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Animal Welfare, Moral Consumers and the Optimal Regulation of Animal Food Production

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Abstract

Within a general equilibrium model, this paper identifies a novel animal welfare externality that occurs if the private animal friendliness in a market economy falls short of the social animal friendliness used by the social planner when determining the efficient allocation. The animal welfare externality causes an inefficiently high quantity and an inefficiently low quality of animal food. Correction of this market failure is attained by taxing animal food output and subsidizing animal food quality. With consumer and producer heterogeneity, regulation is the same but sector-specific, with a more intense regulation in the sector with the worse living conditions of animals.

JEL-Codes: D620, H200, Q180.

Keywords: animal welfare, altruism, morality, non-anthropocentrism, meat tax, subsidy on animal food quality.

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1 Introduction

Over the last decades, animal welfare aspects of the production and consumption of animal food have received increasing attention. In many European countries, public concerns for animal welfare are by now substantial. For example, more than 80% of the Europeans find it important to protect the welfare of farmed animals, believe that animal welfare should be better protected and find the current legislation insufficient to adequately account for the animals' well-being (European Commission, 2015, 2022). In addition, more than 50% of the EU citizens are willing to pay more for animal-based food, if the food is produced under conditions satisfying certain standards concerning the animals' living conditions in animal farming (European Commission, 2015). The consumers' concerns with respect to animal welfare in animal food production are similar in the US, Latin America and China (Wolf et al., 2016, Miranda de la Lama et al., 2017, and Su and Martens, 2017).

Against the background of this recent development, the present paper identifies a novel animal welfare externality that causes market failure and has to be corrected by governmental intervention. Our key argument is that there may be a deviation of the *private animal friendliness* from the *social animal friendliness*. The private animal friendliness measures the degree to which the individual consumer takes into account animal welfare in her market decisions. It is determined by the degree of the consumer's altruism towards animals and the degree of morality that the consumer applies in her food consumption decision. The social animal friendliness measures the degree to which the social planner takes into account animal welfare when determining the efficient allocation. It may reflect altruism and morality of consumers as well as an additional non-anthropocentric welfare weight on animal welfare. We identify plausible conditions under which the private animal friendliness falls short of the social animal friendliness, implying a too high animal food consumption with too bad living conditions of farmed animals in the laissez-faire market economy. Correction of this market failure is attained by taxing animal food output and subsidizing animal food quality. With consumer and producer heterogeneity, regulation is the same but sector-specific, with a more intense regulation in the sector with the worse living conditions of animals.

These results are brought forward in a stylized general equilibrium model of animal food production and consumption, taking explicitly into account animal welfare. On the production side, animal food is produced with the inputs labor and land, and the output animal food is proportional to the animal population used in food production. The welfare of an individual animal held for farming is always negative, but improves by better living conditions of animals which is measured by the inverse of the stocking density. The latter

indicator equals the units of land input per animal and is denoted as the quality of animal life or, equivalently, as the animal food quality. It is a food characteristic that is endogenously determined in the farming process. On the consumption side, we assume a large number of consumers that have preferences regarding the quantity and the quality of animal food. In addition, consumers may be altruistic towards animals, i.e. may receive utility from animal welfare, and they may behave morally with respect to their animal food consumption. As a homo oeconomicus, the individual consumer takes the altruism utility as exogenously given, while as a homo kantianus, the consumer views the altruism utility as endogenous and follows the Kantian categorical imperative to 'do the right thing' in the sense that one should take that and only that animal food consumption that one would advocate all other consumers to take as well. Given these two extreme cases, we follow the modeling of Alger and Weibull (2013, 2016, 2020) and assume that the individual consumer is a homo moralis whose utility is a convex combination of the homo oeconomicus utility and the homo kantianus utility, where the convexity parameter determines the degree of the consumer's morality.¹

Within this model, we compare the efficient allocation with the market allocation in a decentralized economy where demand and supply for animal food quality is guided by an indirect hedonic price à la Rosen (1974). We start with the case where all consumers and producers are identical. In making her market decision, the individual consumer then applies a private animal friendliness that reflects her degree of altruism and morality. In determining the efficient allocation, the social planner takes into account the social animal friendliness which equals the non-anthropocentric welfare weight of animals plus the degree to which the social planner takes into account the altruism utility of consumers. The social planner may completely ignore altruistic preferences in order to avoid double counting of animal welfare in the social welfare function or she may take into account (at least a part) of the consumers' altruistic utility in order to recognize that altruism may constitute a separate component of individual utility. In general, the private animal friendliness in the market economy deviates from the social animal friendliness and thereby gives rise to the animal welfare externality that causes market failure and necessitates governmental intervention.

Even though we cannot exclude that private animal friendliness exceeds social animal friendliness in our formal model, we argue that under plausible assumptions the private animal friendliness is lower than the social animal friendliness. In the laissez-faire economy, animal food consumption is then inefficiently high and animal food/life quality is inefficiently low. To correct this market failure, we identify several policy options. All options contain

¹An alternative approach to model morality is the concept of a Kantian equilibrium developed by Roemer (2010, 2015) and applied by, for instance, Grafton et al. (2017).

at least one tax instrument and one subsidy instrument. While the tax brings down the inefficiently high quantity of animal food, the subsidy corrects the inefficiently low quality of animal food/life. The tax is levied on the output of animal food production. It can be combined by alternative subsidy instruments, for example, a direct one-time or yearly subsidy on the animal food/life quality, a subsidy on the land input in animal food production or a subsidy on the animal food/life quality per unit of the animal food. With the latter subsidy, the net tax revenue of the optimal tax-subsidy scheme is strictly positive, since animal welfare is negative, implying the need for a net tax burden on animal food production, even if the animal welfare externality is completely internalized by regulatory measures.

In an extension with consumer and producer heterogeneity, we generalize our analysis to two groups of consumers and two production sectors. We distinguish between factory farming and outdoor husbandry farming. Consumer groups differ with respect to their degree of altruism and morality. In this extension, the laissez-faire economy is again inefficient due to the animal welfare externality, which may now be different for the two types of animal food. Basically, we show that market failure can be corrected by the same tax-subsidy solution as in the initial model with identical consumers and producers, but the heterogeneity of the animal welfare externality now renders the optimal regulatory policy sector-specific. When comparing the optimal tax and subsidy rates across sectors, not only the deviations of private from the social animal friendliness but also the marginal per-animal welfare and the marginal quality-weighted animal welfare play an important role. Under plausible assumptions, it turns out that the animal welfare externality of factory farming is greater than the animal welfare externality of outdoor husbandry farming. As a consequence, factory farming has to be more strongly regulated such that the tax and subsidy rates levied on factory farming are greater than the corresponding tax and subsidy rates imposed on outdoor husbandry farming. We even identify a special case, where outdoor husbandry farming implements the efficient allocation already under laissez-faire and, thus, needs not to be regulated at all, whereas the policy instruments levied on factory farming are still strictly positive and effectively transform this sector into outdoor husbandry farming.

In general, the animal welfare externality and the need for regulation identified in our paper comes from the deviation of private and social animal friendliness. The constellation that the private animal friendliness falls short of the social animal friendliness turns out to be the more likely, (i) the higher the non-anthropocentric welfare weight of animals in the social welfare function, (ii) the larger the degree to which the social planner takes into account the altruistic utility of consumers and (iii) the more the degree of the consumers' morality lies below 100%. A substantial non-anthropocentric welfare weight of animals as

required in condition (i) may be motivated on philosophic grounds. For example, it is often argued that animals are sentient beings capable of subjective feelings by means of their senses (Ng, 1995, Treich 2022). Hence, their happiness or suffering should be mapped into the social welfare function. Condition (ii) is controversial since, on the one hand, taking into account the consumers' altruistic preferences in the social welfare function may imply double counting of animal welfare (e.g. Milgrom, 1993, Harsanyi, 1995) and, on the other hand, ignoring the consumers' altruistic preferences in the social welfare function may be viewed as paternalistic (e.g. Cremer and Pestieau, 2006). But the truth probably lies somewhere in between, implying that the social planner should take into account at least a part of the consumers' altruism utility in her decision. Finally, condition (iii) is also rather likely. Even though at the beginning of the Introduction we argue that consumers have become more moral over the last decades, there is of course still a large share of consumers that do not behave morally at all, so the average degree of morality should clearly be below 100%.

The optimal tax-subsidy scheme which our formal analysis identifies for correcting the animal welfare externality is closely related to the current policy discussion in practice. Many governments have adapted or are currently thinking of introducing regulations concerning animal welfare. One of the most prominent policy instruments often justified by the improvement of animal welfare is the meat tax, which levies a surcharge on each unit of meat produced by farmers and is currently intensively discussed, for instance, in Germany and France (Bryant, 2022). In addition, the EU has adopted several directives that lay down minimum standards for the protection of animals in the farming purposes, and from 2014-2020 the EU provided financial assistance from the Common Agricultural Policy for farmers who take measures that go beyond the mandatory standards (Vogeler, 2019). Very similar, following the recommendation of the so-called Borchert-Kommission, a commission deployed by the German Federal Ministry of Food and Agriculture (see German Federal Ministry of Food and Agriculture 2020), the German government has agreed to spend almost one billion euros for the period 2023-2026 to transform factory farming into production systems with better living conditions of animals, such as outdoor husbandry. One of the most favored policy instruments is an animal welfare premium per animal, presupposed animals are held under animal-friendly living conditions. To finance the expenditures for the premium, the Borchert-Kommission inter alia has proposed to abolish the reduced VAT rate applied to many food products or to introduce an animal welfare fee in form of an additional meat tax (Spiller and Kühl 2022). These fiscal policies on the national and supranational level may be summarized as taxing meat consumption and subsidizing the animals' living conditions, a tax-subsidy combination which is also the result of our formal analysis. Interestingly, at least

in Germany, it has been proposed to design the meat tax such that it is revenue-neutral and, thus, just covers the expenditures for the quality premium per unit of animal. In contrast, we show that the net governmental revenue of such a policy should be strictly positive.

There is a small but rapidly growing economic literature on animal welfare consideration. Our paper is related to different strands of the literature. First, animal welfare has been introduced into economic models by Blackorby and Donaldson (1992), Eichner and Pethig (2006), Johansson-Stenman (2018) and Espinosa and Treich (2021). These papers include animal welfare into the utilitarian social welfare function and explore the comparative static effects of the animal welfare weight on the socially optimal consumption of animals and animal welfare. Hestermann et al. (2020) turn to a positive analysis and characterize the effects of meat prices on meat consumption in a behavioral-economic model where consumers have beliefs about how strongly animals are harmed in food production. Second, on a more applied level Frey and Pirscher (2018) estimate the marginal willingness-to-pay for animal welfare, while Lusk and Norwood (2011, 2012) examine animal welfare as a public good and outline cost-benefit analysis including farm animals. Third, Bonnet et al. (2020) and Funke et al. (2022) non-formally summarize arguments for meat regulation on the basis of health, environmental and animal welfare aspects. To the best of our knowledge, however, the novel animal welfare externality and the corresponding optimal regulatory scheme that represent the main contribution of our paper have not been studied so far in the literature, neither from a theoretical nor from an empirical point of view.

The remainder of this paper is organized as follows. Section 2 outlines the basic model and Section 3 characterizes the efficient allocation. Section 4 analyzes the decentralized market economy, identifies market failure due to the animal welfare externality and determines the optimal regulatory scheme. In Section 5, we extend the model to two heterogeneous groups of consumers and producers, respectively. Section 6 concludes.

2 The model

Consider an economy where *animal food* is produced in quantity y^s with ℓ_y^d units of the input labor and r_y^d units of the input land according to the convex technology²

$$y^s = Y(\ell_y^d, r_y^d), \tag{1}$$

²We use the convention that lower-case letters represent variables or parameters. The superscripts s and d indicate quantities supplied and demanded, respectively. Upper-case letters are reserved for functions and subscripts attached to them indicate derivatives. In denoting a sum, we use \sum_j as short-cut for $\sum_{j=1}^n$.

with $Y_r > 0$, $Y_\ell > 0$. The perhaps most important example of animal food is meat, but our analysis is also applicable to other kinds of animal food like eggs or milk as well as to animal-based products in cosmetics and clothing. Animal food is proportional to animal biomass which, in turn, is proportional to the animal population. Therefore, we simply take y^s to denote both the quantity of animal food as well as the animal population, i.e. the number of animals raised for the purpose of animal food production.

Animal food production takes place under different living conditions of animals. The one extreme is factory farming where, e.g., a large number of cattle, pigs or chicken are kept in a confined space. The other extreme is outdoor husbandry farming where animals have freewheel. The living conditions of animals are determined by several factors, but one of the main determinants is the amount of land used in animal food production (Madzingira, 2018 p. 110 and 112). Many other determinants are related to land, for instance, the need to use antibiotics in order to control infectious diseases among the animals (Madzingira, 2018 p. 113). In our model, we thus measure the animals' living conditions or, equivalently, the *animals' quality of life* by the amount of land per unit of animal

$$q^s = \frac{r_y^d}{y^s}. \quad (2)$$

This indicator equals the inverse of the so-called stocking density and it is well-known that a high stocking density causes stress, adversely affects animal health and thereby reduces the animal food quality (Son et al., 2022). Hence, we interpret q^s not only as an indicator of the animals' quality of life, but also as the *animal food quality*. Notice that q^s is a product attribute or a product characteristic that is produced along with the quantity of animal food without being an explicit argument of the production technology.

