Sequential calibration of economic simulation models, the cases of CAPRI and a CAPRI-GTAP link

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Introduction

Increasing demand for policy impact assessment regarding social, economic and environmental aspects asks for combined application of different models and tools. CAPRI, a economic modelling system for the agricultural sector with a focus linking different components, has in turn also been repeatedly linked in various manners to more aggregate CGE models (e.g. Britz W. and Hertel T. 2009, Nowicki et al. 2009) and macro-econometric and land use models (Jansson et al. 2008,). Several methodological options for linking quantitative (economic) models are discussed in the literature (see e.g. Britz 2008) such as model chains where outputs from one model become input to the next one, meta-modelling where a reduced form representation of one model is integrated into another one and sequential calibration where models interact iteratively (e.g. Böhringer and Rutherford (2009) and Grant et al. (2006)).

The application of a response surface for linking the CAPRI and GTAP is discussed in Britz & Hertel, (2009) and Britz, Pelikan & Hertel, (2010). We therefore focus in here on the discussion of sequential calibration as a key concept in CAPRI for model linkage which is also applied in recent combined applications of CAPRI and GTAP (Jansson et al. 2009).

Outline

The first part of the paper briefly introduces the concept of sequential calibration as integrated in CAPR to link the supply and demand module. It is based on iteratively updating parameters of behavioural and production function parameters in one model based on the results of second one, while feeding an average of past iterations of endogenous variables such as prices from the updated model back to the second model. The process is repeated until relative differences between iterations fall below a pre-defined threshold. Given a convex and continuously differentiable response of the second model to the endogenous variables fed back, analysis and experience suggest that the process is indeed converging to a fix point. That approach was implemented since 1999 in the very first version of CAPRI to link the regional supply models operating with fixed prices to the global market component of CAPRI. Its simplicity and robustness rendered it also inviting for combined applications of CAPRI and GTAP.

The second part of this paper describes how, based on the basic algorithm implemented in CAPRI, sequential recalibration was used to link CAPRI with GTAP in an application that analysed the impacts of a non-agricultural market access (NAMA) trade agreement. NAMA implies changes in non-agricultural commodities that impact indirectly on agriculture via primary and intermediate factor prices and consumer expenditure. Via the link, the partial model CAPRI computes regionalized impacts on agricultural production, agricultural incomes and derived environmental indicators. The application illustrates how sequential recalibration can be implemented in the context of PE-GE models.

The last section summarizes and concludes.

Iterative calibration of supply and demand in CAPRI

CAPRI (see Britz & Keeney 2010 for a short description of CAPRI and comparison to GTAP) comprises a global spatial multi-commodity model which is sequentially calibrated to its supply component, a layer of regional or farm type programming models covering the EU, Norway, Western Balkans and Turkey (see also Britz 2008). Several reasons exclude a simultaneous solution of these two components, such as maintaining modularity in the system, profiting from flexibility regarding methodological implementation and choice of solution algorithm (explicit optimization or use of behavioural equations) for each component and the cheer size of the overall problem. The latter is due to the fact that both the supply and the market components are already large-scale components. The regionalisation on the supply side for Europe leads to hundreds of regional or even thousands for farm type models with many endogenous variables and equations, while the global market model covers about 50 commodities and about 60 countries and country aggregates in 28 trade blocks for which bilateral trade flows are modelled.

Sequential calibration is chosen in CAPRI mainly as alterative implementations seemed not promising. A model chain is excluded as the two components interacting show overlap in endogenous variables. Both the regional or farm type programming model and the global market model simulate EU primary agriculture supply and feed demand of primary and secondary agricultural products. Simply passing outcomes of one model (say the prices of the market model) to the supply models is hence not feasible. The latter would almost certainly lead to simulation outcomes where the supply and feed demand quantities in the market model would differ substantially from those simulated with the supply models at the same prices.

Generating a response surface as a second possible way to link the two components was not deemed inviting for two main reasons. Firstly, setting up and running the necessary sensitivity experiments for the supply models, collecting their outcomes and estimating the response surface is a demanding exercise (Jansson et al. 2008). It would need to be repeated each time the supply models are updated or shocked with drivers not yet covered or outside the so far covered range or in the response surface. Secondly, the accuracy in predicting sensitive model outcomes such as the budgetary costs of policy programs would probably not be satisfactory for policy impact assessment when using a reduced form representation of EU supply in the market model.

That has drawn our attention to sequential calibration. It allowed in a modular fashion separating code and algorithm for the sequential calibration itself from the two linked components. It thus supports a rather independent maintenance and development of the different modules. Its implementation was eased by an umbrella of a common software implementation in GAMS and highly integrated and consistent data sets and a common baseline across regional scales.

