Assessing the world-wide effects of a shift towards vegetable proteins:
a General Equilibrium Model of Agricultural Trade (GEMAT) and the Global Trade Analysis Project (GTAP)

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ABSTRACT

The present system of food production has a considerable and rapidly increasing impact on the environment. Meat production, in particular, is not attractive from an environmental point of view, as a result of the inefficient animal conversion of feed into meat. However, meat is clearly attractive to consumers all over the world. Since the non-meat protein products presently on the market do not meet the expectations of most western-style consumers, they do not constitute realistic alternatives to meat. The prospects for replacing meat-derived ingredients by non-meat ingredients are more promising. The PROFETAS project (Protein Foods, Environment, Technology and Society) is a Dutch multidisciplinary research program on sustainable food systems, which includes researchers from the fields of plant breeding, food technology, economics, and environmental sciences. The central research question of the project is to what extent a shift from animal to plant protein foods can be environmentally more sustainable than present trends; technologically feasible; and socially desirable. Whereas the technical research concentrates on defining plant-based protein products that closely resemble meat ingredients in terms of taste, texture, and so on, the economic assessment concentrates on the consequences of such a transition for agricultural production and trade, and on its economic feasibility.

A second objective is to contribute to the methodological development of AGE models in agriculture. Therefore, two models are being used. One is the GTAP model that, in PROFETAS, is used at the Agricultural Economics Research Institute (LEI) and is employed to trace changes in production, consumption, trade and welfare for EU countries, other regions of interest as well as the rest of the world. Although there are clear and well-known advantages of using GTAP, the “one size fits all” approach of having a single model framework for widely differing issues and regions clearly also has disadvantages.

The underlying paper describes how the GTAP framework, and the second model (GEMAT), developed at the Centre for World Food Studies (SOW-VU) can contribute to understanding the likely effects of a transition. GEMAT changes some assumptions made within the GTAP model regarding agricultural production, trade, and consumption. In particular, the model includes different land types, with the possibility of conversion by investments; imposes physical constraints on the maximum attainable yield per ha for different crop types in different regions; explicitly incorporates constraints on feed composition for ruminants and monogastrics that follow from dietary requirements for these types of animals; models the production of many feed items as byproducts of the production of food; includes multifunctional agriculture as a means of promoting a production shift towards more environmentally-friendly production; and includes a projected meat demand pattern that shifts with changes in the distribution of income. In addition, there is no Armington assumption imposed to describe trade between countries. On the other hand, institutional elements of world agricultural trade, such as the EU Common Agricultural Policy, are not (yet) included in the model, and its empirical base is much weaker than that of the GTAP framework. Therefore, in this paper, GEMAT is used to show the effects of alternative model structures in the study of a transition from meat to NPFs, whereas GTAP simulations concentrate on changes in policy.

The contributions of this paper are methodological as well as empirical. The results of the model exercises carried out with GEMAT reveal the importance of including the above-mentioned assumptions on agricultural production and consumption. GTAP provides the effects of general macroeconomic trends and

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political developments. In addition, the paper shows the importance of using different models to study different aspects of a complex problem, and as such, shows the limits of the "one size fits all" approach.

1 Introduction

The present system of food production has a considerable and rapidly increasing impact on the environment. Meat production, in particular, is not attractive from an environmental point of view, as a result of the inefficient animal conversion of feed into meat. However, meat is clearly attractive to consumers all over the world. Since the non-meat protein products presently on the market do not meet the expectations of most western-style consumers, they do not constitute realistic alternatives to meat. The prospects for replacing meat-derived ingredients by non-meat ingredients are more promising. The PROFETAS project (Protein Foods, Environment, Technology And Society) is a multidisciplinary research program on sustainable food systems, which includes researchers from the fields of plant breeding, food technology, economics, and environmental sciences. The central research question of the project is to what extent a shift from animal to plant protein foods can be environmentally more sustainable than present trends; technologically feasible; and socially desirable. Whereas the technical research concentrates on defining plant-based protein products that closely resemble meat ingredients in terms of taste, texture, and so on, the economic assessment concentrates on the consequences of such a transition for agricultural production and trade, and on its economic feasibility.

Although, as is argued above, even at present, concerns about the environmental impact of meat production presents a forceful argument in favor of such a transition, projections on world-wide future meat demand as laid down in various authoritative studies stress even more the necessity of limiting meat consumption in the developed world, since they generally expect meat consumption and production to grow at rates similar to that of the past decades (FAO, 2000; OECD, 2001; USDA, 2001; FAPRI, 2001). Given that income effects are the main driving force behind this increase in meat demand (also see Keyzer et al., 2001), changes in the price of meat should be enormous to keep meat demand and, therefore, meat production, at environmentally sustainable levels (e.g. see Van Wesenbeeck and Pavel, forthcoming). This implies that a shift in preferences in the developed world is needed to relieve the tension on meat and feed production.

The underlying paper therefore concentrates on describing the likely effects of such a shift in preferences, while specifically taking into account some of the major characteristics of (future) agricultural production, consumption, and trade, such as the fact that preferences for meat depend on income levels and distribution; that animal diets have to be respected; the growing concern of consumers in developed countries with animal welfare, landscape preservation, and food safety, likely developments in the WTO negotiations and reforms of the EU Common Agricultural Policy, etc. In the simulations, two general equilibrium models are used, namely the GTAP (Global Trade Analysis Project) framework, and GEMAT, a stylized model of world agricultural trade and production, developed at the Centre for World Food Studies (SOW-VU). Table 1 provides a summary of the aspects of agricultural consumption, production, and trade relevant for the PROFETAS project, and indicates to what extent those two models take these effects into account. Of course, many of the issues listed here have been studied in other models before; specifically, the consequences of various reforms of the CAP have been extensively studied in the ECAM/CAPMAT model twin (e.g. see Folmer et al., 1995, Keyzer and Merbis, 2000), as well as the GTAP modeling framework (e.g. Brockmeier et al. 2001).[3]

[3] For a comprehensive overview over GTAP applications see http://www.gtap.agecon.purdue.edu/resources/.

	GEMAT	GTAP
Production		
land use by commodity	++	++
land use by activity and type of land	++	
output mix	++	++
feed related by products	++	+
animal diet based on physical restrictions	++	
connection to processing sector	+	++
changes in technology	+	+
distribution of new technology		++
Environmental aspects	+	
Consumption		
consumption patterns	++	+
shifts in taste	+	+
health concern		
animal welfare		
landscape preservation	++	
Trade		
effects for the rest of the world	+	++
effects for specific countries and regions	++	++
General developments		
market conditions	++	++
national macroeconomic developments		++
national political developments	+	++
international political developments	+	++
international macroeconomic developments		++
international price developments	++	++

Table 1: Agricultural production, consumption, and trade in GEMAT and GTAP

Because the GTAP framework is well known and documented (see Hertel, 1997; and http://www.gtap.agecon.purdue.edu), we will not elaborate on its theoretical background here. Section 2 therefore focuses on the theoretical structure of GEMAT. However, this section also describes some extensions of the standard GTAP framework allowing for a better representation of the problem described above. Section 3 describes scenario definitions and discusses outcomes, while the final section 4 provides some conclusions and an outlook into further research opportunities.

2 Theoretical background

2.1 GEMAT

GEMAT is defined in the "Full format" (Ginsburgh and Waelbroeck, 1981; for an elaborate discussing of this general equilibrium format, see Ginsburgh and Keyzer, 1997, Chapter 3), and therefore differs in set-up from the GTAP framework. The reason for choosing the Full Format is that it is a very flexible and robust format for the inclusion of the characteristics of agricultural production and meat consumption mentioned above. In particular, the model includes different land types, with the possibility of conversion by investments; imposes physical constraints on the maximum attainable yield per ha for different crop types in different regions; explicitly incorporates constraints on feed composition for ruminants and monogastrics that follow from dietary requirements for these types of animals; models the production of many feed items as byproducts of the production of food; includes multifunctional agriculture as a means of promoting a production shift towards more environmentally-friendly production; and includes a projected meat demand pattern that depends on the distribution of income.

