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A model for consumers' preferences for Novel Protein Foods and environmental quality

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Abstract

We develop an environmental Applied General Equilibrium (AGE) model, which includes the economic functions of the environment, to investigate the impacts of consumers' preference changes towards the enhanced consumption of Novel Protein Foods (NPFs) and towards a higher willingness to pay for protection of the environment in the Europe Union (EU). We find that these preference changes impact the pork production and consumption as well as ammonia (NH_3) emissions. Sensitivity analysis shows that the results are more sensitive to the value of the elasticity of utility with respect to environmental quality than to that of the substitution elasticity between pork and NPFs.

JEL classification: C68; D58; Q18

Keywords: AGE models; Environmental economic modelling; Novel Protein Foods; Pork

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1. Introduction

Animal protein production, in particular pork production, has high environmental impacts. Novel Protein Foods (NPFs) are modern plant-protein based food products, designed to have desirable flavour and texture. Technically, NPFs can be made of peas, soybeans, other protein crops and even grass (Linnemann and Dijkstra, 2000). Baggerman and Hamstra (1995) suggested that NPFs can reduce environmental pressures because the conversion from plant proteins into meat proteins is biochemically and environmentally inefficient. An environmental life-cycle assessment (LCA) also shows that NPFs are environmentally more friendly than pork in terms of a few environmental indicators (Zhu and van Ierland, 2004).

Some studies (e.g. MAF, 1997; Miele, 2001; Jin and Koo, 2003) indicate that health and food safety concerns have become pivotal when purchasing food products. For a large number of consumers, these concerns manifest themselves in the selection of products, as seen in increased purchases of diet and low-fat foods. This tends to increase the demand for meat substitutes or meat alternatives. For example, consumers' expenditures on meat alternatives in the Netherlands are increasing over time (Aurelia, 2002). Fonk and Hamstra (1995) suggest that the consumption of NPFs in the next 30 years will replace almost 40% of meat in the Western diet in terms of protein food expenditure. This trend indicates that consumers may shift their preferences for the consumption of proteins from meat to NPFs. This will have clear impacts on the economy and the environment. Some other studies (e.g. Hökby and Söderqvist, 2003; Latacz-Lohmann and Hodge, 2003) indicate that increasing income tends to influence the willingness to pay for environmental services positively and significantly. Therefore, changes in willingness to pay for protection of the environment will have impacts on both the choice of consumption and environmental quality.

In the literature (e.g. Peerlings, 1993; Folmer et al., 1995; Manne et al., 1995; Hertel, 1997; Komen, 2000), there is a variety of agricultural and environmental Applied General Equilibrium (AGE) models investigating the impacts of agricultural policies and environmental policies. However, consumers' concerns (preferences) for protection of the environment in those studies are not embodied in utility functions, and the economic functions of the environment are not properly considered in many current AGE models. Therefore, we are motivated to construct an environmental AGE model that captures the economic functions of the environment in production functions and utility functions. We have chosen the AGE approach for our study, because AGE models have a flexible structure that allows for including the environmental issues. The great strength of general equilibrium analysis is that it models the whole economy explicitly, albeit under restrictive assumptions. Its shortcomings are that it relies heavily on secondary data, models are calibrated to a benchmark period, which is taken to be an equilibrium, and it offers no formal facility for testing the model structure (Reed, 1996). However, all techniques in applied economics have their strengths and weaknesses. AGE models are usually used for analysis of policy changes and shock events (Gunning and Keyzer, 1995). AGE models can be used for assessing the impacts of changes in consumers' preferences, because consumers' preferences determine demand and thus supply in market economy.

The economic system and the environmental system interact. The economic functions of the environment can be summarised into two basic ones: (i) providing inputs to production and (ii) providing amenity services to consumers. Therefore, it is necessary to consider these functions in economic modelling. The input function of the environment can be included in production functions and the environmental amenity as a consumption good can be modelled in utility functions. Such inclusion of the economic functions of the environment ensures that the environment is priced, which leads to the efficient use of the environment.

This paper aims to investigate some economic and environmental consequences of a shift from pork to NPFs in the EU, by means of an AGE model. The first contribution is to develop a theoretical AGE model that explicitly includes the environmental input in the production functions and the consumers' preferences for environmental quality in utility functions. The second contribution is to empirically apply the model to provide some insights into the effects of the enhanced consumption of NPFs and to assess the effects of changes in consumers' willingness to pay for the protection of the environment.

For simulation of enhanced consumption of NPFs, we consider an *exogenous shift* of consumption from meat to NPFs, driven by consumer's health and food safety concerns for animal products. Since pork is the most common protein product, which in 1999 comprises 45% of the EU meat consumption (European Commission, 2002), the enhanced demand for NPFs is assumed to replace part of pork consumption. The exogenous shift is represented by a higher share of expenditures of NPFs in total protein expenditure. The substitution effect between pork and NPFs consumption is represented by the substitution elasticity,[2] which reflects the ease of substitution between two goods due to the change of relative prices. The consumers' concerns for environmental quality are represented by the willingness to pay for the protection of the environment or, more specifically, by the elasticity of utility with respect to environmental quality if environmental quality is included in a Cobb–Douglas utility function. For model application, we calibrate the parameters in production functions and utility functions by the data source of the GTAP model (GTAP, 2004). We have divided the world into three relevant regions: the EU, the other OECD countries (OOECD) and rest of the world (ROW). Finally, we use ammonia (NH_3) emissions to determine the environmental quality for its relevance in protein production, which contributes to acidification.

The paper is organised as follows. Section 2 presents the theoretical structure of the AGE model containing the economic functions of the environment. Section 3 includes the model specification for our study. Section 4 is about the data and model calibration. Section 5 contains the model application to examine the effects of NPFs and consumers' concerns for environmental amenity, and to perform the sensitivity analysis for

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[2] The formal definition of substitution elasticity between two goods (1 and 2) is:

$$\xi_{12} = -\frac{\frac{\partial(x_1/x_2)}{x_1/x_2}}{\frac{\partial(p_1/p_2)}{p_1/p_2}},$$

where x indicates the demand and p the price (Mas-Colell et al., 1995).

substitution elasticity between pork and NPFs and the elasticity of utility with respect to environmental quality. Finally, Section 6 concludes.

2. Theoretical structure of an environmental AGE model

General equilibrium theory tells us that, in competitive equilibrium, the equilibrium price vector p^* provides sufficient information for each agent to take optimal decisions with respect to production and consumption: the decisions of each agent can be decentralised. *Convexity* of a production set and a consumption set allows us to formulate conditions with regard to production technologies and preferences that ensure the existence of a price system, which sustains decentralised optimising production and consumption decisions. The fact that every competitive equilibrium is Pareto-efficient is known as *the first welfare theorem*. An allocation that is an optimal solution to a welfare program is called a welfare optimum. A Pareto-efficient allocation is a welfare optimum with positive welfare weights (Ginsburgh and Keyzer, 2002). Therefore, it follows that every competitive equilibrium can be represented as a welfare optimum and a competitive equilibrium model can be represented by a welfare program.

