Getting the best of both worlds?
Linking CAPRI and GTAP for an economywide assessment of agriculture

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Abstract

Many current research questions in economics span issues from the very small and detailed to the very large and abstract, or require the interdisciplinary study of relations between fields that are causally widely separated and generally not studied together: Such questions stress, in the absence of "The Great Model For Everything", the trade-off between generality and depth, i.e. between covering many aspects of the system studied and details of certain interesting components. This dilemma may be resolved by linking specialized models to exploit their different strengths. This paper develops a link between the general equilibrium model GTAP (offering an economywide perspective) and the partial agricultural model CAPRI (offering a detailed model of the agricultural production and policies).

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1 Introduction

Many of the most interesting current research questions in economics span issues from the very small and detailed to the very large and abstract, or require the interdisciplinary study of relations between fields that are causally wide separated and generally not studied together: What are the implications of general trade liberalization on the physical environment in certain rural regions? Or what do regional differences in policy implementation imply at the global level? Such questions stress, in the absence of “The Great Model For Everything”, the trade-off between generality and depth, i.e. between covering many aspects of the system studied and details of certain interesting components. This dilemma may be resolved by linking specialized models to exploit their different strengths. This paper develops a link between the general equilibrium model GTAP (offering an economywide perspective) and the partial agricultural model CAPRI (offering a detailed model of the agricultural production and policies). [1]

The *ultimate* link would be to *include* CAPRI inside GTAP and solve them simultaneously. This is practically impossible: the two models are implemented in different software packages, in different forms (dual vs. primal) and also require advanced numerical techniques to solve already as stand-alone applications. Instead of a simultaneous solution, an iterative recalibration solution for the linked system was opted for, similar to that which links the CAPRI supply and demand modules (Britz, ed. 2005). Grant, Hertel and Rutherford (GHR) (2006) follow that approach to link a special trade model that includes tariff rate quotas to GTAP, and Böhringer and Rutherford (2006) iteratively link a partial energy model to a CGE model.

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In the case of CAPRI-GTAP, the situation is complicated by the complexity of the partial model, which has not been tailored for this link but rather has a long development history of its own (the development of CAPRI started in 1994 and has continued since). There is also a considerable overlap in terms of results, especially regarding world trade and demand. Jansson et al. (2008) linked CAPRI to an econometric macro model, but failed to obtain a fully consistent solution for all variables. We improve on their approach in terms of consistency.

Our linking approach relies on using the variables and equations of the models as they are, introducing the link by shocking parameters already present in the models. This is similar to Jansson et al. (2008) but contrasts with for example GHR, which replace the original GTAP equations by iso-elastic approximations in the form of supply functions. By maintaining the original model equations, maintenance of the core models is greatly facilitated, and the links can be adopted for other versions of CAPRI and GTAP with less effort. In addition, auxiliary facilities like data exploration tools and the welfare computations in GTAP will keep functioning as in the stand alone applications.

We aim to illustrate the potential of the linked system by analysing a multilateral trade reform, where results are computed for regional nitrate surpluses and agricultural incomes in the EU as well as welfare effects for the world. The results will indicate the interdependence between regional and global economies and regional physical impacts. This level of analysis is not possible with either model by itself. We firmly believe that this kind of analysis will be increasingly important to address future research questions.

The remainder of this paper is organized as follows. We first describe the theoretical background of our linking procedure. Section 3 describes the linked system and the modifications made to CAPRI and GTAP in order to implement the linking. Section 4 shortly describes the database and aggregations used for the linking. (To illustrate the potential of the linked system of models Section 5 describes the results of a simple trade liberalization scenario in terms of both economic and environmental indicators). The last section concludes.

2 A formal treatment of the linking of models

There are many research projects that attempt to link models in different manners. The subject of the current study is the link from low to high level of disaggregation in terms of spatial and product resolution. It is thus conceptually similar to e.g. Jensen et al. (2002) and Helming et al. (2006) that link a partial to a general equilibrium model. Other possibilities include the linking of physical to economic models, or the horizontal linking of models of similar level of aggregation (e.g. in Fischer et al. 1988, Chantreuil et al 2005). The work by Fischer et al. comprises a proof that the linked system has a solution. To their aid, the authors make use of a fixed-point theorem. The other publications referred to above contain no or little general and formal treatment of the linking problem. The purpose of this section is to describe the linking problem in general terms, in order to identify the elements involved and the conditions for obtaining a consistent solution.

2.1 A general approach to linking GE and PE models

In principle, the ideal case of a joint solution of a GE and PE is no different from the solution of a single extended GE. Assuming that the original GE is given in reduced form and the PE as a constrained optimization problem, the extended GE is constructed by merging the original GE equations with the Kuhn-Tucker conditions of the PE. Some of the previously exogenous items (the parameters) of the GE and the PE become endogenous in the new equation system, and new functions are added that map GE variables to PE parameters and vice versa. The problem is thus similar to e.g. the construction of a price equilibrium model by merging microeconomic supply and demand models, where the parameters that are fixed in the individual models (e.g. consumer budget in the consumer model) become endogenous in the linked system, and new equations (e.g. income accounting) are added to the linked system. In practice, it may be difficult to obtain a perfect integration of the models, due to technical as well as theoretical reasons, and special solution methods may be required in order to find an equilibrium solution.