The theoretical framework for the applied model is provided by welfare analysis and its relation with general equilibrium theory. Therefore, the starting point is the most simple welfare programme including production (e.g. see Ginsburgh and Keyzer, 1997, p.20), which reads as:

$$\max_{x_i, y_j^+, y_j^- \geq 0, \text{all } i, j, \; y_j, \text{all } j} \sum_i \alpha_i u_i(x_i) \qquad (1)$$

subject to

$$\sum_i x_i \leq \sum_j (y_j^+ - y_j^-) + \sum_i \omega_i \qquad (p)$$

$$y_j^+ - y_j^- = y_j \qquad (p_j^f)$$

$$F_j(y_j) \leq 0 \qquad (\lambda_j),$$

where α_i is the welfare weight for consumer i, x_i is his consumption bundle, and u_i the utility he derives from this consumption. y_j represents the total vector of in- and outputs, with y_j^+ representing the outputs, and y_j^- the inputs. The transformation function that links inputs and outputs is denoted $F_j(y_j)$. Finally, ω_i represents the initial endowments of consumer i. The symbols in brackets denote the shadowprices of the constraints.

Within this general framework, the special features mentioned in the introduction can be included as is shown in the subsequent sections.

Joint production

To represent joint production of goods, we first formulate the optimization problem of the individual producer. The standard optimization of a competitive producer reads as:

$$\max_{y^+, y^- \geq 0} \; p_y y^+ - C(y^-)$$

subject to

$$y^+ \leq f(y^-),$$

where y^+, and y^- are defined as before, $C(y^-)$ is the cost function, $f(y^-)$ the production function, and p_y the given price of outputs. However, in case of jointness in output, the producer solves:

$$\max_{y_1^+, y_2^+, y^+, y^- \geq 0} \; p_{y_1} y_1^+ + p_{y_2} y_2^+ - C(y^-)$$

subject to

$$y^+ \leq f(y^-)$$

$$y_1^+ \le y^+$$
$$y_2^+ \le y^+,$$

where y_1^+, y_2^+ represent the joint outputs.
Including this in welfare program (1) leads to:

$$max \sum_i \alpha_i u_i(x_i) \tag{2}$$
$$x_i, y_j^+, y_{j1}^+, y_{j2}^+, y_j^- \ge 0, all\ i, j, y_j, all\ j$$

subject to

$$\begin{aligned}
&\sum_i x_i \le \sum_j (y_{j1}^+ + y_{j2}^+ - y_j^-) + \sum_i \omega_i && (p)\\
&y_j^+ - y_j^- = y_j && (p_j^f)\\
&y_{j1}^+ \le y_j^+ && (\lambda_j^1)\\
&y_{j2}^+ \le y_j^+ && (\lambda_j^2)\\
&F_j(y_j) \le 0 && (\lambda_j),
\end{aligned}$$

where the symbols are defined as before.

The inclusion of joint output is particularly important for the modelling of feed production, since many feed items are, in fact, byproducts of the production of goods for human consumption, for example, cakes as byproduct of oils and fats, and grain brans as byproduct of flour production. In addition, also the joint output of agricultural servives (multifunctionality) can be represented.

Non-rivalry in consumption

To represent the consumption of agricultural services, such as a nice landscape, the model must include non-rival consumption goods, g_i. Following standard theory (see e.g. Ginsburgh and Keyzer, 1997, Chapter 9), welfare program (2) is modified as follows to include non-rival consumption goods:

$$max \sum_i \alpha_i u_i(x_i, g_i) \tag{3}$$
$$x_i, g_i, y_j^+, y_{j1}^+, y_{j2}^+, y_j^- \ge 0, all\ i, j, y_j, all\ j, x_g \ge 0$$

subject to

$$\begin{aligned}
&\sum_i x_i + x_g \le \sum_j (y_{j1}^+ + y_{j2}^+ - y_j^-) + \sum_i \omega_i && (p)\\
&g_i \le x_g && (\varphi_i)\\
&y_j^+ - y_j^- = y_j && (p_j^f)\\
&y_{j1}^+ \le y_j^+ && (\lambda_j^1)\\
&y_{j2}^+ \le y_j^+ && (\lambda_j^2)\\
&F_j(y_j) \le 0 && (\lambda_j),
\end{aligned}$$

where g_i is the individual consumption of the non-rival good, while x_g is its common consumption.

Jointly, the possibility of joint outputs and the introduction of non-rival agricultural services facilitates the representation of a choice between two production methods in agriculture. An intensive prodoction method will yield much primary outputs, but generates hardly any agrcultural services as joint output, while extensive farming yields less primary outputs, but substantive agricultural services. If consumers have a preference for agricultural services, then the less intensive agriculture will become feasible. The fact that the two options are available in the model allows an endogenous determination of extensive versus intensive agriculture. In addition, it could be argued that crop growing also has agricultural services as joint outputs. This increases the income farmers get from growing crops instead of producing meat and could therefore be an additional motive for farmers to start producing the protein crops[4] necessary for the transition towards a more vegetarian diet.

Regime switches in preferences for meat

As argued in Keyzer et al. (2001), the demand for meat and meat products does not increase gradually with income. Instead, three different stages can be distinguished. First, at very low income levels, there is a very low consumption of meat. Then, as income reaches a certain threshold value, the demand increases rapidly with income, until the second income threshold is reached where additional demand for meat is very limited as satiation has set in. This implies that there are three different regimes ("lifestyles") that need to be distinguished in the model.

Theoretically, we use a migration[5] approach (see Keyzer, 1995) to represent the choice for one of the three lifestyles. For an individual consumer, the optimisation program reads as follows, where m represents the consumption of meat, $\hat{m}$ committed consumption, $\bar{q}$ the bounds on meat consumption, and H the income of the consumer. The choice between different lifestyles is modelled as the share of n_l in the total, 1. As before, symbols in brackets notate shadowprices of the restrictions. (Keyzer, 1995, also provides a proof that an equilibrium of this problem exists, for other applications of this migration framework, see, for example, Van Wesenbeeck, 2000, Chapters 4 and 6; and Van den Boom, 1998).

$$max_{m_l, x_l, n_l} \sum_l n_l u_l (x_l , m_l)$$

subject to

$$p \sum_l n_l x_l + n_l m_l + n_l \hat{m}_l = H \qquad (\rho)$$

$$n_l \bar{q}_{l-1} \leq n_l m_l + n_l \hat{m}_l \qquad (\underline{\mu}_l)$$

$$n_l m_l + n_l \hat{m}_l \leq n_l \bar{q}_l \qquad (\bar{\mu}_l)$$

$$\sum_l n_l = 1 \qquad (\xi)$$

If we introduce this in (3), we obtain the following welfare program (4):

$$max \sum_i \alpha_i \sum_l n_{i,l} u_{i,l} (x_{i,l} , g_{i,l} , m_{i,l}) \tag{4}$$

[4] Within the PROFETAS project, the focus is on using peas for the production of Novel Protein Foods, but of course, other crops, such as soybeans or other pulses, can be used. Another possibility would be the use of grass for the production of vegetable proteins (for an overview of crops suited within an European context, see e.g. Linnemann and Swaving Dijkstra, 2000 and Swaving Dijkstra et al., 2001)

[5] We note that the use of the term "migration" here differs from the common use of people moving from one location to the other. Instead, here, it has the broader meaning of individuals moving to preferred states (regimes)

$$x_{i,l}, g_{i,l}, m_{i,l}, y_j^+, y_{j1}^+, y_{j2}^+, y_j^-, n_{i,l} \geq 0, all\ \text{i, j, } y_j\text{, all j, } x_g \geq 0$$

subject to

$$\sum_i \sum_l n_{i,l}(x_{i,l} + m_{i,l} + \hat{m}_{i,l}) + x_g \leq \sum_j (y_{j1}^+ + y_{j2}^+ - y_j^-) + \sum_i \omega_i \qquad (p)$$

$$n_{i,l} g_{i,l} \leq x_g \qquad (\varphi_{i,l})$$

$$y_j^+ - y_j^- = y_j \qquad (p_j^f)$$

$$y_{j1}^+ \leq y_j^+ \qquad (\lambda_j^1)$$

$$y_{j2}^+ \leq y_j^+ \qquad (\lambda_j^2)$$

$$F_j(y_j) \leq 0 \qquad (\lambda_j)$$

$$n_{i,l} \overline{q}_{i,l-1} \leq n_{i,l} m_{i,l} + n_{i,l} \hat{m}_{i,l} \qquad (\underline{\mu}_{i,l})$$

$$n_{i,l} m_{i,l} + n_{i,l} \hat{m}_{i,l} \leq n_{i,l} \overline{q}_{i,l} \qquad (\overline{\mu}_{i,l})$$