Mathematically, we can represent a general equilibrium model in several formats (see Ginsburgh and Keyzer, 2002 for a detailed description). For achieving efficient allocation of resources including the environmental resources, we can represent the economic functions of the environment in welfare programs. For this study, we have chosen the Negishi format, because it provides a direct link to welfare analysis of important issues, by starting with a welfare program, which is subsequently decentralised through commodity and agent-specific signals (e.g. prices). Emissions can be viewed as the use of environmental resources, because emissions reduce the availability of the clean resources. Our welfare program considers the input function of emissions and the amenity services of environmental quality. This environmental quality is a function of the total emissions (or the use of the resources). The environmental quality is specified by a transformation function that represents an environmental process transforming the emissions into an environmental quality indicator. In this model, emissions as production input are a rival good for production but the environmental quality as a non-rival good has impacts on consumer utility (e.g. health effect).

The Negishi format consists of an objective function that is a weighted sum of the utilities of all consumers, balance functions for all the commodities and production functions for all the products. The model structure of the Negishi format including the economic functions of the environment is shown in Eqs. (1) to (5):

$$\max \sum_i \alpha_i u_i(x_i, g_i) \tag{1}$$

$$x_i \geq 0, g_i \geq 0 \text{ all } i, y_{ej}^- \geq 0, y_j, \text{ all } j, y_g^+ \geq 0$$

subject to

$$\sum_i x_i \leq \sum_j y_j + \sum_i \omega_i \quad (p) \tag{2}$$

$$\sum_j y_{ej}^- \leq \sum_i \omega_e \quad (p_e) \tag{2'}$$

$$g_i = y_g^+ \quad (\phi_i) \tag{2''}$$

$$F_j\left(y_j, -y_{ej}^-\right) \leq 0 \tag{3}$$

$$F_g\left(y_g^+, -\sum_j y_{ej}^-\right) \leq 0 \tag{3'}$$

with welfare weights α_i, such that

$$px_i + \phi_i g_i = p\omega_i + \sum_j \theta_{ij} \Pi_j(p) \quad (\lambda_i) \tag{4}$$

and

$$\alpha_i = \frac{1}{\lambda_i}, \tag{5}$$

where x_i is the vector of consumption goods and g_i is the vector of environmental quality for consumer i ($i=1, 2, \ldots, m$). y_g^+ is provided by an environmental process according to a transformation function $F_g(.)$ depending on the total emissions $\sum_j y_{ej}^-$. Vector of netput is presented by y_j ($j=1, 2, \ldots, n$): positive element indicates output and negative input. y_{ej}^- is the vector of emission input for producer j. ω is the vector of initial endowments and ω_e is the vector of emission permits. Parameters in brackets (p, p_e, ϕ) are the Lagrange multipliers of the Eqs. (2), (2′) and (2″), which give the vectors of shadow prices of the rival goods, emission permits and non-rival environmental quality. For notational convenience, we assume that vectors x_i, g_i, y_j, y_g^+ and y_{ej}^- refer to the same commodities space R^r but they usually have different entries for the same k ($k=1, 2, \ldots, r$).

In this model, Eq. (1) is the objective function, where u_i is the utility function of each individual i. Utility of each individual i depends on the consumption good x_i and environmental quality g_i. The objective of this welfare program is to maximise total welfare, which is a weighted sum of the utility of all the m consumers in the economy, and the Negishi weight of consumer i is given by α_i.

Eq. (2) is the balance equation for commodities (goods and production factors). $\sum_i x_i$ is the total consumption, $\sum_j y_j$ is the total production and $\sum_i \omega_i$ is the total initial endowment of the commodities. A vector of Lagrange multipliers associated with the balance equation, or a vector of the shadow prices of commodities, is indicated by p within brackets. This equation states that the total consumption of a commodity must be smaller than, or equal to, its total production plus its total initial endowments.

Eq. (2′) refers to the balance of emission permits. The total emission inputs in all production processes should not exceed the total emission permits. Langrange multiplier p_e is the vector of shadow prices of the emission permits.

Eq. (2″) is the balance equation for a vector of environmental quality indicators, which indicates that each individual's consumption should be equal to the total supply of the environmental quality due to its non-rivalry. This constraint also makes it possible to obtain explicit Lagrange multipliers for the values that each consumer attributes to environmental quality. The vector of Lagrange multipliers ϕ_i is the vector of prices that consumers have to pay for the consumption of environmental quality indicators as if the markets for these environmental goods existed or institutional arrangements were made.

Eq. (3) shows that the production plan must follow a feasible production technology, which is represented by a transformation function F_j. F_j is the transformation function for firm j, which uses emission y_{ej}^- as input for producing netput y_j (positive y_j^+ indicates output and negative y_j^- input).

Eq. (3′) shows the production technology of environmental quality. Environmental quality is produced by a specific technology according to a transformation function $F_g(.)$. As such, technology can also be viewed as an exogenous environmental process that transforms total emissions into a certain level of environmental quality y_g^+.

Eq. (4) states that the expenditure of a consumer must be equal to income under equilibrium, where the left-hand side shows the total expenditure and the right-hand side the income of the consumer. The total expenditure includes the total expenditure on the consumption of all rival goods px_i and the payment for the enjoyment of environmental amenity $\phi_i g_i$. The income of consumer i consists of the remuneration for his initial endowments $p\omega_i$ and profits received from firms $\sum_j \theta_{ij} \Pi_j(p)$. θ_{ij} is the profit share of consumer i in firm j and $\Pi_j(p)$ is the profit of firm (producer) j.

Eq. (5) shows how welfare weights are related to the budget constraints in this welfare program. The Lagrange multiplier associated with the budget constraint of consumer i is indicated by λ_i, and its inverse is the welfare weight attributed to consumer i such that an equilibrium exists. The optimal allocation resulting from the equation system from Eqs. (1)–(5) is called the Lindahl equilibrium with non-rival goods (Ginsburgh and Keyzer, 2002). This is an equilibrium without transfers, in which welfare weights are such that each consumer satisfies his budget constraint, including payment for environmental quality. In this model, the consumers reveal their real preferences and will pay for the consumption of the non-rival environmental amenity, i.e. we assume that no free-riding occurs. For further details on the Lindahl equilibrium, see Ginsburgh and Keyzer (2002).

3. Specification of the AGE model

Following the theoretical structure in Section 2, we have specified the model for our study by explicitly considering producers, consumers, production goods, consumption goods, intermediate goods and environmental quality.

3.1. Characteristics of the model

In our AGE model, the world is divided into three regions: the EU, OOECD and ROW. In each region, there is one representative consumer. There are six producers who produce totally six products in each region. The products are distinguished as pork, peas, other food, NPFs, non-food and feed. Pork, other food, non-food and NPFs are the consumption goods. Peas are used for both direct consumption and intermediate input for production of NPFs and feed. Feed is the intermediate good for producing pork and other food, because other animal products are included in the category other food. There are three production factors: labour, capital and land. In this specific study, we only consider the emissions of NH_3, which is a serious problem in animal protein production. The level of NH_3 emissions determines the environmental quality (or air quality).