The economy is inhabited by $n \geq 1$ identical consumers. *Consumption utility* of consumer $i = 1, \dots, n$ is determined by the consumer's demand of y_i^d units of animal food with quality q_i^d as well as the consumer's supply of ℓ_i^s units of labor and r_i^s units of land. It is given by the quasi-concave utility function $U(y_i^d, q_i^d, \ell_i^s, r_i^s)$ with the usual properties $U_y > 0$, $U_q \geq 0$, $U_\ell < 0$, $U_r < 0$. Next to consumption utility, we assume that the consumer receives *utility from being altruistic* towards animals, taking into account animal welfare. Because their only purpose is food production, welfare of livestock animals is obviously negative,³ but it is the higher, the better are the living conditions of the animals (Lusk and Norwood 2012, p. 193, Ng, 2016). Hence, we model welfare of an animal demanded by consumer i

³Allowing for positive welfare of an individual animal would have the strange implication that the total welfare of all animals would be the larger, the more animals are raised for animal production.

as a negative function that is increasing in the animal's living conditions, i.e. $A(q_i^d)$ with $A < 0$, $A_q > 0$ and $A_{qq} \leq 0$. In the following we denote A as *per-animal welfare*. Welfare of all animals demanded by consumer i is given by $y_i^d A(q_i^d)$, and $a := \sum_j y_j^d A(q_j^d)$ represents total welfare of all animals consumed in the economy.⁴ Introducing the altruism parameter $\alpha \in [0, 1]$, consumer i 's utility from altruism towards animals is given by αa .

Total utility of consumer i can simply be computed as the sum of consumption and altruism utility. But there are two extreme cases regarding the way how the consumer takes into account animal welfare. First, a *homo oeconomicus* ignores her impact on animal welfare and takes a as given, because, e.g., she knows that the impact of her animal food consumption on total animal food consumption and, thus, on animal welfare is so small that it is negligible. Formally, if consumer i is a homo oeconomicus, her total utility reads

$$u_i^h = U(y_i^d, q_i^d, \ell_i^s, r_i^s) + \alpha a,$$

where $a = \sum_j y_j^d A(q_j^d)$ is taken as given by the consumer.⁵ Second, a *homo kantiensis* is concerned with 'doing the right thing'. Hence, even if her influence on total consumption is negligible, she chooses her own animal food consumption y_i^d and animal food quality q_i^d under the counterfactual assumption that all other consumers make the same choice. If consumer i is a homo kantiensis, her total utility can be written as

$$u_i^k = U(y_i^d, q_i^d, \ell_i^s, r_i^s) + \alpha n y_i^d A(q_i^d).$$

Notice that the homo kantiensis makes her choice without knowing whether all other consumers really act as she wants them to act. Her motivation is to choose that and only that animal food consumption which she advocates all others to choose as well.

Both the homo oeconomicus and the homo kantiensis are extreme cases. The homo oeconomicus does not behave morally at all, whereas the homo kantiensis has the highest possible degree of morality. To consider more relevant and intermediate propensities of morality, we follow Alger and Weibull (2013, 2016, 2020) and introduce a morality parameter $\kappa \in [0, 1]$. With this parameter, we can model a *homo moralis* whose utility is defined as the weighted average of the homo oeconomicus utility and the homo kantiensis utility, i.e.

⁴Due to the general equilibrium nature of our approach, we may also model animal welfare from the point of view of the production side. Total animal welfare is then equal to $y^s A(q^s)$. This would slightly change the math of our analysis, but would leave completely unchanged our results.

⁵Strictly speaking, a homo oeconomicus would not only take as given the animal welfare a , but she would not be altruistic at all, i.e. $\alpha = 0$. Considering such a 'pure' homo oeconomicus will strengthen the results that we derive in our analysis under the assumption of an 'altruistic' homo oeconomicus.

$u_i^m = (1 - \kappa)u_i^h + \kappa u_i^k$. Inserting u_i^h and u_i^k from above, the utility of a homo moralis reads

$$u_i^m = U(y_i^d, q_i^d, \ell_i^s, r_i^s) + \alpha \left[(1 - \kappa)a + \kappa n y_i^d A(q_i^d) \right]. \quad (3)$$

The homo moralis weights with $1 - \kappa$ the actual animal welfare $a = \sum_j y_j^d A(q_j^d)$, which she takes as exogenously given, and with κ the counterfactual animal welfare $n y_i^d A(q_i^d)$, that would arise if all other consumers would choose the same animal food consumption as she does. The two boundary cases of the homo moralis utility in (3) obviously are the utility u_i^h of the homo oeconomicus if $\kappa = 0$ and the utility u_i^k of the homo kantianus if $\kappa = 1$. In the following, we consider the general case that consumer i is a homo moralis with utility (3).

The description of the model is completed by the *resource constraints*

$$r_y^d = \sum_j r_j^s, \quad (4)$$

$$\ell_y^d = \sum_j \ell_j^s, \quad (5)$$

$$\sum_j y_j^d = y^s, \quad (6)$$

$$q_i^d = q^s \quad \text{for all } i. \quad (7)$$

The inequalities (4)–(6) present conventional resource constraints related, respectively, to land, labor and the quantity of animal food. The constraint (7) shows the public good property of the product attribute quality. It requires that each consumer's demanded animal food quality has to be equal to the animal food quality supplied by the animal food producer.

3 Social optimum

Consider a *social planner* who maximizes a social welfare function in order to obtain the efficient allocation. We first have to clarify how the social planner treats consumption utility, altruism utility, morality and animal welfare. Consumption utility of consumers is assumed to enter the social welfare function in a utilitarian way, which is a standard assumption. With respect to animal welfare, we allow for an anthropocentric or a non-anthropocentric social planner by assuming a non-negative weight attached to animal welfare in the social welfare function. The non-anthropocentric view of taking into account animal welfare may be motivated by the philosophic arguments of Ng (1995) and Treich (2022) which we already mentioned in the Introduction. Regarding altruism and morality, it is controversially discussed whether such preferences should be included in the social welfare. While some

researchers reject this in order to avoid double counting of welfare components (Milgrom, 1993; Harsanyi, 1995), others argue that ‘. . . the social planner cannot paternalistically modify individuals’ preferences’ (Cremer and Pestieau, 2006, p. 1119) or that altruism generates a new utility for the altruistic individuals that should separately enter social welfare (Ng, 1999). Rather than taking the one or other position, we leave this question open and specify the social welfare function such that it may reflect both views.

Formally, the social planner takes into account the utility of the homo moralis consumers as well as the welfare of all animals and works with the *social welfare function*

$$w = \sum_j \left[\underbrace{U(y_j^d, q_j^d, \ell_j^s, r_j^s)}_{\text{consumption utility}} + \underbrace{\beta \left[(1 - \kappa) \sum_k y_k^d A(q_k^d) + \kappa n y_j^d A(q_j^d) \right]}_{\text{altruism and morality}} \right] + \underbrace{\gamma \sum_j y_j^d A(q_j^d)}_{\text{animal welfare}}. \quad (8)$$

The parameter $\gamma \geq 0$ is the social planner’s welfare weight for animals. In case of $\gamma > 0$, the social planner is non-anthropocentric and takes animal welfare into account, while for $\gamma = 0$ the social planner is anthropocentric focusing solely on human welfare. The parameter $\beta \geq 0$ reflects the degree to which the social planner takes into account altruism and morality. If $\alpha > 0$ and $\beta = 0$, the social planner ignores any form of consumer altruism and morality in order to avoid double counting of animal welfare. In the other extreme case with $\alpha = \beta > 0$, the social planner accounts for consumer altruism and morality and calculates with the complete homo moralis utility. We also allow for intermediate levels of altruism and morality in the social welfare function, i.e. $0 < \beta < \alpha$. In any case, the social planner takes into account that animal welfare is determined by animal food consumption, i.e. $a = \sum_k y_k^d A(q_k^d)$, in contrast to the homo moralis consumer who takes as given a when deciding on (y_i^d, q_i^d) .

The social planner maximizes social welfare (8) subject to the technologies (1) and (2) and the resource constraints (4)–(7). The Lagrangian and the full set of first-order conditions of *welfare maximization* are derived in Appendix A. The first-order conditions can be rearranged to yield the conditions in column 1 of Table 1, where we assume an interior solution with $q^s = q_i^d =: q$, $y_i^d = y_i$, $y^s = n y_i =: y$, $r_y^d = r_y$, $r_i^s = r_i$, $\ell_y^d = \ell_y$ and $\ell_i^s = \ell_i$ for all i . The parameter $\mu = \gamma + \beta n \geq 0$ can be interpreted as the *social animal friendliness*, since it reflects all channels through which animal welfare enters the social welfare function. Notice that the morality parameter κ disappears from this expression due to our assumption that all consumers are identical.⁶ The Lagrange multipliers λ_ℓ , λ_r , λ_q , λ_{q_i} and λ_y can be interpreted as shadow prices of labor, land, supplied and demanded animal food quality and animal food quantity, respectively. Since the first-order conditions of welfare maximization

⁶This will be different in the case of heterogenous consumers that we consider in Section 5.

	row	efficiency	market economy
column		1	2
animal production	1	$\frac{1}{Y_\ell} = \frac{\lambda_y}{\lambda_\ell} - \frac{q}{y} \frac{\lambda_q}{\lambda_\ell}$	$\frac{1}{Y_\ell} = \frac{P^y - \tau_y}{p_\ell} - \frac{q}{y} \frac{P_q^y y + \sigma_q}{p_\ell}$
	2	$\frac{Y_r}{Y_\ell} = \frac{\lambda_r}{\lambda_\ell} - \frac{1}{y} \frac{\lambda_q}{\lambda_\ell}$	$\frac{Y_r}{Y_\ell} = \frac{p_r - \sigma_r}{p_\ell} - \frac{1}{y} \frac{(P_q^y + \sigma_{qy})y + \sigma_q}{p_\ell}$
	3	$\frac{\lambda_q}{\lambda_\ell} = n \frac{\lambda_{qi}}{\lambda_\ell}$	---
consumer i (for all i)	4	$-\frac{U_y + \mu A}{U_\ell} = \frac{\lambda_y}{\lambda_\ell}$	$-\frac{U_y + \tilde{\mu} A}{U_\ell} = \frac{P^y}{p_\ell}$
	5	$-\frac{U_q + \mu y_i A_q}{U_\ell} = \frac{\lambda_{qi}}{\lambda_\ell}$	$-\frac{U_q + \tilde{\mu} y_i A_q}{U_\ell} = \frac{P_q^y y_i}{p_\ell}$
	6	$\frac{U_r}{U_\ell} = \frac{\lambda_r}{\lambda_\ell}$	$\frac{U_r}{U_\ell} = \frac{p_r}{p_\ell}$

Table 1: Conditions for efficiency and market equilibrium ($\mu := \gamma + \beta n$, $\tilde{\mu} := \alpha \kappa n$)

determine only relative shadow prices, we choose labor as numeraire and set $\lambda_\ell = 1$. While the shadow prices of land and animal food quality are positive, i.e. $\lambda_r > 0$, $\lambda_q > 0$, $\lambda_{qi} > 0$ due to rows 3, 5 and 6 in column 1 of Table 1, the shadow price of the animal food quantity may be of either sign, since it contains the marginal consumption utility $U_y > 0$ and the per-animal welfare $A < 0$, i.e. $\lambda_y \gtrless 0$ from row 4 in column 1 of Table 1. In the subsequent analysis, we suppose that the marginal consumption utility U_y is more important than per-animal welfare A , so the social marginal value of the animal food is positive and $\lambda_y > 0$.

Inserting in column 1 of Table 1 the conditions from rows 3–6 into the conditions in rows 1 and 2, it is straightforward to prove

Proposition 1. (*Properties of the efficient allocation*)

Efficient allocations are characterized by the allocation rules

$$-\frac{U_y + \mu A}{U_\ell} = \frac{1}{Y_\ell} - \frac{nq}{y} \frac{U_q + \mu y_i A_q}{U_\ell}, \quad (9)$$

$$\frac{U_r}{U_\ell} = \frac{Y_r}{Y_\ell} - \frac{n}{y} \frac{U_q + \mu y_i A_q}{U_\ell}. \quad (10)$$

Equation (9) can be interpreted as the allocation rule for the efficient quantity of animal food y . For constant land input r_y , a marginal increase in y requires a larger labor input ℓ_y and

reduces animal food quality $q = \frac{r_y}{y}$. Hence, (9) states that the social marginal willingness-to-pay for the higher animal food quantity, $-\frac{U_y + \mu A}{U_\ell}$, equals the sum of the marginal production costs of the larger labor input, $\frac{1}{Y_\ell}$, and the social marginal willingness-to-accept for the lower animal food quality, $-\frac{nq}{y} \frac{U_q + \mu y_i A_q}{U_\ell}$. Notice that the social marginal willingness-to-pay for the larger animal food quantity is the net effect of summing up the marginal consumption benefits, $-\frac{U_y}{U_\ell} > 0$, the marginal loss of altruism utility, $-\frac{\beta n A}{U_\ell} < 0$, and the marginal loss of animal welfare, $-\frac{\gamma A}{U_\ell} < 0$. Similar, the social marginal willingness-to-accept for the lower animal food quality encompasses the marginal loss of consumption utility, $-\frac{nq}{y} \frac{U_q}{U_\ell} > 0$, as well as the marginal loss of altruism utility and of animal welfare due to the worse living conditions of animals, $-\frac{nq}{y} \frac{\beta n y_i A_q}{U_\ell} > 0$ and $-\frac{nq}{y} \frac{\gamma y_i A_q}{U_\ell} > 0$, respectively.

In an analogous way, the allocation rule (10) governs the efficient land input r_y in the production of animal food. For constant animal food quantity y , a marginal increase in land input r_y increases the consumers' land supply r_i , reduces labor input ℓ_y in animal food production and increases animal food quality $q = \frac{r_y}{y}$. Hence, (10) states that the social marginal costs of an increase in r_y on the LHS equal the respective social marginal benefits on the RHS, where the social marginal costs are represented by the marginal rate of substitution of land for labor in consumption, $\frac{U_r}{U_\ell}$, and the social marginal benefits equal the sum of the technical rate of substitution of land for labor in producing animal food, $\frac{Y_r}{Y_\ell}$, and the social marginal willingness-to-pay for the higher animal food quality, $-\frac{n}{y} \frac{U_q + \mu y_i A_q}{U_\ell}$. The latter comprises the marginal consumption benefits of the higher food quality, $-\frac{n}{y} \frac{U_q}{U_\ell} > 0$, as well as the marginal benefits from higher altruism utility and animal welfare due to the better living conditions of animals, $-\frac{n}{y} \frac{\beta n y_i A_q}{U_\ell} > 0$ and $-\frac{n}{y} \frac{\gamma y_i A_q}{U_\ell} > 0$, respectively.