$$\sum_l n_{i,l} = 1 \qquad (\xi_i)$$

Implementing GEMAT: the Full Format

The theoretical model presented in the previous section is a welfare program. This implies that the welfare weights are taken as given and are not necessarily such that budgets of individual consumers or regions (the balance of payments) are satisfied. To determine the welfare weights at which budgets do hold, we use the Full Format representation of the AGE model (Ginsburgh and Waelbroeck, 1981, also see Ginsburgh and Keyzer, 1997 for further elaboration of this format, and Van Wesenbeeck, 2000, Chapter 6 for a numerical application of this format to represent strategic behavior in a AGE model of world trade), which implies that the budgets are included in (4), and that a feedback is added to update the welfare weights and the prices used in the budgets until budget constraints are met. In the sequel, we will refer to the welfare program including budgets as the “main program”, and use the term “feedback” for the program that updates welfare weights and prices. The main program thus adds budget constraints to (4) and reads as:

$$max \sum_r \sum_i \alpha_{r,i} \sum_l n_{r,i,l} u_{r,i,l}(x_{r,i,l}, g_{r,i,l}, m_{r,i,l}) \qquad (5)$$

$$x_{r,i,l}, g_{r,i,l}, m_{r,i,l}, y_{r,j}^+, y_{r.j1}^+, y_{r,j2}^+, y_{r,j}^-, n_{r,i,l} \geq 0, \text{all r, i, l, j, } y_{r,j}, z_r\text{, all r,j,} x_{r,g} \geq 0, \text{all r}$$

subject to

$$\sum_r z_r = 0 \qquad (p^w)$$

$$\sum_i \sum_l n_{r,i,l}(x_{r,i,l} + m_{r,i,l} + \hat{m}_{r,i,l}) + x_{r,g} \leq \sum_j (y_{r,j1}^+ + y_{r,j2}^+ - y_{r,j}^-) + \sum_i \omega_{r,i} + z_r \qquad (p_r)$$

$$n_{r,i,l} g_{r,i,l} \leq x_{r,g} \qquad (\varphi_{r,i,l})$$

$$y_{r,j}^+ - y_{r,j}^- = y_{r,j} \qquad (p_{r,j}^f)$$

$$y_{r,j1}^+ \leq y_{r,j}^+ \qquad (\lambda_{r,j}^1)$$

$$y_{r,j2}^+ \leq y_{r,j}^+ \qquad (\lambda_{r,j}^2)$$

$$F_{r,j}(y_{r,j}) \leq 0 \qquad (\lambda_{r,j})$$

$$n_{r,i,l} \overline{q}_{r,i,l-1} \leq n_{r,i,l} m_{r,i,l} + n_{r,i,l} \hat{m}_{r,i,l} \qquad (\underline{\mu}_{r,i,l})$$

$$n_{r,i,l} m_{r,i,l} + n_{r,i,l} \hat{m}_{r,i,l} \leq n_{r,i,l} \overline{q}_{r,i,l} \qquad (\overline{\mu}_{r,i,l})$$

$$\sum_l n_{i,l} = 1 \qquad (\xi_{r,i})$$

$$\overline{p}_r \sum_l n_{r,i,l} x_{r,i,l} + n_{r,i,l} m_{r,i,l} + n_{r,i,l} \hat{m}_{r,i,l} = \overline{p}_r \omega_{r,i} \qquad (\rho_{r,i})$$

$$\overline{p}^{w} z_r = 0 \qquad (\psi_r),$$

while welfare weights and the prices used in the budgets have to be adjusted, until the shadowprices of the individual budgets are equal to zero, and the shadowprices of the balances of payment are equal (but not necessarily equal to zero). These updates are included in the feedback of the Full Format model. In addition, the separation into a main model and a feedback also allows the straightforward inclusion of different and changing lifestyles, and of animal diets. Although details on the implementation of GEMAT (including classifications, and functional forms) are given in the appendix of this paper, the inclusion of consumer lifestyles and animal diets is discussed here, because of their importance in the model structure.

As was shown above, the changes in consumer lifestyles that are associated with a rising income can, theoretically, be represented as a migration problem. However, to keep the main program of the Full Format as simple as possible, in the implementation of the lifestyle approach, we use fixed shares $n_{r,i,l}$ in the main program and update these in the feedback.

The general idea is to use the incomes of the groups and the prices of the commodities from the equilibrium solution of the main program and use these to solve for the individual consumer migration models in the feedback. However, instead of simply using the income of the group as the income of every consumer in this group, we acknowledge the fact that the income used in the main program actually is the average income of this group, and that a distribution of incomes underlies this figure. To mimic the approach taken in Keyzer et al. (2001), for each of the four regions, income distributions corresponding to a certain average per capita income are used. Thus, if average per capita income in a region rises, a group of people in that region will move to another lifestyle regime. In the application, 700 income classes are distinguished. For each of these classes, an individual optimisation is done to determine the share of consumers in this class that would migrate to a rich, poor, or intermediate lifestyle. Then, multiplying these shares with the number of people in each income class and aggregating over all income classes leads to the total number of people in the group that follows a specific lifestyle, the $n_{r,i,l}$. This share is then used in another round of the Full Format main program.

The upper and lower bounds on meat consumption, and the committed consumption for each lifestyle are set following Keyzer et al. (2001); the distributions of income at different levels of average income were calculated by Van Wesenbeeck[6]

Since the distributions of income depend on the level of the average income, it is clear that if no additional assumptions are made, homogeneity of degree zero in prices of the model is lost; if all prices are multiplied by some factor A, incomes would rise with a factor A, and this would lead to another income distribution with another pattern of lifestyles and thus another consumer demand pattern. To overcome this problem, we first calibrate the model such that incomes are in the same range as actually observed incomes on which the distributions are based, and then use the normalisation of prices used in this benchmark model as the base normalisation. For all other normalisations, corrections are made in the prices and income that are reported by the Full Format main program. For example, if, in comparison to the base normalisation, all prices are multiplied by a factor A, then in the lifestyle calculation, all incomes and prices used are divided by that factor. In this way, the homogeneity of degree zero in prices in maintained. Since the upper and lower bounds on meat consumption and the committed consumption are all stated in quantities, no corrections are necessary here.

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[6] The authors thank Ferdinand Pavel for providing the basic data on income distributions by country.

For the description of livestock production, it was argued before that one of the distinguishing features is the fact that specific requirements on the animal diets have to be met. To include this feature in the model, use is made of detailed information on these requirements, as presented in National Research Council (1977, 1981, 1985, 1989, 1994, 1998, 2000) in a separate feed module, that is included in the feedback of the Full Format.

In this module, for beef cattle, goat, sheep, chicken, duck, geese, horses, rabbits, swine, and turkey, a linear program is solved. In these models, feed elements are included at a much more detailed level than in the full format model itself. The objective of the feed programs is to minimize the costs of the feed "package" for one animal for one day, given the dietary requirements of this animal. Therefore, the programs read as:

$$min_{v \geq 0} \sum_f p_f v_f$$

subject to

$$\sum_f q_{m,f} v_f \geq A_m ,$$

where f represents the set of possible feeds, m is the set of possible nutrients, v_f is the amount of feed of type f in kg, $q_{m,f}$ represents the availability of nutrient n in feed type f, and A_m is the daily requirement for one animal of nutrient m.

To obtain the prices used in these optimisations, we map the prices of the aggregate commodities, as follow from solving the Full Format model, to the list of feed composites used in the linear programs. After solving the models, and obtaining the optimal feed mix for one animal for one day, we apply a conversion factor to go from animals to metric tons of meat. Then, we map the demand for the individual feed components back to the aggregates used in the Full Format model and thus obtain the new input-output coefficients for the production of livestock. Finally, an additional step is needed to aggregate the demands for feed from different animals to a total representing the feed demand from the sectors "ruminants" and "monogastrics" as a whole. For this, we assume that the composition of this aggregate remains constant throughout the simulations, and use the shares of the different types of meat to obtain the total feed demand of the sector.

To capture the idea that a technological transition takes time, and since the effects of such a transition will become important in the long run, the model distinguishes two periods, the present (1999/2000) and the future (2020). This implies, among other things, that consumers, producers, and regions can save and borrow, as long as all debts are settled at the end of period 2. Of course, to provide a good representation of the future, exogenous trends on, among other things, population growth, technical progress, yield increases, and land clearing are included.