We specify the economic functions of the environment in AGE model as follows. Firstly, the utility of the representative consumer in each region is determined by the consumption level of private goods and services, and environmental quality. Secondly, we consider that emissions are equivalent to the use of clean environmental resources. Therefore, emissions of NH_3 in this study are specified as input for production. Thirdly, total emissions are constrained by emission permits. As such, (shadow) prices for emission permits can be determined.

3.2. The objective function and utility functions

The objective function of the welfare program in Negishi format is:

$$W = \max \sum_i \alpha_i \log U_i \tag{6}$$

where W is the total welfare, U_i is the utility of region i, α_i is the Negishi weights of region i and i represents the EU, OOECD and ROW, respectively. For the equilibrium solution of the model, the Negishi weights have to be found such that the budget constraints hold. Sequential Joint Maximisation (SJM) method shows that the Negishi weights are the respective shares in total income in the economy (Manne and Rutherford, 1994; Ermoliev et al., 1996; Rutherford, 1999).

The utility function in our model is a nested function combining Constant Elasticity of Substitution (CES) function and Cobb–Douglas (C-D) function with three levels (see Fig. 1). At level 1, it is a C-D function with substitution between the consumption of a composite of rival goods (i.e. proteins, other food, non-food and peas) and a non-rival good (i.e. environmental quality). At level 2, it is a C-D function for a composite of rival goods with substitution among proteins, other food, non-food and peas. At level 3, it is a CES function for a composite of proteins with substitution between pork and NPFs. The utility function can be written as:

$$U_i = g_i^{\varepsilon_i} \left(\prod_s C_{si}^{\beta_{si}} \right)^{1-\varepsilon_i} \tag{7}$$

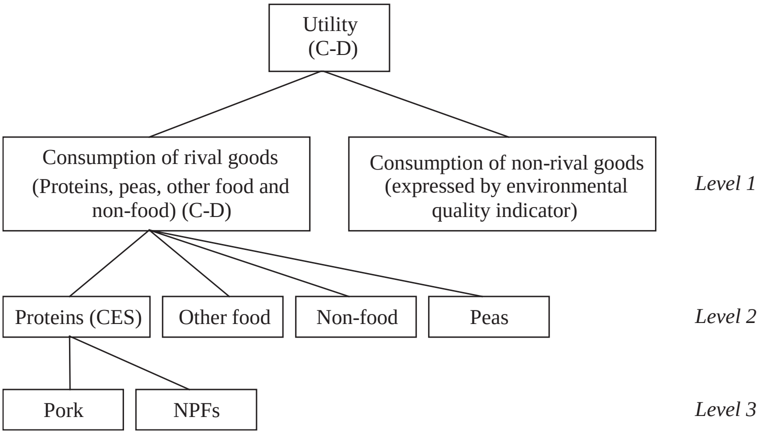

Fig. 1. Nesting structure of the utility function.

where i indicates consumer (i=EU, OOECD, ROW), g is environmental quality and C_s is the consumption of rival good s (s=proteins, other food, non-food and peas). ε is the elasticity of utility with respect to environmental quality and β_s is the utility elasticities with respect to consumption of rival goods s. Consumption of a composite of proteins (C_{protein}) is defined in a CES function with substitution between pork and NPFs as:

$$C_{\text{proteins},i} = \left[\delta_i^{\frac{1}{\sigma}} C_{\text{NPFs},i}^{\frac{\sigma-1}{\sigma}} + (1-\delta_i)^{\frac{1}{\sigma}} C_{\text{pork},i}^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \tag{8}$$

where σ is the elasticity of substitution between pork and NPFs, δ is the expenditure share of NPFs in protein consumption,[3] and C_{NPFs} and C_{pork} are the consumption of NPFs and pork.

3.3. Environmental quality

The environmental quality indicator should indicate the state of the environment and reflect the environmental amenity. The environmental quality is influenced by the level of emissions from, for example, industrial and agricultural processes, according to a transformation function. Environmental quality (or air quality) can be determined by the total emissions of NH_3 by means of a linear function:

$$y_g^+ = \overline{\psi} - TM \tag{9}$$

where $\bar{\psi}$ is the intercept and TM is the total level of emissions from all producers in region i. The intercept can be given by the tolerable emission level, which also

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[3] For model calibration, we use $C_{\text{proteins}} = B\left[SC_{\text{NPFs}}^{\frac{\sigma-1}{\sigma}} + (1-S)C_{\text{pork}}^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$, where S is the share of NPFs in CES function, $S = \frac{\delta^{1/\sigma}}{\delta^{1/\sigma}+(1-\delta)^{1/\sigma}}$ (Shoven and Whalley, 1992) and B is the scaling term which will be used to ensure that the price of the composite good equals to the cost of the amounts of C_{NPFs} and C_{pork} that have produced it, i.e. $B = [S^{\sigma} + (1-S)^{\sigma}]^{\frac{1}{\sigma-1}}$ for a nested CES (Reed and Blake, 2002). But if this composite is nested in a Cobb–Douglas utility function, B does not influence the results; thus, B can be chosen as one.

determines the emission bounds or emission permits. The total level of emissions can be viewed as a by-product of the total production. This relationship shows that the higher the emissions the lower the environmental quality (or air quality). The environmental quality can be viewed as a product produced by an exogenous environmental process and owned by consumers. In each region, there are different specifications for intercept in Eq. (9) depending on the local environmental capacity. In this study, we use two times the base year NH_3 emission level for this intercept for each region. For a better comparison of air quality change among different scenarios in Section 5, we specify air quality as:

$$y_g^+ = 100 \times \frac{(2\mathrm{TM}_0 - \mathrm{TM})}{\mathrm{TM}_0}, \tag{10}$$

where TM_0 is the total NH_3 emission in specific region in the base year and TM is the real emission in scenarios. In the base year, TM equals TM_0; therefore, $y_g^+=100$.

3.4. Production functions

In our model, emissions are viewed as the use of a natural resource because producers deplete the environmental resources when they emit pollutants. To price the use of the environmental goods, emission permits are attributed and as a result users have to pay for emissions. This treatment provides us with the price signals of the emissions and tools to implement proper environmental policy. When emissions are treated as the use of the environmental goods, they are, in fact, the input for the production process. The production function of producer j looks like:

$$Y_{i,j} = A_{i,j}\mathrm{EM}_{i,j}^{\xi_{i,j}}\left[\left(\mathrm{LB}_{i,j}\right)^{\eta_{1i,j}}\left(\mathrm{KL}_{i,j}\right)^{\eta_{2i,j}}\left(\mathrm{LD}_{i,j}\right)^{\eta_{3i,j}}\left(\mathrm{IFD}_{i,j}\right)^{\eta_{4i,j}}\left(\mathrm{IP}_{i,j}\right)^{\eta_{5i,j}}\right]^{1-\xi_{i,j}} \tag{11}$$

where Y is the production quantity, EM is the emission input, ξ is the cost share of the emissions for production $0<\xi<1$ and η_f (f=1, 2, ..., 5) is the cost share of each input for production without considering the cost of emission permits, with $\sum_{f=1}^{5}\eta_f = 1$. We have five normal inputs: LB reflects labour input, LD land input, KL capital input, IFD the feed input and IP the pea input for production. Some of these inputs can be zero if they are not used in production. EM can be thought of as the use of ‘environmental services’, as a firm must dispose of its emissions in the environment. Alternatively, we can think of the firm as requiring emission permits in order to produce (Copeland and Taylor, 2003).