4 Market economy and market failure

In this section we turn to a *decentralized economy with competitive markets* where the government can impose various taxes and subsidies in order to correct potential market failure. Land and labor are supplied by consumers and demanded by the animal food production sector at price p_r and p_ℓ , respectively. Animal food is traded among consumers and producers at price P^y . Since the animal food quality is a product attribute, we take up the indirect market concept of a hedonic price function introduced by Rosen (1974). That is, we assume that the animal food price depends on the animal food quality, formally $P^y(q)$. The (implicit) price of the animal food quality – or, equivalently, of the living conditions of animals in food production – is then reflected by the derivative $P_q^y(q)$.

The animal food producer chooses inputs and outputs to maximize her profit subject to the animal food production technology and the definition of animal food quality, i.e.

$$\max_{\ell_y^d, r_y^d, y^s, q^s} \pi_y = \left[P^y(q^s) - \tau_y + \sigma_{qy}q^s \right] y^s + \sigma_q q^s - p_\ell \ell_y^d - (p_r - \sigma_r)r_y^d \quad \text{s.t. (1), (2)}. \quad (11)$$

In the maximization problem (11), τ_y is a tax per unit of animal food, σ_r is a subsidy per unit of land, σ_q is a subsidy on the animal food quality and σ_{qy} is a subsidy on the animal food quality per unit of animal food. As a homo moralis, consumer i chooses demand and supply such that her utility is maximized, taking into account her budget constraint. Formally, the consumer's maximization problem can be written as

$$\max_{y_i^d, q_i^d, r_i^s, \ell_i^s} \quad (3) \quad \text{s.t.} \quad P^y(q_i^d)y_i^d = p_\ell \ell_i^s + p_r r_i^s + \psi, \quad (12)$$

where $\psi = \frac{1}{n}\pi_y + \frac{1}{n}(\tau_y y^s - \sigma_{qy}q^s y^s - \sigma_q q^s - \sigma_r r_y^d)$ is a lump-sum transfer, consisting of the animal producer's profit and the government's net tax revenues equally distributed among consumers. The transfer is taken as given by the consumer. According to the budget constraint in (12), the expenditures for animal food, including an implicit payment for quality, are financed by labor income, land income and the lump-sum transfer. We ignore taxes and subsidies levied on consumers, because they are typically harder to administer.⁷

The Lagrangians and the full set of first-order conditions to the maximization problems (11) and (12) are given in Appendix B. The first-order conditions can be rearranged to the conditions listed in column 2 of Table 1, where we again restrict attention to an interior solution with $q^s = q_i^d =: q$, $y_i^d = y_i$, $y^s = ny_i =: y$, $r_y^d = r_y$, $r_i^s = r_i$, $\ell_y^d = \ell_y$ and $\ell_i^s = \ell_i$ for all i . The parameter $\tilde{\mu} = \alpha\kappa n$ can be interpreted as *private animal friendliness*, since it shows how altruism and morality induces the individual consumer to take into account animal welfare. As the competitive equilibrium determines only relative prices, we set $p_\ell = 1$. Inserting this together with rows 4–6 into rows 1 and 2 of column 2 in Table 1 yields

$$-\frac{U_y + \tilde{\mu}A}{U_\ell} = \frac{1}{Y_\ell} - \frac{nq}{y} \frac{U_q + \tilde{\mu}y_i A_q}{U_\ell} + \tau_y + \frac{q}{y} \sigma_q, \quad (13)$$

$$\frac{U_r}{U_\ell} = \frac{Y_r}{Y_\ell} - \frac{n}{y} \frac{U_q + \tilde{\mu}y_i A_q}{U_\ell} + \sigma_r + \sigma_{qy} + \frac{1}{y} \sigma_q. \quad (14)$$

Equations (13) and (14) are the allocation rules for the animal food quantity y and land input r_y in the competitive equilibrium, for given tax and subsidy rates $(\tau_y, \sigma_{qy}, \sigma_q, \sigma_r)$.

To check the *efficiency properties of the decentralized economy* without government interference, we compare columns 1 and 2 of Table 1, or equivalently, the market allocation

⁷In our model, it is straightforward to show that for every policy levied on producers there exists an equivalent policy levied on consumers that implements the efficient allocation.

rules (13) and (14) with the efficient allocation rules (9) and (10), and set $\tau_y = \sigma_{qy} = \sigma_q = \sigma_r = 0$. A crucial role in the comparison plays the deviation of the private animal friendliness $\tilde{\mu} = \alpha\kappa n$ from the social animal friendliness $\mu = \gamma + \beta n$. We begin with the special case in which both kinds of animal friendliness just coincide and immediately obtain

Proposition 2. (*Efficiency if social and private animal friendliness coincide*)

Suppose that $\mu = \tilde{\mu}$. Set $\tau_y = \sigma_{qy} = \sigma_q = \sigma_r = 0$, $p_\ell = \lambda_\ell = 1$, $p_r = \lambda_r$, $P^y = \lambda_y$ and $P_q^y y_i = P_q^y \frac{y}{n} = \lambda_{qi} = \frac{1}{n} \lambda_q$. Then, the market economy yields an efficient allocation.

If the private animal friendliness $\tilde{\mu}$ equals the social animal friendliness μ , no externalities arise in the laissez-faire economy. The market price of one unit of land, p_r , equals the shadow price of land, λ_r , which reflects the marginal rate of substitution of land for labor, $\frac{U_r}{U_\ell}$. The market price of one unit of animal food, P^y , displays the shadow price of animal food, λ_y , which is equal to the social marginal willingness-to-pay for the animal food quantity, $-\frac{U_y + \mu A}{U_\ell}$. Finally, the (implicit) market price of the animal food quality, $P_q^y \frac{y}{n}$, reflects the shadow price of animal food quality, $\lambda_{qi} = \frac{1}{n} \lambda_q$, and thereby the social marginal willingness-to-pay for the quality, $-\frac{nq}{y} \frac{U_q + \mu y_i A_q}{U_\ell}$. In sum, all social marginal costs and social marginal benefits of animal food production are captured by market prices and the laissez-faire economy is capable of supporting allocative efficiency, as proven in Proposition 2.

However, the equality of private and social animal friendliness seems to be a rather generic and specific case. For example, if the social planner fully double counts, i.e. takes the consumers' altruism in the social welfare function ($\beta = \alpha$), but places no additional weight on animal welfare ($\gamma = 0$), the condition $\mu = \tilde{\mu}$ is satisfied only if all consumers are homo kantians ($\kappa = 1$), which is unrealistic. In general, private and social animal friendliness differ and it seems plausible to assume that social animal friendliness exceeds private animal friendliness ($\mu = \gamma + \beta n > \alpha\kappa n = \tilde{\mu}$). This is the case, for instance, if the social planner takes into account the altruistic preferences of consumers ($\beta = \alpha$) and is non-anthropocentric, i.e. animals obtain a separate weight in the social welfare function ($\gamma > 0$). And even if the social planner avoids double counting ($\beta = 0$), the social animal friendliness is still larger than the private animal friendliness, if the degree of non-anthropocentrism γ is large relatively to the consumers' morality κ , such that $\mu = \gamma > \alpha\kappa n = \tilde{\mu}$.

In the remainder of the paper, we therefore assume $\mu > \tilde{\mu}$. The animal welfare is then not appropriately reflected in the market economy and an *animal welfare externality* arises. The consequences of this externality for the efficiency properties of the laissez-faire economy are given in Proposition 3, which is proven in Appendix C.

Proposition 3. (*Inefficiency in the laissez-faire economy.*)

Suppose that $\mu > \tilde{\mu}$. Set $\tau_y = \sigma_{qy} = \sigma_q = \sigma_r = 0$. Then, the allocation in the market economy is inefficient. If the animal food production technology Y is linear homogenous with substitution elasticity θ and the consumption utility function takes the functional form $U(y_i^d, q_i^d, r_i^s, \ell_i^s) = [\eta(y_i^d)^{-\rho} + \nu(q_i^d y_i^d)^{-\rho}]^{-\frac{h}{\rho}} - R(r_i^s) - \ell_i^s$ with $\eta, \nu \geq 0$, $\rho \geq -1$, $0 < h \leq 1$, $h + \rho \geq 0$, $R_r > 0$ and $R_{rr} \geq 0$, then in the market economy

- (i) the animal food quantity y is inefficiently high and has inefficiently low quality q ,
- (ii) land input in animal food production, r_y , is inefficiently high if $h = 1$ or $\eta = 0$, while it is inefficiently low if $A_{qq} = 0$, $\nu = 0$ and $\theta \rightarrow \infty$.

For $\mu > \tilde{\mu}$, in the laissez-faire economy the consumers take into account only a part of the animal welfare contained in the social welfare function and, hence, the laissez-faire economy is inefficient due to an animal welfare externality. This externality applies to the quantity and quality of animal food and, thus, in the laissez-faire economy the animal food quantity y is too high with a too low quality q , implying too bad living conditions for animals in food production. While the complexity of our general equilibrium approach forces us to prove the inefficiency of y and q in part (i) of Proposition 3 only under some specific assumptions regarding technologies and preferences, it is intuitively plausible that it also holds under more general specifications of our model. In contrast, part (ii) of Proposition 3 shows that the land input in animal production, r_y , may be inefficiently low or high, even under the specific conditions imposed in the proposition. The reason is that the animal welfare externality is of first order only with respect to the animal food quantity and quality, since only q and y directly enter the expression for animal welfare, while it is of second order with respect to land input r_y . Hence, according to the definition $q = \frac{r_y}{y}$ the inefficiently low q and the inefficiently high y leave room for an inefficiently low or high r_y .

Correcting the market failure identified in Proposition 3 necessitates *governmental intervention*. In order to see what the potential remedies in terms of taxes and subsidies are, we compare the market allocation rules (13) and (14) with the efficient allocation rules (9) and (10) without setting all tax and subsidy rates equal to zero, as we do in the context of Proposition 3. Taking into account $U_\ell = -\lambda_\ell = -1$, the comparison yields

Proposition 4. (*Efficient regulation*)

Suppose that $\mu > \tilde{\mu}$. Set $p_\ell = \lambda_\ell = 1$, $p_r = \lambda_r$, $P^y = \lambda_y + \tau_y - (\sigma_r + \sigma_{qy})q$, $P_q^y y_i = P_q^y \frac{y}{n} =$

$\lambda_{qi} - \frac{y}{n}(\sigma_r + \sigma_{qy}) - \frac{1}{n}\sigma_q$ and

$$\tau_y + \frac{q}{y}\sigma_q = -(\mu - \tilde{\mu})A + (\mu - \tilde{\mu})qA_q > 0, \quad \sigma_r + \sigma_{qy} + \frac{1}{y}\sigma_q = (\mu - \tilde{\mu})A_q > 0. \quad (15)$$

Then, the allocation in the market economy is efficient.

If $\mu > \tilde{\mu}$, then the marginal effect of the animal food quantity y on total animal welfare, formally A , as well as the marginal effect of animal food quality q on animal welfare, formally yA_q , are not fully reflected by market prices in the laissez-faire economy. Instead, these effects have to be brought into the price system by tax and subsidy instruments in order to restore efficiency, as shown by the optimal regulatory policy (15) in Proposition 4. There are ample combinations of tax and subsidy rates that render the market allocation socially optimal. As a general property of efficient regulation, it is not possible to correct the inefficiency by only one instrument, since then one of the two equations in (15) is violated. This is plausible since the animal welfare externality exerts first-order distortions on both the animal food quantity y and quality q and, thus, at least two instruments are needed. Moreover, efficient regulation always consists of a tax and a subsidy. Using only taxes or only subsidies does not satisfy (15). This is also obvious, because in the laissez-faire economy the animal food quantity y is distorted upwards, necessitating a tax element, whereas the animal food quality q is distorted downwards, pointing to a subsidy element.

To be more specific, we highlight some special cases of the efficient regulation system in (15). The most obvious tax-subsidy combination directly regulates the animal food quantity and quality, y and q , and is obtained by setting $\sigma_r = \sigma_{qy} = 0$ in (15). We then obtain

$$\tau_y = -(\mu - \tilde{\mu})A > 0, \quad \sigma_q = (\mu - \tilde{\mu})yA_q > 0. \quad (16)$$

The missing effect of the animal food quantity y on animal welfare is internalized by a tax on the animal food quantity, τ_y , while the missing effect of animal food quality q on animal welfare is corrected by a subsidy on animal food quality, σ_q . These two instruments give the market participants in the decentralized economy the incentive to reduce the animal food quantity and to increase the animal food quality, so the living conditions of animals in food production are improved up to their efficient level. In practice, the tax τ_y may be implemented as a meat tax, while the subsidy σ_q may be a one-time or yearly premium for animal food producers that ensures sufficiently standards in the living conditions of animals.

Because efficiency requires at least one tax element, it is obvious to keep the tax on the animal food quantity, τ_y , but to consider alternative options for the subsidy. The first

one is obtained by setting $\sigma_q = \sigma_{qy} = 0$ in (15). Efficient regulation then becomes

$$\tau_y = -(\mu - \tilde{\mu})A + (\mu - \tilde{\mu})qA_q > 0, \quad \sigma_r = (\mu - \tilde{\mu})A_q > 0. \quad (17)$$

The optimal policy in (17) combines the tax on the animal food quantity, τ_y , with a subsidy on land input in animal food production, σ_r . This combination is less straightforward than the policy in (16), since it does not directly target the animal food quality q . Instead, it regulates the animal food quality $q = \frac{\tau_y}{y}$ indirectly. It adds to the tax on the animal food quantity, τ_y , the element $(\mu - \tilde{\mu})qA_q > 0$, which together with the land subsidy σ_r induces the producer to increase the quality up to its efficient level. The remaining part $-(\mu - \tilde{\mu})A$ of the tax τ_y is as in the policy (16) and corrects the inefficiently high animal food quantity.