Consider the following simplified case, with one GE linked with one PE model. Let y and α denote the vector of variables (endogenous) and parameters (exogenous) respectively in the GE, and denote an optimal solution to the GE by the equation system $f(y;\alpha) = 0$, where f is a vector of functions of the same length as y. Similarly for the PE, denote the vector of variables by z, the parameters by β, and the vector of equilibrium conditions[2] by $g(z;\beta) = 0$.

Endogenous results of the GE are mapped to parameters of the PE by the vector valued function Γ, or, with B the set of all possible parameter vectors of the PE and Y the set of all possible solutions (the solution space) to the GE, Γ: Y $\rightarrow$ B. The endogenous results of the PE, which was assumed to be more disaggregated than the GE, are aggregated to the level of the GE by the function h. If the sub-vector of the variables y of the GE that correspond to aggregated results of the partial model is denoted by subscript p (for "partial") and the rest of y is subscripted by n (for "not partial"), we have that $y = (y_n, y_p)$. With Z denoting the solution space of the PE, we write h: Z $\rightarrow$ Y_p.

If the model chain is solved optimally, then the PE returns exactly the same solution as the GE model when aggregated to the appropriate level, and we may write the following optimality condition for the linked system:

$$y_p = h(z). \tag{1}$$

Consider a "partial closure" of the GE that is obtained by fixing y_n and dropping a corresponding number of equations, so that only y_p is endogenous in the sub-vector of

[2] For the moment, we ignore explicit representation of inequality constraints and complementary slackness conditions.

functions f_p (and denote the dropped equations by f_n, so $f = (f_n,f_p)$). Then the smaller model defined by

$$f_p(y_p;y_n,\alpha) = 0 \qquad (2)$$

is an approximation to the partial model g. In order for the condition (1) to hold, the parameters of (2) generally need to be changed. That parameter change is at the core of the iterative recalibration algorithm, and we refer to it here as "to shift the functions".

In shifting the functions, it is not desirable to change the fixed sectors (the values of elements of y_n), since the partial model does not (by definition of "partial") deliver any information about the behaviour of those sectors. Thus, we want to split also the parameter vector α in two parts, where one part is specific to the sub-vector of functions f_p (the partial closure of the macro model). This is always technically possible (but potentially economically meaningless or worse[3]), by introducing an additional parameter vector δ of the same dimension as y_p such that the new system of equations is $f_p(y_p - \delta;y_n,\alpha) = 0$. Note that assigning to δ any other value than the null vector is likely to violate the equations of the full GE, and thus constitute a shock to it. Denote the extended parameter vector (δ,α) by γ, and denote the shifting operation that maps y_n,y_p and α into δ by

$$\Phi(y_n,y_p;\alpha) = \{\delta\colon f_p(y_p - \delta;y_n,\alpha) = 0\}. \qquad (3)$$

When the models are linked, the parameter vectors δ and β become endogenous to the model system, and we then seek a joint optimal solution in terms of (y,z,δ,β) to both models characterized by

$$f(y_n,y_p,\delta;\alpha) = 0$$
$$\Phi(y_n,y_p;\alpha) = \delta$$

[3] Take for example a general equilibrium (GE) model linked to a partial model of demand for a specific kind of goods. If the parameters of the demand system of the GE model contains fixed budget shares, those share parameter become meaningless, or at least not shares anymore, by the introduction of a demand shift term δ as shown above.

$$h(z) = y_p \quad (4)$$

$$g(z,\beta) = 0$$

$$\Gamma(y) = \beta.$$

By shifting the equations f_p, the macro model is adjusted to approximate the partial model in the point y_p. There are several alternative methods of making that approximation. For example, the equations f_p can be removed and replaced by a new set of equations that are simpler to shift and provide a better approximation to the partial model. Examples include point approximations by constants, first and second order approximations. Almost trivial is the point approximation obtained by replacing f_p by a vector of constants, i.e. $\delta - y_p = 0$, where δ is given by the solution of the partial model $h(z)$, i.e. $\Phi(y_n,z;\alpha) = \{\delta: \delta = h(z)\}$. In other words, dropping f_p from the system f and fixing y_p to $h(z)$. Such a simple approximation may, however, lead to convergence problems in the iterative solution algorithm, as we will show below. Using f_p that is a first or second order approximation to the PE can improve convergence tremendously, but is not further discussed here.

2.2 Baseline calibration

Another challenge in linking models is to obtain a joint baseline. The models may rely on different data sources, use different units of measurement and contain slightly different assumptions (e.g. functional forms). The task of the joint baseline calibration is essentially to choose parameters[4] of the mapping Γ and the aggregation function h so that if no exogenous shock is introduced, the stand-alone models give precisely the same result as the linked system. We distinguish two approaches, which we term “differential” and “harmonizing”.

The differential baseline calibration approach implies calibrating the function h and the mapping Γ so that for the "standard" parameter sets α^* and β^*, it holds that

[4] In the exposition here, the parameters of Γ and h are omitted in order to reduce the number of symbols in use, and because they are not our primary concern.

$\Gamma(y^*) = \beta^*$

$h(z^*) = y_p^*$

where y* is the solution of the macro model parameterized by α^*, i.e. the vector that solves $f(y^*;\alpha^*) = 0$, and z* similarly solves $f(z^*;\beta^*) = 0$. In ordinary language, this implies freezing any differences between overlapping variables of the models in the baseline, and keeping them constant in consequent simulations.