3.5. Balance equations

In the applied model, we consider factors to be mobile between different sectors, but immobile among the three regions. We note C for consumption, X for net export and Y for production. Variables with a bar stand for exogenous ones. The balance equations for goods without intermediate use are as follows,

$$C_{i,j} + X_{i,j} \le Y_{i,j}, \qquad j = \text{pork, other food, non-food and NPFs.} \tag{12}$$

Peas are used both for direct consumption and intermediate use for production of NPFs and feed. The balance equation for peas is as follows:

$$C_{i,\text{peas}} + \sum_j \text{IP}_{i,j} + X_{i,\text{peas}} \leq Y_{i,\text{peas}}. \tag{13}$$

Feed is used for producing pork and other food but not for consumption. The balance equation for feed looks like:

$$\sum_j \text{IFD}_{i,j} + X_{i,\text{feed}} \leq Y_{i,\text{feed}} \tag{14}$$

Similarly, factor balance equations can be written as,

$$\sum_j \text{LB}_{ij} \leq \overline{\text{LB}}_i \tag{15}$$

$$\sum_j \text{KL}_{ij} \leq \overline{\text{KL}}_i \tag{16}$$

$$\sum_j \text{LD}_{ij} \leq \overline{\text{LD}}_i \tag{17}$$

Since emissions in this model are treated as input in the production function, an emission permit system for each region can be implemented. Thus the following relationship holds,

$$\sum_j \text{EM}_{ij} \leq \overline{EM}_i \tag{18}$$

where EM_{ij} is the use of emission input in region i for good j. $\overline{EM}_i$ is the permitted level of total emissions in region i. This permitted emission level can be an emission permit for a specific environmental policy, or the real level of emissions in the base year, depending on the study purpose. For example, in benchmarking, it is the emission level in the base year. For an environmental policy study, it can be an exogenous emission permit, which is in fact determined by the ecological limit. For the regeneration of the environment, emission should not be above a certain level. Since the ecological limit for NH_3 emission is very much location-dependent and our focus is not on exogenous environmental policy analysis, we will not implement exogenous emission permits in our study. Instead, we use the emission levels in 1998 for the benchmark and we use the real emission level in scenario studies to get a proper shadow price of emission permits. Based on the emission factors determined by the base year emissions and production levels, we can get the real emission level in feedback program[4] when the model is applied to different scenarios.

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[4] See Ginsburgh and Keyzer (2002) for distinctions between main program and feedback program.

The balance of environmental quality considering its non-rivalry is:

$$g_i = y_g^+. \tag{19}$$

The equality indicates the non-rivalry of the environmental quality. It means that the consumption by one agent does not limit the consumption by another.

3.6. Budget constraints

Budget constraints say that the expenditure of the consumer should not exceed his income:

$$\sum_{k_\mathrm{C}} \left(p_{k_\mathrm{C}} \cdot C_{i,k_\mathrm{C}}\right) + \phi_i g_i \leq h_i, \qquad k_\mathrm{C} = \text{pork, NPFs, other food, non} - \text{food and peas}, \tag{20}$$

where $\sum_{k_\mathrm{C}} \left(p_{k_\mathrm{C}} \cdot C_{i,k_\mathrm{C}}\right)$ is the total expenditure on the consumption of all rival goods, $\phi_i g_i$ is the payment for environmental quality (or air quality) and h is income. Income consists of remuneration of endowments and profits received from firms. Non-rival environmental quality is also entitled to the consumer. When emissions are used as input, income from emission permits should also be accounted. The income is:

$$h_i = w_i \overline{\mathrm{LB}}_i + r_i \overline{\mathrm{KL}}_i + r_{Ni} \overline{\mathrm{LD}}_i + p_{mi} \overline{\mathrm{EM}}_i + \phi_i g_i. \tag{21}$$

Under constant returns to scale, profits are zero so that income is the value of initial endowments, which are employed in production. The income should be equal to the total revenue of the production sectors and the entitled ‘environmental sector’:

$$h_i = \sum_j \left(p_j \cdot Y_{ij}\right) + \phi_i y_g^+, \tag{22}$$

where p_j is the price scalar of good j. The first item of the right-hand side $\sum_j \left(p_j \cdot Y_{ij}\right)$ is the revenue of all the production sectors and the second item $\phi_i y_g^+$ is the revenue of the ‘environmental sector’, which produces the level of environmental quality.

4. Data and calibration

4.1. The data

For calibrating the model, we mainly use the GTAP data source (GTAP, 2004) for the economic data. For our purpose, we construct three SAM tables for the three regions by aggregation. We aggregate the data according to the structure of the production functions. Except for the factor inputs for production, the original input–output tables also contain other inputs, which are the inputs from other production sectors. These inputs are the so-called ‘intermediate inputs’. In our study, we only consider feed as the intermediate input for production of pork and other food, and peas as the intermediate input for production of NPFs and feed, but we aggregate all the other intermediate inputs into ‘capital’. The three

Table 1
Total endowments in billion and NH_3 emissions in million tons

	Labour	Capital	Land	NH_3 emissions
EU	4240.820	11,575.894	41.741	2.879
OOECD	9082.629	19,955.044	99.314	7.776
ROW	2871.850	10,434.586	204.483	32.385

SAM tables are included in Tables A1, A2 and A3 of Appendix A. Positive entries refer to supply and negative ones refer to use of the commodities in the tables.

The total NH_3 emissions for each region and the emission distribution over production sectors are based on RIVM (2004). The emission distribution is included in Table A4 of Appendix A. Since emissions in our model are treated as input for production, we present the total endowments and also the total levels of NH_3 emissions in Table 1.

4.2. Calibration

The entries in the SAM are in value terms. When we calibrate the model, we follow the commonly used units convention, the Harberger convention. That means we set all the prices equal to unity in the benchmark (Shoven and Whalley, 1992). According to the cost shares of production inputs in total output of production goods and expenditure shares of consumption goods, we calibrate the parameters in production functions and utility functions. Since the real SAM does not contain the emissions, we have to modify it by including the emission input in each sector in a base run. The parameters in production functions and utility functions are included in Tables A5 and A6 of Appendix B.

5. Model application to scenarios and results

5.1. Scenarios

As we mentioned in the introduction, there are two trends of consumers' preference: a life style change towards less meat and more NPFs in the EU, and a higher willingness to pay for the protection of the environment. Therefore, we wish to assess the impacts of these changes by applying the model to the following scenarios.