Having argued why sequential calibration might be inviting for CAPRI, we turn now to its concept and implementation. The two figures to the right and below depict graphically the sequential calibration process. We will start with the flow

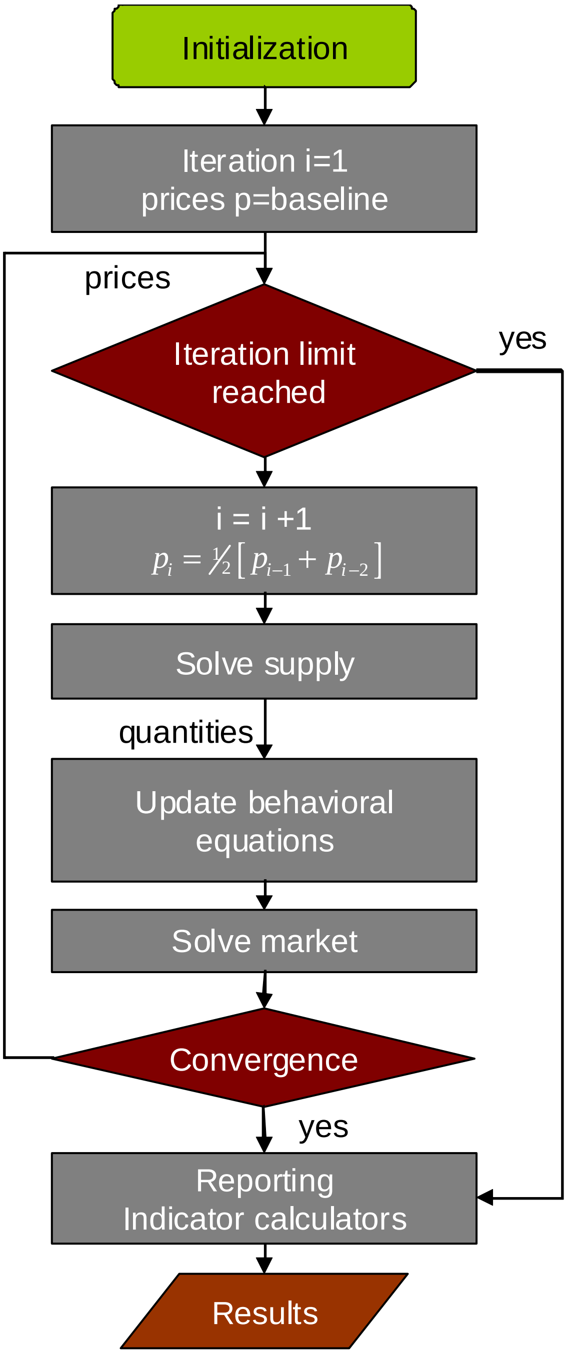


Figure 1: Flowchart of the iterative solution process

chart shedding light on the algorithm, before turning to a more economic interpretation. After an initialization block which loads data and parameters and defines the shocks for the scenario to run, prices are set to the baseline and the iteration loop is started. Each iteration starts with a check if a pre-defined iteration limit is reached to avoid an infinite loop in case of errors. Next, the iteration counter is increased, and prices are set to the simple average of the last two iterations. Also, not shown in here, policy variables such as subsidies paid per ha might be updated as well as price dependent I/O coefficients in the supply model. The supply models are then solved independently from each other in parallel in a grid at the interpolated current prices. Once all models are solved, their results for supply and feed demand are aggregated from single regions or farm types in regions to countries. The behavioural equations in the market for countries covered by the supply part are then redefined such that they would recover at the prices used in the supply models the supply and feed demand quantities simulated during the last solve. The newly calibrated behavioural equations will introduce a shock to the market model, and solving it will generate a new vector of prices. If the supply and demand function follow regularity conditions, the process will reduce differences between iterations monotonically, however, given numerical accuracy and the need to limit solution time, some convergence thresholds as in any numerical solver needs to be introduced. Hence, at the end of the loop, a convergence test is performed. Currently, two types of thresholds are used:

- Minimum absolute deviations for quantities for any product and country between iteration (at 1000 tons for production and 5000 tons for feed, and for prices at 0.05 €/ton)
- Minimum relative deviations in quantities and prices at 0.05% between iterations for any product and country, in case of quantities for those items where starting values exceed ten times the above the mentioned absolute deviations.

As long as for any country – product – item combination one of the thresholds is exceeded, a new iteration will be started. Even for larger shocks, the model typically finishes after about twenty iterations.

Now, we turn to a more intuitive description of the process for an economist as depicted in figure 2. The implicit marginal cost curve (= supply curve) of the aggregate of all regional supply models is depicted with *mc*, and assumed to remain constant during the solution sequence for our thought experiment. That is usually not the case, as changes in cross-prices or policy instruments will shift the *mc*-curve during iterations. The left and hand right hand refer to a situation with over-estimated and under-estimated supply reactions in the market part, respectively.

The supply model is solved first at baseline price p_0 and yields supply of S_0. The supply curves of the market model – here assumed to be linear - are now shifted by changing the constant term to comprise the point (p_0,S_0). Solving the market model yield prices p_1, and a new simulation with the supply models will yield new supply quantities S_1 where p_1 intersects with the mc-curve. The supply curve will then be shifted again to cross these points (dotted lines). A new solve of the market model will return prices p_2. The dashed lines show then iteration 2, and in both cases, differences in between iterations become smaller. On the left hand side with the overestimated supply elasticites shows prices growing over iterations to convergence, however with decreasing differences, whereas, on the right hand side with underestimated supply responsiveness, prices will fluctuate around the convergence point with decreasing amplitude.

