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Is Meat Too Cheap? Towards Optimal Meat Taxation

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Abstract

Livestock is known to play a significant role in climate change and to negatively impact global nitrogen cycles and biodiversity. However, economically efficient policies for regulating meat production and consumption are under-researched. In the absence of first-best policy instruments for the livestock sector, second-best consumption taxes on meat can address multiple environmental externalities simultaneously, while improving diet-related public health. Here, we review the empirical basis for the 'social costs of meat' and study rationales for regulatory efforts to tax meat in high-income countries from the perspective of public, behavioural and welfare economics: (i) multiple environmental externalities, (ii) adverse effects on one's own health, (iii) animal welfare, (iv) learning curves for 'alternative protein technologies', and (v) distributional effects. We conclude that meat is significantly underpriced and provide preliminary estimates of the environmental social costs associated with meat consumption. We identify several directions for future research towards optimal meat taxation.

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1. Introduction

Throughout human history, livestock farming and meat consumption have played an important role in economic development and culinary traditions. Today, livestock farming supports many livelihoods, and meat is regarded as an important source of protein and micronutrients in many parts of the world. Despite these benefits, there is a growing consensus that the recent global trajectory of meat production and consumption is unsustainable. Livestock farming plays a significant role in many of the most pressing environmental challenges of our time, including climate change, biodiversity loss, and nitrogen pollution (see *Figure 1*). A failure to mitigate greenhouse gas emissions from the agricultural sector, where livestock is a leading source of pollution, could preclude meeting the 1.5 degrees climate objective, and complicate the path to limiting climate change to well below two degrees of warming (Clark et al., 2020). In high-income countries, high levels of meat consumption also pose significant risks for public health. The World Health Organization declared processed meat as carcinogenic and unprocessed red meat as likely carcinogenic and there is evidence they may increase the risk of coronary heart disease, stroke, and type-2 diabetes (Godfray et al., 2018). In its current form, livestock production also increases the risks to public health from zoonotic diseases and antimicrobial resistance (Espinosa et al., 2020, O'Neill et al., 2016), with potentially very large impacts.

The negative externalities of meat are currently not reflected in retail prices and have remained largely unaddressed by policymakers. The lack of regulatory attention that meat has been receiving appears especially pronounced when compared to progress in other major polluting sectors, such as electricity and transportation. For example, even though roughly 13 percent of global GHG emissions can be attributed to livestock farming (Poore and Nemecek, 2018), the sector is not covered by the vast majority of carbon pricing policies. There are several factors that may explain why meat has been largely ignored by regulators: the economic entities involved (typically farm businesses) are much smaller and emissions sources are more heterogenous than in other sectors, which makes policies hard to implement due to high monitoring and transaction costs. For the most relevant externalities, cost-effective mitigation options are currently limited, with potential breakthrough solutions like alternative protein technologies only in the very early stages of development and deployment. That implies a stronger role for demand-side abatement, likely to be met with strong opposition by those invested in the incumbent sector. Finally, meat consumption has a strong cultural component, prompting policymakers to fear that consumers will react with strong opposition to higher prices.

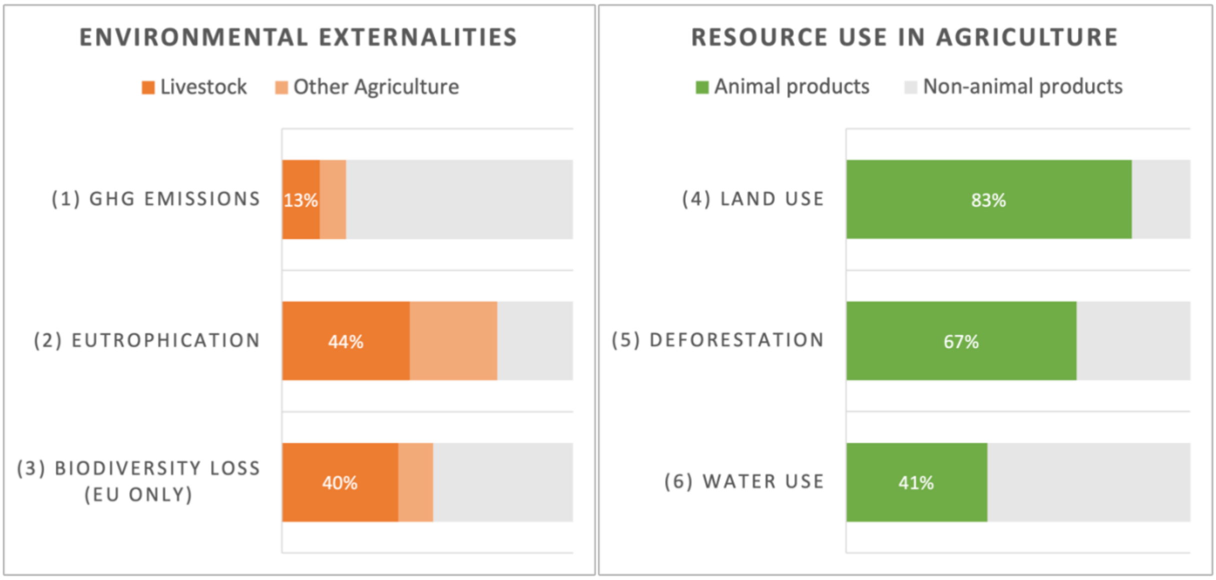

Figure 1: *The share of livestock in major environmental challenges and resource use in agriculture. (1), (2), (4) and (5) from Poore and Nemecek (2018); (3) only for the European Union (Leip et al., 2015); (6) from Heinke et al. (2020); (5) and (6) only for animal feed.*

More recently, however, the requirements of a net-zero carbon transition, and calls for 'building back better' after the Covid-19 pandemic, have raised not only the need, but also the prospects of more stringent regulation of meat in developed countries. From the perspective of environmental economics, it is clear that appropriate pricing of meat, which reflects its social costs, should be at the core of such regulation. Taxing meat is not itself "first best" and would be altogether unnecessary if appropriate prices on carbon and other externalities were in place. However, in the absence of such policies, the strategy of singling out meat (or possibly meat and dairy[9]) as a high-polluting food category is supported by environmental research: Environmental impacts attributable to most animal products are much higher than those of plant-based products (Poore and Nemecek, 2018), and research indicates that carbon taxes on plant-based foods would be close to zero (Springmann et al., 2017). Indeed, regulators seem increasingly open to the idea of raising meat prices: In the United Kingdom, for instance, the government has signalled that it is entertaining the idea of introducing bespoke carbon taxes on meat and dairy, as selected high-carbon goods (Helm, 2021).