Finally, we combine the tax on the animal food quantity by a subsidy on animal food quality per unit of animal food. Setting $\sigma_q = \sigma_r = 0$ in (15), it follows

$$\tau_y = -(\mu - \tilde{\mu})A + (\mu - \tilde{\mu})qA_q > 0, \quad \sigma_{qy} = (\mu - \tilde{\mu})A_q > 0. \quad (18)$$

The subsidy σ_{qy} gives the producer the incentive to increase animal food quality and thereby the living conditions of animals in food production, similar to the direct quality subsidy σ_q . However, σ_{qy} falls on both the animal food quality q and the animal food quantity y and, thus, distorts the quantity upwards. This unintended distortion has to be correct by adding to the tax rate on the animal food quantity, τ_y , the element $(\mu - \tilde{\mu})qA_q > 0$, as in policy (17). The subsidy σ_{qy} can also be interpreted as a premium for animal food producers that ensures sufficiently high standards for the living conditions of animals, but in contrast to σ_q it is related to each unit of animal food and not calculated on a one-time or yearly basis.

The tax subsidy scheme in (18) comes closest to the regulation currently discussed in many countries. The tax on the animal food quantity, τ_y , can be interpreted as a meat tax and the subsidy on animal food quality per unit of animal food, σ_{qy} , is similar to the animal welfare premium which is currently under consideration, for instance, in the German agriculture policy, see our discussion in the Introduction. Interestingly, under the optimal policy (18), the net tax payments of the animal food producer read

$$(\tau_y - \sigma_{qy}q)y = -(\mu - \tilde{\mu})yA > 0. \quad (19)$$

Accordingly, under this policy the producer has to pay more taxes for the animal food quantity than it receives as subsidy for the animal food quality. The net tax payments of the producer are strictly positive. Intuitively, the reason is that animal welfare still remains negative ($A < 0$), even if the producer is induced to choose the efficient quantity and quality

of animal food. It is worth mentioning that this property of optimal regulation derived by our formal analysis stands in stark contrast to the policy proposed by the Borchert-Kommission in Germany, which recommends revenue neutrality of the tax-subsidy combination. Notice also that financing the animal welfare premium by general tax revenues from the federal budget, as alternatively proposed by the Borchert-Kommission, is not efficient either, since then meat would not be regulated by a tax τ_y levied on the output of animal food producers.

5 Heterogeneous consumers and animal food producers

In this section, we investigate how consumer and producer heterogeneity influences the animal welfare externality and the optimal regulation of animal food production. For that purpose, we introduce into our basic model two groups of consumers and two groups of producers. We distinguish between outdoor animal husbandry which uses ℓ_o^d units of labor and r_o^d units of land in order to produce y_o^s units of animal food with quality q_o^s , and factory farming which uses ℓ_f^d units of labor and r_f^d units of land in order to produce y_f^s units of animal food with quality q_f^s . The associated production technologies are

$$y_o^s = Y^o(\ell_o^d, r_o^d), \quad y_f^s = Y^f(\ell_f^d, r_f^d), \quad (20)$$

where the production functions Y^o and Y^f possess the same properties as the production function Y in the basic model. The animals' living conditions or, equivalently, the quality of animal food in the two sectors are determined by

$$q_o^s = \frac{r_o^d}{y_o^s}, \quad q_f^s = \frac{r_f^d}{y_f^s}. \quad (21)$$

The set of total consumers is denoted by N and divided into two subsets O and F with $O \cup F = N$. The group sizes are n_o and n_f , respectively, with $n_o + n_f = n$. The two types of consumers may differ in their morality and/or their altruism for animal welfare, i.e. $\kappa_o \neq \kappa_f$ and/or $\alpha_o \neq \alpha_f$. We assume that consumers of group O only purchase animal food from outdoor animal husbandry, whereas consumers of group F only purchase animal food from factory farming. The consumers' demanded quantity and quality of animal food as well as the consumers' labor and land supply is denoted by the same variables as in the basic model, except that we now add the group indices o and f to the subscripts. All consumers are homo moralis and, thus, utility of consumer $i \in O$ is

$$u_{io}^m = U^o(y_{io}^d, q_{io}^d, \ell_{io}^s, r_{io}^s) + \alpha_o [(1 - \kappa_o)a + \kappa_o n y_{io}^d A(q_{io}^d)], \quad (22)$$

while utility of consumer $i \in F$ can be written as

$$u_{if}^m = U^f(y_{if}^d, q_{if}^d, \ell_{if}^s, r_{if}^s) + \alpha_f [(1 - \kappa_f)a + \kappa_f n y_{if}^d A(q_{if}^d)], \quad (23)$$

where the utility functions U^o and U^f possess the same properties as the utility function U in the basic model. In (22) and (23), we again assume that the homo oeconomicus part of the homo moralis takes as given the animal welfare a , which is now defined as

$$a = \sum_{j \in O} y_{jo}^d A(q_{jo}^d) + \sum_{j \in F} y_{jf}^d A(q_{jf}^d). \quad (24)$$

The model is closed by the resource constraints

$$r_o^d + r_f^d = \sum_{j \in O} r_{jo}^s + \sum_{j \in F} r_{jf}^s, \quad (25)$$

$$\ell_o^d + \ell_f^d = \sum_{j \in O} \ell_{jo}^s + \sum_{j \in F} \ell_{jf}^s, \quad (26)$$

$$\sum_{j \in O} y_{jo}^d = y_o^s, \quad (27)$$

$$\sum_{j \in F} y_{jf}^d = y_f^s, \quad (28)$$

$$q_{io}^d = q_o^s, \quad \text{for all } i \in O, \quad (29)$$

$$q_{if}^d = q_f^s, \quad \text{for all } i \in F, \quad (30)$$

which have the same meaning as in the basic model.

In order to derive the efficient allocation in the extended model, consider a social planner who maximizes the social welfare function

$$\begin{aligned} w = & \sum_{j \in O} \left\{ U^o(y_{jo}^d, q_{jo}^d, \ell_{jo}^s, r_{jo}^s) + \beta_o \left[(1 - \kappa_o) \left[\sum_{k \in O} y_{ko}^d A(q_{ko}^d) + \sum_{k \in F} y_{kf}^d A(q_{kf}^d) \right] + \kappa_o n y_{jo}^d A(q_{jo}^d) \right] \right\} \\ & + \sum_{j \in F} \left\{ U^f(y_{jf}^d, q_{jf}^d, \ell_{jf}^s, r_{jf}^s) + \beta_f \left[(1 - \kappa_f) \left[\sum_{k \in O} y_{ko}^d A(q_{ko}^d) + \sum_{k \in F} y_{kf}^d A(q_{kf}^d) \right] + \kappa_f n y_{jf}^d A(q_{jf}^d) \right] \right\} \\ & + \gamma \left[\sum_{j \in O} y_{jo}^d A(q_{jo}^d) + \sum_{j \in F} y_{jf}^d A(q_{jf}^d) \right], \end{aligned}$$

subject to (20), (21) and (25)–(30). The parameters β_o and β_f reflect the degree to which the social planner takes into account altruism and morality of type- O and type- F consumers, respectively. By the same Lagrangian techniques as in the basic model, it is straightforward to derive the first-order conditions in column 1 of Table 2. Inserting in this column the rows

	row	Pareto efficiency	indirect markets
column		1	2
animal production O	1	$\frac{1}{Y_\ell^o} = \frac{\lambda_{y_o}}{\lambda_\ell} - \frac{q_o}{y_o} \frac{\lambda_{q_o}}{\lambda_\ell}$	$\frac{1}{Y_\ell^o} = \frac{P^{y_o} - \tau_{y_o}}{p_\ell} - \frac{q_o}{y_o} \frac{P_q^{y_o} y_o}{p_\ell}$
	2	$\frac{Y_r^o}{Y_\ell^o} = \frac{\lambda_r}{\lambda_\ell} - \frac{1}{y_o} \frac{\lambda_{q_o}}{\lambda_\ell}$	$\frac{Y_r^o}{Y_\ell^o} = \frac{p_r}{p_\ell} - \frac{1}{y_o} \frac{(P_q^{y_o} + \sigma_{qy_o}) y_o}{p_\ell}$
	3	$\frac{\lambda_{q_o}}{\lambda_\ell} = \sum_{j \in O} \frac{\lambda_{qj_o}}{\lambda_\ell}$	--
animal production F	4	$\frac{1}{Y_\ell^f} = \frac{\lambda_{y_f}}{\lambda_\ell} - \frac{q_f}{y_f} \frac{\lambda_{q_f}}{\lambda_\ell}$	$\frac{1}{Y_\ell^f} = \frac{P^{y_f} - \tau_{y_f}}{p_\ell} - \frac{q_f}{y_f} \frac{P_q^{y_f} y_f}{p_\ell}$
	5	$\frac{Y_r^f}{Y_\ell^f} = \frac{\lambda_r}{\lambda_\ell} - \frac{1}{y_f} \frac{\lambda_{q_f}}{\lambda_\ell}$	$\frac{Y_r^f}{Y_\ell^f} = \frac{p_r}{p_\ell} - \frac{1}{y_f} \frac{(P_q^{y_f} + \sigma_{qy_f}) y_f}{p_\ell}$
	6	$\frac{\lambda_{q_f}}{\lambda_\ell} = \sum_{j \in F} \frac{\lambda_{qj_f}}{\lambda_\ell}$	--
consumer $i \in O$	7	$-\frac{U_y^o + \mu_o A^o}{U_\ell^o} = \frac{\lambda_{y_o}}{\lambda_\ell}$	$-\frac{U_y^o + \tilde{\mu}_o A^o}{U_\ell^o} = \frac{P^{y_o}}{p_\ell}$
	8	$-\frac{U_q^o + \mu_o y_{io} A_q^o}{U_\ell^o} = \frac{\lambda_{qio}}{\lambda_\ell}$	$-\frac{U_q^o + \tilde{\mu}_o y_{io} A_q^o}{U_\ell^o} = \frac{P_q^{y_o} y_{io}}{p_\ell}$
	9	$\frac{U_r^o}{U_\ell^o} = \frac{\lambda_r}{\lambda_\ell}$	$\frac{U_r^o}{U_\ell^o} = \frac{p_r}{p_\ell}$
consumer $i \in F$	10	$-\frac{U_y^f + \mu_f A^f}{U_\ell^f} = \frac{\lambda_{y_f}}{\lambda_\ell}$	$-\frac{U_y^f + \tilde{\mu}_f A^f}{U_\ell^f} = \frac{P^{y_f}}{p_\ell}$
	11	$-\frac{U_q^f + \mu_f y_{if} A_q^f}{U_\ell^f} = \frac{\lambda_{qif}}{\lambda_\ell}$	$-\frac{U_q^f + \tilde{\mu}_f y_{if} A_q^f}{U_\ell^f} = \frac{P_q^{y_f} y_{if}}{p_\ell}$
	12	$\frac{U_r^f}{U_\ell^f} = \frac{\lambda_r}{\lambda_\ell}$	$\frac{U_r^f}{U_\ell^f} = \frac{p_r}{p_\ell}$

Table 2: Conditions for efficiency and market equilibrium with heterogenous consumers and animal food producers ($\mu_o = \gamma + \beta_o(n_o + \kappa_o n_f) + \beta_f(1 - \kappa_f)n_f$, $\mu_f = \gamma + \beta_f(n_f + \kappa_f n_o) + \beta_o(1 - \kappa_o)n_o$, $\tilde{\mu}_o = \alpha_o n \kappa_o$, $\tilde{\mu}_f = \alpha_f n \kappa_f$)

7–12 into rows 1–6 yields the efficient allocation rules

$$-\frac{U_y^o + \mu_o A^o}{U_\ell^o} = \frac{1}{Y_\ell^o} - \frac{n_o q_o}{y_o} \frac{U_q^o + \mu_o y_{io} A_q^o}{U_\ell^o}, \quad (31)$$

$$\frac{U_r^o}{U_\ell^o} = \frac{Y_r^o}{Y_\ell^o} - \frac{n_o}{y_o} \frac{U_q^o + \mu_o y_{io} A_q^o}{U_\ell^o}, \quad (32)$$

$$-\frac{U_y^f + \mu_f A^f}{U_\ell^f} = \frac{1}{Y_\ell^f} - \frac{n_f q_f}{y_f} \frac{U_q^f + \mu_f y_{if} A_q^f}{U_\ell^f}, \quad (33)$$

$$\frac{U_r^f}{U_\ell^f} = \frac{Y_r^f}{Y_\ell^f} - \frac{n_f}{y_f} \frac{U_q^f + \mu_f y_{if} A_q^f}{U_\ell^f}, \quad (34)$$

where $\mu_o = \gamma + \beta_o(n_o + \kappa_o n_f) + \beta_f(1 - \kappa_f)n_f$ and $\mu_f = \gamma + \beta_f(n_f + \kappa_f n_o) + \beta_o(1 - \kappa_o)n_o$ is the social animal friendliness with respect to the animals in the O -sector and the F -sector, respectively. The expressions A^z and A_q^z are short-cuts for $A(q_z)$ and $A_q(q_z)$ for $z = o, f$. The above allocation rules are the same and have the same interpretation as in the basic model, except that we now have two separate sets of efficient allocation rules, one set for type- O animal food, (31) and (32), and one set for type- F animal food, (33) and (34).