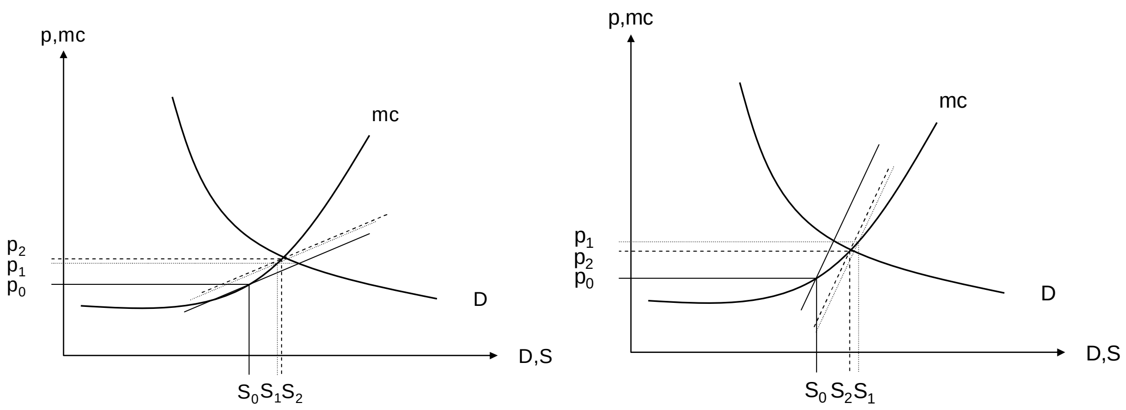


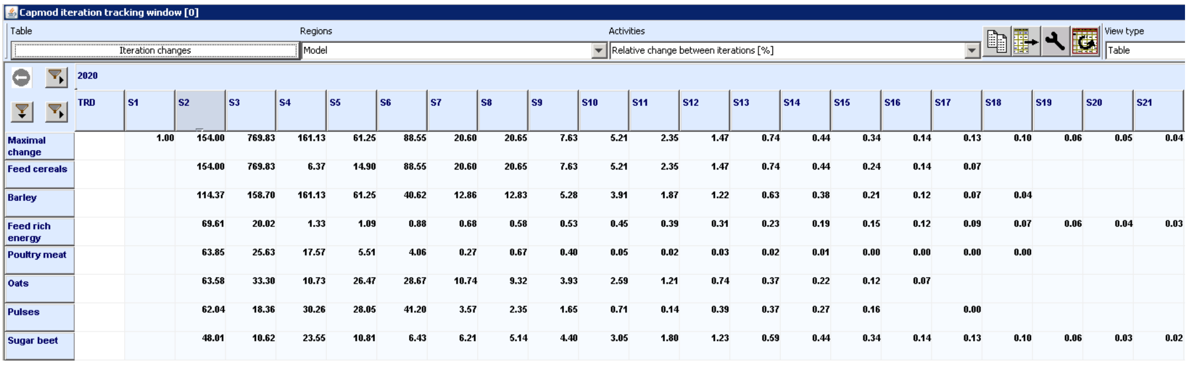
Figure 2: Sequential calibration

A crucial element steering the convergence is clearly a reasonable close second order approximations of the supply model, in the above figure visible as the fixed slope of the supply curve in the market model. Heckelei 2002 provides the functional relation for a quadratic programming model with linear (in)equalities between the supply responses, the quadratic cost function terms and the coefficients relating to binding constraints:

$$\frac{\partial \mathbf{x}}{\partial \mathbf{gm}} = \mathbf{Q}^{-1} - \mathbf{Q}^{-1}\mathbf{A}'\left(\mathbf{AQ}^{-1}\mathbf{A}'\right)^{-1}\mathbf{AQ}^{-1} \qquad (1)$$

Where **x** denotes the decision variables, **gm** the vector of gross margins, **A** the constraint coefficient matrix and **Q** the quadratic terms of the variable costs function. The matrix remains constant while simulating changes in the cross margins as long as the basis does not change, i.e. inequalities in the model switching between binding and not-binding. Based on the fixed output coefficients for the production processes in CAPRI, the change in activities levels can be easily converted in a change of outputs, and a price change mapped into a change of the gross margin. Accordingly, based on (1), we are able to estimate a matrix $\partial Q/\partial p$ of own- and cross price supply and feed demand effects directly from the parameters of the regional programming models. The fixed character of $\partial Q/\partial p$ renders it inviting to use a normalized quadratic profit or cost function for supply and feed demand respectively in the market model which uses $\partial Q/\partial p$, normalized by a price index for all non-agricultural goods, directly as functional parameters. It would yield linear own price supply and feed demand functions as shown in the figure above. The linear nature of the functions helps also speeding up the solution process of the global market model.

The iterative procedure is a key element in the functioning of CAPRI, and therefore, tools track the process at the runtime. Key results (activity levels, supply, feed and prices for individual countries and aggregates of countries for each of the iterations) as well as performance criteria (seconds used for certain steps in the model, convergence) are stored for each of the iterations. They can be accessed with a small GUI while the model continues to run, so that problems can be detected early and the current run might be stopped, or key development already analyzed. The figure below depicts an example of a WTO liberalisation scenario according to the Falconer proposal including TRQ expansions, introducing a larger shock in the system with e.g. dramatic changes in the border protection of Norway. The model converged after 21 iterations between the supply and market part. As seen, the maximal relative difference for any country – product – item combination between consecutive iterations was rather large in the beginning, up to several 100%. It dropped to around 5% in the tenth iteration and then quickly to less then 1% in iteration 15, and finally below to the convergence thresholds in iteration 21.



