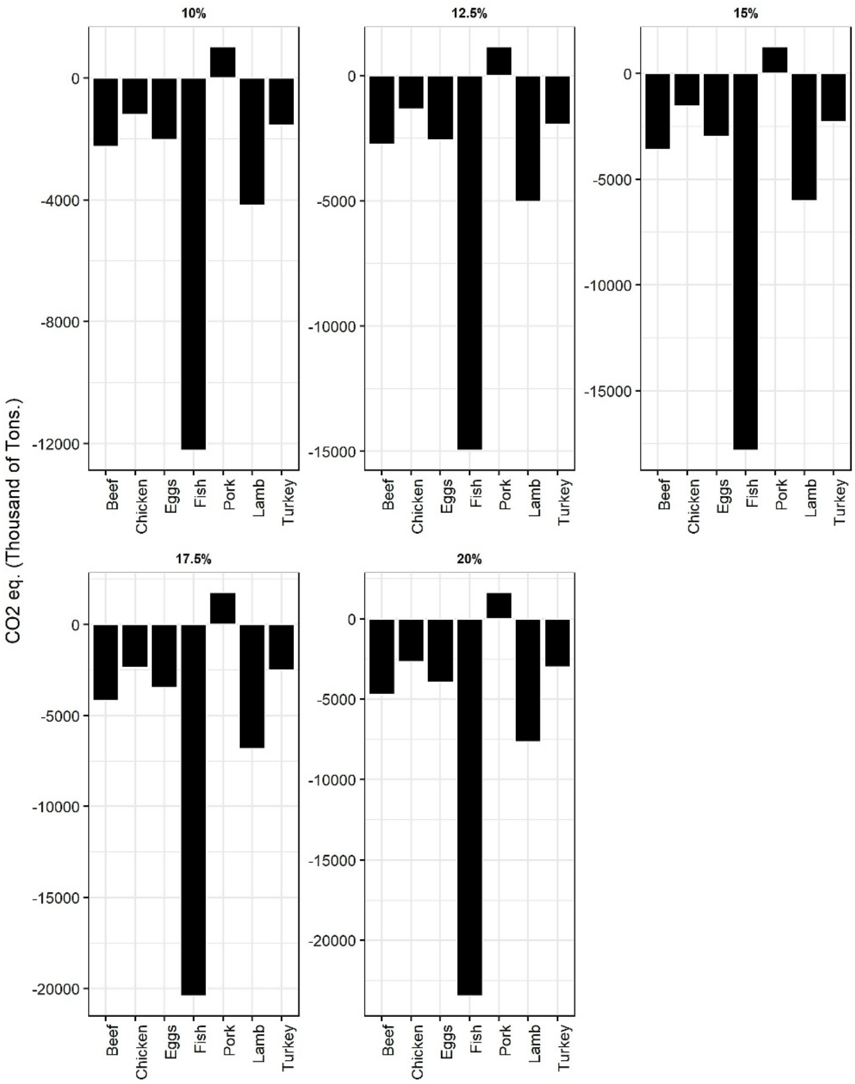

Fig. 11. Total change in the CFP of the ASFs caused by different tax rates on one specific product through the 2004Q1-2015Q2 period in Spain. Abscises represent the specific taxed product.

From a policy-making approach, the study shows that taxing a specific ASF must be carried out with great care, otherwise there may be undesirable effects on food consumption, and consequently not only will food total CFP be affected, but also nutrition. For instance, a tax on fish is the most effective at reducing the overall emissions; however, the nutritional quality of the diet might worsen due to the reduction in long-term fish consumption. It must be kept in mind that reducing the CFP of ASFs is a global challenge which requires inter-disciplinary collaboration (agricultural engineers, economists, nutritionists, etc) together with the implementation of political instruments so as to give different perspectives and provide new insights.

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