In the market economy, the animal food producer in the O -sector maximizes profit

$$\pi_{y_o} = [P^y(q_o^s) - \tau_{y_o} + \sigma_{qy_o} q_o^s] y_o^s - p_\ell \ell_o^d - p_r r_o^d,$$

subject to the respective first condition in equations (20) and (21), while the animal food producer in the F -sector maximizes profit

$$\pi_{y_f} = [P^y(q_f^s) - \tau_{y_f} + \sigma_{qy_f} q_f^s] y_f^s - p_\ell \ell_f^d - p_r r_f^d,$$

subject to the respective second condition in equations (20) and (21). For simplicity, we ignore the subsidies on land and animal food quality, i.e. $\sigma_r = \sigma_q = 0$. The remaining policy instruments are the same as in the basic model, but may now be sector-specific and, therefore, we add the indices o and f to the subscript of these instruments. Consumer $i \in O$ maximizes her utility (22), subject to the budget constraint

$$P^y(q_{io}^d) y_{io}^d = p_\ell \ell_{io}^s + p_r r_{io}^s + \psi,$$

while consumer $i \in F$ maximizes her utility (23) subject to the budget constraint

$$P^y(q_{if}^d) y_{if}^d = p_\ell \ell_{if}^s + p_r r_{if}^s + \psi,$$

where ψ is again a lump-sum transfer containing firms' profit and net tax revenues of the government. Setting up the Lagrangians of the above maximization problems, it is straightforward to prove the conditions in column 2 of Table 2, and from these conditions together

with the numeraire assumption $p_\ell = 1$ we obtain the market allocation rules

$$-\frac{U_y^o + \tilde{\mu}_o A^o}{U_\ell^o} = \frac{1}{Y_\ell^o} - \frac{n_o q_o}{y_o} \frac{U_q^o + \tilde{\mu}_o y_{io} A_q^o}{U_\ell^o} + \tau_{yo}, \quad (35)$$

$$\frac{U_r^o}{U_\ell^o} = \frac{Y_r^o}{Y_\ell^o} - \frac{n_o}{y_o} \frac{U_q^o + \tilde{\mu}_o y_{io} A_q^o}{U_\ell^o} + \sigma_{qyo}, \quad (36)$$

$$-\frac{U_y^f + \tilde{\mu}_f A^f}{U_\ell^f} = \frac{1}{Y_\ell^f} - \frac{n_f q_f}{y_f} \frac{U_q^f + \tilde{\mu}_f y_{if} A_q^f}{U_\ell^f} + \tau_{yf}, \quad (37)$$

$$\frac{U_r^f}{U_\ell^f} = \frac{Y_r^f}{Y_\ell^f} - \frac{n_f}{y_f} \frac{U_q^f + \tilde{\mu}_f y_{if} A_q^f}{U_\ell^f} + \sigma_{qyf}, \quad (38)$$

where $\tilde{\mu}_o = \alpha_o n \kappa_o$ and $\tilde{\mu}_f = \alpha_f n \kappa_f$ represent the private animal friendliness in the O - and F -sector, respectively. Equations (35) and (36) guide the market allocation of type- O animal food, whereas (37) and (38) are the market allocation rules of type- F animal food.

Comparing columns 1 and 2 in Table 2 or, equivalently, the efficient allocation rules (31)–(34) with the market allocation rules (35)–(38) yields

Proposition 5. (*Efficient Regulation with heterogeneous consumers and producers*)

Suppose $\mu_o > \tilde{\mu}_o$ and $\mu_f > \tilde{\mu}_f$. Set $p_\ell = \lambda_\ell = 1$, $p_r = \lambda_r$, $P^{yo} = \lambda_{yo} + \tau_{yo} - \sigma_{qyo} q_o$, $P_q^{yo} \frac{y_o}{n_o} = \lambda_{qio} - \frac{y_o}{n_o} \sigma_{qyo}$, $P^{yf} = \lambda_{yf} + \tau_{yf} - \sigma_{qyf} q_f$, $P_q^{yf} \frac{y_f}{n_f} = \lambda_{qif} - \frac{y_f}{n_f} \sigma_{qyf}$ and

$$\tau_{yo} = -(\mu_o - \tilde{\mu}_o) [A(q_o) - q_o A_q(q_o)] > 0, \quad \sigma_{qyo} = (\mu_o - \tilde{\mu}_o) A_q(q_o) > 0, \quad (39)$$

$$\tau_{yf} = -(\mu_f - \tilde{\mu}_f) [A(q_f) - q_f A_q(q_f)] > 0, \quad \sigma_{qyf} = (\mu_f - \tilde{\mu}_f) A_q(q_f) > 0. \quad (40)$$

Then, the allocation in the market economy is efficient.

Proposition 5 shows that the regulatory policy from the basic model, specified in Proposition 4 or, equivalently, for $\sigma_r = \sigma_q = 0$ in equation (18), carries over to each type of animal food in the model with consumer and producer heterogeneity. The policy $(\tau_{yo}, \sigma_{qyo})$ in (39) internalizes the animal welfare externality of animal food from outdoor husbandry, while the policy $(\tau_{yf}, \sigma_{qyf})$ in (40) internalizes the animal welfare externality of animal food from factory farming. The important insight from Proposition 5 is that the policies for the two sectors may differ, implying the need of sector-specific regulation.

To further illustrate Proposition 5, we investigate the question which of the two sectors is more heavily regulated. For this purpose, we restrict attention to heterogeneity stemming from differences in the parameters that determine the social and private animal friendliness, i.e. γ , α_z , β_z and κ_z for $z = o, f$. Hence, we abstract from heterogeneity in preferences and technologies and, accordingly, assume that utility and production functions are identical

across groups, i.e. $U^o = U^f \equiv U$ and $Y^o = Y^f \equiv Y$,⁸ and that the consumer groups are of equal size, i.e. $n_o = n_f$. Under these conditions, there are cases where efficient food production is the same in both sectors. For example, if $\beta_o = \beta_f = 0$, then $\mu_o = \mu_f = \gamma$, rendering the efficient allocation rules (31) and (32) for the O -sector identical to the efficient allocation rules (33) and (34) for the F -sector. It follows that $q_o = q_f$ and $y_o = y_f$ in the Pareto optimum. Even though such cases will play an important role in our discussion of Proposition 5, we will also consider cases where the parameter constellation implies different efficient food production in the two sectors. In any case and without loss of generality, we always focus on parameter constellations where $q_o \geq q_f$ holds in the Pareto optimum, so the efficient living conditions of animals in the O -sector are at least as good as in the F -sector.

Closer inspection of Proposition 5 shows that the magnitude of regulation is mainly determined by two factors. First, the tax and subsidy rates in (39) and (40) contain the deviation of the private from the social animal friendliness, i.e. $\mu_o - \tilde{\mu}_o$ and $\mu_f - \tilde{\mu}_f$. Making use of the definitions of μ_o , $\tilde{\mu}_o$, μ_f and $\tilde{\mu}_f$, it is straightforward to show that

$$\mu_o - \tilde{\mu}_o \underset{\geq}{\cong} \mu_f - \tilde{\mu}_f \iff (\beta_o - \alpha_o)\kappa_o \underset{\geq}{\cong} (\beta_f - \alpha_f)\kappa_f. \quad (41)$$

Second, the efficient instruments (39) and (40) are influenced by marginal changes in the per-animal welfare and marginal changes in the quality-weighted per-animal welfare. The former is given by $A_q(q) > 0$ and decreasing in q due to $A_{qq}(q) < 0$. The latter is defined as

$$\Delta(q) := -A(q) + qA_q(q) > 0 \quad \text{with} \quad \Delta_q(q) = qA_{qq}(q) < 0, \quad (42)$$

and, therefore, also decreasing in q . To disentangle the two sources of differences in regulating the animal food sectors, we consider different degrees to which the social planner avoids double counting of animal welfare in the social welfare function.

(i) No double counting: Suppose that there is no double counting of animal welfare in the social welfare function, i.e. $\beta_o = \beta_f = 0$. As already stated above, the efficient quantity and quality are then identical in both sectors, i.e. $y_o = y_f$ and $q_o = q_f$. It follows $A_q(q_o) = A_q(q_f)$ and $\Delta(q_o) = \Delta(q_f)$ according to (42). In this case, deviations of the private from the social animal friendliness alone determine which animal food sector has to be regulated more strongly. Formally, from (39) and (40) we obtain

$$\tau_{y_o} \underset{\geq}{\cong} \tau_{y_f} \quad \text{and} \quad \sigma_{y_o q_o} \underset{\geq}{\cong} \sigma_{y_f q_f} \iff \mu_o - \tilde{\mu}_o \underset{\geq}{\cong} \mu_f - \tilde{\mu}_f. \quad (43)$$

⁸Notice that heterogenous preferences for different kinds of animal food are already captured by the dependences of the utility function on the animal food quality, even if the utility function is the same for both types of consumers. Similar, different kinds of production circumstances are reflected by different values of the supplied animal food quality, even if the technology is the same in both sectors.

Making use of (41) and $\beta_o = \beta_f = 0$ yields

$$\mu_o - \tilde{\mu}_o \begin{matrix} \geq \\ \leq \end{matrix} \mu_f - \tilde{\mu}_f \iff \alpha_o \kappa_o \begin{matrix} \geq \\ \leq \end{matrix} \alpha_f \kappa_f. \quad (44)$$

It seems plausible that O -type consumers have both a higher altruism and a higher morality than F -type consumers. We then obtain $\alpha_o \kappa_o > \alpha_f \kappa_f$ and $\mu_o - \tilde{\mu}_o < \mu_f - \tilde{\mu}_f$ from (44) as well as $\tau_{y_o} < \tau_{y_f}$ and $\sigma_{y_{q_o}} < \sigma_{y_{q_f}}$ from (43), so regulation is weaker in the O -sector than in the F -sector. Intuitively, in being more altruistic and moral, O -type consumers internalize a larger share of the animal welfare externality and, thus, have to be regulated less. In the polar case where the anthropocentric welfare weight is just equal to the O -type consumers' altruism and morality, i.e. $\gamma = \alpha_o \kappa_o > \alpha_f \kappa_f$, we additionally have $\mu_o = \tilde{\mu}_o$ and outdoor husbandry needs not to be regulated at all, as in the laissez-faire economy the O -sector already implements the efficient quantity and quality of animal food. In contrast, we have $\mu_f > \tilde{\mu}_f$, so the tax on the F -type animal food quantity and the subsidy on the F -type animal food quality are still positive, providing the factory farming sector the incentive to choose the efficient animal food quantity $y_f = y_o$ and the efficient animal food quality $q_f = q_o$. In this polar case, optimal regulation transforms factory farming into outdoor farming, where the latter sector already produces efficiently in the absence of any regulation.

(ii) Full double counting. With full double counting, i.e. $\beta_o = \alpha_o$ and $\beta_f = \alpha_f$, we infer from (41) that $\mu_o - \tilde{\mu}_o = \mu_f - \tilde{\mu}_f$. In this case, differences in the marginal changes of per-animal welfare and quality-weighted per-animal welfare alone determine which animal food sector is regulated more heavily. From (39) and (40) we obtain

$$\tau_{y_o} \begin{matrix} \geq \\ \leq \end{matrix} \tau_{y_f} \iff \Delta(q_o) \begin{matrix} \geq \\ \leq \end{matrix} \Delta(q_f), \quad (45)$$

$$\sigma_{y_{q_o}} \begin{matrix} \geq \\ \leq \end{matrix} \sigma_{y_{q_f}} \iff A_q(q_o) \begin{matrix} \geq \\ \leq \end{matrix} A_q(q_f). \quad (46)$$

Making use of $A_{qq}(q) < 0$ and $\Delta_q(q) < 0$ from (42), we have

$$\Delta(q_o) \begin{matrix} \geq \\ \leq \end{matrix} \Delta(q_f) \quad \text{and} \quad A_q(q_o) \begin{matrix} \geq \\ \leq \end{matrix} A_q(q_f) \iff q_o \begin{matrix} \geq \\ \leq \end{matrix} q_f. \quad (47)$$

Under the plausible assumption that altruism is stronger for O -type consumers than for F -type consumers, i.e. $\beta_o = \alpha_o > \alpha_f = \beta_f$, the Pareto optimal animal living conditions at outdoor husbandry farming should be better than at factory farming, i.e. $q_o > q_f$. From (45), (46) and (47) we then again obtain $\tau_{y_o} < \tau_{y_f}$ and $\sigma_{y_o} < \sigma_{y_f}$. Intuitively, although the deviations of the private from the social animal friendliness are identical, type O animal food has to be less strongly regulated than type F animal food, because – for $q_o > q_f$ in the Pareto optimum – the animal welfare externality caused by O -type animal food is smaller than the animal welfare externality caused by F -type animal food.

(iii) Partial double counting: Finally, we turn to partial double counting, i.e. $0 < \beta_o < \alpha_o$ and $0 < \beta_f < \alpha_f$. In addition, we consider the plausible constellation $\mu_o - \tilde{\mu}_o < \mu_f - \tilde{\mu}_f$ which accordingly to (41) occurs if, e.g., the degree of double counting is identical in both sectors, so $\beta_o - \alpha_o = \beta_f - \alpha_f < 0$, and the morality of O -type consumers is larger than the morality of F -type consumers, so $\kappa_o > \kappa_f$. If the efficient animal food qualities satisfy $q_o > q_f$, as presupposed and plausible, it also follows $A_q(q_o) < A_q(q_f)$ as well as $\Delta(q_o) < \Delta(q_f)$ from (42). Taking all this into account in (39) and (40) again implies $\tau_{yo} < \tau_{yf}$ and $\sigma_{yo} < \sigma_{yf}$, so the tax and subsidy rates are smaller in the O -sector than in the F -sector.

To sum up (i)–(iii), in all cases considered we suppose plausible constellations of the model parameters and show that the optimal regulatory instruments in Proposition 5 have to be smaller in the O -sector than in the F -sector. Hence, in the presence of consumer and producer heterogeneity, the government is well advised to levy smaller tax and subsidy rates on factory farming than on outdoor husbandry in animal food production.

6 Conclusion

This paper identifies a novel animal welfare externality that requires a tax-subsidy regulation of animal food production to ensure efficiency. The animal welfare externality occurs if private animal friendliness falls short of social animal friendliness, where animal friendliness is determined by altruism, morality and a non-anthropocentric valuation of the animals' life. In a decentralized laissez-faire market economy, the quantity of animal food is inefficiently high, while the quality of animal food and, thus, the living conditions of animals in the production process are inefficiently low. A tax on the animal food quantity combined with a subsidy on the animal food quality or on the land input in the animal food production corrects this market failure. If the subsidy is imposed on animal quality per unit of animal food, our policy comes close to, for example, the policy proposal of the Borchert-Kommission in Germany. In contrast to the latter, we show that the net tax revenues of the tax-subsidy scheme have to be strictly positive in order to give animal food producers the incentive to take into account that animal welfare remains negative, even if the animal welfare externality is fully corrected. By extending our basic model to heterogeneous consumers and two types of farming - factory farming and outdoor husbandry farming - it turns out that sector-specific regulation is necessary to correct for the animal welfare externalities. Under plausible constellations, factory farming has to be stronger regulated than outdoor husbandry farming.