In the *first* scenario, we simulate an exogenous shift from pork to NPFs due to the technological possibility of producing NPFs and the consumer acceptance of NPFs. This will increase the consumption of NPFs. The parameter changes under this scenario relative to the base run are the share of NPFs in the consumption of protein foods (including pork and NPFs in this model) (δ) and the increased substitution elasticity between pork and NPFs (σ). See Table 2 for the detailed numbers. Thus, we apply the model to analyse the impacts of exogenously enhanced consumption of NPFs.

On the basis of this scenario, we consider in the *second* scenario a more ambitious case where consumers are willing to pay for the protection of the environment for enjoying environmental amenity. Since exogenous environmental policies, such as an emission bound, cause inefficiency, we consider an efficient mechanism: users pay for the

Table 2
Parameters under scenarios and sensitivity analysis

Scenarios	Contents
Base run	Substitution elasticity between NPFs and pork is $\sigma=0.56$ in the EU, 0.58 in the OOECD and 0.5 in the ROW. Expenditure share of NPFs in protein $\delta=2.5\%$ in the EU.
Scenario 1: enhanced consumption of NPFs in the EU	Expenditure share of NPFs in protein: $\delta=25\%$, substitution elasticity between NPFs and pork: $\sigma=0.9$ in the EU.
Scenario 2: environmental willingness to pay in the EU	Under scenario 1, $\sigma=1.5$, willingness to pay for the environmental quality $\varepsilon=1\%$ in EU.
Sensitivity analysis	The range of σ is from 0.5 to 1.5 and for ε is 0% to 10%.

environmental resource use. If this mechanism can be implemented, efficiency can be achieved. In this applied model, we introduce a small value of willingness to pay for environmental quality, i.e. the marginal utility with respect to environmental quality. This parameter is embodied in the utility function with the C-D functional form (see Eq. (7)) and it is also called utility elasticity with respect to the environmental quality (ε). It reflects the expenditure share for environmental amenity in the total budget for both rival goods and non-rival environmental amenity. In this scenario, we consider 1% of the budget to be spent on environmental quality (or more specially, air quality) related to NH_3 emissions for protection of the environment. We analyse how this value affects the economic variables and environmental emissions.

However, the values of parameters σ and ε cannot be observed from existing data. Therefore, we perform *sensitivity analysis* for the values of these two parameters for the impact analysis of NPFs and willingness to pay for the protection of air quality. For σ, we consider a range of the values $0.5<\sigma<1.5$ because we do not think NPFs are *perfect* substitutes for pork. For ε, we consider a range of 0% to 10% because we do not expect consumer willingness to pay for the protection of the environment to exceed 10% of their total expenditure considering the present level of 3% of total environmental expenditures in GDP. Thus, in the sensitivity analysis, we change the value for σ from 0.5 to 1.5 and for ε from 0 to 0.10. Table 2 gives the detailed description of the parameters for the scenario studies and sensitivity analysis.

The model was solved by GAMS (Brooke et al., 1997) for different scenarios. The results of all simulations for the scenarios are compared with a benchmark. The comparison gives the implications of the enhanced demand for NPFs in the EU with the different levels of environmental concerns to the economy and environmental quality.

5.2. The results

5.2.1. Base run: quantities of production, consumption and international trade

After the model parameters are fully calibrated by the base year data, we rerun the model considering the emissions as input in production for the base run. The results for quantities of production, consumption and international trade in the base run are shown in Table 3. This is our benchmark.

Table 3
Quantities (units) of production, consumption and international trade in the base run

		Pork	Peas	Other food	NPFs	Non-food	Feed
Production	EU	39.1	35.0	1028.6	1.0	14,767.1	47.4
	OOECD	75.0	121.1	1622.0	1.4	27,333.0	91.8
	ROW	179.8	259.6	1663.9	2.1	11,429.4	131.0
Consumption	EU	38.8	42.2	1042.3	1.0	14,675.7	
	OOECD	77.8	124.2	1679.7	1.5	27,404.5	
	ROW	177.3	242.5	1592.5	1.9	11,450.3	
Trade*	EU	+0.3	−7.9	−13.8	−0.0	+91.4	−8.8
	OOECD	−2.8	−4.9	−57.7	−0.1	−73.5	−5.0
	ROW	+2.5	+12.8	+71.5	+0.1	−17.9	+13.8

*Note for trade, '−' means imports and '+' exports.

In the benchmark, the trade pattern is that the EU exports some pork and non-food, and imports peas, other food, non-food and feed. Though it is not reported in the table, air quality in each region is 100.

5.2.2. Scenario 1: impacts of enhanced demand for NPFs

In scenario 1, the expenditure share of NPFs in protein consumption is increased from 2.5% to 25% and the substitution elasticity is increased from 0.56 to 0.9. These changes reflect the enhanced demand for NPFs. The impacts of such changes can be seen from both production and consumption sides (Table 4).

On the consumption side, the EU will increase the demand for NPFs by a factor of about 9.0 and decrease pork consumption by 23%. This is determined by the exogenous shift of expenditure. This change has almost no impacts on the consumption of other goods in the EU and neither on the overall consumption in the other two regions. There are, however, impacts on the production pattern due to the possibility of international trade. In this case, each region will produce using its comparative advantage.

Table 4 shows that production of NPFs in the EU will increase to about 9.4 times and the production of pork will decrease by 7.5%. Accompanying the increase in production of

Table 4
Percentage changes of production and consumption as compared to the base run and real quantities in trade due to enhanced demand of NPFs ($\delta = 25\%$, $\sigma = 0.9$)

		Pork	Peas	Other food	NPFs	Non-food	Feed
Production (%)	EU	−7.5	0.6	−0.5	935.6	0.0	−11.1
	OOECD	−8.3	0.8	−0.3	−89.9	0.0	−6.0
	ROW	−0.0	−0.4	−0.2	65.0	−0.0	6.8
Consumption (%)	EU	−23.4	0.0	−0.3	898.0	0.0	
	OOECD	−0.1	−0.0	−0.2	−0.1	0.0	
	ROW	−0.0	−0.0	−0.4	−0.0	0.0	
Net export (units)	EU	6.5	−7.8	−16.1	−0.2	91.8	−13.5
	OOECD	−9.0	−3.7	−58.3	−1.3	−66.0	−9.1
	ROW	2.6	11.4	74.5	1.5	−25.8	22.6

For the production and consumption, '−' means a decrease and '+' means an increase, but for the net export, '−' means imports and '+' exports. This also holds for Table 5.

NPFs, production of peas will increase by 0.6%. Feed production will decrease by 11% because less pork is produced. The impacts on non-food and other food are very small. Observing the enhanced demand for NPFs, ROW will increase its production of NPFs by 65% for exporting to the EU, but cannot cover all EU demand because it still has to increase it production of feed. As such, the EU still has to produce most of the NPFs.