	TRD	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21
Maximal change		1.00	154.00	769.83	161.13	61.25	88.55	20.60	20.65	7.63	5.21	2.35	1.47	0.74	0.44	0.34	0.14	0.13	0.10	0.06	0.05	0.04
Feed cereals			154.00	769.83	6.37	14.90	88.55	20.60	20.65	7.63	5.21	2.35	1.47	0.74	0.44	0.24	0.14	0.07				
Barley			114.37	158.70	161.13	61.25	40.62	12.86	12.83	5.28	3.91	1.87	1.22	0.63	0.38	0.21	0.12	0.07	0.04			
Feed rich energy			69.61	20.02	1.33	1.09	0.88	0.68	0.58	0.53	0.45	0.39	0.31	0.23	0.19	0.15	0.12	0.09	0.07	0.06	0.04	0.03
Poultry meat			63.85	25.63	17.57	5.51	4.06	0.27	0.67	0.40	0.05	0.02	0.03	0.02	0.01	0.00	0.00	0.00	0.00			
Oats			63.58	33.30	10.73	26.47	28.67	10.74	9.32	3.93	2.59	1.21	0.74	0.37	0.22	0.12	0.07					
Pulses			62.04	18.36	30.26	28.05	41.20	3.57	2.35	1.65	0.71	0.14	0.39	0.37	0.27	0.16		0.00				
Sugar beet			48.01	10.62	23.55	10.81	6.43	6.21	5.14	4.40	3.05	1.80	1.23	0.59	0.44	0.34	0.14	0.13	0.10	0.06	0.03	0.02

Figure 3: Screen shot of the GUI to track the sequential calibration algorithm in CAPRI showing relative changes between iteration in a WTO liberalization scenario.

In order to assess the algorithm, it might be interesting to also analyse processing times. The whole simulation exercise from which the example was taken took about 40 minutes on a powerful multi-processor machine. 31% of the total time was used for model initialization (ca. 4 minutes) and the extensive post model reporting (ca. 8 minutes), which calculates different environmental indicators, aggregates across products, activities and regions, decomposes yield and input use changes etc.. Solving the market model with its about 40.000 equations and variables, where the huge shock was introduced, took about 10 minutes in sum over the first three iterations or around 27% of the total time. The remaining 18 iterations took hence in average only 53 seconds each to solve the 280 regional programming, update the behavioural equations of the market model, solve it again, as well as update policy parameters and yields.

The profiling gives an indication both about the performance of modern solvers and modelling languages, but also clearly a hint how an efficient modular set-up of an economic simulation system might impact on solution time. Each of the regional models features about 450 equations and 550 variables, leading in sum to about 125.000 equations and 150.000 variables, many of which are quadratic. Building a super model consisting simultaneously of all regional programming models and the market model would probably provoke higher solution times while leading to a tremendously large single model much harder to debug and analyze, compared to the single still rather small programming models. It would also require writing the programming models in first order conditions to allow using MCP, rendering them less transparent. Using the farm type layer in CAPRI will increase the number of supply models to around 2000, multiplying the number of equations and variables of the supply side by factor 6-8. It is at least doubtful if a non-linear MCP model of the resulting size can be solved.

Iterative calibration of CAPRI and GTAP

The previous section described how iterative recalibration is used *within* CAPRI to obtain convergence between the supply and market models. The same principle can also be applied to the CAPRI system as a whole, to link it with other models. Such links have been implemented in different ways and with different models, as mentioned in the introduction above. Whereas Britz and Hertel (2009) and Britz et. al. (2010) link the supply side of CAPRI to GTAP based on a response surface approach, Jansson et al. (2009) linked CAPRI with GTAP, and Jansson et al. (2008) linked CAPRI with NEMESIS based on sequential calibration. In this section the linking with GTAP as implemented by Jansson et al. (2009) based on sequential calibration is reviewed, and simulation experiments performed with the intention to find out to what extent the link matters to model results.

Linking strategy

The iterative link of CAPRI with GTAP was introduced in four steps. First, an aggregation of the GTAP data base was created where the regions overlap as closely as possible with the CAPRI regions and the product list overlaps as closely as possible with the CAPRI product list. That aggregation was used to compute labour and capital use coefficients for the agricultural activities of CAPRI. This step was necessary because standard CAPRI does not explicitly contain labour and capital. Next, a second aggregation was performed, with identical region definitions, where all agricultural sectors of GTAP that have a counterpart in CAPRI were aggregated to source a CGE with basically a single agricultural sector. No particular details about agriculture are longer needed in GTAP since that detail is subsequently provided by CAPRI. The remaining sectors of GTAP can be aggregated in any way required by the analysis. Thirdly, a special partial closure, here called *shifter*, was created for GTAP where the single agricultural sector is solved in isolation with exogenous prices and quantities and endogenous technical shift parameters (a closure swap). Fourth, an additional module to CAPRI was created that reads GTAP results and translates those results into shocks for CAPRI, and another module that aggregates CAPRI results to the level of the entire agricultural sector, as required by shifter and GTAP.