There are several interesting extensions of our analysis. In a supplementary appendix, we already introduce alternative reasons that are often used to justify regulation of animal food production in our model, in particular, greenhouse gas emissions from animal food production, biodiversity loss stemming from animal farming and health effects related to animal food consumption (see Funke et al., 2020).⁹ In contrast to our rationale based on animal welfare considerations, greenhouse gas emissions and biodiversity loss do not justify a regulatory tax-subsidy scheme. While greenhouse gas emissions require only to further increase the tax on the animal food quantity in order to internalize the additional emission externality, biodiversity loss even lowers the optimal subsidy on the quality of animal food/life, since a higher quality requires more land input in animal food production which reduces biodiversity. Health effects of animal food consumption adds both a tax element on the animal food quantity as well as a subsidy element on the animal food/life quality. In contrast to our rationale based on animal welfare considerations, however, the health rationale for the tax-subsidy solution requires a paternalistic approach, because regulation is only needed if consumers misperceive the effects of animal food consumption on their own health due to, for instance, self-control problems.

A further important task is to estimate the size of the animal welfare externality and the magnitude of the policy instruments for correcting this externality. Such an estimation may be done by an empirical calibration of a computable general equilibrium model. A corresponding analysis, which should also take into account other aspects like, for example, the above-mentioned alternative rationales for regulation of animal food production or further sectors of the economy, is beyond the scope of the present paper and left for future research.

Appendix

A. Efficiency conditions. The Lagrangian of welfare maximization is given by

$$\begin{aligned} \mathcal{L} = & \sum_j \left[U(y_j^d, q_j^d, \ell_j^s, r_j^s) + \beta \left[(1 - \kappa) \sum_k y_k^d A(q_k^d) + \kappa n y_j^d A(q_j^d) \right] \right] + \gamma \sum_j y_j^d A(q_j^d) \\ & + \phi_y \left[Y(\ell_y^d, r_y^d) - y^s \right] + \lambda_q \left(\frac{r_y^d}{y^s} - q^s \right) + \lambda_\ell \left(\sum_j \ell_j^s - \ell_y^d \right) + \lambda_r \left(\sum_j r_j^s - r_y^d \right) \\ & + \lambda_y \left(y^s - \sum_j y_j^d \right) + \sum_j \lambda_{qj} \left(q^s - q_j^d \right), \end{aligned}$$

⁹Formal details on these extensions can be obtained from the authors upon request.

where ϕ_y , λ_q , λ_ℓ , λ_r , λ_y and λ_{q_i} are Lagrange multipliers. Taking the derivatives of the Lagrangian, we obtain the first-order conditions of welfare maximization

$$\mathcal{L}_{\ell_y^d} = \phi_y Y_\ell - \lambda_\ell = 0, \quad (\text{A1})$$

$$\mathcal{L}_{r_y^d} = \phi_y Y_r + \frac{\lambda_q}{y^s} - \lambda_r = 0, \quad (\text{A2})$$

$$\mathcal{L}_{y^s} = -\phi_y - \lambda_q \frac{r_y^d}{(y^s)^2} + \lambda_y = 0, \quad (\text{A3})$$

$$\mathcal{L}_{q^s} = -\lambda_q + \sum_j \lambda_{q_j} = 0, \quad (\text{A4})$$

$$\mathcal{L}_{y_i^d} = U_y + [\gamma + \beta(1 - \kappa)n]A + \beta\kappa nA - \lambda_y = 0, \quad \text{for all } i, \quad (\text{A5})$$

$$\mathcal{L}_{q_i^d} = U_q + [\gamma + \beta(1 - \kappa)n]y_i^d A_q + \beta\kappa n y_i^d A_q - \lambda_{q_i} = 0, \quad \text{for all } i, \quad (\text{A6})$$

$$\mathcal{L}_{r_i^s} = U_r + \lambda_r = 0, \quad \text{for all } i, \quad (\text{A7})$$

$$\mathcal{L}_{\ell_i^s} = U_\ell + \lambda_\ell = 0, \quad \text{for all } i. \quad (\text{A8})$$

Solving (A3) for ϕ_y , taking into account $r_y^d = r_y$, $y^s = y$, $q = r_y/y$ and inserting into (A1) gives the condition in column 1, row 1 of Table 1. Dividing (A2) by (A1) and using $y^s = y$ implies the condition in column 1, row 2 of Table 1. The condition in column 1, row 3 of Table 1 follows from (A4). Notice that λ_{q_i} is the same for all i due to our assumption of identical consumers. Finally, the conditions in column 1, row 4, 5 and 6 are obtained by dividing (A5), (A6) and (A7), respectively, by (A8) and using $y_i^d = y_i$ as well as $\mu = \gamma + \beta n$.

B. Market equilibrium conditions. The Langrangians of the producer's and consumer's maximization problem can be written as, respectively,

$$\begin{aligned} \mathcal{L}^y = & \left[P^y(q^s) - \tau_y + \sigma_{qy}q^s \right] y^s + \sigma_q q^s - p_\ell \ell_y^d - (p_r - \sigma_r) r_y^d \\ & + \omega_y \left[Y(\ell_y^d, r_y^d) - y^s \right] + \omega_q \left(\frac{r_y^d}{y^s} - q^s \right), \end{aligned}$$

$$\mathcal{L}^c = U(y_i^d, q_i^d, \ell_i^s, r_i^s) + \alpha \left[(1 - \kappa)a + \kappa n y_i^d A(q_i^d) \right] + \omega_c \left[p_\ell \ell_i^s + p_r r_i^s + \psi - P^y(q_i^d) y_i^d \right],$$

where ω_y , ω_q and ω_c are Lagrange multipliers. Taking the derivatives of these Lagrangians, we obtain the first-order conditions in the market equilibrium

$$\mathcal{L}_{\ell_y^d}^y = \omega_y Y_\ell - p_\ell = 0, \quad (\text{B1})$$

$$\mathcal{L}_{r_y^d}^y = \omega_y Y_r + \frac{\omega_q}{y^s} - p_r + \sigma_r = 0, \quad (\text{B2})$$

$$\mathcal{L}_{y^s}^y = -\omega_y - \omega_q \frac{r_y^d}{(y^s)^2} + P^y - \tau_y + \sigma_{qy}q^s = 0, \quad (\text{B3})$$

$$\mathcal{L}_{q^s}^y = -\omega_q + (P_q^y + \sigma_{qy})y^s + \sigma_q = 0, \quad (\text{B4})$$

$$\mathcal{L}_{y_i^d}^c = U_y + \alpha\kappa nA - \omega_c P^y = 0, \quad \text{for all } i, \quad (\text{B5})$$

$$\mathcal{L}_{q_i^d}^c = U_q + \alpha\kappa n y_i^d A_q - \omega_c P_q^y y_i^d = 0, \quad \text{for all } i, \quad (\text{B6})$$

$$\mathcal{L}_{r_i^s}^c = U_r + \omega_c p_r = 0, \quad \text{for all } i, \quad (\text{B7})$$

$$\mathcal{L}_{\ell_i^s}^c = U_\ell + \omega_c p_\ell = 0, \quad \text{for all } i. \quad (\text{B8})$$

Solving (B4) for ω_q , inserting into (B3), solving the resulting expression for ω_y , plugging into (B1) and using $r_y^d = r_y$, $y^s = y$, $q^s = q = r_y/y$ gives the condition in column 2, row 1 of Table 1. Dividing (B2) by (B1), using again ω_q from (B4) and taking into account that $y^s = y$, yields the condition in column 2, row 2 of Table 1. Finally, the conditions in column 2, row 4, 5 and 6 of Table 1 are obtained by dividing (B5), (B6) and (B7), respectively, by (B8) and taking into account $y_i^d = y_i$ as well as $\tilde{\mu} = \alpha\kappa n$.

C. Proof of Proposition 3. Setting in column 2 of Table 1 the tax and subsidy rates as well as the market prices as in Proposition 2, we see that the market equilibrium conditions in the laissez-faire economy are the same as the efficiency conditions in column 1 of Table 1, except that they contain $\tilde{\mu}$ instead of μ . Hence, for $\mu > \tilde{\mu}$ the idea of the proof is to run a comparative static analysis of the efficiency conditions in column 1 of Table 1 with respect to the social animal friendliness μ . A decrease in μ then mimics the transition from the efficient allocation to the market allocation under laissez-faire.

If the utility function U takes the functional form specified in Proposition 3, it is quasi-linear in labor and, thus, $U_\ell = -1$. Taking into account $\lambda_\ell = -U_\ell = 1$, the efficiency conditions in column 1 of Table 1 together with (1), (2) and (4)–(6) can be rewritten as

$$\frac{1}{Y_\ell(\ell_y, r_y)} = \lambda_y - \frac{q}{y}\lambda_q, \quad (\text{C1})$$

$$\frac{Y_r(\ell_y, r_y)}{Y_\ell(\ell_y, r_y)} = \lambda_r - \frac{\lambda_q}{y}, \quad (\text{C2})$$

$$\lambda_q = n\lambda_{q_i}, \quad (\text{C3})$$

$$U_y(y_i, q, r_i, \ell_i) + \mu A(q) = \lambda_y, \quad (\text{C4})$$

$$U_q(y_i, q, r_i, \ell_i) + \mu y_i A_q(q) = \lambda_{q_i}, \quad (\text{C5})$$

$$-U_r(y_i, q, r_i, \ell_i) = \lambda_r, \quad (\text{C6})$$

$$y = Y(\ell_y, r_y), \quad (\text{C7})$$

$$r_y = qy, \quad (\text{C8})$$

$$r_y = nr_i, \quad (\text{C9})$$

$$\ell_y = n\ell_i, \quad (\text{C10})$$

$$y = ny_i. \quad (\text{C11})$$

Equations (C1)–(C11) represent a set of eleven equations determining the eleven variables ℓ_y , r_y , q , y , ℓ_i , r_i , y_i , λ_y , λ_q , λ_{qi} and λ_r as functions of the parameter μ . We conduct a comparative static analysis of these equations using the so-called hat calculus introduced by Jones (1965). Defining $\hat{x} := \frac{dx}{x}$ for $x \in \{\ell_y, r_y, q, y, \ell_i, r_i, y_i, \lambda_y, \lambda_q, \lambda_{qi}, \lambda_r, \mu\}$ and totally differentiating (C3) and (C9)–(C11) yields $\hat{\lambda}_q = \hat{\lambda}_{qi}$, $\hat{r}_y = \hat{r}_i$, $\hat{\ell}_y = \hat{\ell}_i$ and $\hat{y} = \hat{y}_i$. Using these relations in the total differential of (C1), (C2) and (C4)–(C8), taking into account that U_y , U_q as well as U_r no longer depend on ℓ_i due to $U_\ell = -1$, implies

$$-\frac{1}{(Y_\ell)^2} \left(\ell_y Y_{\ell\ell} \hat{\ell}_y + r_y Y_{\ell r} \hat{r}_y \right) = \lambda_y \hat{\lambda}_y - \frac{q\lambda_q}{y} \hat{\lambda}_q + \lambda_q \frac{q}{y} (\hat{y} - \hat{q}), \quad (\text{C12})$$

$$\frac{1}{\theta} \frac{Y_r}{Y_\ell} \left(\hat{\ell}_y - \hat{r}_y \right) = \lambda_r \hat{\lambda}_r - \frac{\lambda_q}{y} \hat{\lambda}_q + \frac{\lambda_q}{y} \hat{y}, \quad (\text{C13})$$

$$U_{yy} y_i \hat{y} + (U_{yq} + \mu A_q) q \hat{q} + U_{yr} r_i \hat{r}_y + A \mu \hat{\mu} = \lambda_y \hat{\lambda}_y, \quad (\text{C14})$$

$$\begin{aligned} (U_{qy} + \mu A_q) y_i \hat{y} + (U_{qq} + \mu y_i A_{qq}) q \hat{q} \\ + U_{qr} r_i \hat{r}_y + y_i A_q \mu \hat{\mu} = \lambda_{qi} \hat{\lambda}_q. \end{aligned} \quad (\text{C15})$$

$$-U_{ry} y_i \hat{y} - U_{rq} q \hat{q} - U_{rr} r_i \hat{r}_y = \lambda_r \hat{\lambda}_r, \quad (\text{C16})$$

$$\hat{y} = \frac{\ell_y Y_\ell}{y} \hat{\ell}_y + \frac{r_y Y_r}{y} \hat{r}_y, \quad (\text{C17})$$

$$\hat{r}_y = \hat{q} + \hat{y}, \quad (\text{C18})$$

where in (C13) we have used the homogeneity properties $y = \ell_y Y_\ell + r_y Y_r$, $\ell_y Y_{\ell\ell} + r_y Y_{\ell r} = 0$, $\ell_y Y_{\ell r} + r_y Y_{rr} = 0$ and $Y_{rr} = \frac{\ell_y^2}{r_y^2} Y_{\ell\ell}$ of Y , and where $\theta := -\frac{q Y_r Y_\ell}{\ell_y Y_{\ell\ell}} > 0$ is the substitution elasticity of labor and land in animal food production (see Uzawa, 1962, eq. (1)).