2.2 GTAP

This section explains in brief the extensions of the standard GTAP model used in this paper. For an extensive description of the extended methodology see Herok (forthcoming).

Extension 1: Introduction of an innovative product

The use of a fully equipped database like GTAP presents the problem of including products that did not exist in the base period. Thus a method for creating a new product within a CGE context has to be found. The selected approach describes the process of an innovation as an evolutionary process: the basic idea emerges from one existing part of the economy but its further development is not necessarily representative of its sector of origin. Therefore at first a sector was chosen out of which the new product may emerge and secondly this very sector was split into two.[7] The logic behind the idea of an "innovation-split" is that a newly invented product will need some resources to be produced. Consequently, it has to be decided what kind of resources will be needed and where they will come from.

Up to now only a "vision" of the new innovative product has been developed within the PROFETAS project. A comprehensive production plan with detailed information about necessary inputs and very clear characteristics of the product has not been created yet. Nevertheless, the main assumption is that the novel protein food will result from a plant protein, most likely a kind of vegetable, and that it will be processed into a consumable good acting as a meat substitute. Using this information, the vegetable oils and fats sector of the GTAP database, which includes all kinds of products resulting from oil and protein plants, has been chosen as a promising sector out of which novel protein food can be invented. The aggregate vegetables, oils and fats is quite suitable as a basic sector because it consist of different agricultural products, providing no ex-ante restriction on the possible basis of the new product. This makes sense in a way that not just one but different products may be a starting point for the creation of meat substitutes. Consequently a very small portion (0.1%) of this sector was taken out and assumed to be the new innovative product.

Creating a new product goes hand in hand with the introduction of some behavioural parameters. On the production side the elasticities for NPFs were set equal to those for meat[8] as were the substitution parameters of the consumers (SUBPAR). Compared to meat consumption, it is assumed that the consumption of NPFs increases stronger with an increase in income. Therefore the income parameter of NPFs in the CDE function was set equal to that of the services sector, which shows the highest income effects. On the political side, neither domestic instruments nor tariffs were introduced.

Extension 2: New Intra EU trade structure

Including *Armington* elasticities into a modelling framework implies specific national market power on international markets. Connected to this is the "small country effect" which in case of policy changes leads to unrealistic high responses of smaller countries (Brown, 1987). This fact can also be observed while dealing with small regions in the GTAP model. In our analysis it only affects the smaller EU regions, and therefore, the method developed by Herok et al. (2002) was used to allow for a better representation of these countries. In this approach products from different EU countries are treated equally on the world markets, while they act as heterogeneous goods on EU markets. The idea was implemented by including two additional nests into the standard GTAP structure.

3 Scenario definition and results

3.1 GEMAT

First of all, we define a "business as usual" (BAU) scenario, which represents a situation where standard assumptions on consumption and feed technology are made, i.e. in this scenario, there

[7] To split the GTAP database an additional free software (DAGG) is needed. It can be obtained from http://www.monash.edu.au/policy/gpmark.htm. This software allows for the aggregation and disaggregation of an existing database.

[8] For those familiar with GTAP terminology this includes ESUBD, ESUBM as well as ESUBVA.

are no lifestyle changes and no restrictions on animal diets are included. This scenario is used as the benchmark against which the other scenarios are compared, and therefore, it is calibrated as good as possible to reflect actually observed patterns of production and consumption, including a low preference for vegetarian products, and a low preference for agricultural services at present.

The goal of the numerical exercises with GEMAT in this paper is to illustrate the effects of alternative model structures, given a change in model parameters, in this case a change in preferences in the EU region from meat to novel protein foods. Given this objective, we discuss four alternatives:

1. SHIFT, where the only change made with respect to the BAU scenario is the change in preferences for meat and NPFs, realised by assuming a 20% decrease in the CES share parameter with respect to meat products and a 100% increase in the CES share parameter with respect to NPFs for the EU consumers of all lifestyles.
2. GREEN, where the change in preferences for meat is accompanied by an increasing preference for agricultural services, realised by increasing the CES share parameter for agricultural services by 50%, for the EU consumers of all lifestyles.
3. DIET, which is the GREEN scenario complemented with the requirement that animal diets need to be respected
4. LIFESTYLE, which is the DIET scenario where lifestyle changes are included.

Again, we emphasise that these four scenarios mainly serve to show the implications of adding the assumptions specified in these alternative specifications, and therefore to provide support for the inclusion of these characteristics in applied general equilibrium models focusing on agricultural production and consumption trends. Future applied work on GEMAT will include a better tuning of the model to reflect actual composition of the economies, production locations et cetera. Here, a selection of model outcomes for each of these four scenarios is made, that best illustrate the effects of changing model structure on outcomes. For reasons of exposition, we concentrate on the following indicators: GDP per capita in 2020, meat consumption and production in 2020, NPF production and consumption in 2020, and the pressure on crop land in 2020. All results are presented in % deviations from the Business As Usual scenario.