The harmonizing baseline calibration approach implies adjusting one or both models so that they give fully consistent results in the baseline, both as stand-alone applications and as a linked system. Example: Given that the PE results z^* are to be respected by the GE in the baseline, we may compute (y_n,α,δ) such that $f(y_n,h(z^*),\delta,\alpha) = 0$, while keeping the variables *yn* that are still free "close" to the original forecast, i.e., for some metric F that measures the deviation of y_n from y_n^*, solving

$$\min_{y_n,\alpha|y_p^*} F\left(y_n, y_n^*\right)$$

$$\text{subject to} \quad f(y_n,y_p,\alpha) = 0$$

$$y_p = h(z^*)$$

2.3 Iterative solution and some potential problems

For technical reasons, the system (4) generally cannot be solved simultaneously. The models *f* and *g* are potentially implemented in different software, and the parameters δ, α and β are exogenous each time a model is solved. Instead of a simultaneous solution, the system can be solved iteratively. In its simplest form, an iterative solution algorithm involves the following steps:

Step 0: Set $i := 1$, $y^0 = y^*$, $z^0 = z^*$ (stars indicating calibrated baseline values)

Step 1: Compute $\delta_i = \Phi(y_n^i, h(z^i{-}1), \alpha)$

Step 2: Solve $f(y^i,\delta,\alpha) = 0$ with respect to y^i given (δ,α)

Step 3: Compute $\beta = \Gamma(y^i)$

Step 4: Solve $g(z^i;\beta) = 0$ with respect to z_i given β.

Step 5: Using some metric d, compute DEV = $d(z^i,z^i{-}1)$. IF DEV < tolerance, THEN terminate, ELSE set $i := i + 1$ and go to step 1.

This simple algorithm need not converge even though a solution exists (which is assumed to be the case).

One case when it may diverge is when f_p are dropped and y_p fixed to $h(z)$ as discussed above. In that case, the familiar divergent cobweb model can result, as illustrated in figure 1. The simple macro model in the figure contains only the demand schedule D and a market balance, and is solved for market clearing price at an exogenous supply quantity q, or $D(p) = q$. The supply quantity q is the result of the iteratively linked partial model, represented in the figure by the supply schedule S. Let p^0 be an initial price that enters the partial model, resulting in quantity q^0. That quantity in turns enters as fixed supply into the macro model, which is solved for price p^1, and so on. In the case shown by the figure, the model system will not converge, even though a unique equilibrium obviously exists. The black dots show the sequence of solutions to the macro model, and the dashed line shows the iterative solution path. One can see that the system will converge only if the slope of the supply schedule is greater than the (negative of the) slope of the demand schedule.

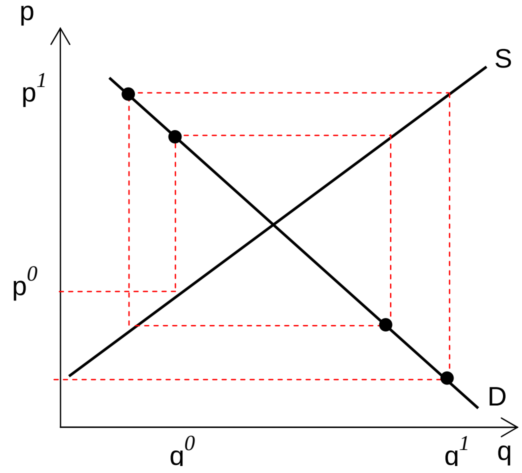

Figure 1. Cobweb with diversion. Demand schedule d symbolizes the macro model, supply schedule s the partial model, and the dashed line the iterative solution path.

In figure 1, the partial model was approximated inside the macro model by a constant supply, iteratively adjusted to the result of the true partial model. Those implicit vertical supply schedules were left out in the figure for clarity. There are better approximations than vertical lines. In figure 2, the partial model is iteratively approximated by a line *R* with finite positive slope *(dotted line)*, and this line is iteratively shifted to account for the last outcome of the partial model. The macro model now consists of $D(p)$, $R(p)$ and the market clearing condition $D(p) = R(p)$. Solid dots denote solutions to the macro model and empty dots solutions of the partial model.

Again, let p^0 be the initial price, inserted into the partial model *S* and resulting in the quantity $q^0 = S(p^0)$. The linear approximation R is shifted to run through the point (q^0,p^0) by re-computing the intercept of R. The operation of re-computing the intercept is the implementation of the function Φ previously mentioned. The macro model $D(p) = R(p)$ is solved, and the resulting equilibrium price p^1 is submitted to the partial model to start a new iteration. The reader can verify that the algorithm will converge under a wider range of slopes for *R*, i.e. in the figure the sequences of filled and empty dots will approach a common equilibrium.

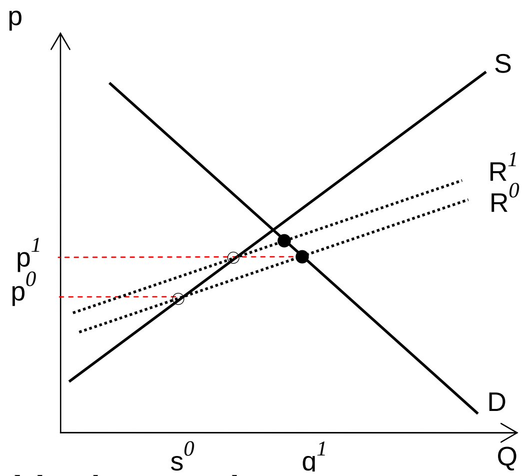

Figure 2. *Cobweb model with iterative linear approximations. Lower case s denotes quantity in the partial model.*