This article investigates the potential of consumption taxes on meat in high-income countries to address multiple externalities. Consumption taxes could alleviate concerns about leakage and competitiveness impacts and high monitoring costs associated with levying taxes at the source. When

[9] For simplicity, we omit dairy products from our analysis but note that appropriate dairy pricing is another important avenue for research. Some of our theoretical conclusions seem transferable to this context.

targeted externality-correcting policy instruments across the whole agricultural sector are unavailable, meat taxes are an attractive instrument, as they can lead to progress on multiple policy objectives where livestock farming and meat consumption have a major role. In environmental economics, this logic is reminiscent of taxing transportation fuel, which similarly addresses many externalities at once, including air and noise pollution, climate change, and congestion (Parry and Small, 2005). In contrast to optimal fuel pricing, however, economically efficient policies for regulating meat in a "second-best context" (see below for definition) are under-researched[10]. Previous work in environmental economics has predominantly focussed on single categories of externalities (e.g. Wirsenius et al., 2011), with the recent exception of Bonnet et al. (2020) and Katare et al. (2020).

We proceed as follows: The next section reviews the empirical basis for the 'social costs of meat'. The subsequent section applies this knowledge to taxation theory, assessing several elements from public, behavioural and welfare economics, which could motivate regulatory efforts to tax meat: (i) multiple environmental externalities, (ii) health 'internality' (i.e., adverse effects on one's own health), (iii) animal welfare, (iv) learning curves for 'alternative protein technologies', and (v) distributional effects. In the final section, we contextualise our conclusions by discussing the political economy of taxing meat.

Our review of research in environmental economics on the social cost of meat indicates that meat is currently significantly underpriced. The social costs from climate change and nutrient pollution for beef add up to between 35–56 percent of average retail prices in high-income countries (central value; pork and lamb: +19 percent, poultry: +25 percent). Additionally, accounting for biodiversity loss and diet-related health impacts would increase this number substantially. While no inference can be made on the optimal second-best tax rate for meat products, these results can inform future economic modelling studies. Specific normative positions on animal welfare and distributional impacts can also be important rationales for designing optimal meat taxes.

[10] In a systematic literature review, we classified only six articles as relevant from a public economics perspective, searching for optimal meat taxation by "meat OR animal OR livestock OR beef OR pork OR poultry) AND (tax* OR pric*) AND (social cost* OR Pigou* OR optimal* OR efficien*" across RePEC IDEAS and Google Scholar (first 100 entries).

2. The social cost of meat

Pricing meat appropriately requires assessment of the magnitude of environmental externalities and health effects associated with livestock farming and meat consumption. This section highlights empirical evidence and progress in the economic valuation of environmental externalities and diet-related health impacts. While large-scale threats such as zoonotic disease emergence (Jones et al., 2019) and antimicrobial resistance (O'Neill, 2016), as well as concerns over animal welfare (see Section 3.3), provide additional reasons for more stringent livestock regulation, our empirical summary is limited to those externalities, for which social costs appear more tractable.

2.1. Evidence on environmental externalities

With farm-to-fork environmental impact assessments through life-cycle analysis, there is now a robust empirical basis for linking meat products to environmental outcomes, such as greenhouse gas emissions, pollution from phosphorus and nitrogen, land and water use (Poore and Nemecek, 2018). At a global scale, the main environmental externalities from livestock are (1) climate change, (2) nutrient pollution and (3) biodiversity loss. Meat production contributes to climate change through the emission of methane (from enteric fermentation in ruminants and manure storage), nitrous oxide (from fertilizer application and manure processing) and carbon dioxide (from feed-related direct land-use changes and energy use) (Gerber et al., 2013). Nutrient pollution, in the form of ammonia (NH3), nitrogen oxides (NOx), nitrates (NO3−) and organic N, results in soil acidification, eutrophication of oceans and freshwater pollution (Uwizeye et al., 2021). Through ammonia emissions and particulate matter from animal manure, livestock is also a significant contributor to local air pollution, causing respiratory health issues in agricultural workers, local residents and the general population (Lavaine et al., 2020). Biodiversity loss from livestock farming is largely driven by land use change (FAO, 2019).[11]

Figure 2 combines life-cycle assessments for meat products with social cost estimates to quantify the economic value of environmental damages from different meat types, expressed in USD-per-kilogram. While climate economics has converged on robust global estimates of the social cost of carbon, economic valuations are much scarcer for other impacts, such as nutrient pollution (Brink et al., 2011).

[11] Under certain rearing conditions, animal farming can have positive externalities, for example through carbon sequestration from grazing. Globally, however, these effects are strongly outweighed by negative impacts (Godfray et al., 2018, Garnett et al., 2017).

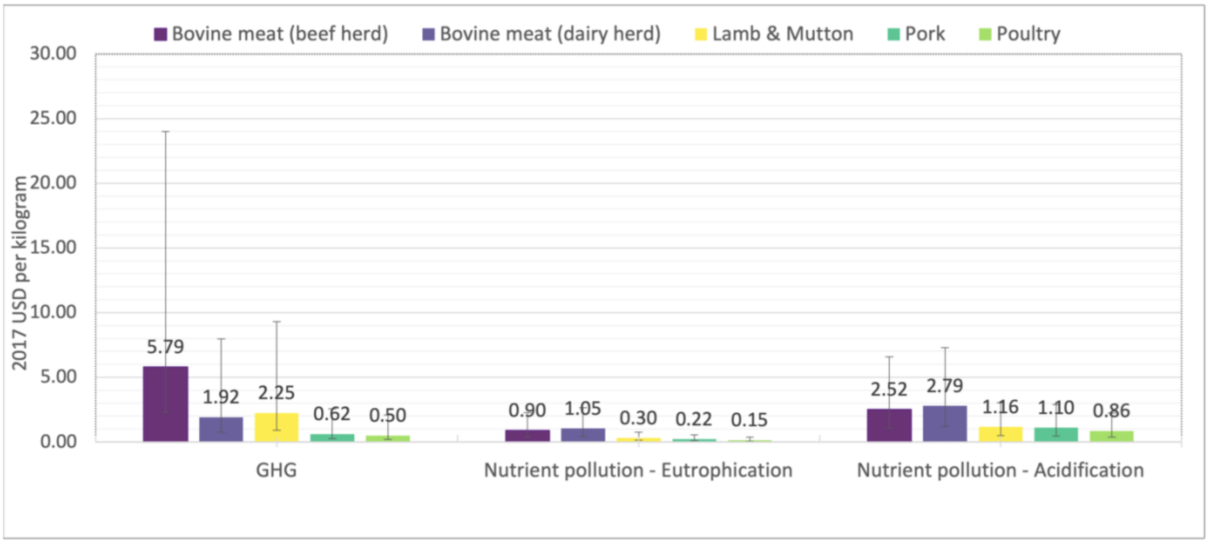

***Figure 2**: Environment-related social costs from climate change and nitrogen pollution for selected meat types, in sum 5.76-9.21 USD/kg for beef, 3.71 USD/kg for lamb and mutton, 1.94 USD/kg for pork and 1.51 for poultry. Social costs from biodiversity loss cannot currently be quantified reliably. Life-cycle environmental impacts from Poore and Nemecek (2018). See Supplementary Information.*

This is, among other factors, due to the spatial variation in the dose-response relationship of pollutants and the difficulty of assessing the counterfactual condition of natural ecosystems.