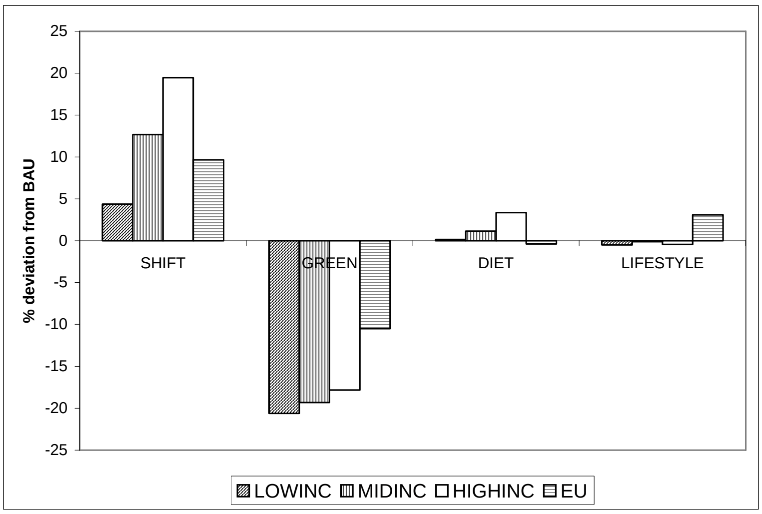

Figure 1: GDP per capita, 2020, % deviation from BAU scenario

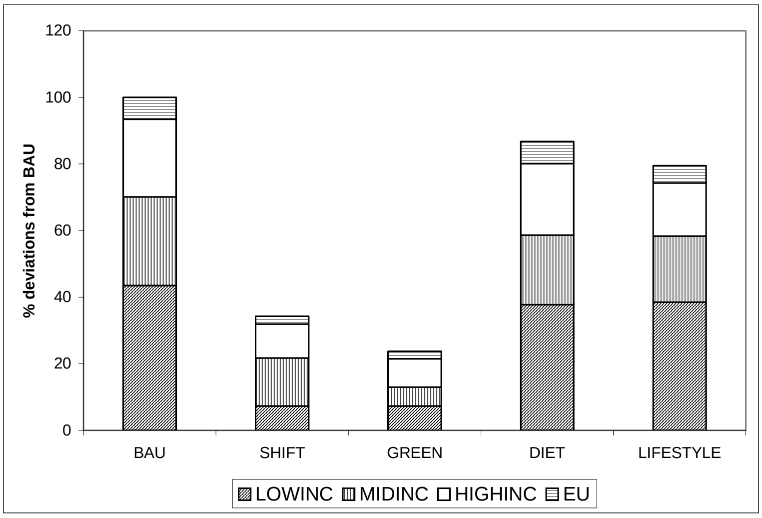

Figure 2: Meat consumption, 2020, % deviation from BAU scenario

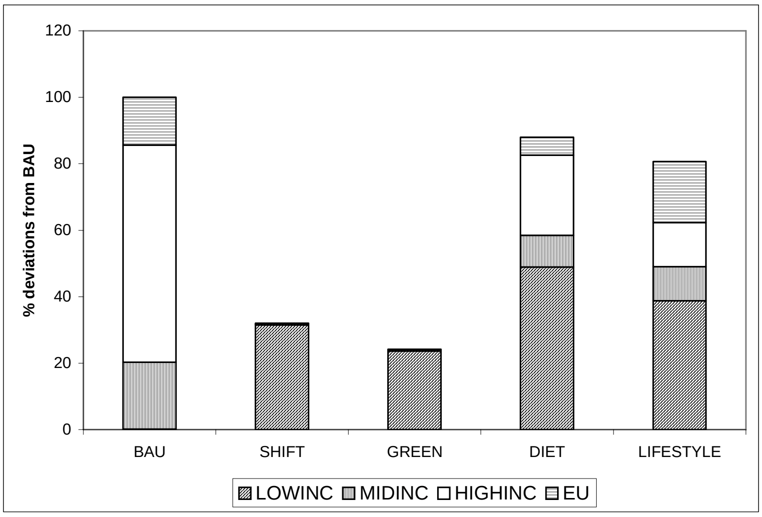

Figure 3: Meat production, 2020, % deviation from BAU scenario

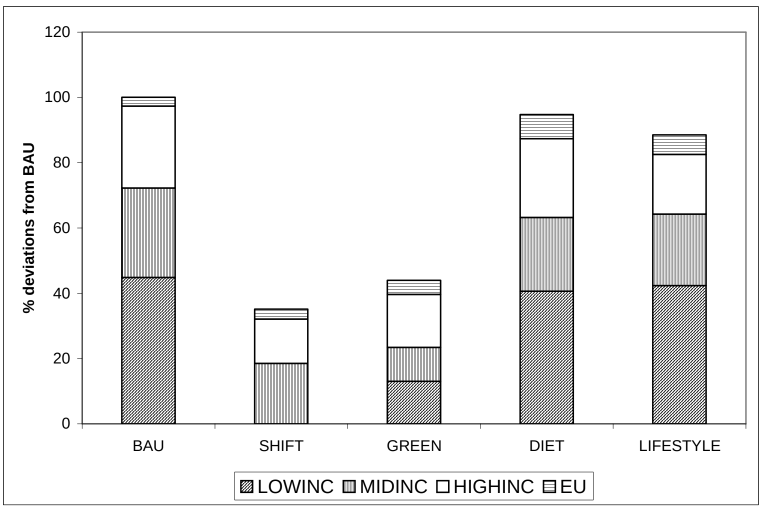

Figure 4: NPF consumption, 2020, % deviation from BAU scenario

Figure 5: Pressure on cropland, % deviation from BAU scenario

As can be seen from figures 1-5, there are major differences between outcomes under alternative assumptions on model structure, and especially adding the requirement that animals have certain dietary requirements that need to be respected has an important impact on the scenario results.

Secondly, we note that the response of the model with respect to the changes in the model parameters defining the scenarios is rather "violent" in all but the DIET and LIFESTYLE scenarios. This is something we will work on in future research, and is due to the lack of institutional structure that is imposed on the model, and to the fact that calibration of the model is far from finished, which causes the model to overstate the importance of agriculture in the economies of the regions, which in turn leads to the extremely large model responses. Therefore, we stress that the results presented above are illustrative only. Yet, it is interesting to note that the LIFESTYLE scenario clearly shows that the driving force of meat demand in developing countries is the shift in lifestyle that accompanies an increase in per capita income: in the low and middle income countries, meat demand continues to rise, while meat demand in the EU and also in the other high-income countries falls. In the EU, this is due to the assumed shift in preferences, accompanied by the lifestyle effect of satiation in meat at high income levels, in the other high-income regions, the effect is entirely caused by satiation effects, as more people shift from the intermediate to the satiated rich lifestyle.

Regarding the pressure on land, figure 5 presents the effects of a transition on the shadowprices of the land use bound, i.e. it indicates the loss associated with not taking into production more land than is currently allowed in the model (which guarantees that no natureland is taken into production). Therefore, this shadowprice provides a good instrument to measure the pressure on cropland. Under all scenarios, the pressure on cropland decreases most for the Lowinc region, since this is the region where most of the feed used in animal production is grown. For Midinc countries, this trend is also clearly visible, but the effect is much smaller, since this region is a large producer of ruminants, and therefore uses relatively little land for the production of feed.

The effects of forcing animal diets shows that not taking these into account would underestimate the pressure exercised by the feed demand on land use: for all regions, the pressure on land is higher than that in the SHIFT and GREEN scenarios. For the EU, the effect is much less than that for the other high-income countries, since the higher preference for extensive agriculture led to a change in agricultural production structures that made the production of animals less dependent on commercial feed.

Finally, including shifts in regimes in response to shifting income distributions dampens the results found under the DIET scenario somewhat, since, as was explained before, especially in the Highinc region, many people shift from the intermediate to the rich, satiated lifestyle.

3.2 GTAP

While GEMAT focuses on specific and detailed developments, GTAP is used to model the general and international political framework. In the following, two types of simulations will be presented: the first includes general macroeconomic trends, which are independent of the introduction of NPFs. The additional information concerning GDP growth and trends in production factors was taken from Wamsley et al. (2000). The second describes future political developments relevant for the European Union.[9] The scenarios were organized along a path which follows the expected time frame of future changes. The results of each scenario were used as the base data for the following scenario.

1. AG includes the Agenda 2000 reform package of the EU.
2. 2006 includes projections for the period 2002-2006.
3. ENLG includes an Eastern enlargement of the EU with the adoption of all border and domestic instruments including direct payments.
4. 2010 includes projections for the period 2007-2010.
5. CAP includes a possible next Common Agricultural Policy (CAP) reform with a reduction in direct payments by 30% and the abolition of milk and sugar quotas.
6. WTO includes a possible next WTO round with a reduction of all border instruments worldwide by 20%.
7. 2020 includes projections for the period 2011-2020.

The simulations form preliminary scenarios, which have to be defined in greater detail in the future. This becomes particularly relevant in regard to the distribution and diffusion of the new innovative product.[10] However, they already provide a clearer vision about the relevance of different influences.

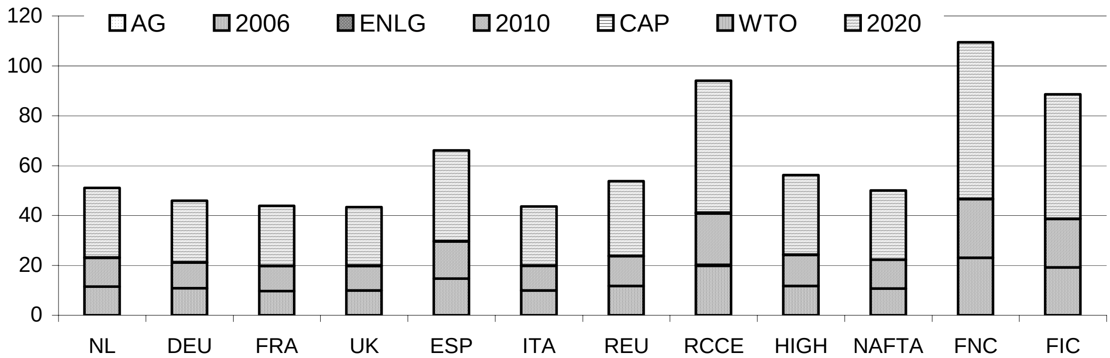

Figure 6: Changes in GDP in % [11]

[9] For a description of the modelling of Agenda 2000 and Eastern enlargement see Brockmeier et al. (2001).
[10] For a better description of the diffusion process using a spillover mechanisms see Herok (forthcoming).
[11] For the description of the regional and product aggregation see appendix.

Figure 6 demonstrates that political developments only have a minor impact on the GDP. Here the changes result mainly from the macroeconomic projections. This is somewhat different for the production and consumption of meat and NPFs[12], where both macroeconomic changes and politics may have a strong influence.

Production and consumption of red meat will have their highest growth rates in the regions FNC and FIC (food neutral and food insecure countries), where the rising GDP forms the main driving force, and the RCEE (Central and Eastern European Associate countries) where the accession to the EU provides additional incentives for producers (see table 2).