Under some circumstances, the iterating system will not converge even with the linear approximation. That may happen if, in the example above, the demand schedule is close to vertical and/or the slope of the approximation *R* is very big. In such cases, some another or an additional mechanism is required in order to find the equilibrium. One such mechanism is to work with partial adjustments[5]. If partial adjustment is implemented in the partial model, then the mapping Γ computing the parameter β (= p) is not, as in the figures above, just $p^i = p^{i-1}$ (as was the case in both the previous examples), but $p^i = \sum_{j=1}^{i-1} a_j p^{i-j}$, where a_j are weights that sum to one. For example, choosing $a_1 = 0.5$, $a_2 = 0.5$ and all other $a_j = 0$ implies taking the simple average of the last two iterations. The reader may try this on the cobweb model in figure 1, and will find that the system in that case would converge very quickly.

Both convergence methods—the iterative approximations and the partial adjustments—may be used simultaneously, and are then capable of handling a great range of possible situations.

[5] Partial adjustments in the sense that only a fraction of the current solution of the macro model is going into the new parameters of the partial model. Alternatively, this could be expressed as a "lagged expectation" in the partial model, though that term is loaded with too much economic content and suggests a misleading interpretation of iterations as "time".

3 Implementing a link between CAPRI and GTAP

Linking the models unfortunately requires as much (or perhaps more) software development as economic theory. Albeit the focus here is on content and not on form, some words have to be spent on the technical realization. From a software point of view, the point of departure is that the models are implemented in different software packages (GAMS and GEMPACK in our case), so that they cannot communicate directly with one another. A prerequisite, though, is that both models can be executed from a command prompt. This allows the design of a program that steers the GE and PE models and determines convergence. We first provide a general outline of the way in which we link CAPRI and GTAP. We then describe in more detail the changes made to CAPRI and GTAP to implement the link.

3.1 General description of the linked system

The linkage between CAPRI and GTAP is illustrated in figure 3. In the figure, shaded boxes denote computer programs (models), and rhomboids denote data sets. Starting by solving GTAP (bottom left), we particularly solve for the price vector *W* containing prices of agricultural intermediate inputs, capital and labour, and the vector *M* of consumer expenditures per country (aggregate). Those data are written to the dataset *DG*.

Next, CAPRI is solved, using W and M as exogenous variables (parameters). CAPRI computes for the aggregate agricultural sector price indices of output P per region, total supply S, demand D disaggregated into human consumption, processing consumption and intermediate demand by agriculture itself, and trade flows T. This is written to the dataset DP.

Finally, the program SHIFT computes shocks for GTAP. If we, as is common "GTAP language" use lower case letters to denote percent change relative to a baseline, then the shocks computed by SHIFT are such that, given prices (w,p) the agricultural sector would produce s, demand for agricultural goods would equal d and agricultural trade flows are t. That is we shock the agricultural producers of GTAP so that they, in a partial setting, would replicate the outcome of CAPRI, and similar for consumption and trade of agricultural goods. The program SHIFT essentially implements the equation system (3) by solving a partial closure of GTAP, but instead of simple shifters δ, we solve for shock parameters of the standard GTAP (see details below).

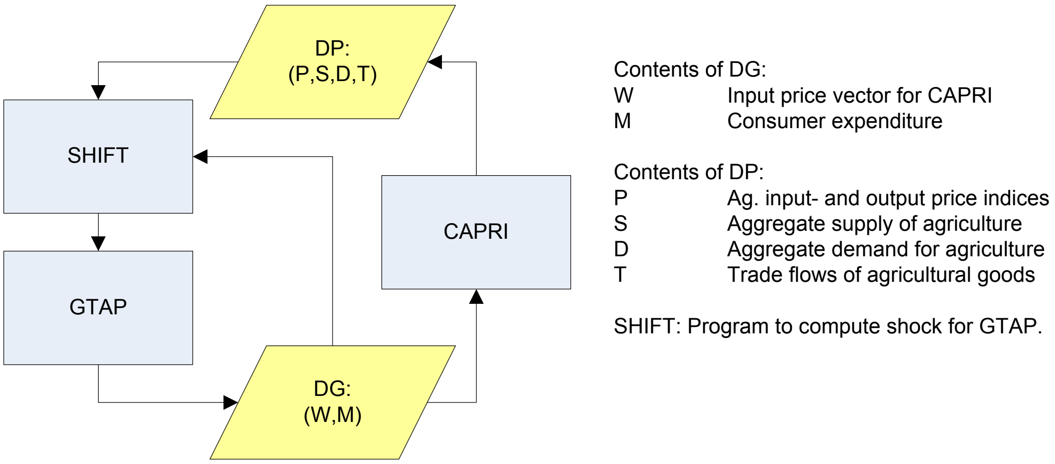

Fig. 3. Flow of information in the linked system

The solution algorithm outlined above is an instance of "sequential recalibration", similar to the implementations in GHR, Böhringer and Rutherford (2006) and Britz (ed. 2005). It works by iteratively recalibrating the behavioural functions of the three agent's agricultural producers, consumers and traders, and obtains this by shocking the parameters of the standard GTAP model. The approach thus on the on hand requires no modification of GTAP, but on the other hand requires the additional program SHIFT.

3.2 Adjustments to CAPRI

For CAPRI, the required modifications, though theoretically simpler, implies more technical overhead, since firstly they involve changes to parameters that are otherwise not used as scenario variables, and secondly because CAPRI implements all code for steering the model chain, like conversions between data files of GEMPACK (HAR-files) and GAMS (GDX-files), and determines convergence.