The social costs of biodiversity loss have not been quantified to date. However, a growing body of research within economics and environmental science asserts the immense economic value of natural ecosystems and the role of transforming or reducing livestock farming in maintaining biodiversity (Dasgupta, 2021; Machovina et al., 2015). Studying the optimal expansion of agricultural land in a quantitative two-sector growth model of the global economy, Lanz, Dietz and Swanson (2018) find that the negative effect of biodiversity loss on agricultural productivity alone could justify a moratorium on further land conversion as socially optimal. In practice the associated social costs will be much higher once the total economic damage from destroyed ecosystems is included, for example the loss of regulating, supporting and cultural ecosystem services. Global modelling studies on land-use and biodiversity further indicate that reducing agricultural land expansion will play an important role in reversing biodiversity loss (Williams et al., 2020). Leclère et al. (2020) find that maintaining global terrestrial biodiversity without negative impacts on food security requires significant transformation of the global food system, including more plant-based diets. Eventually, linking global estimates of the social cost of biodiversity loss to livestock farming will require robust and comparable impact assessments that account for composition and functionality of biodiversity.

2.2. Evidence on diet-related health impacts

In high-income countries, the detrimental health impacts of some meats, in particular of red meat (which includes beef, lamb, and pork) and of processed meat (which includes bacon and sausages), are now well established. The World Health Organization has declared processed meat carcinogenic and unprocessed red meat likely carcinogenic to humans based on epidemiological and mechanistic evidence (Bouvard et al, 2015). There is moderate to strong evidence from meta-analyses of epidemiological cohort studies that red and processed meat increases risks for coronary heart disease, stroke, and type-2 diabetes (Schwingshackl et al, 2017; Bechthold et al, 2019). The effects of unhealthy diets on the individual are a form of self-inflicted harm and therefore not an externality. Health impacts can, however, also affect macroeconomic outcomes: the diet-related health consequences from meat consumption can indirectly lead to productivity losses. In addition, in countries with universal health-care coverage where costs are collectivized, such risks increase the cost of the public health system.

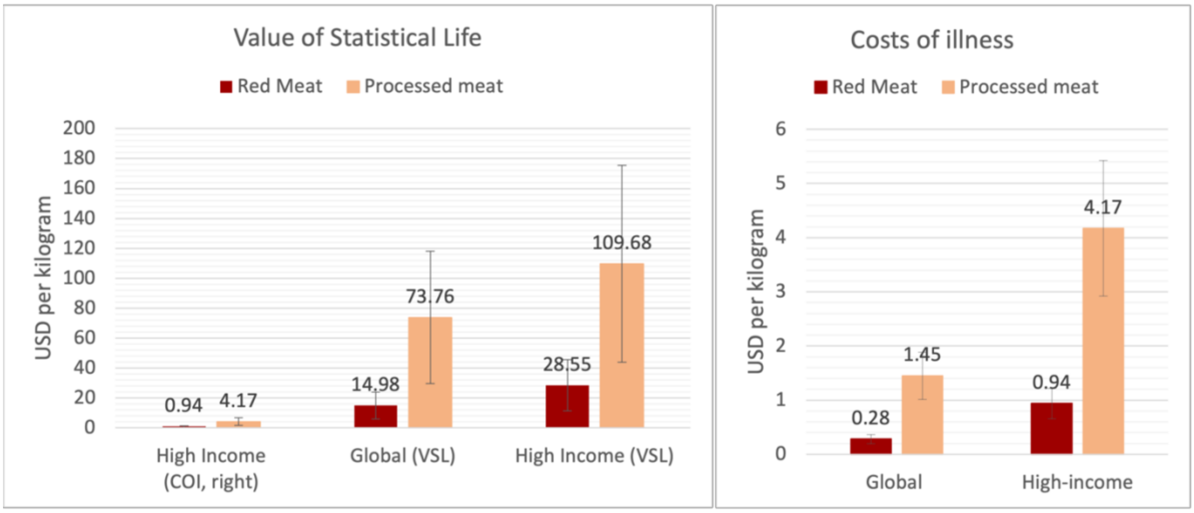

Figure 3: *Diet-related health damages and health costs per kilogram of meat consumed, based on one additional serving of meat per day, from Springmann et al. (2016, 2018, 2020). Privately incurred harms from meat consumption (left) are valued one to two orders of magnitude over costs-associated with specific resulting diseases (right). See also Supplementary Information.*

Figure 3 illustrates the costs associated with diet-related health impacts in high-income countries and for the global average, based on an increase of meat consumption of one additional serving per day. The valuation based on statistical life (VSL, left) can be understood as a measure of the privately incurred harms from meat consumption (Springmann et al., 2016; Springmann, 2020), based on the willingness to pay for a mortality risk reduction in a defined time period (OECD, 2012). In contrast, the cost-of-illness approach (right) captures the direct and indirect costs associated with treating a specific disease, including medical and health-care costs (direct), and costs of informal care and from lost working days (indirect) (Springmann et al., 2016, 2018).

3. The public economics of meat: consumption taxes in the second-best

Although the social costs from livestock-related environmental damages and health effects are significant, they have remained largely unaddressed in fiscal policy. In most countries, the only taxes on meat are currently value-added taxes, often at reduced rates. What the ‘optimal’ tax level on meat should be depends on which externalities, and other regulatory objectives, are to be addressed. For example, optimal consumption taxes should generally contain a ‘Ramsey taxation element’: inelastic goods should be taxed higher than elastic goods for the general purpose of revenue-raising. The optimal tax level also depends, in part, on specific (and perhaps less familiar) normative positions, such as on animal welfare and improving health, and their consequences for taxing meat. Furthermore, in imperfectly regulated markets, meat taxes have to be designed with remaining uncorrected distortions in mind. To clarify, in a first-best setting, livestock farming and meat consumption, as any other form of agricultural production and food consumption, should be subject to targeted externality-correcting instruments: optimal carbon pricing, nitrogen regulation and ecosystem valuation. In the absence of these options, however, meat taxes can be an attractive second-best instrument to make progress on many regulatory objectives at once, for which livestock production and meat consumption are of primary importance.