Using (C14)–(C18) to successively eliminate $\hat{\lambda}_y$, $\hat{\lambda}_q$, $\hat{\lambda}_r$, $\hat{\ell}_y$ and \hat{r}_y from (C12) and (C13) and accounting again for the homogeneity properties of Y , the expression $\frac{\lambda_q}{y} = \frac{\lambda_{qi}}{y_i} = \mu A' + \frac{U_q}{y_i}$ from (C5), the functional form $U(y_i, q, r_i, \ell_i) = \tilde{U}(y_i, q) - R(r_i) - \ell_i$ with $\tilde{U}(y_i, q) = [\eta y_i^{-\rho} + \nu (q y_i)^{-\rho}]^{-\frac{h}{\rho}}$, $\eta, \nu \geq 0$, $\rho \geq -1$, $0 < h \leq 1$, $h + \rho \geq 0$, $R_r > 0$ and $R_{rr} \geq 0$ as well as the definition $L := \frac{y Y_{\ell\ell}}{Y_\ell^3} = -\frac{q y Y_r}{\theta \ell_y Y_\ell^2} \leq 0$, we obtain after some tedious rearrangements

$$\phi_q \hat{q} + \phi_y \hat{y} = (A - q A_q) \mu \hat{\mu}, \quad \psi_q \hat{q} + \psi_y \hat{y} = -A_q \mu \hat{\mu}, \quad (\text{C19})$$

with

$$\phi_q = L + q^2 \mu A_{qq} + \frac{q}{y_i} U_q - q U_{qy} + \frac{q^2}{y_i} U_{qq} = L + q^2 \mu A_{qq} - \frac{\eta \nu (h + \rho) h q^\rho \tilde{U}}{y_i (\nu + \eta q^\rho)^2} < 0, \quad (\text{C20})$$

$$\phi_y = -\frac{q}{y_i} U_q + q U_{qy} - y_i U_{yy} = \frac{\eta (1 - h) h q^\rho \tilde{U}}{y_i (\nu + \eta q^\rho)} > 0, \quad (\text{C21})$$

$$\psi_q = \frac{L}{q} + q\mu A_{qq} + r_i U_{rr} + \frac{q}{y_i} U_{qq} = \frac{L}{q} + q\mu A_{qq} - r_i R_{rr} - \frac{\nu h[\nu(1-h) + \eta(1+\rho)q^\rho] \tilde{U}}{q y_i (\nu + \eta q^\rho)^2} < 0, \quad (\text{C22})$$

$$\psi_y = r_i U_{rr} - \frac{1}{y_i} U_q + U_{yy} = -r_i R_{rr} - \frac{\nu(1-h)h\tilde{U}}{q y_i (\nu + \eta q^\rho)} < 0. \quad (\text{C23})$$

Solving (C19) by applying Cramer's rule, we get

$$\frac{\hat{q}}{\mu\hat{\mu}} = \frac{A\psi_y + A_q(\phi_y - q\psi_y)}{D}, \quad \frac{\hat{y}}{\mu\hat{\mu}} = -\frac{A\psi_q + A_q(\phi_q - q\psi_q)}{D}, \quad (\text{C24})$$

where $D = \phi_q\psi_y - \phi_y\psi_q > 0$. From (C18), it additionally holds

$$\frac{\hat{r}_y}{\mu\hat{\mu}} = \frac{\hat{q}}{\mu\hat{\mu}} + \frac{\hat{y}}{\mu\hat{\mu}} = \frac{A(\psi_y - \psi_q) - A_q(\phi_q - \phi_y - q\psi_q + q\psi_y)}{D}. \quad (\text{C25})$$

Using (C20)–(C23), straightforward but tedious calculations yield

$$\phi_q - q\psi_q = q r_i R_{rr} + \frac{\nu(1-h)h\tilde{U}}{y_i(\nu + \eta q^\rho)} > 0 \quad (\text{C26})$$

and

$$\begin{aligned} & A(\psi_y - \psi_q) - A_q(\phi_q - \phi_y - q\psi_q + q\psi_y) = \\ & \underbrace{-A\left(\frac{L}{q} + q\mu A_{qq}\right)}_{\leq 0} + \underbrace{A\frac{\eta\nu h(h+\rho)q^\rho\tilde{U}}{q y_i(\nu + \eta q^\rho)^2}}_{\leq 0} + \underbrace{A_q\frac{\eta(1-h)h q^\rho\tilde{U}}{y_i(\nu + \eta q^\rho)}}_{\geq 0}. \end{aligned} \quad (\text{C27})$$

Using the signs of the expressions in (C20)–(C23) and (C26) as well as $D > 0$, $A < 0$ and $A_q > 0$ in (C24), we infer $\frac{\hat{q}}{\mu\hat{\mu}} > 0$ and $\frac{\hat{y}}{\mu\hat{\mu}} < 0$, which proves part (i) of Proposition 3. From (C25) and (C27) we can prove part (ii) as follows. If $h = 1$ or $\eta = 0$, then the last term in (C27) vanishes and the sum of the remaining terms is strictly negative, so (C25) together with $D > 0$ implies $\frac{\hat{r}_y}{\mu\hat{\mu}} < 0$. In contrast, if $A_{qq} = 0$, $\nu = 0$ and $\theta \rightarrow \infty$, so that $L \rightarrow 0$, then the first two terms in (C27) vanish, while the last term stays positive, so (C25) together with $D > 0$ implies $\frac{\hat{r}_y}{\mu\hat{\mu}} > 0$. This completes the proof of Proposition 3.

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Supplementary Appendix

In this supplementary appendix, we consider three further aspects that are mentioned and discussed in connection with the reduction of animal food consumption (e.g. Treich 2022). The main question we address is whether these aspects can also be used to justify the tax-subsidy combination identified as efficient in the main text. We assume that the animal welfare is still present and confine the set of tax instruments to the tax on the animal food quantity, τ_y , and the subsidy on the animal food quality per unit of animal food, σ_{qy} .

Greenhouse gas emissions. Our first extensions takes into account greenhouse gas emissions of animal food production. Accordingly to Poore and Nemecek (2018), general food production is responsible for approximately 26 % of global greenhouse gase emissions, from which 58 % are related to animal-based food (Xu et al., 2021). To model such emissions, we assume that emissions are proportional to the animal food quantity and denote by $\bar{e} \geq 0$ the emissions intensity of animal food. Emissions generated by consumer i 's animal food consumption are therefore equal to $\bar{e}y_i^d$, whereas total emissions are represented by $\bar{e} \sum_j y_j^d$.¹⁰ Each consumer suffers a climate damage from these emissions denoted by $z = Z \left(\bar{e} \sum_j y_j^d \right)$ with $Z_e > 0$ and $Z_{ee} > 0$. The utility of a homo moralis consumer in (3) turns into

$$u_i^m = U(y_i^d, q_i^d, \ell_i^s, r_i^s) + \alpha \left[(1 - \kappa)a + \kappa n y_i^d A(q_i^d) \right] - (1 - \kappa)z - \kappa Z(n \bar{e} y_i^d), \quad (\text{S1})$$

where the consumer takes as given both the animal welfare a and the environmental damage z , in case she behaves as homo oeconomicus, and assumes that all other consumers choose the same animal food consumption and emission level as she does, in case she acts like a homo kantianensis. The social welfare function (8) can be rewritten as

$$w = \sum_j \left[U(y_j^d, q_j^d, \ell_j^s, r_j^s) + \beta \left[(1 - \kappa) \sum_k y_k^d A(q_k^d) + \kappa n y_j^d A(q_j^d) \right] - (1 - \kappa)Z \left(\bar{e} \sum_k y_k^d \right) - \kappa Z(n \bar{e} y_j^d) \right] + \gamma \sum_j y_j^d A(q_j^d), \quad (\text{S2})$$

where, in contrast to the homo oeconomicus consumer, the social planner takes into account that animal welfare depends on animal food consumption due to $a = \sum_j y_j^d A(q_j^d)$ and that the climate damage depends on emissions according to $z = Z \left(\bar{e} \sum_j y_j^d \right)$. In a decentralized

¹⁰We can also model emissions from the point of view of the production side, such that total emissions are given by $\bar{e}y^s$. Similar to the modeling of animal welfare, this would slightly change the math of the analysis, but would leave completely unchanged the results due to the general equilibrium nature of our model.

	row	efficiency	markets
column		1	2
animal	1	$\frac{1}{Y_\ell} = \frac{\lambda_y}{\lambda_\ell} - \frac{q}{y} \frac{\lambda_q}{\lambda_\ell}$	$\frac{1}{Y_\ell} = \frac{P^y - \tau_y}{p_\ell} - \frac{q}{y} \frac{P_q^y y}{p_\ell}$
production	2	$\frac{Y_r}{Y_\ell} = \frac{\lambda_r}{\lambda_\ell} - \frac{1}{y} \frac{\lambda_q}{\lambda_\ell}$	$\frac{Y_r}{Y_\ell} = \frac{p_r}{p_\ell} - \frac{1}{y} \frac{(P_q^y + \sigma_{qy})y}{p_\ell}$
	3	$\frac{\lambda_q}{\lambda_\ell} = n \frac{\lambda_{qi}}{\lambda_\ell}$	---
consumer i	4	$-\frac{U_y + \mu A - n\bar{e}Z_e}{U_\ell} = \frac{\lambda_y}{\lambda_\ell}$	$-\frac{U_y + \tilde{\mu}A - \kappa n\bar{e}Z_e}{U_\ell} = \frac{P^y}{p_\ell}$
(for all i)	5	$-\frac{U_q + \mu y_i A_q}{U_\ell} = \frac{\lambda_{qi}}{\lambda_\ell}$	$-\frac{U_q + \tilde{\mu} y_i A_q}{U_\ell} = \frac{P_q^y y_i}{p_\ell}$
	6	$\frac{U_r}{U_\ell} = \frac{\lambda_r}{\lambda_\ell}$	$\frac{U_r}{U_\ell} = \frac{p_r}{p_\ell}$

Table 3: Conditions for efficiency and market equilibrium in the presence of emissions

economy, the maximization problems (11) and (12) remain unchanged, except of setting $\sigma_q = \sigma_r = 0$ in (11) and replacing (3) by (S1) in (12).

By the same Lagrangian techniques as in the basic model, it is straightforward to derive the efficiency conditions displayed in column 1 of Table 3 and the market equilibrium conditions listed in column 2 of Table 3. Plugging rows 4-6 into rows 1-3 of this table, we obtain from column 1 the efficient allocations rules

$$-\frac{U_y + \mu A - n\bar{e}Z_e}{U_\ell} = \frac{1}{Y_\ell} - \frac{nq}{y} \frac{U_q + \mu y_i A_q}{U_\ell}, \quad (\text{S3})$$

$$\frac{U_r}{U_\ell} = \frac{Y_r}{Y_\ell} - \frac{n}{y} \frac{U_q + \mu y_i A_q}{U_{\ell_i}}, \quad (\text{S4})$$

whereas column 2 implies the market allocations rules

$$-\frac{U_y + \tilde{\mu}A - \kappa n\bar{e}Z_e}{U_\ell} = \frac{1}{Y_\ell} - \frac{nq}{y} \frac{U_q + \tilde{\mu} y_i A_q}{U_\ell} + \tau_y, \quad (\text{S5})$$

$$\frac{U_r}{U_\ell} = \frac{Y_r}{Y_\ell} - \frac{n}{y} \frac{U_q + \tilde{\mu} y_i A_q}{U_\ell} + \sigma_{qy}. \quad (\text{S6})$$

Remembering that we set $\sigma_r = \sigma_q = 0$ in the extended models and comparing (S3)–(S6) with the corresponding rules (9), (10), (13) and (14) in the basic model, we see that the rules (S4) and (S6) for land input, r_y , remain completely unchanged, whereas the rules for the animal food quantity (S3) and (S5) comprise additional terms with the marginal environmental

damage. While the efficient allocation rule (S3) contains the full marginal damage $n\bar{e}Z_e$, the market allocation rule (S5) reflects only the morally internalized marginal damage $\kappa n\bar{e}Z_e$. Next to the animal welfare externality, we therefore obtain an emission externality which further distorts the laissez-faire economy.

Comparing (S3) and (S4) with (S5) and (S6) and using $U_\ell = -\lambda_\ell = -1$ yields

Proposition 6. (*Efficient regulation with greenhouse gas emissions*)

Suppose that $\mu > \tilde{\mu}$. Set $p_\ell = \lambda_\ell = 1$, $p_r = \lambda_r$, $P^y = \lambda_y + \tau_y - \sigma_{qy}q$, $P_q^y \frac{y}{n} = \lambda_{qi} - \frac{y}{n}\sigma_{qy}$ and

$$\tau_y = -(\mu - \tilde{\mu})A + (\mu - \tilde{\mu})qA_q + (1 - \kappa)n\bar{e}Z_e > 0, \quad \sigma_{qy} = (\mu - \tilde{\mu})A_q > 0. \quad (\text{S7})$$

Then, the market economy is efficient.

Contrasting the policy identified in Proposition 6 with the policy in Proposition 4 or, equivalently (18), we see that greenhouse case emissions add a further element $(1 - \kappa)n\bar{e}Z_e > 0$ to the tax on the animal food quantity, τ_y . While all terms containing A and A_q internalize the animal welfare externality in the same way as in the basic model, the new term $(1 - \kappa)n\bar{e}Z_e$ corrects the emission externality which consumers cause since they internalize only the part κ of the environmental damage. Importantly, the new term only enters the tax on the animal food quantity, τ_y , leaving unchanged the subsidy on the animal food quality, σ_{qy} . Hence, considering only the emission externality, i.e. setting $\mu = \tilde{\mu}$ in (S7), would not be sufficient to justify the tax-subsidy solution which we highlighted in our basic model.

Biodiversity loss. Land use for agriculture is among the major drivers of biodiversity loss (Newbold et al., 2015). The rapid expansion of animal farming over the last decades has destroyed the habitat of wildlife species and significantly contributed to biodiversity loss. Around 50% of the earth's land surface are currently under agriculture use (Ritchie and Rosner, 2019), and human pressures are rapidly intensifying in places with high biodiversity (Venter et al., 2016). To capture the link between land use and biodiversity loss in our formal model, assume that total land available is fixed and denoted by $\bar{r} > 0$. Taking into account the consumers' land supply for animal food production, the amount of land remaining for the community of wildlife species is $\bar{r} - \sum_j r_j^s$.¹¹ This habitat provides a benefit for consumers represented by the function $b = B\left(\bar{r} - \sum_j r_j^s\right)$ with $B_r > 0$ and $B_{rr} < 0$, which can be interpreted as an indicator of biodiversity or ecosystem services whose significance for

¹¹Alternatively, we may define the remaining land available for wildlife species as $\bar{r} - r_y$. Due to the general equilibrium property of our approach, this will change the math but not the results.

consumers ranges from esthetic to life-supporting. With this modification of our basic model, the utility of the homo moralis consumer i in (3) can be rewritten as

$$u_i^m = U(y_i^d, q_i^d, \ell_i^s, r_i^s) + \alpha \left[(1 - \kappa)a + \kappa n y_i^d A(q_i^d) \right] + (1 - \kappa)b + \kappa B(\bar{r} - n r_i^s), \quad (\text{S8})$$

where the consumer takes as given both the animal welfare a and the biodiversity utility b , in case she acts like a homo oeconomicus, and assumes that all other consumers choose the same animal food consumption and land supply as she does, in case she behaves as a homo kantianus. The social welfare function (8) turns into

$$w = \sum_j \left[U(y_j^d, q_j^d, \ell_j^s, r_j^s) + \beta \left[(1 - \kappa) \sum_k y_k^d A(q_k^d) + \kappa n y_j^d A(q_j^d) \right] + (1 - \kappa)B\left(\bar{r} - \sum_k r_k^s\right) + \kappa B(\bar{r} - n r_j^s) \right] + \gamma \sum_j y_j^d A(q_j^d), \quad (\text{S9})$$

where we assume that the social planner, in contrast to the homo oeconomicus consumer, takes into account not only the relation between food consumption and animal welfare, i.e. $a = \sum_j y_j^d A(q_j^d)$, but also the relation between land use and biodiversity, i.e. $b = B(\bar{r} - \sum_j r_j^s)$. In the decentralized market economy, profit maximization of the animal food producer and utility maximization of consumer i is still given by (11) and (12), respectively, except of setting $\sigma_q = \sigma_r = 0$ in (11) and replacing (3) by (S8) in (12).