That module provides also technically a bridge between GAMS and GemPack by performing the necessary changes in file formats, and to start a GTAP simulation from GAMS.

The shifter module and the additional input and output modules for CAPRI were plugged into the existing iterative solution algorithm for CAPRI, modifying figure 1 to become figure 4.

From an economical viewpoint, GTAP in CAPRI plays the role an additional model providing solutions for factor markets which otherwise are exogenous in CAPRI.

Starting with a solution for the CAPRI supply and market models, the results for the entire agricultural sector are aggregated to a single sector corresponding to the single ag. sector used in GTAP. The items calculated and used by GTAP are shown in table 1.

The aggregated outputs of CAPRI shown in table 1 are used by shifter to compute a shock for the technical parameters of the agricultural production nest of GTAP such that the agricultural sector of GTAP exactly reproduces the aggregated result of CAPRI at the input and endowment prices that were sent to CAPRI in the previous iteration.

In order to compute the price indices for outputs *ps*, intermediate inputs *pf* and endowments *pfe*, respectively, a Laspeyres index was used with baseline quantities as weights, shown below.

The endowment prices other than land were outputs of GTAP in the previous iteration, used as shocks in CAPRI, and then passed on to shifter unchanged. For traded intermediate inputs, which are also outputs of GTAP exogenous in CAPRI, a recomputation is needed in order to account for any aggregation effects arising whence CAPRI recognizes a more disaggregated set of intermediate inputs than GTAP.

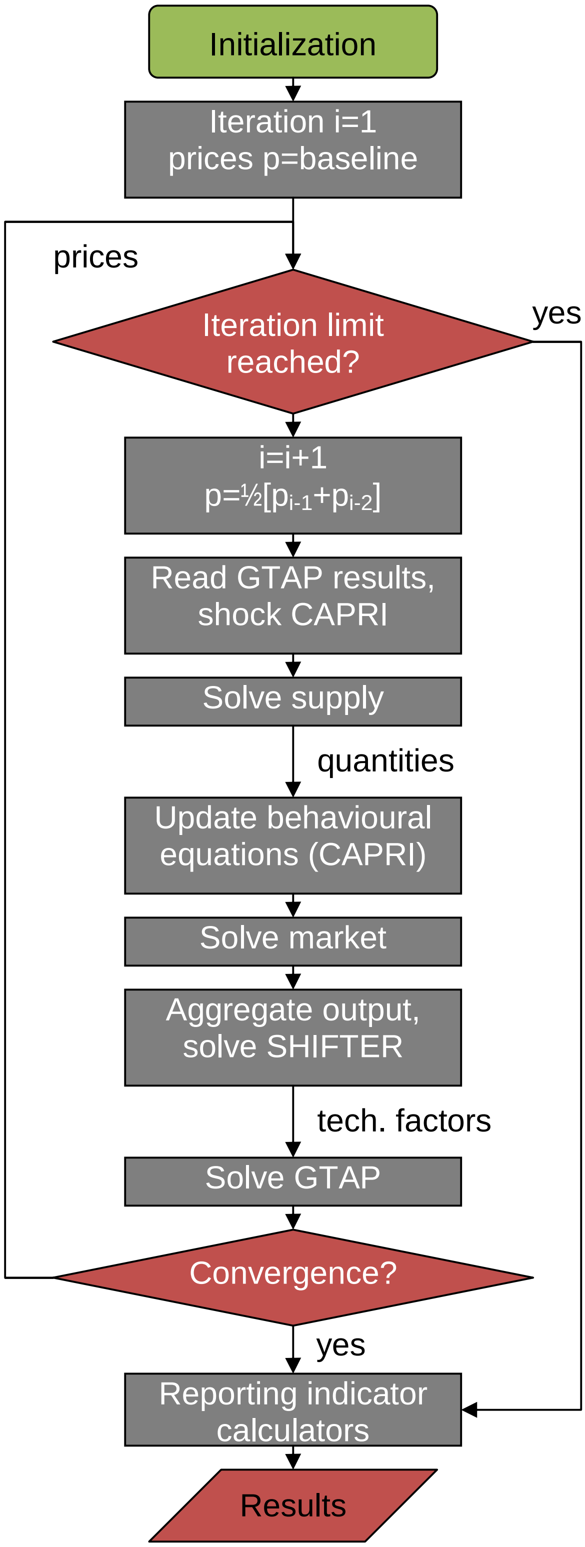


Figure 4: Flowchart of the augmented iterative solution process with GTAP

Table 1: Aggregate outputs of CAPRI used in iterative recalibration of GTAP. All variables are computed as percentage change compared to the baseline scenario, and the index r denotes the common set of regions of CAPRI and GTAP.