Figure 4*: Potential components of a tax on meat and their anticipated sign effect on second-best tax levels, relative to the sum of environmental external costs. Currently, meat is generally only subject to (reduced) VAT.*

POTENTIAL COMPONENTS OF A TAX ON MEAT	**RELEVANT EFFECT**	**IMPACT ON THE TAX RATE +/– relative to baseline**
BASELINE: Environmental damages *(naive tax rate)*	**Sum of social costs from climate change, nutrient pollution and biodiversity loss**	
Environmental second-best interactions	There are synergies between mitigating different environmental damages.	–
	Livestock farming entails indirect land-use and water-use effects on suboptimally regulated resource markets.	+
Health internality *(i.e., privately incurred health damages from eating too much meat)*	Consumers display behavioural failures in food choices.	+
	Consumers may react to higher meat prices by substituting towards other unhealthy products.	–
Animal welfare	Higher meat prices lower returns to self-deception with respect to animal welfare, crowding in social preferences.	+
	Higher meat prices decrease animal populations; under good conditions, additional animal lives may be worth living.	–
Indirect support for 'alternative protein' technologies	There are uncorrected innovation-related market failures for alternative protein technologies.	+
Distributional concern	Tax incidence falls disproportionately on poorer households.	–
	Meat tax is complemented by progressive revenue recycling.	+
	Health benefits from taxing meat fall on poor households.	+
Ramsey tax component	Fiscal revenue generation	+

In addition to the baseline of taxing meat based on environmental externalities, this section explores further motives and second-best considerations for designing meat taxes. *Figure 4* summarizes potential components of a second-best meat tax and their anticipated sign effect on tax levels.

3.1. Interaction of multiple environmental externalities

When regulating a set of simultaneously occurring, overlapping distortions and inefficiencies, economic theory asserts that the optimal policy response is generally different from the sum of its parts. In the presence of at least one persistent uncorrected distortion, any attempt to combine 'regular' first-best policies has no guarantee to increase welfare (Lipsey and Lancaster, 1956). Practically, this means that social costs from multiple inefficiencies (see Figures 2 and 3) cannot simply be added up, but that their interaction needs to be carefully considered: a second-best optimal meat tax under multiple externalities may be more, or less, than the sum of its parts. This point generally holds for multiple market failures and inefficiencies (see also Section 3.2-6); here we first discuss its application to the multiple environmental externalities of meat consumption.

As a simple example, take two prominent environmental externalities of livestock farming, greenhouse gas emissions and nutrient pollution: A fully externality-correcting tax on GHG emissions from livestock will likely have the co-benefit of reducing local nutrient pollution. As has been demonstrated in other contexts (c.f. Parry and Small 2005 for optimal fuel taxes), a tax that simply adds up the Pigouvian tax levels for both local pollution and GHG emissions will be sub-optimally high, as it did not account for the synergistic effect that one tax component has on the other. Despite much quantitative work on co-benefits of climate change mitigation, research on second-best interactions between carbon emissions and local environmental pollution from livestock farming is lacking.

Furthermore, what in environmental science are called 'indirect land-use effects' may have a significant effect on optimal tax design. Animal-based products relate to 83% percent of all agricultural land use (Poore and Nemecek, 2018). Increasing or decreasing meat consumption will therefore lead to a general equilibrium effect on global land markets. This will increase or decrease pressure on other forms of land use (including via export substitution; Hertel 2019, Schwerhoff and Wehkamp, 2018), which are significant drivers of deforestation and biodiversity loss. The same logic may apply to water markets. Importantly, such 'indirect effects' are a second-best consideration because they would need not be taken into account if there were complete, optimally regulated global land and water markets, where appropriate scarcity-weighted prices can unlock unrealised conservation opportunities. However, existing instruments on these markets, such as the international REDD(+) scheme for forest protection, are insufficient in both ambition and coverage. In the absence of optimal regulation on the relevant global markets, livestock farming may therefore excessively contribute to deforestation, biodiversity loss and water scarcity in some parts of the world.

3.2. Health internalities

A growing body of literature in behavioural economics suggests that consumers do not adequately account for the risks to their own health when eating large quantities of meat, resulting in long-term 'internalities' from diet-related disease. Correcting these uninternalized costs on the self is another potential rationale for higher taxes on meat. Corrective taxes on health-related internalities have several precedents in real-world policy. Governments around the world have imposed taxes on products that are widely accepted to be corrosive for public health, including tobacco, alcohol and sugary beverages. The closest example to meat taxation was the tax on saturated fats introduced in Denmark in 2011 (though later repealed). Econometric ex-post analysis shows it led to a significant reduction in demand for selected meat products (Jensen et al., 2015). However, nutritional studies have found that the health outcomes of such taxes critically depend on cross-price elasticities of demand (Mytton et al., 2007), indicating that health-motivated meat taxes need to be carefully targeted to avoid consumers substituting red and processed meat with other unhealthy products.

Treating the negative health effects of meat-heavy diets as an internality (an adverse effect on one's own health) that merits governmental intervention is a distinct normative standpoint that requires careful justification. Specifically, this position is based on the premise that dietary choices do not maximize individual welfare. This is the case when the risk of diet-related disease is not sufficiently known to consumers (incomplete information), or not sufficiently deliberately chosen at the point of consumption. As for the latter, people's diet-related choices can be subject to a multitude of behavioural effects, including lack of willpower, projection bias and time-inconsistent preferences (Griffith, 2018). A crucial question for policy design is whether such 'behavioural failures', similarly to market failures, should entail governmental correction. For welfare economics, this requires, at least a selective relaxation of the standard conception of welfare as utility maximization based on revealed preferences, i.e., the notion that people are best off with what they choose (Bernheim and Rangel, 2009), or an entirely different conception of individual well-being. Some policymakers may actively choose to embrace alternative notions of welfare, such as long-run subjective well-being ("happiness"), or context-specific regulatory objectives for public health, which could justify regulating internalities from meat (over)consumption (Fleurbaey and Blanchet, 2013).

Within public economics, several propositions have been made on the optimal design of corrective taxes in the presence of health internalities (Allcott et al., 2019; Griffith et al., 2018, 2019; van den Bijgaart et al., 2020). As far as these results are transferable to the case of meat taxation, we can expect that the second-best tax rate on meat increases with the magnitude and pervasiveness of internalities in the population, and the responsiveness of consumers to meat price changes. Depending on distributive considerations, the optimal internality tax may increase if low-income households display stronger diet-related behavioural failures and are more elastic to price changes compared to the rest of the population.

Irrespective of one's position on the normative question of internality correction, behavioural biases in dietary behaviour complicate the regulation of meat. Such biases may also impact whether taxation is successful in changing food choices, which suggests further non-market-based interventions. Simultaneous failure of markets and consumer behaviour pervade many applications of environmental economics, including residential energy efficiency (Lindén et al., 2006), car markets (Greene et al. 2011) and unhealthy low levels of physical activity in urban transport (van den Bijgaart et al., 2020). Meat consumption thus provides another key example of an 'environmental-behavioural second-best problem' (Shogren and Taylor, 2008).