A specific adaptation of CAPRI that was made for the link with GTAP was the introduction of *quasi-input-coefficients* for labour (skilled and unskilled) and capital. CAPRI works by maximisation of modified gross value added (MGVA), which is revenues plus subsidies minus variable costs, thus excluding payments to labour and capital. CAPRI is calibrated using a method related to positive mathematical programming (Howitt 1995, see Jansson 2007 for implementation in CAPRI), where a behavioural term is added that covers all economic and physical influences not explicitly captured in the model. For the link with GTAP, an algorithm was added that designates a part of that behavioural term as costs for labour and capital, and consequently shifts the term in proportion to price changes for labour and capital in GTAP.

The coefficients for labour and capital use per production activity in CAPRI were obtained from GTAP database version 6.2, with agriculture disaggregated and for regions similar to CAPRI member states, by multiplying the cost shares for labour and capital in GTAP with the marginal revenues in CAPRI. The resulting coefficients were treated as Leontief input coefficients in CAPRI, and consequently. The remaining part of the behavioural term in CAPRI can not be assigned to any specific production factor, and this poses a potential consistency problem in the link with GTAP.

In addition to prices for labour and capital, the following exogenous items in CAPRI were shocked by the results of GTAP: Consumer expenditure, Consumer price index of all non-agricultural commodities, Prices of traded variable inputs not produced by agriculture and price of service inputs.

3.3 Adjustments to GTAP

As stated earlier, our approach to linking focuses on translating the results from CAPRI into shocks for GTAP without adjusting the structure of GTAP itself. This allows us to utilize the welfare decomposition and other reporting tools of GTAP straight away. A key benefit of this approach is that we can easily track contribution of the link to CAPRI to the total (welfare) changes in the GTAP model. Another benefit of this approach is that the linking procedure can be transferred to different versions of the GTAP model. We develop the link using the standard GTAP model (Version 6.2a of May 2007) available from the GTAP website. Apart from the advantage of the using a less elaborate model during development, our research interests focus on agriculture which is modelled in detail through CAPRI and therefore does not require more elaborate modelling in GTAP.

We maintain the GTAP model 'as is' in our modelling exercise. The challenge regarding the linking of GTAP is in developing the SHIFT program in figure 3. Although we aim at shocking consumption and trade for a consistent link at a later stage, for now we focus on agricultural production. In our linked system CAPRI models in detail the agricultural sector while GTAP accounts for the rest of the economy, capitalizing on the different strengths of each model. In the GTAP model there is a single agricultural sector which represents the aggregate result of the CAPRI model[6]. To incorporate the results from CAPRI we need to shift the parameters in the production function for this agricultural sector which is done by SHIFT program.

The aim of the SHIFT program is to change the technical shifters in the GTAP model such that the behaviour of CAPRI is replicated by the agricultural sector in GTAP. Figure 4 provides a schematic description of the production structure of GTAP (taken from the GTAP TABLO code) and the production structure used for the SHIFT program. Since we focus on the agricultural sector the SHIFT program is reduced to a model of the agricultural sector. For now we ignore the results on trade flows from CAPRI. The sector model in the SHIFT program is thus limited to the use of endowments (*qfe*) through a value-added aggregate (*qva*) and the use of intermediate inputs (*qf*) to produce output (*qo*).

[6] In fact not all 20 agriculture-related sectors in GTAP are aggregated to a single agricultural sector. The actual aggregation is based on a mapping of CAPRI to GTAP sectors. For more detail see section 4.

Since the GTAP model is formulated in linearized form the parameters of the different CES functions that determine the production (α in the terminology section 2) are not explicit in the equations but can be adjusted through the technical shifters. The added benefit of the use of the technical shifters is that we can trace the shifts induced by the CAPRI model and separate these from the parameters derived from the GTAP database. The aim of the SHIFT program is then to determine the technical shifters determining the allocation between value-added and intermediate inputs (*ava*(*j*,*r*)), among intermediate inputs (*af*(*i*,*j*,*r*)) and among endowments (*afe*(*i*,*j*,*r*)) such that the results of the CAPRI model are replicated.

In order to determine these technical shifters we need five equations (figure 5). By replacing the set of produced commodities (prod_comm) with the agricultural sector (agri_comm) we can directly copy these equations from the GTAP model. The technical shifters are then computed from changes in quantities and price by a closure in which the technical shifters are endogenous and the quantities and prices are exogenous (figure 6).

When implementing this closure a singularity problem occurs since the technical shifter for the value-added nest (*ava*(*j*,*r*)) is dependent on the technical shifters in lower nest of endowments (*afe*(*i*,*j*,*r*)). It is indeed a property of all CES functions that all the “share parameters” can be multiplied by a uniform factor *t* and the parameter in front of the CES function by another factor that is a function of *t* in such a way that the resulting function is identical to the original function. the case for all CES function. In other words, a given shock in the value of value-added can be generated by an infinitely many combinations of shocks to *ava* and *afe*, and we need to swap one of the shifters with another variable in order to obtain a specific solution. In the case of CAPRI we have limited information on changes in labour and capital. We therefore solved the singularity by fixing the technical shifter of capital (alternatively we could have used labour) and endogenizing the use of capital (capital is the only element of the set flex_endw used in the closure file).