Impacts on the international trade are as follows. The EU will increase its pork export from 0.3 units to 6.5 units. Due to the comparative advantage of pork production in the EU, the EU will export more pork to the OOECD. The import of NPFs in the EU will be increased from 0.1 to 0.2 units. The import of feed will increase from 8.8 units to 13.5 units because by switching to more production of NPFs less feed is domestically produced. There are almost no impacts on the non-food sector and other food sector. To summarise, the major impact of scenario 1 is on the sectors of NPFs and pork as well as the related feed and pea sectors.

For air quality, it will be 103 in the EU, 102 in the OOECD and 99 in ROW. That means emissions in the EU will decrease from 2.88 to 2.79 million tons, in the OOECD emissions decrease from 7.77 to 7.58 and in the ROW will increase from 32.38 to 32.67 million tons. The enhanced consumption in the EU will change the emission levels for other regions because of international trade. Now more feed has to be produced in the ROW, which will increase emissions there. The OOECD has lower emissions because it decreases the production of pork and feed. Although the EU has changed its emission through production, the impacts on emissions also occurs in the other regions because of international trade.

5.2.3. Scenario 2: impacts of environmental concerns and enhanced demand for NPFs

When consumers highly value the air quality, they are definitely willing to pay for a high level of air quality. As well, we can also expect a higher value of substitution elasticity between NPFs and pork if consumers are more concerned about air quality. In this scenario we check how the emissions, production and consumption will adjust if the EU consumers are willing to pay 1% of their income for air quality determined by NH_3 emissions, and if the substitution elasticity is simultaneously increased to 1.5 (see Table 5).

Under this scenario, the production of NPFs in the EU will increase by a factor of 9.4 due to the exogenous shift and the environmental concerns of the consumers. The pork

Table 5
Percentage changes of production and consumption, and real quantities in trade due to enhanced demand of NPFs and environmental concern ($\sigma = 1.5$, $\varepsilon = 1\%$)

		Pork	Peas	Other food	NPFs	Non-food	Feed
Production (%)	EU	−61.9	12.0	−0.1	935.6	0.1	−16.6
	OOECD	5.4	−1.2	−0.1	0.5	0.0	0.1
	ROW	5.1	−0.9	−0.1	3.0	−0.1	4.4
Consumption (%)	EU	−24.4	0.2	0.1	898.0	0.1	
	OOECD	−0.6	0.0	−0.1	−1.3	0.0	
	ROW	−0.6	0.0	−0.2	−1.1	−0.1	
Net export (units)	EU	−14.5	−3.9	−14.9	−0.2	92.0	−12.0
	OOECD	1.7	−6.3	−57.4	−0.1	−73.6	−5.5
	ROW	12.7	10.2	72.2	0.2	−18.5	17.5

production will then decrease by about 62% because of its high emissions of ammonia. Meanwhile, the production of peas will increase by 12% because remaining production factors from pork production will be used for producing low-emission products and more NPFs production requires more peas. The feed production will decrease by about 16% because less pork is produced.

On the consumption side, consumption of NPFs will be about 9 times more than the benchmark, while the pork consumption will decrease 24%. The pork consumption is lower than scenario 1 because, as air quality is directly determined by emissions, it is logical to reduce the production and consumption with the highest emission factor when expenditure on air quality is increased. The price of pork slightly increases due to the restriction of production, which also leads to lower consumption in other regions. The impact on the consumption of other goods (peas, other food and non-food) is very small.

Concerning international trade, the EU has to import pork when the expenditure on air quality is increased. Pork is the first product that will be reduced given the high emission factors (see Table A7 in Appendix B). In the base year, almost 1% of pork production in the EU is exported but under scenario 2, 50% (14.5 units of pork) of its total consumption (29 units) of pork is imported. Accompanying the increase in the production of NPFs, pea imports decrease by 50% because more peas are produced in the EU. The impact on international trade of pork and peas is larger than under scenario 1.

Regarding air quality, there is a dramatic change in the EU, though little change in other regions. It is 190 in the EU and 99 in the OOECD and in ROW. That means emissions in the EU will decrease by 90% from 2.879 to 0.288 million tons, but there is a slight increase (about 1%) in other regions (from 7.776 to 7.834 in OOECD and from 32.385 to 32.816 in ROW). Due to the value of air quality in the EU, reducing emission can increase utility. Therefore, there is a trade-off between high air quality with low production of pork and high consumption of pork with low air quality. The environmental concerns with the enhanced consumption of NPFs in the EU will change the emission levels for other regions because of international trade. Since the EU will even import some pork from other regions, more pork has to be produced in the OOECD and ROW, which will increase emissions there.

5.2.4. Sensitivity analysis for substitution elasticity σ and utility elasticity ε

Results are also calculated for different values of σ and ε. Since the value of substitution elasticity between pork and NPFs under scenario 1 ($\sigma=0.9$) is only an estimate, we carry out a sensitivity analysis for this value. We change the value of σ from 0.5 to 1.5 for scenario 1 for the sensitivity analysis of σ. Fig. 2 shows that pork consumption will decrease compared to the base run (38.8 units, see Table 3), but will not change with respect to the value of σ under scenario 1. Since under scenario 1 we have a fixed expenditure share of NPFs in the consumption of pork and NPFs, thus the substitution elasticity will not change the pork and NPFs consumption.

Fig. 3 shows that pork production in the EU decreases after the enhanced consumption of NPFs, and the extent of this change increases with the value of σ. Production will change because the substitution elasticities will change the relative prices of pork and NPFs and the producer will react to such a price change. As σ increases, the price ratio of NPFs to pork increases; therefore, pork becomes cheaper and less pork will be produced.

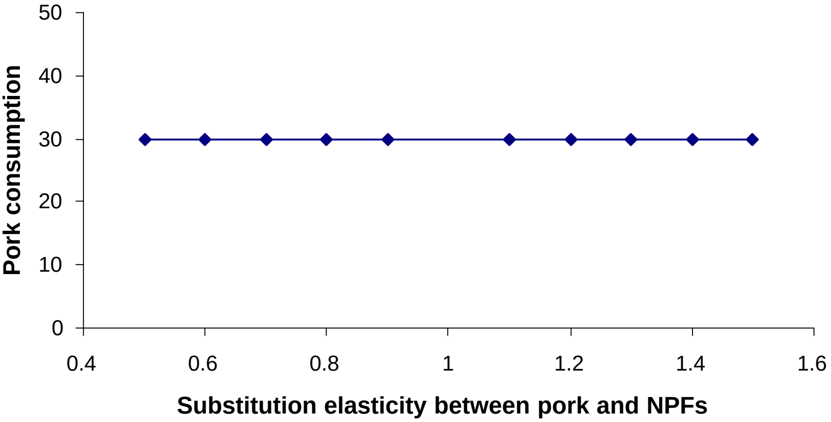

Fig. 2. Pork consumption in the EU under different values of σ for scenario 1.

We also observe from the figure that pork production is higher for $\sigma<1$ and lower for $\sigma>1$. There is an abrupt jump around $\sigma=1$. This is due to the CES function: when σ is close to one, the function becomes undefined. Therefore, the figure shows the irregularities around $\sigma=1$.