The Agenda 2000 leads to small changes in the distribution of red meat production and a minor total reduction in the EU (-0.9%, not shown). The enlargement results in additional regional shifts but increases the total output in the EU (+0.2%, not shown). The CAP reform and the WTO scenario include reductions in the political support of red meat production, which lead to a decrease in output. The consumption of meat is only marginally affected by political changes. Here again macroeconomic developments dominate the results.

	production							consumption						
	AG	2006	ENLG	2010	CAP	WTO	2020	AG	2006	ENLG	2010	CAP	WTO	2020
NL	-4.0	4.9	-0.8	4.5	8.1	-1.4	9.2	0.3	2.2	0.1	2.0	0.0	0.2	4.4
DEU	-1.2	3.0	-0.5	3.0	2.8	-1.5	7.3	0.6	2.1	0.1	1.7	0.1	0.1	3.1
FRA	1.6	4.5	0.2	4.5	-2.4	-0.8	10.2	1.0	4.5	0.1	4.4	-0.8	0.0	9.8
UK	-2.4	3.5	0.0	3.4	-2.2	-2.3	7.5	0.4	2.1	0.0	2.0	-0.3	0.2	4.2
ESP	0.5	7.8	0.1	7.6	-3.1	-0.4	16.1	0.8	5.9	0.1	5.2	-1.4	0.1	8.9
ITA	0.8	2.3	-0.3	2.4	-0.5	-0.5	5.9	0.6	2.5	0.2	2.4	-0.3	0.0	5.7
REU	-0.2	5.0	-0.3	5.2	-2.4	-0.4	12.4	0.4	3.2	0.1	3.0	-0.3	0.1	6.3
RCCE	0.1	7.5	4.7	7.8	4.2	-0.4	18.4	0.0	9.9	0.2	9.5	0.5	0.0	20.7
HIGH	0.4	5.7	-0.2	6.1	0.2	1.0	14.2	0.0	6.0	0.0	6.2	0.0	0.7	14.2
NAFTA	0.0	5.7	0.0	5.7	-0.1	0.1	13.3	0.0	4.8	0.0	5.5	-0.1	-0.1	15.0
FNC	0.1	10.3	-0.1	10.2	0.1	-0.5	23.6	0.0	11.0	0.0	10.6	0.0	0.2	24.5
FIC	0.1	10.1	-0.1	9.3	0.2	-0.2	19.6	0.0	12.3	0.0	11.9	0.0	0.1	28.2

Table 2: Changes in production and consumption of red meat (in %)[9]

	production							consumption						
	AG	2006	ENLG	2010	CAP	WTO	2020	AG	2006	ENLG	2010	CAP	WTO	2020
NL	2.0	9.8	0.9	10.3	1.2	-0.6	28.6	0.1	13.5	0.3	13.4	-0.1	0.2	32.3
DEU	0.1	10.5	-0.3	10.9	0.5	-0.3	29.4	0.2	14.8	0.2	13.6	0.0	0.0	32.2
FRA	-0.3	7.5	-0.5	8.4	-1.4	-0.7	21.8	0.0	12.7	0.1	12.9	-0.2	0.1	30.5
UK	0.1	11.4	-0.3	11.8	-3.1	-0.1	30.1	0.1	11.8	0.1	11.2	0.1	0.1	26.1
ESP	0.1	12.3	-0.4	13.4	-2.2	-0.7	34.2	0.0	14.2	0.2	13.0	-0.4	0.1	27.0
ITA	-0.7	11.0	-0.4	11.9	-2.4	-0.5	32.5	0.1	14.6	0.2	14.2	-0.3	0.1	35.0
REU	-0.6	12.0	-0.1	13.2	-3.2	-0.8	36.9	0.1	14.0	0.2	13.7	-0.1	0.1	33.1
RCCE	-0.1	16.6	3.9	17.9	-0.7	-0.6	46.6	0.0	27.2	1.9	26.0	0.4	0.1	61.6
HIGH	0.0	6.4	0.1	7.0	0.1	6.3	19.6	0.0	14.4	0.0	14.8	-0.1	1.4	36.2
NAFTA	0.0	8.5	0.1	7.6	0.1	-1.2	17.0	0.0	9.8	0.0	11.1	-0.1	-0.1	28.8
FNC	0.0	16.6	0.1	16.8	0.5	0.5	41.2	0.0	26.9	-0.1	25.8	0.0	0.3	64.9

[12] Although other meat was also included in the simulations (see appendix) for the sake of simplicity the analysis was restricted to red meat.

FIC	0.0	13.9	-0.1	12.5	0.4	-0.4	26.8	0.0	21.2	0.0	20.5	0.0	0.2	51.0

Table 3: Changes in production and consumption of NPFs (in %)

The macroeconomic projections lead to an increased output of NPFs in all regions (see table 3). These results are based on the assumption that NPFs can be produced and consumed worldwide without any technological or political restrictions. As the invention of this product will take place in one region and will then follow a certain diffusion path this may not be realistic. This paper, however, was restricted to this approach to keep the simulations simple.

Since no trade barriers or domestic measures were introduced for the NPFs, changes in the political regime only influence NPFs indirectly through cross effects with other products, mainly land using goods, especially vegetables and processed vegetables. As already mentioned these scenarios are just a first step. Regarding the environmental background it seems quite realistic that the introduction of NPFs might be accompanied by a product specific policy scheme and/or policy measures designed to diminish the negative environmental effects of meat production. These can be included into the simulations to provide a more realistic scenario.

4 Concluding remarks and directions for further research

4.1 Qualifications of the models

As shown in this paper, the GEMAT Full Format is very suited for the inclusion of additional constraints on technology (such as animal diets) as well as the representation of utility functions that diverge from the standard assumptions, extensions that we feel are essential for a correct representation of meat demand and agricultural production. GTAP can provide additional useful insights into the discussion about meat and meat substitutes, especially concerning macroeconomic developments, politics and, although no explicitly shown in this paper, trade effects.

The introduction of NPFs into the models allows for the simulation of various developments even though, as always, much depends on the availability of data. Due to the scarcity of information numerous assumptions have to be made so far. But, since the PROFETAS project is still on going it can be assumed that some data gaps will be filled in the near future. Aside from the general data problem, many other extensions are possible that would greatly improve the description of agricultural production and consumption patterns within AGE models, but could not be included here yet.

Obviously, a very important omission is the lack of spatial specificity in the description of agricultural production, which requires integrating information on agro-ecological constraints on production within a spatially explicit economic model (as is done in, for example, Albersen et al. (2000).

Another important assumption that is made within the models is that the production of agricultural goods itself as well as the processing of these goods is carried out by fully competitive producers. This neglects the fact that, partly because of rising consumer concerns, agricultural production is increasingly being vertically integrated, which implies that market structure is changing, and in addition, these vertically integrated conglomerates may try to control markets by engaging in strategic behaviour. In GEMAT this could be incorporated as described in Keyzer and Van Wesenbeeck (1999) and Van Wesenbeeck (2000), but is not included here to keep the exposition clear and tractable. It is also quite realistic that in the beginning the newly invented NPFs are produced by only a small amount of firms leading to monopolistic behaviour on the markets. This can also be included into the models (for the GTAP model, see e.g. Francois, 1998).

A third possible extension would be to include uncertainty and risk in the model, two important aspects of agricultural production. This could relate to uncertainty about natural circumstances, such as weather conditions, but also, specifically in the EU context, to uncertainty about reforms in agricultural policies.

As already mentioned in the paper the worldwide distribution and diffusion process of the newly invented NPFs needs a better representation in the GTAP model. This can implemented using the method developed by Van Meijl and Van Tongeren (1999).

Finally, to improve the empirical relevance of the model institutional arrangements such as the EU Common Agricultural Policy should be included. However, in the PROFETAS project, in addition to the GTAP and GEMAT models, the CAPMAT/ECAM model twin, explicitly developed for the study of CAP reforms, is used to get a more detailed picture of the effects of a transition for agriculture in the EU-15 member countries. Therefore, again, we stress the importance of using several models to assess the different aspects of the problem instead of concentrating on a single model tool.

4.2 Conclusion

This paper emphasised that different aspects of an economic problem may call for the use of different model frameworks. Here, we concentrated on the effects of a transition from meat to Novel Protein Foods, and showed, on the one hand, the importance of assumptions made with respect to agricultural production and consumption technologies and patterns (within the GEMAT model), and on the other hand, the equal importance of representing institutional arrangements affecting agricultural production and trade (using GTAP). Of course, it is clear that on both accounts, many improvements of the models are called for to arrive at a better representation of agricultural production, consumption, and trade.

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6 Appendix

6.1 Classifications and functional forms in GEMAT

Commodities

Grass
Rye grass for forage, clover for forage, alfalfa for forage, other grasses for forage, range pastures, improved pastures.

Grains
Wheat, rice, barley, maize, rye, oats, millets, sorghum, buckwheat, quinoa, fonio, triticale, canary seed, mixed grain, other cereals.