On the one hand, endogenising capital use in SHIFT poses a potential inconsistency, since capital input is treated as fixed (coefficient) in CAPRI in the current implementation. On the other hand, we need to ensure satisfaction of the zero profit conditions, and since CAPRI contains a behavioural term that does not add income to any agent in GTAP, we chose to adjust capital and interpret any change in capital use in GTAP as directly corresponding to the change in the value of the behavioural term in CAPRI.

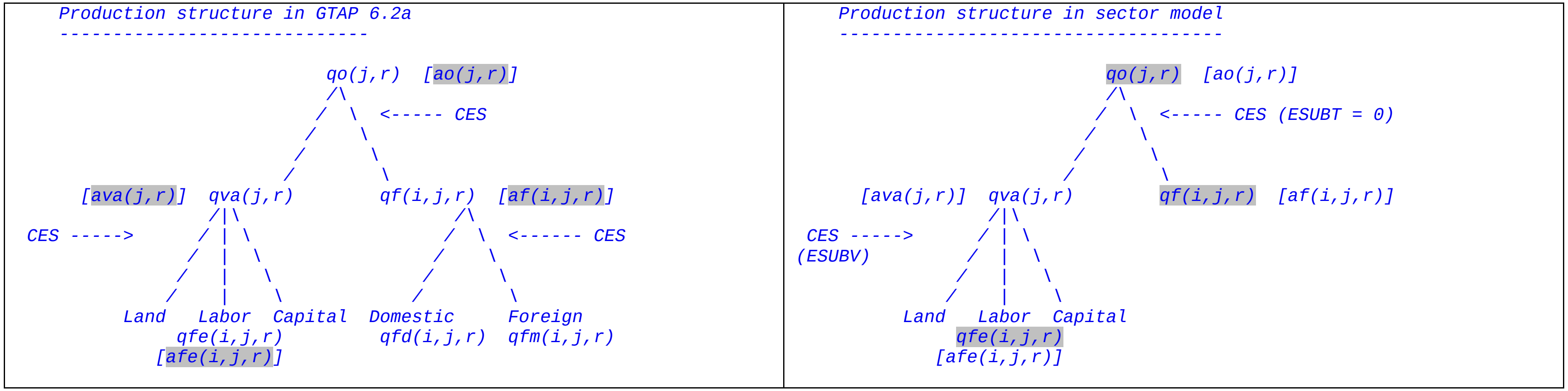

Fig. 4. Structure of the production function in GTAP (left pane) and of agricultural production in the SHIFT program (right pane).

Note: variables in grey are exogenous, for example ava(j,r) is exogenous in GTAP but endogenous in the SHIFT program.

```
!< -----------------------------------------------------------------------
    EQUATIONS
   -----------------------------------------------------------------------  >!

! Determine ava(j,r) to replicate share of value-added and intermediates!
Equation ZEROPROFITS
# industry zero pure profits condition (HT 6) #
(all,j,AGRI_COMM)(all,r,REG)
    ps(j,r) + ao(j,r)
        = sum(i,ENDW_COMM, STC(i,j,r) * [pfe(i,j,r) - afe(i,j,r) - ava(j,r)])
        + sum(i,TRAD_COMM, STC(i,j,r) * [pf(i,j,r)  - af(i,j,r)])
        + profitslack(j,r);

! Determine pva!
Equation VAPRICE
# effective price of primary factor composite in each sector/region (HT 33) #
(all,j,AGRI_COMM)(all,r,REG)
    pva(j,r) = sum(k,ENDW_COMM, SVA(k,j,r) * [pfe(k,j,r) - afe(k,j,r)]);

! Determine qva!
Equation VADEMAND
# sector demands for primary factor composite #
(all,j,AGRI_COMM)(all,r,REG)
    qva(j,r)
        = -ava(j,r) + qo(j,r) - ao(j,r)
        - ESUBT(j) * [pva(j,r) - ava(j,r) - ps(j,r) - ao(j,r)];

! Determine shift in afe(i,j,r) to replicate use of primary factors!
Equation ENDWDEMAND
# demands for endowment commodities (HT 34) #
(all,i,ENDW_COMM)(all,j,AGRI_COMM)(all,r,REG)
    qfe(i,j,r)
        = - afe(i,j,r) + qva(j,r)
        - ESUBVA(j) * [pfe(i,j,r) - afe(i,j,r) - pva(j,r)];

! Determine shift in af(i,j,r) to replicate use of intermediate inputs!
Equation INTDEMAND
# industry demands for intermediate inputs, including cgds #
(all,i,TRAD_COMM)(all,j,AGRI_COMM)(all,r,REG)
    qf(i,j,r)
        = - af(i,j,r) + qo(j,r) - ao(j,r)
        - ESUBT(j) * [pf(i,j,r) - af(i,j,r) - ps(j,r) - ao(j,r)];
```