We change the value of ε from 0 to 0.10 under scenario 2 for the sensitivity analysis. Fig. 4 shows that the enhanced consumption of NPFs, in combination with a willingness to pay for the environmental amenity, will decrease the production of pork in the EU, but such a decrease is sensitive to the value of ε. As ε increases from zero to a very low value, there will be a drop in pork production. If air quality is paid for, there will be an adjustment in production patterns because the emission factors are very different. The dirtiest good will be the first to be reduced in production. We can, however, observe from the figure that when the value of ε is small (<3%), the results are very sensitive to the value of ε. This is because the model can choose between low pork production with high air quality and high

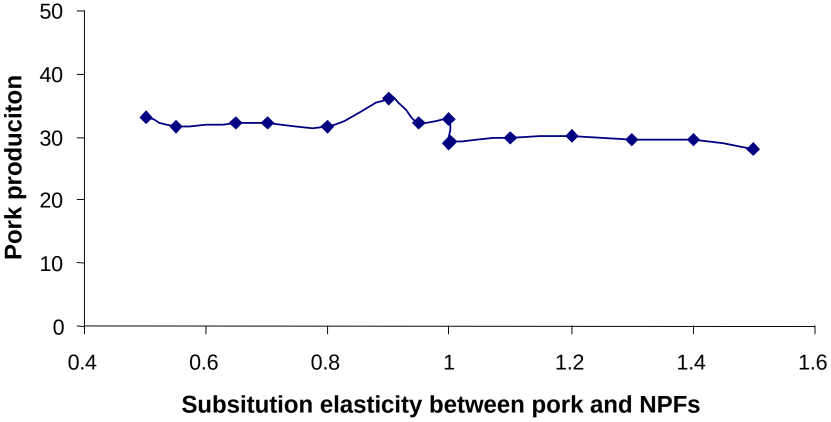

Fig. 3. Pork production in the EU under different values of σ for scenario 1.

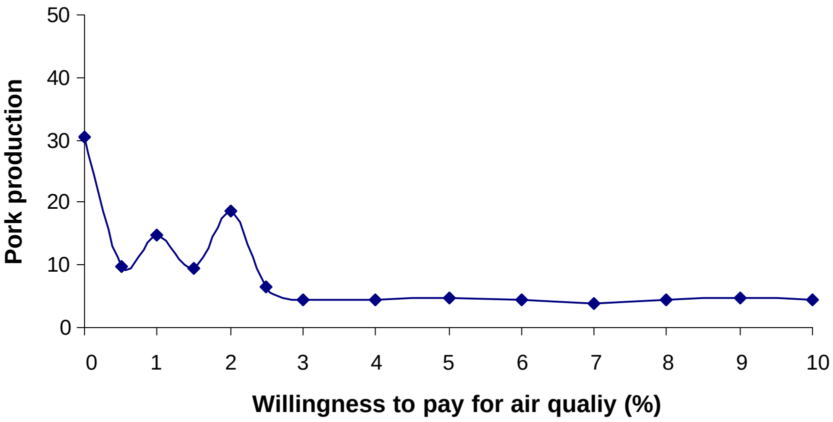

Fig. 4. Pork production in the EU under different values ε for scenario 2.

pork production with low air quality. Therefore, the pattern of pork production, with respect to environmental payment, shows non-smoothness. If ε is larger than 3%, substantial pork will be replaced by NPFs and the model results will become stable and reach the point at which pork production becomes very low and stable.

5.2.5. Qualification of the results

The results are based on an aggregate model thus they only provide some general insights into the tendencies of the changes that might occur. The model does not consider the possible trade barriers and transportation costs of international trade thus they may overestimate the extent of changes. In reality, more factors prevent such a strong reaction to some changes in a small sector. For example, the skills of the labour forces restrict the movement from one sector to another. Therefore, interpretation of the model results should be cautious.

6. Conclusions and discussion

This paper presents an AGE model that captures the use of the environment in production functions and the environmental quality in utility functions. The model is applied to two scenarios related to preference changes: an exogenous shift from pork to NPFs and a higher willingness to pay for the protection of the environment for its environmental amenity.

Under the first scenario, we found that enhanced demand for NPFs will impact the pork production in the EU. The other related sectors, such as feed and peas, are also affected. The EU will decrease its pork production by 8% and feed production by 11%. The ROW will increase the production of NPFs by 65% for exporting to the EU and increase feed production because the EU will import feed. The pork consumption in the EU decreases by 23%. The export of pork is increased due to the demand in the other OECD countries. The impacts on other food and non-food sectors are very small. Introducing NPFs in the EU will not change the consumption pattern in other regions but will change the production patterns through international trade. For example, other OECD countries will increase production of peas, while ROW will increase production of NPFs. For the emissions, the EU will have a 3% decrease of emissions through less pork production. The other OECD countries will have a 2% decrease of NH_3 emission due to the import of pork from the EU, whereas the ROW will have a 2% increase of NH_3 emission from its increased feed production.

Under the second scenario, the pork production will decrease further due to its associated high emission factor if the mechanism that users pay for the use of environmental resources is implemented. The EU will enjoy a much higher air quality if consumers are really paying for air quality. The EU will reduce its pork production by 62% and feed production by 16%. It will increase production of NPFs by about 9 times and increase 12% of pea production. The consumption of pork is decreased by 24%, which is not very different from scenario 1. This is because pork can be imported from other regions. The impacts on sectors of other food and non-food are very small. The major impacts are on the pork and NPFs sectors, and on related sectors like feed and peas. Emissions in the EU will decrease by 90%, but there is a slight increase (about 1%) in other regions.

The model has also been applied to examine the impacts of NPFs in the EU under different values of the elasticity of utility with respect to environmental quality and substitution elasticity between pork and NPFs. The study shows that an increase in the values of both parameters will generally increase the production and consumption of NPFs and decrease pork consumption in the EU. Pork production in the EU decreases with the increase of substitution elasticity. Pork production in the EU in general decreases with an increase of the value of the willingness to pay for protection of the environment (i.e. air quality). The results are, however, more sensitive to the latter than to the former, that is, the value of elasticity of utility with respect to environmental quality is more responsive to the results than to that of the substitution elasticity. Especially when willingness to pay is around 1%, the model results are very sensitive. Until it achieves about 3%, it becomes stable and, as it increases, the results do not change substantially because pork production reaches a lower bound.

The implication of the study is that the elasticity of utility with respect to environmental quality is very important factor for the results. The elasticity of utility with respect to the environment is related to consumers' attitudes towards environmental quality. Stimulating the environmental concerns of consumers and providing them information about the environmental performance of the products are important for a sustainable consumption pattern. As well, the substitution effect depends on the relative prices of NPFs to pork. Lowering the price of NPFs helps to raise the replacement of pork by NPFs.