Roots and tubers
Potatoes, sweet potatoes, cassava, yautia, taro, yams, other roots and tubers

Oilcrops
Soybeans, groundnuts, coconuts, oil palm fruit, olives, karite nuts, castor beans, sunflower seed, rapeseed, tung nuts, jojoba seeds, safflower seeds, sesame seeds, mustard seeds, poppy seeds, melon seeds, tallow tree seeds, kapok seeds, seed cotton, linseed, hempseed, other oilseeds.

Pulses
Dry beans, broad beans, dry peas, chick-peas, cow peas, vetches, lupins, other pulses.

Other agriculture
Sugar cane, sugar maple, sweet sorghum, sugar palm, brazil nuts, cashew nuts, almonds, walnuts, pistachios, kola nuts, hazelnuts, areca nuts, other nuts not elsewhere specified, cabbages, artichokes, asparagus, lettuce, spinach, cassava leaves, fresh tomatoes, cauliflower, pumkins,

cucumbers, eggplants, chillies, onions, garlic, leeks, chives, green beans, green broad beens, string beans, carrots, okra, green corn, mushrooms, watermelons, cantaloupes, other fresh vegetables, bananas, plantains, oranges, tangarines, lemons, limes, grapefruits, other citrus fruits, apples, pears, quinces, other pome fruit, apricots, sour cherries, cherries, peaches, nectarines, plums, other stone fruit, strawberries, raspberries, gooseberries, currants, blueberries, cranberries, other berries, grapes, figs, persimons, kiwi fruit, mangoes, avocados, pineapples, dates, cashewapples, papayas, other tropical fruit, other fresh fruit, pepper, pimento, vanilla, cinnamon, cloves, nutmeg, anise, ginger, other spices, green coffee, cocoa beans, tea, mate, other tea, chicory roots, hops.

Ruminants
Meat of cattle, buffalo meat, meat of sheep, goat meat, meat of camels, meat of other camels.

Monogastrics
Pig meat, chicken meat, duck meat, goose meat, turkey meat, meat of pigeons and other birds not elsewhere specified, horse meat, meat of asses, meat of mules, rabbit meat, meat of other domestic rodents.

Meat products
Beef and veal (dried, salted, smoked), meat extracts, sausages of beef and veal, beef and veal preparations not elsewhere specified, homogenized meat preparations, liver preparations, pork, bacon and ham, sausages of pig meat, pig meat preparations, lard, fatty liver preparations, canned chicken meat, rendered fat of poultry.

Vegetable oils and fats
Oil of soybeans, oil of groundnuts, oil of coconuts, oil of palm fruit, oil of palm kernel, oil of olives, oil of olive residues, butter of karite nuts, oil of castor beans, oil of sunflower, oil of rapeseed, oil of tung nuts, jojoba oil, oil of safflower seeds, oil of sesame seed, oil of mustard seed, oil of poppy seeds, vegetable tallow, stillingia oil, oil of kapok, oil of cottonseed, oil of linseed, oil of hempseed, other oil of vegetable origin, oil of rice bran, oil of maize.

Other agricultural products
Flour of wheat, bulgur, pastry, wheat-fermented beverages, husked rice, milled husked rice, milled rice, broken rice, flour of rice, rice-fermented beverages, pot barley, pearled barley, malt, malt extract, beer of barley, germ of maize, flour of maize, beer of maize, flour of rye, rolled oats, flour of millet, beer of millet, flour of sorghum, beer of sorghum, flour of buckwheat, flour of fonio, flour of triticale, flour of mixed grain, flour of cereals not elsewhere specified, infant food, wafers, breakfast cereals, cereal preparations, flour of potatoes, frozen potatoes, tapioca of potatoes, flour of cassava, tapioca of cassava, dried cassava, flour of other roots and tubers, dried other roots and tubers, cane sugar, beet sugar, non-centrifugal sugar, molasses, maple sugar and syrups, sugar and syrups not elsewhere specified, juice of tomatoes, paste of tomatoes, peeled tomatoes, frozen sweet corn, prepared sweet corn, dried mushrooms, canned mushrooms, juice of vegetables, dehydrated vegetables, vegetables in vinegar, preserved vegetables not elsewhere specified, frozen vegetables, orange juice, tangarine juice, lemon juice, concentrated lemon juice, grapefruit juice, concentrated grapefruit juice, other juice of citrus fruit, concentrated juice of other citrus fruit, cider, apple juice, concentrated apple juice, dried apricots, dried plums, plum juice, raisins, grape juice, must of grape, wine, vermouths, marc of grape, dried figs, juice of mangos, mango pulp, canned pineapples, pineapple juice, dried other tropical fruits, other dried

fruits, other fruit juice, other prepared fruits, flour of fruits, pulp for feed, roasted coffee, coffee substitutes, cocoa paste, cocoa husks and shells, cocoa butter.

Oilseed cakes
Cake of copra, cake of palm kernel, cake of sunflower seed, cake of rapeseed, cake of safflower seed, cake of sesame seed, cake of mustard seed, cake of poppy seed, cake of kapok, cake of cottonseed, cake of linseed, cake of hempseed, cake of other oilseeds.

Grain brans
Bran of wheat, bran of rice, bran of barley, bran of maize, bran of rye, bran of oats, bran of millet, bran of sorghum, bran of buckwheat, bran of fonio, bran of triticale, bran of mixed grain, bran of other cereals.

Novel Protein Foods
Since products in this aggregate are, by definition, new, there are no existing products that could be taken to represent these products. Therefore, some preliminary information on the production process that is forthcoming in the PROFETAS project was used to represent the transformation from pulses to NPF products.

Industrial products
All processed products not elsewhere specified.

Industrial services
All services rendered in an economy

Agricultural services
Non-rival services such as landscape preservation.

Regions

Lowinc
Angola, Bangladesh, Benin, Bhutan, Botswana, Burkina Faso, Burundi, Cambodia, Cameroon, Cape Verde, Central African Republic, Chad, China, Comoros, Congo, Dem,Rep., Cote d'Ivoire, Eritrea, Ethiopia, Fiji, Gambia, Ghana, Guinea, Guinea-Bissau, India, Indonesia, Kenya, Kiribati, Korea, Rep., Lao, Lesotho, Madagascar, Malawi, Malaysia, Maldives, Mali, Mauritania, Mauritius, Mongolia, Mozambique, Namibia, Nepal, Niger, Nigeria, Pakistan, Papua New Guinea, Philippines, Samoa, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Solomon Islands, South Africa, Sri Lanka, Sudan, Swaziland, Tanzania, Thailand, Togo, Tonga, Uganda, Vanuatu, Vietnam, Zambia, Zimbabwe.

Midinc
Albania, Algeria, Antigua and Barbuda, Argentina, Armenia, Azerbaijan, Bahrain, Belarus, Belize, Bolivia, Brazil, Bulgaria, Chile, Colombia, Costa Rica, Croatia, Czech Republic, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, Georgia, Grenada, Guatamala, Guyana, Haiti, Honduras, Hungary, Iran, Jamaica, Jordan, Kazakhstan, Kyrgyz republic, Latvia, Lebanon, Lithuania, Macedonia, Mexico, Moldova, Morocco, Nicaragua, Panama, Paraguay, Peru, Poland, Romania, Russian Federation, Saudi Arabia, Slovak Republic,

St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Syria, Tajikistan, Trinidad and Tobago, Tunesia, Turkey, Turkmenistan, Ukraine, Uruguay, Uzbekistan, Venezuela, Yemen.

Highinc
Australia, Bahamas, Bermuda, Brunei, Canada, Cyprus, French Polynesia, Hong Kong, Iceland, Israel, Japan, Malta, New Zealand, Norway, Singapore, Slovenia, Switzerland, United Arab Emirates, United States.

EU
Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.

Agents
Consumers: Urban, rural.
Producers: Within agriculture, intensively and extensively producing farms. Within non-agriculture, industrial producers, and, finally, we represent stock holdings from one period to the other as production.