Fig. 5. Equations in the SHIFT program

```
!   Initial run for SECTOR model:
!   *   shocks come from GTAP model simulation
!   *   ava, af and afe should be zero

!   base data
!   ---------
file gtapsets = ..\data\sets.har;
file gtapparm = ..\data\default.prm;
file gtapdata = ..\data\BaseData.har;
file extrasets = ..\data\Xsets.har;

!   Extra sets
!   -------
Xset flex_endw (capital);
Xsubset flex_endw is subset of ENDW_COMM;
Xset fix_endw = endw_comm - flex_endw;

!   Closure
!   -------
exogenous
  qo
  ps
  qfe(fix_endw,agri_comm,reg)
  pfe
  qf
  pf
  ao
  afe(flex_endw,AGRI_COMM,REG)
  profitslack
  ;
```

```
endogenous
  ava                                       ! ZEROPROFITS
  qfe(flex_endw,agri_comm,reg)              ! ZEROPROFITS
  pva                                       ! VAPRICE
  qva                                       ! VADEMAND
  afe(fix_endw,AGRI_COMM,REG)               ! ENDWDEMAND
  af                                        ! INTDEMAND
  ;

!   shocks
!   ------
shock qo = file ..\gtap\TMS_10_shocks.har header "QO";
shock ps = file ..\gtap\TMS_10_shocks.har header "PS";
shock qfe(fix_endw,agri_comm,reg) = file ..\gtap\TMS_10_shocks.har header "QFFX";
shock pfe = file ..\gtap\TMS_10_shocks.har header "PFE";
shock qf = file ..\gtap\TMS_10_shocks.har header "QF";
shock pf = file ..\gtap\TMS_10_shocks.har header "PF";
```

Fig. 6. Relevant parts of the initialization file of the SHIFT program

The initial run of the sector model is done with shocks that area generated by GTAP. This allows a consistency check on the code since all technical shifters should be zero when results from GTAP are used. Six pieces of information are needed to run the model (all in percentage changes compared to the GTAP data on which the GTAP model runs[7]): agricultural output (*qo*) and price (*ps*), inputs of endowments (*qfe)* and their price (*pfe)* and intermediate inputs (*qf*) and their price (*pf*). This information is obtained from the CAPRI results and summarizes the aggregate behaviour of the agricultural sector.

4 Database and mapping between CAPRI and GTAP

We implement the GTAP model using the GTAP database Version 7 (pre release 4) with 2004 as its base year. This database contains 106 regions and 57 sectors, of which 20 are related to agriculture. CAPRI offers a detailed depiction of the agricultural sector on regional level in the EU, with around 250 regions and around 50 agricultural primary and secondary products. CAPRI also contains a world-wide trade module, where 18 regional blocks trade bilaterally, using a two-stage Armington differentiation of imports similar to that in GTAP.

To capitalize on the strengths of each model CAPRI models the agricultural sectors through around 50 agricultural products (both primary and processed) in our linked system.

[7] In the initialization run this is the GTAP version 7 database, subsequent runs are done on the updated datafile from the previous iteration.

Since CAPRI has been developed for the European situation it does not include some crops which are part of GTAP. Using the HS classification as a common ground we assess to what extent the CAPRI sectors cover the agricultural sectors in GTAP. We find that for the majority of agricultural sectors there is a good concordance (for 12 sectors at least 84 percent of trade is covered) or for processed goods there is a good concordance in terms of related primary products (like the grains). Only in the case of beverages and tobacco CAPRI covers only malt and none of the other lines. This is a relatively large sector in terms of trade (10%) and it is therefore kepe outside of the agricultural aggregate. Finally, plant-based fibres composes only a small part of international trade (1.86 percent), but cotton forms an important part of the Doha round. Plant-based fibres are therefore also kept outside the aggregate agricultural sector.

The result in terms of concordance would then be that all CAPRI's agricultural sectors map into a single agricultural GTAP sector. Next to this agricultural sector the GTAP model includes beverages and tobacco and plant-based fibres as separate sectors. These sectors have no direct concordance with CAPRI, but may be linked through the use of inputs from or supply of outputs to the agricultural sector.

The discussion on sectors so far has focussed on agriculture. Besides agriculture the GTAP database also contains 37 manufacturing and services sectors. Given our intent to include a large number of regions to facilitate the mapping to CAPRI regions the number of sectors in the GTAP model needs to be restricted as much as possible. In addition there are very limited possibilities for linking non-agricultural intermediate inputs from CAPRI to GTAP sectors due to incompatibilities of definitions. We therefore have no reason for keeping specific non-agricultural sectors separate. We use a grouping in four non-agricultural sectors: natural resource extraction, labour intensive manufacturing, capital intensive manufacturing, and services. This rather coarse grouping does capture key characteristics (reliance on natural resources, factor intensity and tradability) important for the supply response. Table 1 presents the sector aggregation used in the GTAP model.

Table 1: Sector aggregation in the GTAP model

No.	Code	Description	Old sectors
1	Agri	Primary & processed agriculture	Paddy rice; Wheat; Cereal grains nec; Vegetables, fruit, nuts; Oil seeds; Sugar cane, sugar beet; Crops nec; Cattle,sheep,goats,horses; Animal products nec; Raw milk; Wool, silk-worm cocoons; Meat: cattle,sheep,goats,horse; Meat products nec; Vegetable oils and fats; Dairy products; Processed rice; Sugar.
2	PFood	Processed food and beverages	Food products nec; Beverages and tobacco products.
3	Fibers	Cotton and other fibre crops	Plant-based fibers.
4	Extract	Natural resource extraction	Forestry; Fishing; Coal; Oil; Gas; Minerals nec.
5	LabMan	Labor intensive manufacturing	Textiles; Wearing apparel; Leather products; Wood products; Paper products, publishing; Metal products; Motor vehicles and parts; Transport equipment nec.
6	CapMan	Capital intensive manufacturing	Petroleum, coal products; Chemical,rubber,plastic prods; Mineral products nec; Ferrous metals; Metals nec; Electronic equipment; Machinery and equipment nec; Manufactures nec.
7	Svces	Services and activities NES	Electricity; Gas manufacture, distribution; Water; Construction; Trade; Transport nec; Sea transport; Air transport; Communication; Financial services nec; Insurance; Business services nec; Recreation and other services; PubAdmin/Defence/Health/Educat; Dwellings.