Again applying the same Lagrangian methods as in the basic model, we can derive the efficiency conditions in column 1 of Table 4 as well as the market equilibrium conditions in column 2 of Table 4. Inserting rows 4-6 into rows 1-3 yields the efficient allocation rules

$$-\frac{U_y + \mu A}{U_\ell} = \frac{1}{Y_\ell} - \frac{nq}{y} \frac{U_q + \mu y_i A_q}{U_\ell}, \quad (\text{S10})$$

$$\frac{U_r - nB_r}{U_\ell} = \frac{Y_r}{Y_\ell} - \frac{n}{y} \frac{U_q + \mu y_i A_q}{U_{\ell_i}}, \quad (\text{S11})$$

and the market allocation rules

$$-\frac{U_y + \tilde{\mu} A}{U_\ell} = \frac{1}{Y_\ell} - \frac{nq}{y} \frac{U_q + \tilde{\mu} y_i A_q}{U_\ell} + \tau_y, \quad (\text{S12})$$

$$\frac{U_r - \kappa n B_r}{U_\ell} = \frac{Y_r}{Y_\ell} - \frac{n}{y} \frac{U_q + \tilde{\mu} y_i A_q}{U_\ell} + \sigma_{qy}. \quad (\text{S13})$$

Comparing these allocation rules with the rules (9), (10), (13) and (14) for $\sigma_r = \sigma_q = 0$ in the basic model, we see that the rules (S10) and (S12) for the animal food quantity remain unchanged, whereas the rules (S11) and (S13) for the land input in animal food production comprise additional terms reflecting the marginal biodiversity utility B_r . Because

	row	efficiency	markets
column		1	2
animal	1	$\frac{1}{Y_\ell} = \frac{\lambda_y}{\lambda_\ell} - \frac{q}{y} \frac{\lambda_q}{\lambda_\ell}$	$\frac{1}{Y_\ell} = \frac{P^y - \tau_y}{p_\ell} - \frac{q}{y} \frac{P_q^y y}{p_\ell}$
production	2	$\frac{Y_r}{Y_\ell} = \frac{\lambda_r}{\lambda_\ell} - \frac{1}{y} \frac{\lambda_q}{\lambda_\ell}$	$\frac{Y_r}{Y_\ell} = \frac{p_r}{p_\ell} - \frac{1}{y} \frac{(P_q^y + \sigma_{qy})y}{p_\ell}$
	3	$\frac{\lambda_q}{\lambda_\ell} = n \frac{\lambda_{qi}}{\lambda_\ell}$	--
consumer i	4	$-\frac{U_y + \mu A}{U_\ell} = \frac{\lambda_y}{\lambda_\ell}$	$-\frac{U_y + \tilde{\mu} A}{U_\ell} = \frac{P^y}{p_\ell}$
(for all i)	5	$-\frac{U_q + \mu y_i A_q}{U_\ell} = \frac{\lambda_{qi}}{\lambda_\ell}$	$-\frac{U_q + \tilde{\mu} y_i A_q}{U_\ell} = \frac{P_q^y y_i}{p_\ell}$
	6	$\frac{U_r - n B_r}{U_\ell} = \frac{\lambda_r}{\lambda_\ell}$	$\frac{U_r - \kappa n B_r}{U_\ell} = \frac{p_r}{p_\ell}$

Table 4: Conditions for efficiency and market equilibrium in the presence of biodiversity

the efficient allocation rule (S11) contains the full marginal biodiversity utility nB_r , while the market allocation rule (S13) comprises only the morally internalized marginal biodiversity utility κnB_r , a biodiversity externality arises next to the animal welfare externality.

In order to see the implications of the additional biodiversity externality for optimal regulatory policy, we compare (S10) and (S11) with (S12) and (S13) and obtain

Proposition 7. (*Efficient regulation with biodiversity loss*)

Suppose that $\mu > \tilde{\mu}$. Set $p_\ell = \lambda_\ell = 1$, $p_r = \lambda_r - (1 - \kappa)nB_r$, $P^y = \lambda_y + \tau_y - \sigma_{qy}q + (1 - \kappa)qnB_r$, $P_q^y \frac{y}{n} = \lambda_{qi} - \frac{y}{n}\sigma_{qy} - (1 - \kappa)yB_r$ and

$$\tau_y = -(\mu - \tilde{\mu})A + (\mu - \tilde{\mu})qA_q > 0, \quad \sigma_{qy} = (\mu - \tilde{\mu})A_q - (1 - \kappa)nB_r \geq 0. \quad (\text{S14})$$

Then, the market economy is efficient.

While moral consumers internalize the fraction κ of the biodiversity externality, the remaining fraction $1 - \kappa$ has to be corrected for by the regulatory policy. According to (S14), this is done by the subsidy on the animal quality per unit of land, σ_{qy} , which now contains the additional tax element $-(1 - \kappa)nB_r < 0$. Intuitively, the biodiversity externality implies that land use for animal production is too excessive, in contrast to the animal welfare externality according to which the animals' quality of life and, thus, land use in animal farming is too

low. Hence, both externalities exert opposing effects on the quality subsidy, such that σ_{qy} is indeterminate in sign. This result immediately implies that also biodiversity considerations, in contrast to animal welfare concerns, are not suitable to justify the tax-subsidy solution for which our basic analysis provides a foundation.

Health. Excessive consumption of (red) meat increases the incidence of cancer, metabolic diseases such as type 2 diabetes, cardiovascular diseases or other chronic diseases. It may have a negative impact on life expectancy (Gonzalez et al., 2020). Moreover, antibiotics that are commonly used in livestock farming for the treatment and prevention of diseases and growth promotion also may cause health problems and generate antibiotic resistant bacteria to humans and, thereby, allergies, reproductive disorders and even carcinogenicity (Bacanli and Basyran, 2019). In order to investigate such health effects of animal food consumption, we introduce the health costs $H(y_i, q_i)$ of consumer i which are increasing in the animal food quantity, $H_y > 0$, and decreasing in the animal food quality, $H_q < 0$.¹² We assume that consumers suffer from a self-control problem and take into account only a part $\delta \in [0, 1[$ of their health costs. Hence, consumer i 's utility (3) now reads

$$u_i^m = U(y_i^d, q_i^d, \ell_i^s, r_i^s) + \alpha \left[(1 - \kappa) \sum_j y_j^d A(q_j^d) + \kappa n y_i^d A(q_i^d) \right] - \delta H(y_i^d, q_i^d). \quad (\text{S15})$$

The social welfare function (8) can be rewritten as

$$w = \sum_j \left[U(y_j^d, q_j^d, \ell_j^s, r_j^s) + \beta \left[(1 - \kappa) \sum_k y_k^d A(q_k^d) + \kappa n y_j^d A(q_j^d) \right] \right] + \gamma \sum_j y_j^d A(q_j^d) - \sum_j H(y_j^d, q_j^d). \quad (\text{S16})$$

Notice that the social planner is paternalistic and takes into account the true health costs.

By the same Lagrangian methods as in the basic model, we can derive the first-order conditions for the efficient solution and the market allocation in column 1 and column 2 of Table 5, respectively. Inserting rows 4-6 into rows 1-3 in column 2 of Table 5 yields the allocation rules for the efficient solution

$$-\frac{U_y + \mu A - H_y}{U_\ell} = \frac{1}{Y_\ell} - \frac{nq}{y} \frac{U_q + \mu y_i A_q - H_q}{U_\ell}, \quad (\text{S17})$$

$$\frac{U_r}{U_\ell} = \frac{Y_r}{Y_\ell} - \frac{n}{y} \frac{U_q + \mu y_i A_q - H_q}{U_\ell}. \quad (\text{S18})$$

¹²We refrain from explicitly modeling cross-consumers effects of animal food consumption on health costs, like those generated by antibiotic resistance due to the extensive use of antibiotics in food production.

	row	efficiency	markets
column		1	2
animal	1	$\frac{1}{Y_\ell} = \frac{\lambda_y}{\lambda_\ell} - \frac{q \lambda_q}{y \lambda_\ell}$	$\frac{1}{Y_\ell} = \frac{P^y - \tau_y}{p_\ell} - \frac{q P_q^y y}{y p_\ell}$
production	2	$\frac{Y_r}{Y_\ell} = \frac{\lambda_r}{\lambda_\ell} - \frac{1 \lambda_q}{y \lambda_\ell}$	$\frac{Y_r}{Y_\ell} = \frac{p_r}{p_\ell} - \frac{1 (P_q^y + \sigma_{qy}) y}{y p_\ell}$
	3	$\frac{\lambda_q}{\lambda_\ell} = n \frac{\lambda_{qi}}{\lambda_\ell}$	---
consumer i	4	$-\frac{U_y + \mu A - H_y}{U_\ell} = \frac{\lambda_y}{\lambda_\ell}$	$-\frac{U_y + \tilde{\mu} A - \delta H_y}{U_\ell} = \frac{P^y}{p_\ell}$
(for all i)	5	$-\frac{U_q + \mu y_i A_q - H_q}{U_\ell} = \frac{\lambda_{qi}}{\lambda_\ell}$	$-\frac{U_q + \tilde{\mu} y_i A_q - \delta H_q}{U_\ell} = \frac{P_q^y y_i}{p_\ell}$
	6	$\frac{U_r}{U_\ell} = \frac{\lambda_r}{\lambda_\ell}$	$\frac{U_r}{U_\ell} = \frac{p_r}{p_\ell}$

Table 5: Conditions for efficiency and market equilibrium in the presence of health effects

Plugging rows 4-6 into rows 1 and 2 in column 2 of Table 5 implies that the allocation rules for the decentralized market economy are given by

$$-\frac{U_y + \tilde{\mu} A - \delta H_y}{U_\ell} = \frac{1}{Y_\ell} - \frac{nq}{y} \frac{U_q + \tilde{\mu} y_i A_q - \delta H_q}{U_\ell} + \tau_y, \quad (\text{S19})$$

$$\frac{U_r}{U_\ell} = \frac{Y_r}{Y_\ell} - \frac{n}{y} \frac{U_q + \tilde{\mu} y_i A_q - \delta H_q}{U_\ell} + \sigma_{qy}. \quad (\text{S20})$$

Next to the deviation of the social and private animal friendliness, i.e. $\mu \neq \tilde{\mu}$, and the associated animal welfare externality, the difference between perceived and true health costs, i.e. $\delta \in [0, 1[$, causes a *health internality*, since in the market economy consumers ignore a part of their true health costs when deciding on their animal food consumption.

In order to identify the changes in governmental intervention caused by the health internality, we compare the efficient and market allocation rules in (S17)–(S20) to obtain

Proposition 8. (*Efficient regulation with health effects*)

Suppose that $\mu > \tilde{\mu}$. Set $p_\ell = \lambda_\ell = 1$, $p_r = \lambda_r$, $P^y = \lambda_y + \tau_y - \sigma_{qy} q$, $P_q^y \frac{y}{n} = \lambda_{qi} - \frac{y}{n} \sigma_{qy}$ and

$$\tau_y = -(\mu - \tilde{\mu})A + (\mu - \tilde{\mu})qA_q + (1 - \delta) \left(H_y - \frac{nq}{y} H_q \right) > 0, \quad (\text{S21})$$

$$\sigma_{qy} = (\mu - \tilde{\mu})A_q - (1 - \delta) \frac{n}{y} H_q > 0. \quad (\text{S22})$$

Then, the market economy is efficient.

Comparing Proposition 8 with Proposition 4 for $\sigma_r = \sigma_q = 0$ or, equivalently, with equation (18), we see that the health externality adds a new element to both the tax on the animal food quantity, τ_y , and the subsidy on animal quality per unit of animal food, σ_{qy} . Since consumers take into account only a part of their health costs and since these health costs are increasing in the quantity of animal food and decreasing in the quality of animal food, in the laissez-faire economy the animal food quantity is too high and the animal food quality is too low. These distortions are corrected for by the mark-up $(1 - \delta) \left(H_y - \frac{nq}{y} H_q \right) > 0$ in the tax rate τ_y , providing the animal food producer the incentive to bring down the animal food quantity, and the mark-up $-(1 - \delta) \frac{n}{y} H_q > 0$ in the subsidy rate σ_{qy} , giving the animal food producer the incentive to improve the living conditions of animals. Hence, similar to the animal welfare externality, also the health externality is capable of justifying the tax-subsidy solution which is in the focus of our analysis. But there is an important methodological difference between the animal welfare externality and the health externality. While the latter requires a paternalistic social planner, the former is still present even if the social planner is non-paternalistic. Formally, for a non-paternalistic social planner we have to set $\delta = 1$ in Proposition 8, such that the health externality and the associated mark-ups in the tax rate (S21) and the subsidy rate (S22) disappear. As long as $\gamma > 0$ and/or $\kappa < 1$, however, both instruments are still positive due to the animal welfare externality, even if the social planner is non-paternalistic in the sense that she allows double counting with $\beta = \alpha$.

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