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Appendix A. Social accounting matrices and NH_3 emissions for all regions

Table A1: SAM in 2000 for the EU

	Pork	Peas	Other food	NPFs	Feed	Non-food	Consumer	Export	Import	Total
Pork	39,080	0	0	0	0	0	−38,781	−6651	6352	0
Peas	0	35,029	0	−21	−580	0	−42,172	−13,885	21,629	0
Other food	0	0	102,7232	0	0	0	−1,039,722	−187,593	200,083	0
NPFs	0	0	0	989	0	0	−1005	−182	198	0
Feed	−7719	0	−49,749	0	48,542	0	0	0	8926	0
Non-food	0	0	0	0	0	14,765,651	−14,674,625	−2,460,011	2,368,985	0
Factor input										
Labour	−5688	−14,299	−187,394	−162	−9390	−4,023,886	4,240,819			0
Capital	−25,249	−18,301	−753,533	−806	−36,240	−10,741,765	11,575,894			0
Land	−424	−2429	−36,556	0	−2332	0	41,741			0
Trade							−62,149	2,668,322	−2,606,173	0
Total	0	0	0	0	0	0	0	0	0	

Table A2: SAM in 2000 for other OECD countries

	Pork	Peas	Other food	NPFs	Feed	Non-food	Consumer	Export	Import	Total
Pork	75,198	0	0	0	0	0	− 77,663	− 5569	8034	0
Peas	0	121,500	0	− 51	− 1997	0	− 124,097	− 11,075	15,720	0
Other food	0	0	1,618,586	0	0	0	− 1,675,085	− 130279	186,778	0
NPFs	0	0	0	1389	0	0	− 1465	− 85	161	0
Feed	− 17,153	0	− 83,038	0	93,384	0	0	0	6807	0
Non-food	0	0	0	0	0	27,329,170	− 27,402,701	− 2,335,386	2,408,917	0
Factor input										
Labour	− 9670	− 37,585	− 242,224	− 239	− 15,717	− 8,777,195	9,082,630			0
Capital	− 45,766	− 64,101	− 1,221,305	− 1099	− 70,798	− 18,551,975	199,55044			0
Land	− 2609	− 19,814	− 72,019	0	− 4872	0	99,314			0
Trade							144,023	2,482,394	− 2,626,417	0
Total	0	0	0	0	0	0	0	0	0	

Table A3: SAM in 2000 for the ROW

	Pork	Peas	Other food	NPFs	Feed	Non-food	Consumer	Export	Import	Total
Pork	178,804	0	0	0	0	0	−176,637	−14,274	12,107	0
Peas	0	258,616	0	−221	−4455	0	−241,552	−25,243	12,855	0
Other food	0	0	1,651,954	0	0	0	−1,582,965	−235,616	166,627	0
NPFs	0	0	0	2011	0	0	−1919	−326	234	0
Feed	−44,178		−70,388		130,299	0	0	−23,347	7614	0
Non-food	0	0	0	0	0	11,408,477	−11,425,972	−1,834,204	1,851,699	0
Factor input										
Labour	−34,559	−85,415	−293,885	−202	−18,974	−2,438,815	2,871,850			0
Capital	−83,774	−121,710	−1,158,882	−1588	−98,970	−8,969,662	10,434,586			0
Land	−16,293	−51,491	−128,799	0	−7900	0	204,483			0
Trade							−81,874	2,133,010	−2,051,136	0
Total	0	0	0	0	0	0	0	0	0	

Table A4: NH_3 emissions and distribution in three regions

		Pork	Peas	Other food	NPFs	Feed	Non-food	Total
Distribution (%)	EU	0.200	0.001	0.579	0	0.120	0.100	1
	OOECD	0.170	0.001	0.500	0	0.140	0.180	1
	ROW	0.150	0.001	0.490	0	0.150	0.200	1
Emissions (ton)	EU	575.74	2.879	1666.767	0	345.444	287.87	2878.7
	OOECD	1321.886	7.776	3957.882	0	1088.612	1399.644	7775.8
	ROW	4857.78	32.385	16,160.22	0	4857.78	6477.04	32,385.2

Source: based on RIVM (2004).

Appendix B. Parameters in production and utility functions

B.1. Production function

$$Y_{i,j} = A_{i,j}\mathrm{EM}_{i,j}^{\xi_{i,j}}\left[\left(\mathrm{LB}_{i,j}\right)^{\eta_{1i,j}}\left(\mathrm{KL}_{i,j}\right)^{\eta_{2i,j}}\left(\mathrm{LD}_{i,j}\right)^{\eta_{3i,j}}\left(\mathrm{IFD}_{i,j}\right)^{\eta_{4i,j}}\left(\mathrm{IP}_{i,j}\right)^{\eta_{5i,j}}\right]^{1-\xi_{i,j}}.$$

The parameters are presented in Table A5.

Table A5: Parameters in production functions

		Pork	Peas	Other food	NPFs	Feed	Non-food
A	EU	2.70340	2.43700	2.25630	1.72440	2.16310	1.79670
	OOECD	2.97230	2.70930	2.23180	1.83940	2.22650	1.87440
	ROW	3.76620	2.83790	2.54770	1.93480	2.46400	1.68780
ξ	EU	0.014518	0.000082	0.001620		0.007066	0.000019
	OOECD	0.017275	0.000064	0.002439		0.011523	0.000051
	ROW	0.026450	0.000125	0.009688		0.035942	0.000567
η_1 (labour)	EU	0.1455	0.4082	0.1824	0.1638	0.1934	0.2725
	OOECD	0.1286	0.3093	0.1497	0.1721	0.1683	0.3212
	ROW	0.1933	0.3303	0.1779	0.1004	0.1456	0.2138
η_2 (capital)	EU	0.6461	0.5225	0.7336	0.815	0.7466	0.7275
	OOECD	0.6086	0.5276	0.7546	0.7912	0.7581	0.6788
	ROW	0.4685	0.4706	0.7015	0.7897	0.7596	0.7862
η_3 (land)	EU	0.0108	0.0693	0.0356		0.048	
	OOECD	0.0347	0.1631	0.0445		0.0522	
	ROW	0.0911	0.1991	0.078		0.0606	
η_4 (feed)	EU	0.1975		0.0484			
	OOECD	0.2281		0.0513			
	ROW	0.2471		0.0426			
η_5 (peas)	EU				0.0212	0.0119	
	OOECD				0.0367	0.0214	
	ROW				0.1099	0.0342	

B.2. Utility function

$$U_i = g_i^{\varepsilon_i}\left(\prod_s C_{si}^{\beta_{si}}\right)^{1-\varepsilon_i}, \qquad s = \text{proteins, other food, non} - \text{food and peas.}$$

The parameters are presented in Table A6.
Table A6: Parameters in utility functions

	ε	β			
		Peas	Other foods	Non-food	Proteins
EU	0 or 1%	0.00266974	0.06582058	0.92899099	0.00251869
OOECD	0	0.00423811	0.05720721	0.93585228	0.00270240
ROW	0	0.01798728	0.11787622	0.85084025	0.01329625

Table A7: Emission factors of different products in different regions

	Pork	Peas	Other food	NPFs	Non-food	Feed
EU	14.587	0.083	1.624	0	0.020	7.110
OECD	17.278	0.064	2.450	0	0.051	11.543
ROW	26.773	0.127	9.809	0	0.576	36.459

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