The limited number of sectors allows more detail in terms of regions and therefore a close match between the GTAP and CAPRI regions. Using the CAPRI regions as a starting point the closest possible approximation in GTAP regions is made resulting in a regional aggregation with 55 regions (see table 2).

5 Analyzing trade liberalization with the linked system

To assess the value-added of the linked system of CAPRI and GTAP we analyze a simplified trade liberalization scenario consisting of a reduction in tariffs according to a tiered formula described in the Doha draft modalities for agriculture released on February 8, 2008 by the WTO. Comparison with the results from stand-alone versions of the models provides a benchmark to assess the value-added of linking the models. We limit the scenario to agricultural liberalization only to gauge the effect of economywide results provided by GTAP. Since CAPRI is an agricultural sector model it will not account for the impact of liberalization of non-agricultural trade, which would be included in a more realistic Doha scenario. This would however obscure the effects of the just the economywide feedbacks to a change in the agricultural sector.

[results to be inserted

Table 2: Regional aggregation in the GTAP model

No.	Code	Description	Old regions	No.	Code	Description	old regions
1	DE000000	Germany	Germany.	30	REU	Rest of Europe	Switzerland; Rest of Eastern Europe; Rest of Europ
2	SE000000	Sweden	Sweden.	31	RBU	Russia, Belarus and Ukraine	Belarus; Russian Federation; Ukraine.
3	FR000000	France	France.	32	USA	USA	United States of America.
4	IR000000	Ireland	Ireland.	33	CAN	Canada	Canada.
5	DK000000	Denmark	Denmark.	34	MEX	Mexico	Mexico.
6	ES000000	Spain	Spain.	35	VEN	Venezuela	Venezuela.
7	EL000000	Greece	Greece.	36	ARG	Argentina	Argentina.
8	AT000000	Austria	Austria.	37	BRA	Brazil	Brazil.
9	FI000000	Finland	Finland.	38	CHL	Chile	Chile.
10	IT000000	Italy	Italy.	39	URU	Uruguay	Uruguay.
11	UK000000	United Kingdom	United Kingdom.	40	PAR	Paraguay	Paraguay.
12	BL000000	Belgium	Belgium; Luxembourg.	41	BOL	Bolivia	Bolivia.
13	NL000000	Netherlands	Netherlands.	42	RSA	Rest of South America	Colombia; Ecuador; Peru; Rest of Central America
14	PT000000	Portugal	Portugal.	43	IND	India	India.
15	CY000000	Cyprus	Cyprus.	44	CHN	China	China; Hong Kong.
16	CZ000000	Czech Republic	Czech Republic.	45	JAP	Japan	Japan.
17	EE000000	Estonia	Estonia.	46	ANZ	Australia and New Zealand	Australia; New Zealand.
18	HU000000	Hungary	Hungary.	47	MOR	Morocco	Morocco.
19	LT000000	Lithuania	Lithuania.	48	TUN	Tunesia	Tunisia.
20	LV000000	Latvia	Latvia.	49	ALG	Algeria	Rest of North Africa.
21	MT000000	Malta	Malta.	50	EGY	Egypt	Egypt.
22	PL000000	Poland	Poland.	51	TUR	Turkey	Turkey.
23	SI000000	Slovenia	Slovenia.	52	ISR	Israel	Rest of Western Asia.
24	SK000000	Slovak Republic	Slovakia.	53	LDC	LDC	Bangladesh; Rest of South Asia; Rest of Western Africa; Central Africa; South Central Africa; Madagascar; Malawi; Mozambique; Tanzania; Uganda; Zambia; Rest of Eastern Africa.
25	NO000000	Norway	Rest of EFTA.	54	ACP	ACP non LDC	Rest of Oceania; Nigeria; Senegal; Mauritius; Zimbabwe; Botswana; South Africa; Rest of South African Customs .
26	BG000000	Bulgaria	Bulgaria.	55	ROW	Rest of world	Korea; Taiwan; Rest of East Asia; Cambodia; Indonesia; Malaysia; Philippines; Singapore; Thailand; Viet Nam; Rest of Southeast Asia; Pakistan; Sri Lanka; Rest of North America; Rest o South America; Nicaragua; Caribbean; Kazakhstan Kyrgyztan; Rest of Former Soviet Union; Armenia Azerbaijan; Georgia; Iran Islamic Republic of.
27	RO000000	Romania	Romania.				
28	AL000000	Albania	Albania.				
29	HR000000	Croatia	Croatia.				

6 Conclusions

This paper outlines a general approach to linking partial and general equilibrium models to capitalize on the sectoral detail of the partial model and the economywide perspective of the general equilibrium model. This approach is implemented to a link CAPRI (with as its main strength the detailed modelling of the European agricultural sector) and GTAP (with at its main strength its global economywide coverage). The approach outlined in this paper has as its main strengths that it uses the CAPRI and GTAP model as they are used in stand-alone mode and the explicitly tracing the contribution of the link to CAPRI to the GTAP results. Using the models as they are implies that the procedure for linking can be transferred to other (updated) versions of the model with minimal effort. By including the results from CAPRI through technical shifters standard in the GTAP model we can trace the impact of the CAPRI results using the standard decomposition tools available for GTAP.

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