3.3. Animal welfare

There seems to be a broad consensus in most societies that if animals are reared for human consumption it should be done in such a way that they do not suffer high levels of pain or distress prior to slaughter. Some go further and believe meat production and consumption is ethically unacceptable. Calls for higher animal welfare standards have increased in recent decades, especially in high-income countries, while an ethical unwillingness to consume meat is one of several reasons for a modest increase in the number of people identifying as vegetarians or vegans. This issue is particularly complex as while animal science is increasingly able to define and measure physiological proxies for welfare, the nature of animal emotions and cognition remain elusive (Dawkins, 2012; Broom, 2014).

There is evidence that many people care about animal welfare and are willing to pay a premium for more welfare-friendly meat (Clark et al., 2017). However, there are several reasons why society's aggregate wish for a certain standard of animal welfare may be frustrated in the absence of regulation. First, consumers may not have access to point-of-sale information about the welfare status of different meat types, and where welfare labelling exists, they may not have the time or ability to act on it, or may not trust it. Second, consumers concerned about overall standards may be unwilling to pay a price premium for high-welfare meat in the presence of free-riding by others. Finally, there may be a preference gap between what consumers state they wish and real purchase decisions (Grethe, 2017). Psychological literature shows consumers may display cognitive dissonance, holding unrealistic beliefs that they are simultaneously supporting high welfare standards but buying cheap meat (Bastian and Loughnan, 2017). The extent of this cognitive dissonance can be influenced by meat prices: higher prices lower the returns from self-deception and hence magnify the price elasticity (Hestermann et al. 2020).

In practice, many countries set a regulatory base for minimum animal welfare standards. Regulation stops the worst abuses and may be cheaper for the industry than more complex fiscal interventions. Nonetheless, there are two rationales for levying meat taxes to drive standards beyond the regulatory minimum:

First, if society decides it wishes for a level of animal welfare above that provided by the market, then it may choose to use fiscal instruments to raise standards. Just as unaddressed market failures lead to the suboptimal provision of animal welfare as a public good, so the behavioural and other limitations described can be seen as distortions leading to the suboptimal provision of “merit goods” (Besley, 1988). It then remains a question of second-best modelling whether the desired level of animal welfare is optimally provided by tighter standards, animal welfare subsidies or taxes on meat. For example, higher meat prices could crowd in social preferences by stipulating realism about animal welfare and mitigating behavioural limitations. Moreover, meat taxes generate fiscal revenue, a part of which could be redistributed to livestock farmers to help them improve rearing conditions, as has been recently discussed in Germany under the term "animal welfare levy”.

Second, there is a long tradition in philosophy that animal welfare should matter intrinsically and not just be determined anthropocentrically by society’s preferences (Bentham 1780, Singer 1975). In a recent addition in welfare economics, there have been propositions how animal welfare could be incorporated within an expanded multispecies utilitarian social welfare function (Johansson-Stenman 2018), though to do so objectively remains a challenge for current animal behavioural science. Blackorby and Donaldson (1992) pioneer a two-species model in which humans derive utility from eating animals, while society cares about the welfare of both humans and of animals. Note that, from a perspective of population ethics, further potential animal lives are not generally neural. Reducing meat production, however, means that there are less animals. Espinosa and Treich (2020) suggest that, if rearing conditions are sufficiently good so that a further potential animal life creates additional welfare, a meat tax could be welfare-reducing.

3.4. Development and adoption of ‘alternative protein' products

A reduction in the consumption of meat is likely to be accompanied by a shift to meat substitutes, which in general have a lower environmental impact, especially when they are plant-based (Smetana et al, 2015). There is a large variety of such substitutes, ranging from unprocessed foods such as beans or lentils, to more processed plant-based products (meat analogues) such as tofu and Quorn, to novel products such as lab-based, or 'cultured' meat[12]. However, for the most novel products information about upscaling is not yet available. Over the past decade, continued innovation has allowed for the commercialization of a larger variety of meat analogues, many with a close semblance to meat, such as the 'Beyond' and 'Impossible' burgers. The first proof of concept of cultured meat was showcased in 2013: a burger reputed to have cost over $250K. Costs have already decreased substantially but much uncertainty remains around the costs of mass production (Rubio et al. 2020, Treich, 2021).

By further encouraging the uptake of meat substitutes, the introduction of a meat tax, as an indirect alternative to higher R&D subsidies, could accelerate the development and commercialization of cultured meat and meat analogues. This indirect effect of meat taxes on innovation might be a justification for higher present-day taxes on meat consumption. There are several reasons for this. First, evidence from other domains suggests that innovation spillovers are particularly high for novel products (Dechezleprêtre et al., 2017) and in R&D-intensive industries (Bloom et al, 2013). Second, the development of cultured meat and meat analogues makes a durable shift away from meat more likely. In addition to providing cheap and desirable alternatives to meat, support for innovation in meat substitutes can act as a commitment device for policymakers (Harstad, 2020). Conversely, in the absence of an 'appropriate' price for meat, there exists a rationale for either subsidizing the consumption of meat substitutes or setting subsidies on meat substitute R&D in excess of the Pigouvian level, by analogy to second-best subsidies in the absence of adequate carbon pricing (Acemoglu et al. 2012; Kalkuhl et al., 2012).

Meat taxes can encourage the uptake of alternative protein products by decreasing their relative price and thereby making them more competitive with conventional meat products. The success of meat alternatives, however, will to a large extent depend on the degree of substitutability between meat and alternative protein products, with those that are cheap and have the taste and "mouth-feel" of meat more likely to gain the largest market share (Carlsson et al., 2021). Moreover, the public perception of meat alternatives matters, including whether alternative protein products may not be perceived as "wholesome" or "natural", and the fact that the consumption of meat has a strong cultural component which alternative proteins may not be able to replace. Lab-grown meats might

[12] The terminology around these innovations is still in flux and depends on the narratives and motives of different stakeholders. While some producers in the field of cellular agriculture pushed for 'clean meat', suggestive of a not further defined set of positive properties, the academic discourse largely converges on the more neutral and broad term 'alternative proteins', which we use alongside 'meat substitutes' (Sexton, Garnett and Lorimer, 2019).

fare better on the second point eventually. They are, however, likely associated with similarly detrimental health impacts as the products they seek to replace, whilst unprocessed plant-based protein sources are already readily available and associated with both health benefits and low environmental impacts (World Economic Forum, 2019).

3.5. Distributional effects

A frequent concern about meat taxes is that the tax burden would fall disproportionately on low-income households, as these spend a larger share of their income on food. This raises the question of whether a meat tax should be adjusted for distributional effects.

The fact that relative spending on food falls with rising income is one of the most repeatedly verified relationships in economics. This so-called Engel's Law is a main argument behind reduced VAT rates on foodstuffs in many countries and also at the basis of distributional arguments against carbon taxation (Grainger and Kolstad, 2010). Empirical studies have shown that, in most European countries, for the weighted EU-average and for the US, the relationship of relative meat expenditure with income follows Engel's Law (see Figure 5; Klenert et al. 2021; Bureau of Labor Statistics, 2020).