Variable	Description
ps("agri",r)	Laspeyres price index of agricultural outputs of region r
qo("agri",r)	Total output index of agriculture
pf("agri","agri",r)	Laspeyres price index for agricultural inputs produced by agriculture
qf(c,"agri",r)	Index for inputs used in agriculture, including intermediates produced by agriculture itself
qfe(e,"agri",r)	Use of endowment e by agriculture
pfe("land","agri",r)	Agricultural land rent, including any subsidies, in region r

The computation of the quantity indices *qo*, *qf* and *qfe* were done so that the relation "current plain value index V" = "price index P" × "volume index Q" holds in the following manner (where i denotes the outputs or inputs for which to compute the index):

1) V = Σ_i[p(i,"sim")*q(i,"sim")] / Σ_i[p(i,"ref")*q(i,"ref")]

2) P = Σ_i[p(i,"sim")*q(i,"ref")] / Σ_i[p(i,"ref")*q(i,"ref")]

3) Q = V / P = Σ_i[p(i,"sim")*q(i,"sim")] / Σ_i[p(i,"sim")*q(i,"ref")]

In contrast with the link of supply and demand inside CAPRI that works with a second-order approximation of supply within the market model, the linking of CAPRI with GTAP works with a first-order approximation, only. That means that the agricultural sector of GTAP is calibrated to the solution point of CAPRI. The advantage of doing so is that the GTAP model need not be modified at all in order to be linked with CAPRI — the existing technical shift parameters of GTAP do the work for us. The drawback is that convergence may be slower than what would otherwise be the case.

The results of GTAP used in CAPRI were, at this stage, only input prices, household expenditure and a price index of household consumption. The input prices of GTAP were mapped as closely as possible to CAPRI inputs. For all endowments except land, the relative price changes of GTAP were multiplied by the input coefficients per production activity initially derived in order to come up with the change in costs for all "endowments except land". That cost change was added to a dedicated cost parameter in the CAPRI supply model. Household expenditure and price index were used to directly shock the corresponding (exogenous) parameters of the CAPRI market model.

Does the link matter?

In order to investigate the interaction of the models a baseline and a non-agricultural trade liberalization (NAMA) scenario were developed, the latter implying large reductions in border protection for non-agricultural products imported into the EU. The liberalization scenario was designed in such a way that only non-agricultural variables present in GTAP were shocked whereas CAPRI was affected only by the interaction with GTAP.

GTAP was first solved without CAPRI, to obtain a benchmark for the system prior to linking. The corresponding benchmark for CAPRI is the baseline, since NAMA contained no direct shock for CAPRI. Then the linked system was solved, and the results compared with the benchmark results. The outcomes are reported below.

This section presents results of GTAP "standalone" and for the linked system. The focus is on prices and quantities of commodities for EU countries. In order to improve clarity of the exposition, we choose the font *Arial italic* when we refer to sectors and products in the models.

Results of GTAP standalone

First, GTAP was solved (Euler 16 steps) without CAPRI in order to generate a benchmark against which to evaluate the results of the linked system. The results of the standalone solution of GTAP for the NAMA scenario compared with the baseline are shown in table 2. Columns for natural resources and fibres have been omitted because they generally constitute a very small share of agricultural (*Agri*) firms' costs.

Table 2: Price changes of agriculture's purchases in NAMA with GTAP standalone, for selected EU member states.

	Agri	*PFood*	*Extract*	*LabMan*	*CapMan*	*Svces*	*Land*	*UnSkLab*	*SkLab*	*Capital*
BE+LU	-0.13	-0.18	-0.05	-0.52	-0.30	-0.11	0.26	-0.10	-0.06	-0.06
DK	-0.12	-0.26	-0.31	-0.33	-0.20	-0.10	0.47	-0.09	-0.06	-0.06
DE	-0.13	-0.17	-0.03	-0.38	-0.21	-0.14	-0.01	-0.13	-0.12	-0.12
EL	-0.11	-0.13	-0.05	-0.33	-0.19	-0.11	-0.16	-0.09	-0.08	-0.08
ES	-0.20	-0.25	-0.11	-0.41	-0.26	-0.24	0.25	-0.23	-0.22	-0.22
FR	-0.20	-0.23	-0.10	-0.39	-0.25	-0.23	0.32	-0.23	-0.22	-0.22
IE	-0.19	-0.21	-0.08	-0.46	-0.22	-0.16	0.28	-0.18	-0.16	-0.25
IT	-0.11	-0.16	-0.04	-0.28	-0.20	-0.11	-0.13	-0.10	-0.10	-0.10
NL	-0.16	-0.22	0.11	-0.41	-0.25	-0.22	0.58	-0.24	-0.21	-0.21
AT	-0.18	-0.21	-0.16	-0.37	-0.22	-0.20	0.21	-0.23	-0.19	-0.22
PT	-0.27	-0.32	-0.10	-0.39	-0.28	-0.32	0.06	-0.34	-0.32	-0.33
FI0	-0.37	-0.38	-0.32	-0.48	-0.32	-0.39	0.24	-0.43	-0.39	-0.43
SE	-0.23	-0.28	-0.18	-0.39	-0.27	-0.25	0.13	-0.25	-0.22	-0.26
UK	-0.21	-0.26	-0.08	-0.43	-0.29	-0.25	0.19	-0.26	-0.23	-0.23

The general picture that emerges from the table is that input prices of *Agri* are reduced, except for the endowment *Land*. *Land* prices are influenced on the one hand by substitution with other inputs (downward pressure) and on the other hand by the changes in total output of agriculture, shown in figure 5. *Land* is imperfectly mobile between sectors of the economy, and is predominantly used by *Agri*. When input prices of agriculture decrease, profits increase and also production. Increased production leads to increased demand for *Land*, which tends to increase its price. In order to clear output markets, the output price of *Agri* also drops, and in the equilibrium, agricultural production actually decreases in two member states (IT and EL, not shown). The slight decrease in output of *Agri* leads to net decreases of prices for *Land* in those member states.