6.2 Functional forms

Land production
Initially, in each period, all land is assumed to be grassland. Converting this land to cropland or cityland requires investments in this land, i.e. these two types of land need to be "produced". For both types of land, there is an upper bound on the total acreage that can be converted from grass. This reflects restrictions on soil and climate that prohibit the use of specific types of land as land for crops or city building. For the conversion of land, we assume that there is no flexibility in the choice between inputs per region, i.e. per region, only a single technology is available to convert grassland to cropland and to cityland. Therefore, we use a Leontieff production function:

$$\begin{aligned}
y_{r,crop} &= min_k \; a_{crop,r,k} q_{crop,r,k} \\
y_{r,city} &= min_k \; a_{city,r,k} q_{city,r,k} \\
y_{r,crop} &\leq \bar{y}_{r,crop} \\
y_{r,city} &\leq \bar{y}_{r,city}
\end{aligned}$$

where $y_{r,crop}$, $y_{r,city}$ represent the output of cropland and cityland, respectively, $a_{crop,r,k}$, $a_{city,r,k}$ are the input-output coefficients, $q_{crop,r,k}$, $q_{city,r,k}$ are the inputs necessary to convert the land, and $\bar{y}_{r,crop}$, $\bar{y}_{r,city}$ are the upper bounds on the amount of grassland that can be converted to cropland and cityland, respectively.

Production of roots and tubers, oilcrops, pulses, grains, grass , other agriculture
Since the yield per ha of agricultural products is limited, even under very high input use, the functional form must reflect these characteristic. Therefore, we use a nested production function. At the highest level, we have a Leontieff technology, where the production is limited to be the minimum of the land input times the maximum attainable yield, and the other inputs times their contribution. This implies that production cannot increase indefinitely and that an increase in

other inputs becomes ineffective at some level. However, substitution is possible between the other inputs to changes in relative prices; production can, for example, become more labour intensive. Therefore, at the lower level, we use a CES function. This yields the following functional form:

$$y = min(a_l q_l, a_v v),\text{ where } v = \left(\sum_k (a_k q_k)^{-\rho}\right)^{-1/\rho}.$$

To implement this function, we first use Shephard's lemma do decompose the demand for other inputs in a part with fixed input-output coefficients used in the main program of the Full Format, and update these in the feedback, and next, we use the fixed coefficients of the Leontieff upper part to determine the total demand for v, the composite input, and land (obviously, the coefficient of land input should reflect maximum attainable yield per ha). Therefore, in the main program of the Full Format, we include the relations:

$q_l = 1/a_l * y$

$v = 1/a_v * y$

$q_k = 1/a_q * y$, where we update the coefficient in the feedback as $1/\hat{a}_{cap,r,k} = 1/\hat{a}^0_{cap,r,k} \left(p_{r,cap}/p_{r,k}\right)^{\sigma_{cap,r}}$.

To reflect that substitution between inputs is limited, we allow changes in input-output coefficients only within a band width of 50% of the base coefficient.

We distinguish two types of production: monocultures, where crop yield is high, capital intensity is high, and there are little or no agricultural services as joint output, and extensive production, which is more labour intensive, has lower yields per ha, but does have agricultural services as joint output.

Production of ruminants and monogastrics

In the model, the production of ruminants and monogastrics is basically modelled as though they were crops. This implies that also here, there is an upper bound to the "yield per ha" that can be achieved, as even intensive livestock breeding has some maximum to the number of animals per ha. As was the case in crop production, also here a distinction is made between high intensity livestock farming, with a high input of feed, and a high yield in terms of tons of meat per ha, but with no agricultural services as joint output, and extensive farming, with lower yields, less feed and more grass as inputs, and joint output of agricultural services.

The determination of feed demand is described in section 2 of the paper. The functional form used to represent the production of livestock again uses a Leontieff production function at the highest level, indicating the feed intake cannot be substituted for by increasing the input of other production factors, while at the lower level, a CES function describes the substitution possibilities between these other production factors.

Production of agricultural services

Agricultural services are assumed to be a joint output of the production of ruminants, monogastrics, other agricultural products, peas and grass. For intensive livestock production, the joint output will be zero; for extensive livestock farming, it will be positive. The same holds for intensive versus extensive crop production (monocultures versus more mixed crop agriculture).

Production of meat products, novel protein products, industrial products, industrial services

All these products are produced using a CES function. Using Shephard's Lemma, the CES function is implemented through the updating of given input-output coefficients in response to changing relative prices: $\hat{a}_{cap,r,k} = \hat{a}^{0}_{cap,r,k}\left(p_{r,cap} / p_{r,k}\right)^{\sigma_{cap,r}}$, where $\hat{a}_{cap,r,k}$ is the updated input-output coefficient (note that this is input demand!), $\hat{a}^{0}_{cap,r,k}$ is the base input-output coefficient, and $\sigma_{cap,r}$ is the elasticity of substitution. The updating of the coefficient is done in the feedback of the Full Format; in the main program, these coefficients are taken as given. To reflect that the possibilities for substitution between inputs is limited, there is a cone of substitution that restricts the value of the input-output coefficients to remain lower than 150% of the base value, and higher than 50% of the base value.

Production of oils and fats, oilseed cakes, other agricultural products, grain brans
These products are joint outputs of oilcrops (oils and fats, and oilseed cakes), and grains (other agricultural products, and grain brans). Other agricultural products can also be made from other agriculture. The reason for explicitly modelling the production of these products as joint outputs is that feed components often are produced as byproducts, and this implies that the demand for feed is not the only driving force behind the production of the crops that also deliver the feed components. For example, in case of grain brans, probably the main driving force is the consumer demand for flour, and the brans are then fed to animals, complemented with other feed components to satisfy their dietary requirements. Since we consider the ratios of oils/oilseeds, and brans/grains to be given, we use a Leontieff technology to represent the relation between the two outputs and the input, but allow substitution between other production factors that are necessary in the production of the products through a CES function. Therefore, we follow the approach taken in the production of roots and tubers, grains, grass etc., and represent the jointness of the production as indicated in section 2.1.

Utility
For the representation of consumer preferences, we use a CES utility function. However, since substitution between meat and NPFs is one of the most important aspects that the model must be able to represent, we nest the choice between meat and NPFs. This leads to the following utility function:

$$U_i = \left[(a_i x_i)^{\rho} + (a_g x_g)^{\rho} + ((a_{m,i,v} m_{i,v})^{\rho_p} + ((a_{m,i,m} m_{i,m})^{\rho_m})^{\rho/\rho_m}\right]^{1/\rho}$$

Of course, this function will differ between lifestyles.

6.3 Aggregation of GTAP Version 5

Commodities

Cereals: paddy rice, wheat, cereal grains
Oilseeds
Sugar: sugar crops, sugar
Other crops: plant-based fibres, other crops
Vegetables, fruits and nuts
Raw milk
Cattle: bovine cattle, sheep, goats & horses

Other animal products
Fishing
Vegetable oils and fats
Novel protein food (newly introduced)
Dairy products
Red meat: bovine cattle, sheep & goat meat products
Other meat
Other agriculture & food processing:
wool, silkworm cocoons, processed rice, beverages and tobacco products, food products
Chemicals
Machinery:
motor vehicles & parts, transport equipment, electronic equipment, machinery & equipment
Manufactures: forestry, coal, oil, gas, other minerals, textiles, wearing apparel, leather products, wool products, paper products, publishing, petroleum, coal products, other mineral products, ferrous metals, other metals, metal products, other manufactures,
Services: electricity, gas manufacture, distribution, water, construction, trade, transport, communication, financial services, insurance, business recreational services, public administration and defence, education, health, dwellings

Regions

The Netherlands (NL)
Germany (DEU)
France (FRA)
Great Britain (UK)
Spain (ESP)
Italy (ITA)

Rest of EU (REU); Austria, Belgium, Denmark, Greece, Finland, Ireland, Luxembourg, Portugal, Sweden

Central and Eastern Europe EU associates (RCCE): Hungary, Poland, Rest of CEECs
High-income countries (HIGH): Australia, New Zealand, Taiwan, Singapore, Japan, Korea, Switzerland, rest of EFTA,

NAFTA (NAFTA): USA, Canada, Mexico

Food neutral countries (FNC): China, Indonesia, Malaysia, Thailand, Colombia, Venezuela, Rest of Andean Pact, Argentina, Uruguay, Brazil, Chile, rest of South America, Former Soviet Union, Turkey, Morocco, rest of Middle East, rest of North Africa, rest of SACU

Food insecure countries (FIC): Peru, Central American and Caribbean, India, Sri Lanka, Vietnam, Bangladesh, Philippines, rest of South Asia, Botswana, Malawi, Mozambique, Tanzania, Zambia, Zimbabwe, other Southern Africa, Uganda, rest of Sub-Saharan Africa, rest of the World