If meat taxes are differentiated by meat type, for example if they are based on emission intensity, their distributional effect additionally depends on how households allocate their expenditure across different meat types. The tax burden can be expected to be high especially for those groups in society that predominantly consume meat types with high social costs (e.g. beef). For EU countries, Klenert et al. (2021) show that relative expenditure patterns on different meat types vary significantly. For instance, due to the peculiar, inverted U-shape of the relative beef expenditure curve in France, a GHG-intensity-based tax would affect the three middle quintiles most, as they spend a larger part of their expenditure on beef than the lowest and the highest quintile. By comparison, a tax on poultry would likely be strongly regressive in France as relative poultry expenditure follows the typical Engel’s Law shape.

Beyond partial equilibrium distributional impacts, a complete assessment of the distributional consequences of meat taxes would also need to take into account the heterogeneity in households’ responses, general equilibrium effects and the use of the meat tax revenue. A tax on meat differs in its impact from other environmental taxes, in that consumers can immediately substitute away from the taxed goods, without major investments or suffering adverse effects. This implies a stronger

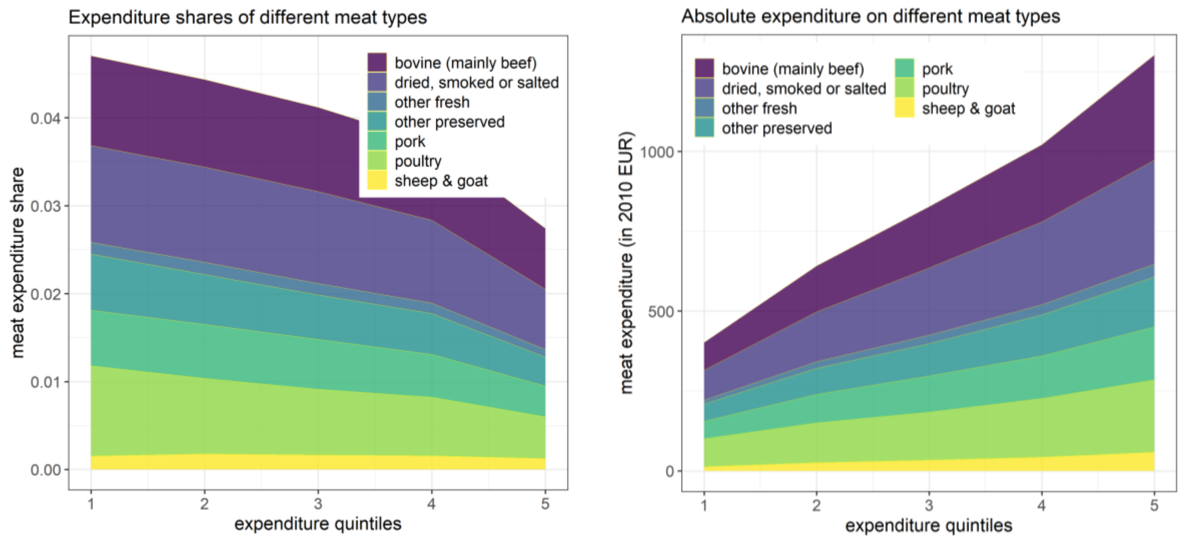

Figure 5: *Relative and absolute expenditure shares on different types of meat across expenditure quintiles for the European Union (country-weighted EU aggregate). (Source: Klenert et al. 2021)*

demand reaction to meat taxes compared to, for example, fuel taxes, particularly for low-income households, and hence a higher price elasticity. Due to their stronger reaction to price increases, low-income households might more than proportionately benefit from the long-run health effects from reduced meat consumption. Allcott et al. (2019) argue that the more health benefits are skewed toward low-income consumers the greater the justification for increasing the tax on unhealthy products such as meat, which is in line with Springmann et al. (2017, 2018), who estimate the greatest health benefit for populations with the greatest dietary shift away from meat products.

In optimal environmental taxation models that feature heterogeneous households, a frequent outcome is that externality taxes should not be corrected for their distributional impact, as it can be better offset by adjusting the tax and transfer system (Jacobs and de Mooij, 2015). This result depends on the marginal social value of government vs. private funds: Only if they are equal, income and environmental taxes can be set independently. Whether or not this is the case, depends on several assumptions, such as which policy instruments are available to bring about redistribution, and the shape of the utility function (Jacobs and van der Ploeg, 2019). When policy instruments such as income taxes are not at their optimum, the marginal social value of government funds does not equal that of private funds (Jacobs, 2018) and the separability between externality and income taxes does not hold anymore (Sandmo, 1975). This might justify corrections to optimal externality taxes for distributional reasons or additional policies aimed at offsetting the potential regressive effect of the tax.

Further work in environmental taxation has studied the distributional outcomes of taxes combined with revenue recycling. Applying the conclusions of such work to meat taxes suggests that the use of the tax revenue can make meat taxation packages more progressive. If relative spending on a good decreases with income, but absolute spending increases, taxing this good and returning the revenue as a per-capita lump-sum is progressive (Klenert and Mattauch, 2016). Hence, the simplest way of balancing the potentially regressive initial distributional effects of a meat tax would be uniform lump-sum redistribution of the revenue (Rausch et al., 2011). If that is politically infeasible, using the revenue to further cut the reduced VAT rate on food, or to subsidize fruit and vegetables (Springmann et al, 2017), would also be progressive; however, additional analysis would be required to determine whether this fully offsets the initial regressive impact of the tax.

Finally, and most speculatively, meat taxation in high-income countries may have overall positive impacts on global food security. Animal products have large opportunity costs (Shepon et al., 2018): some of the land used for livestock grazing and animal feed could be used to produce plant-based food for humans. Reducing meat production would thus increase production possibilities of other foods and lower global food prices. This could benefit consumers in the global south – especially the increasing fraction of urban dwellers who are more connected to global markets than the rural poor.

4. Discussion

In a second-best setting, meat taxation is an attractive instrument because it advances many regulatory objectives at once, even if only partially. Nevertheless, meat taxes may need to be complemented by direct regulation and subsidies. The role of taxes within a broader policy package to support sustainable meat production and consumption also depends on their political feasibility.

4.1. Demand- or supply-side regulation?

While policymakers usually have a choice between taxing meat at the source or levying consumption taxes on final products, the second-best meat tax that we have been assessing is a downstream tax by design. One advantage is that consumption taxes can ease competitiveness concerns, as they would affect meat from all sources and reduce the risk of domestic producers being undercut by imports from countries with lower environmental regulations. Compared to other polluting industries, upstream entities (i.e. farms) in the livestock sector are also comparatively small and scattered, resulting in high monitoring costs for farm-specific pollution and animal husbandry conditions. In the presence of high monitoring costs, Schmutzler and Goulder (1997) have demonstrated that consumption taxes may be more efficient, if production-side abatement options are limited and the taxed goods can be easily substituted. For the climate externalities specifically, there is evidence that potential efficiency gains on the production side are ultimately constrained, at least in light of net-zero requirements (Wirsenius et al., 2011; Clark et al. 2020). Given the scale of the regulatory issues and the potentially uncompromising constraints on input factors such as agricultural land expansion, it can more generally be assumed that per-capita meat demand needs to decline, justifying a strong emphasis on demand-side solutions.