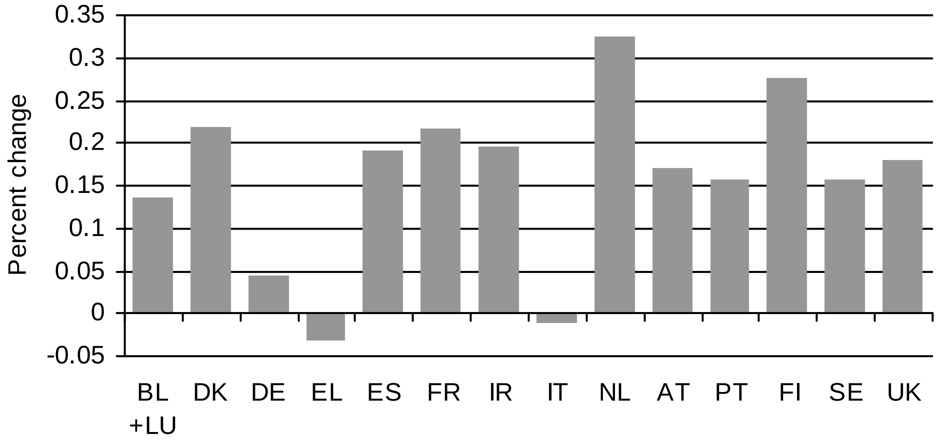


Figure 5: Change (%) in output quantity of *Agri* in NAMA with GTAP standalone, for selected EU member states.

Results of GTAP standalone versus linked with CAPRI

In this section we compare the results from GTAP of the NAMA scenario with and without CAPRI linked, in order to investigate to what extent the linking of CAPRI matters. Focus is again on selected EU member states.

Table 3: Effect of link on input prices in GTAP, for selected EU member states, % difference.

	Agri	*PFood*	*Extract*	*LabMan*	*CapMan*	*Svces*	*Land*	*UnSkLab*	*SkLab*	*Capital*
BL +LU	116.65	16.19	-11.09	0.15	0.03	2.71	-97.08	-12.19	-11.89	34.65
DK	166.23	15.54	-2.21	-0.84	-0.84	-2.87	-136.27	-34.36	-37.46	44.06
DE	112.46	17.40	-21.02	0.16	0.00	1.93	1899.18	-6.99	-5.15	11.38
EL	62.75	18.72	-11.32	1.32	1.03	5.24	158.90	0.34	-2.00	12.89
ES	108.59	21.86	-5.44	0.32	0.27	1.57	-33.01	-12.02	-6.05	12.42
FR	93.83	15.89	-6.01	0.31	0.28	1.13	69.27	-6.35	-3.93	9.22
IR	68.79	13.64	-9.17	0.17	0.63	0.74	94.99	-7.76	-7.75	6.27
IT	85.22	18.24	-15.32	0.54	0.05	0.74	198.15	-5.10	-4.79	3.34
NL	98.72	17.60	-5.50	-0.07	-0.36	0.05	-46.52	-8.84	-5.38	8.39
AT	98.53	16.13	-3.29	0.38	0.22	0.98	35.44	-5.73	-4.22	7.48

PT	103.90	22.06	-5.44	4.40	4.30	9.13	-403.15	-4.31	1.41	36.12
FI	91.96	15.62	-0.76	1.00	0.62	1.95	66.60	-7.44	-4.43	10.08
SE	160.43	16.13	-2.38	0.20	-0.07	0.40	-227.83	-7.70	-6.88	9.92
UK	91.03	7.55	-7.53	0.02	-0.03	0.89	305.85	-4.09	-3.42	6.71

Table 3 shows the relative difference (%) of input prices with the linked system relative to the standalone simulation with GTAP. The numbers have been computed as

$$\mathrm{Sign}(p_2 - p_1)*\mathrm{abs}(100*(p_2/p_1 - 1)) \qquad (2)$$

where p_1 is the price change in NAMA when solved "standalone" and p_2 is the price change in NAMA when the linked system is solved. Thus, note that we talk about *the percentage change of the percentage change* in simulation. As would be expected, the effect is large on items directly linked to CAPRI, i.e. the prices of *Agri* and *Land*, whereas the input price reaction of other items is smaller the less their relation to agriculture. The most remarkable change of results is that of *Land* price in Germany. The price change with the link is about 20 times larger. However, table 2 reveals that the price change with GTAP standalone was only 0.01% in Germany, and thus an increase by a factor 20 is not longer very remarkable.

Of the sectors not directly influenced by CAPRI, the largest effect is seen in processed foods *PFood*. This is only natural because *Agri* is an important input into *PFood*. Also on the sector *Extract* there is a clear change of some results, most of all for BL+LU, DE, EL and IT. Those instances, however, arise due to the fact that the effect in "Standalone" is almost zero (see table 2) so that also an absolutely small effect of the link seems large (in equation 2, p_1 is small).