Nevertheless, a marked disadvantage of consumption taxes on meat is that they neglect potential efficiency gains at the source. Where efficiency gains are significant (e.g. animal welfare and prevention of antimicrobial resistance) or highly localized (e.g. deforestation hotspots), complementary policies are needed to incentivize necessary transformations. Moreover, a second-best meat tax does not resolve trade-offs between different regulatory goals. For example, while some extensive forms of livestock rearing will benefit animal welfare, they may aggravate certain environmental damages. Likewise, 'cultured meat' innovations may help consumers to substitute away from products which are environmentally harmful but may not alleviate the disease burden that is associated with red and processed meat, no matter whether it is lab-grown or not. Finally, the necessary transformations in the livestock sector cannot be achieved without adjusting existing supply-side policies, including reform of former direct and current indirect subsidies, as for example under the European Union's Common Agricultural Policy.

4.2. Political economy considerations

The FAO (2020) estimates that the livestock industry makes up 40 percent and 20 percent of agricultural output in developed and developing countries respectively, and globally provides livelihoods for 1.3 billion people. Attempts to change the fiscal status of livestock products will be resisted by major vested interests, and there is the potential for unintended consequences that affect the wellbeing of large numbers of people, especially those on low income. Understanding these political economy constraints, and avoiding or mitigating undesirable negative trade-offs, will increase the chances that interventions with net societal benefits are also politically feasible.

Revenues generated from meat taxes could be assigned to correcting market failures in a way that both benefits current livestock producers and produces societal benefits. For example, farmland currently used for livestock might, with lower stocking density or conversion to other uses, provide a variety of provisioning, regulating or cultural ecosystem services that justify public payment. Rewarding farmers more generously for the public goods provided by their farmlands, while incentivizing more sustainable land uses, could be an effective and equitable way to ease opposition to more stringent regulation. For instance, Gren et al. (2021) demonstrate for Sweden that assigning the revenues of a climate tax on food products to farmers for selected ecosystem services, such as peatland restoration for enhanced carbon sequestration, can significantly enhance the environmental effectiveness of the tax policy, while also increasing the net income of farmers.

Consumer elasticities for food and other livestock products are personally and culturally derived. It may be that as the environmental and health externalities of meat consumption and production become more apparent, consumer behaviour and preferences eventually evolve so that individuals eat less but more expensive meat. The success of some niche premium brands marketed on both quality and environmental sustainability suggests a pathway to a more radical change in the meat sector, which might also provide a sustainable future to the livestock industry.

4.3. Public support and cultural dynamics of food choice

Meat taxes could be met with strong public opposition. In the context of a survey of citizens' preferences for climate policy in France, Douenne and Fabre (2020) have found that meat taxes are one of the most unpopular measures, with only 17 percent of French respondents supporting them. It is unclear whether that is because citizens are unaware of the mitigation potential of changing meat consumption patterns, sceptical of the 'Pigouvian' effectiveness of meat taxes or feel that their 'way of life' and cultural identity are being attacked.

Nevertheless, the design of actual meat taxation policies can be modified to increase public support. Work on public support for carbon pricing suggests that the framing of the tax proposal and use of revenues are decisive determinants for getting citizens on board (Klenert et al., 2018). In a study of German, US American and Chinese citizens, Fesenfeld et al. (2020) demonstrate that policy packaging can enhance support of meat taxes. The public support for taxes has been highest when they were at a moderate level and combined with popular policies such as animal welfare standards, discounts on vegetarian meals and information campaigns. More ambitious meat taxes can also be made more appealing by simultaneously lowering agricultural subsidies to meat farmers, introducing more stringent farming standards, and using tax revenue to support low-income households.

Another concern is how meat taxes will influence social preferences for voluntary meat reduction. Research on motivations to reduce meat consumption because of biased-beliefs on animal welfare suggests meat taxes may crowd in social preferences, by lowering the returns to self-deception (Hestermann et al. 2020). This suggests that even moderate meat taxes may have a leveraged impact by making the uninternalized social costs embedded in meat products more visible to consumers. After all, consumption habits matter in explaining meat demand (Holt and Goodwin, 1997). When dietary preferences are endogenous, there is also a rationale to complement meat taxes with broader changes in the retail and food-consumption environments experienced by consumers to harness the dynamics of socio-cultural dietary choice and so make meat-reduced diets more attractive (Hawkes et al., 2015; Mattauch, Hepburn & Stern, 2018).

5. Conclusion

Environmental science and economic analyses lead us to conclude that meat is significantly underpriced when the relevant externalities are properly costed, though precisely by how much is currently unknown. It seems highly desirable to provide policymakers and society with as accurate an estimate as possible of true costs, as the level of meat consumption is an important factor affecting the scale of and responses to some of the greatest environmental problems of our time. Consumption taxes on meat can help mitigate some of these negative environmental effects while, in addition, promoting public health as high levels of meat consumption are associated with increased risk of a number of diseases.

Our review indicates that, as a lower bound, the global environmental social costs, when they are added up, are on average between 5.76-9.21 USD/kg for beef (depending on the production of dairy by-products), 3.71 USD/kg for lamb and mutton, 1.94 USD/kg for pork and 1.51 USD/kg for poultry (see Figure 2). This estimate is likely conservative as it does not include the social cost of attributable biodiversity loss and health effects from livestock-related air pollution. The average retail price for beef in high-income countries in 2017 was 16.53 USD/kg (10.49 USD/kg for pork; 19.04 USD/kg for lamb; 6.15 USD/kg for poultry) (World Bank, 2020). As noted above, optimal taxation theory requires careful consideration of interaction effects when modelling tax levels. Nevertheless, as a first 'ballpark estimate' (i.e. ignoring interaction effects), our review suggests that an environmental tax on meat in high-income countries would at least increase its current retail price between roughly 20-60%, depending on meat type. Including the valuation of privately incurred health effects would approximately triple the appropriate tax on unprocessed beef.

Our review further indicates that progress in environmental economics is needed to understand the economic damages from animal agriculture and design optimal meat taxes. Economic valuation of the consequences of biodiversity loss driven by livestock farming is scarce, both due to a lack of comprehensive and comparable impact assessments that can be extrapolated to a global scale, and due to the lack of robust social cost estimates for biodiversity damages. Indirect land-use effects, arising from the additional pressure that livestock puts on land expansion and deforestation in suboptimally regulated global land markets, may significantly add to the direct environmental damages from livestock production and consumption of animal-based products. Further, second-best modelling of taxes and other instruments could elucidate the interplay of environmental regulation, diet-related adverse health effects of meat consumption and distributional effects. A nascent literature in welfare economics, moreover, has explored the role of animal welfare in economic valuation, clarifying the impact of different normative possibilities and the interplay between meat taxes and improvements in animal welfare standards.

We call for further research in public economics to disentangle and quantify the effects of related normative positions on animal welfare and diet-related health. With more meat-reducing policies such as consumption taxes being introduced, econometric approaches to evaluating such policies by causal inference methods is another important space for future research. Finally, technologies for alternative proteins and meat substitutes will impact the demand for meat this decade: while estimates of their expected cost-decreases exist, further research should examine how these alternatives to meat are best fostered by regulation, given livestock's importance in multiple global environmental problems.

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Supplementary Material

S1 Economic valuation of environmental externalities

Our valuation of environmental externalities of meat (see Figure 2) draws from existing research in lifecycle analysis (LCA) and relevant social cost(-benefit) analysis in environmental economics. While previous research has looked into the social costs of carbon associated with animal products (e.g. Pieper et al., 2021; Cline, 2020), our review is the first to make a preliminary attempt at bringing SCC valuations of livestock impacts together with the social costs of nitrogen pollution, for which economic valuations are still comparatively scarce and hence subject to large uncertainty. Including biodiversity in this assessment is currently beyond reach primarily because relevant life-cycle analysis (at a global level) is lacking.

We further note the limitations of using LCA as a point-in-time assessment of environmental damages in social cost-benefit analysis. In the future, modern state-of-the art econometric methods (Burke et al. 2015, Dell et al 2018), could be used for better estimation of the environmental impacts from meat consumption, potentially then extended to nutrient pollution and biodiversity loss. Eventually, such models could also be used to obtain improved social cost estimates (for carbon, see Ricke et al. 2018).

Environmental impacts

Environmental impacts in per-kilogram for Figure 1 were obtained from Poore and Nemecek (2018) based on a meta study of life cycle analyses. Poore and Nemecek provide environmental impact estimates based on emissions across the entire value chain of the food system, including processing, transport, packaging and retail. Assuming that (at least part of the) greenhouse gas emissions from these latter categories will be subject to carbon pricing, or other climate policy instruments, we only included direct agricultural GHG emissions (at the farm stage, from animal feed and land-use change). For eutrophication and acidification, separate disaggregate data for the agricultural stage were not available. Across all three impact categories, food system emissions and pollution from processing, packaging, transport and retail were, however, comparatively small (around 18% of all food system emissions for GHG emissions and acidification, around 3% for eutrophication; Poore and Nemecek (2018), Supplement S17).

Social Cost of Carbon (SCC)

We obtain our central value of the social costs of carbon (100.67 USD/kgCO2) from an average of the central estimates by Pindyck (2019), Hänsel et al. (2020) and Cai et al. (2016). As a lower bound, we use 40 USD/kgCO_2 (Nordhaus, 2018; van den Bijgaart et al., 2016). The upper bound is 417 USD/kgCO_2 (Ricke et al., 2018).

Table T1: Summary of SCC estimates, adapted from van den Bijgaart et al. (2020)

Source	SCC range	2017 USD/tCO_2
Nordhaus (2018)	25.4-157.5	41.3
Pindyck (2019)	80 - 100	90
Hänsel et al. (2020)	16.2 - 494.4	96
Cai et al. (2016)	50-166	116
Ricke et al. (2018)	177 - 805	417

Social costs of nutrient pollution

Social cost estimates for nutrient pollution are scarce, and hence subject to large uncertainty. Our analysis is based on The European Nitrogen Assessment (Brink et al., 2011) and CE Delft's Environmental Prices Handbook for the EU28 (2015). The obtained values are hence specific to the European Union and may not necessarily be transferable to other geographies. Brink et al. (2011) derive their estimates from a meta-analysis of peer-reviewed case studies. CE Delft (2015) provides average environmental external costs for pollution source in the EU28 in 2015. Chemical units were converted to make values comparable to the relevant LCA units from Poore and Nemecek (2018) – kgSO_2 equivalents and kgPO_4 equivalents. Our central value for the social costs of eutrophication is 5.04 USD/kgPO_4e (as an average of Brink et al. and CE Delft), with a range of 2.13 – 12.73 USD/kgPO_4e. Our central value for the social costs of acidification is 20.9 USD/kgSO_4e (as an average of Brink et al. and CE Delft), with a range of 6.97 – 34.83 USD/kgSO_4e (see Supplementary Data). For consistency with the social costs of carbon, the estimates were converted to 2017 USD.

Table T2: Summary of estimates for the social cost of eutrophication

Source	Eutrophication	
	Social cost range	*Central value*
Brink et al. (2011)	5–20 €/kgN (N-runoff)	12.5 €/kgN (N-runoff)
CE Delft (2015)	N/A	1.86 €/kgPO_4-e (freshwater) 3.11 €/kgN (marine)

Table T3: Summary of estimates for the social cost of acidification

Source	Acidification	
	Social cost range	*Central value*
Brink et al. (2011)	2–10€/kgN (N-deposition)	6 €/kgN (N-deposition)
CE Delft (2015)	N/A	4.95/kgSO_2-e

Difficulties with estimating Social Costs of Biodiversity Loss

The difficulty of obtaining social cost of biodiversity impacts from livestock stems both from a lack of appropriate measures in lifecycle analyses, and a lack of robust economic valuations of biodiversity loss at a global and disaggregate level. While there are inherent difficulties with reducing biodiversity impacts to a single metric (for example in lifecycle analysis), measures such as Mean Species Abundance (MSA) or Potentially Disappeared Fraction (PDF) could make biodiversity assessments more comparable in the future, and allow, at least in approximation, for global impact assessments (FAO, 2019).

S2 Discussion of Health Valuations

Value of Statistical Life

We use the value of statistical life (VSL), a measure eliciting the willingness to pay for mortality risk reduction as a way of quantifying the value society places on a life. It is commonly used in cost-benefit analyses, to convert lives saved from healthier diets to $ amounts, and the most common measure to estimate the privately incurred harm from unhealthy choices, focussing on mortality risk, not morbidity.

It is well-known that the VSL differs across countries and settings due to a variety of factors. For example, Moran and Monje (2016) place a central value of VSL used for the US at $9.26 million, with a range of $5.4m-13.4 million. The WHO puts a central value of VSL for the UK at a more conservative, $4.36 million with a range of $2.2m-12.6 million (Thomas, 2020).

Figure 3 is based on values from Springmann (2020), and the left-hand side uses the VSL values from OECD (2012) and Lindhjem et al. (2011). Following OECD recommendations, this implies a VSL base value for the EU-27 of USD 3.5 million, and we then used a benefit-transfer method to calculate VSLs in other high-income regions (see Springmann et al. 2016).

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