The change of prices of *Capital* and Labour (*SkLab* and *UnSkLab*) are typically affected by a few percent, and the general pattern is that the price change with the linked system is smaller than with GTAP standalone.

Results of CAPRI for the linked system

As an aggregate, output of agriculture increases in response to lower prices for inputs, but certain reallocations also take place within the agricultural sector.

Prices of endowments as well as variable inputs fall, as discussed above. Initially, this induces producers to use more intensive technologies, e.g. higher cereals yields using more variable inputs, labour and capital. Increased production increases demand for and the opportunity cost (shadow price) of land. Activities with less capital use, labour use or variable costs — prominently fodder activities — benefit less from the lower input prices but suffer from higher opportunity costs for land, and are consequently reduced. This impacts on animal husbandry via higher feed prices, not offset by lower capital, labour or variable input costs.

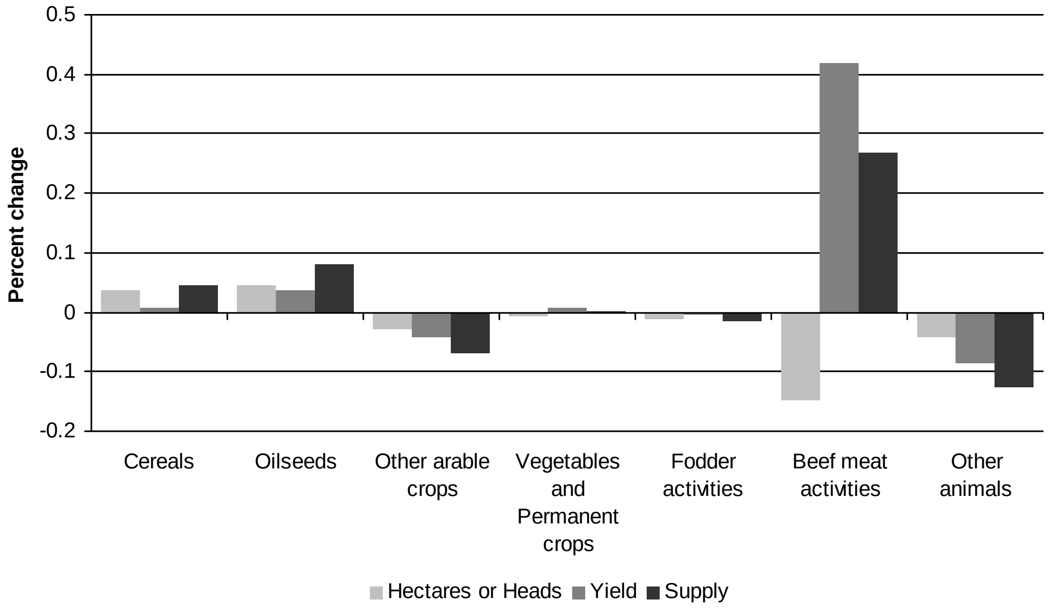


Figure 6: Production results for CAPRI for EU27 and selected sectors in the NAMA simulation compared with the baseline.

Figure 6 shows results of the NAMA simulation in CAPRI, percentage change of production of selected product aggregates for EU27. In general, the impact of the NAMA scenario on agriculture is small. For the important product group cereals, the impact is less than a tenth of a percent , and foe all sectors the effect is below half a percent.

The biggest negative impact is for the group “other animals”, which contains mainly pigs and poultry. For those sectors, the net impact is negative despite the fact that capital, labour and most variable inputs are becoming cheaper. The explanation is twofold. Firstly, the sectors depend strongly on cereals and other crop products for feeding, and those products get more expensive. Secondly, pigs and poultry are almost entirely fed by concentrates, whereas ruminants might switch to non-marketable feed such as grasslands. Albeit non-ruminants can rely either on cereals or a mix of protein rich cakes and energy rich products, such by-products of the milling industry, the market will also let prices increases for the substitutes to cereals.

Thus, whereas the relative price changes lead to reduced animal stock but higher total production for the bovine sectors, similar mechanisms lead to a decline in total production of pigs and poultry meat. The extent to which this would also occur in reality is an empirical question.

Discussion

In CAPRI, the introduction of sequential recalibration was the key to allow for price feedback in the overall modelling system given the need for a large number of rather detailed programming models on the supply side. The success of the methodology in the core CAPRI model is certainly also linked to a mutually consistent data base and baseline for the linked components, a careful choice of functional forms and, finally, the possible to derive a second order approximation from the structure and parameterization of the supply models. Not at least, both components are integrated into one single GAMS program.

The experiences with the CAPRI-GTAP link based on sequential calibration are somewhat mixed. Firstly, the data bases for CAPRI and GTAP are far from being harmonized. Passing relative changes back and forth carries the risk that convergence cannot be achieved. Secondly, linking models operating in different software environments in an automated way is far more demanding. In such cases, using a meta-model approach as in Britz & Hertel 2009 might be a more elegant solution. Finally, linking large systems such as CAPRI and GTAP in a fully consistent way is technically demanding, since there is likely some overlap between many variables and parameters of the two systems, in particular between variables of the CAPRI market part (tariffs, trade flows etc). At some point, the marginal improvement in consistency of linking an additional pair of variables is likely to be perceived as smaller than the effort required for doing so.

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