D2.2: REPORT ON MODEL LINKAGES, WITH GENERAL PARTS AND INCLUDING ASSESSMENTS ON THE KEY SPECIFIC LINKAGES WITH BILATERAL AUTHORSHIP

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 773499 SUPREMA

PROJECT	Support for Policy Relevant Modelling of Agriculture (SUPREMA)
PROJECT NUMBER	773499
TYPE OF FUNDING	Coordination and Support Action
DELIVERABLE	D.2.2 (REPORT ON MODEL LINKAGES, WITH GENERAL PARTS AND INCLUDING ASSESSMENTS ON THE KEY SPECIFIC LINKAGES WITH BILATERAL AUTHORSHIP)
WP NAME/WP NUMBER	The tools - model enhancement and integration - WP 2
TASK	2.2
VERSION	Version 2
DISSEMINATION LEVEL	Public
DATE	06/05/2020
LEAD BENEFICIARY	Thuenen
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INTERNAL REVIEWER	Approval by WP leader

DOCUMENT HISTORY

Version	Initials/NAME	DATE	COMMENTS-DESCRIPTION OF ACTIONS
1	V.01	03/06/2020	Report

Table of Contents

TABLES

FIGURES

Executive summary

Changes with respect to the DoA

No changes.

Dissemination and uptake

This Deliverable presents the linkages of the SUPREMA models. This Deliverable will be made available to all participants and put on the SUPREMA website.

Short Summary of results

This deliverable describes the enhancements achieved in SUPREMA with respect to the model linkages. We present chapter-wise the linkages between the models and document the applicability of the linkage with different simulation shocks. Where applicable, we show the advance, achieved with the linkage, compared to stand alone simulation.

Evidence of accomplishment

Deliverable 2.2

Glossary / Acronyms

AGCLIM50	CHALLENGES OF GLOBAL AGRICULTURE IN A CLIMATE CHANGE CONTEXT
AGMEMOD	AGRICULTURAL MEMBER STATES MODELLING
AGMIP	AGRICULTURAL MODEL INTERCOMPARISON AND IMPROVEMENT PROJECT
AROPAJ	ECONOMIC FARM MODEL INCLUDING GHG EMISSIONS
C4	FOUR-CARBON MOLECULE
CAP	COMMON AGRICULTURAL POLICY
CAPRI	COMMON AGRICULTURAL POLICY REGIONAL IMPACT
CES	CONSTANT ELASTICITIY OF SUBSTITUTION
CGE	COMPUTABLE GENERAL EQUILIBRIUM
CONAB	COMPANHIA NACIONAL DE ABASTECIMENTO
CV	COEFFICIENT OF VARIATION
EcAMPA	ECONOMIC ASSESSMENT OF GHG MITIGATION POLICY OPTIONS FOR EU AGRICULTURE
ECM	ERROR CORRECTION MODEL
EPIC	ENVIRONMENTAL POLICY INTEGRATED CLIMATE
EU	EUROPEAN UNION
EUCLIMIT	EU ECONOMY-WIDE CLIMATE MITIGATION MODELLING
FADN	FARM ACCOUNTANCY DATA NETWORK
FAO	FOOD AND AGRICULTURE ORGANIZATION
FAOSTAT	FOOD AND AGRICULTURE ORGANIZATION CORPORATE STATISTICAL DATABASE
FARMIS	FARM MODELLING INFORMATION SYSTEM
FRA	FOREST RESOURCES ASSESSMENTS
G4M	GLOBAL FORESTRY MODEL
GAINS	GREENHOUSE GAS - AIR POLLUTION INTERACTIONS AND SYNERGIES MODEL
GAMS	GENERAL ALGEBRAIC MODELING SYSTEM
GDP	GROSS DOMESTIC PRODUCT
GE	GENERAL EQUILIBRIUM
GHG	GREENHOUSE GAS
GJ	GIGAJOULE
GLOBIOM	GLOBAL BIOSPHERE MANAGEMENT MODEL
GSC	GLOBAL SUPPLY CHAIN
GUI	GRAPHICAL USER INTERFACE
IEA	INTERNATIONAL ENERGY AGENCY
IFM-CAP	INDIVIDUAL FARM MODEL FOR THE COMMON AGRICULTURAL POLICY
IMAGE	INTEGRATED MODEL TO ASSESS THE GLOBAL ENVIRONMENT
LCA	LIFE CYCLE ASSESSMENT
LULUCF	LAND USE, LAND-USE CHANGE, AND FORESTRY
MAGNET	MODULAR APPLIED GENERAL EQUILIBRIUM TOOL
MCMC	MARKOV CHAIN MONTE CARLO
MESSAGE	MODEL FOR ENERGY SUPPLY STRATEGY ALTERNATIVES AND THEIR GENERAL ENVIRONMENTAL IMPACT
MITERRA	MITERRA-EUROPE
MNL	MULTINOMIAL LOGIT
MS	MEMBER STATES
MTO	MEDIUM-TERM OUTLOOK
N	NITROGEN
NUTS	NOMENCLATURE OF TERRITORIAL UNITS FOR STATISTICS
OECD	ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT
P	PHOSPHORUS
PE	PARTIAL EQUILIBRIUM
PRIMES	PRICE-INDUCED MARKET EQUILIBRIUM SYSTEM
PT	PRICE TRANSMISSION
SUPREMA	SUPPORT FOR POLICY RELEVANT MODELLING OF AGRICULTURE
USDA	UNITED STATES DEPARTMENT OF AGRICULTURE
VECM	VECTOR ERROR CORRECTION MODEL

1 Introduction

There are different methods for modelling economic modelling linkages. Britz (2008) differentiated among model chains without calibration of the interlinked models, models with one-way calibration and models with sequential calibration. The without calibration approach shocks a model with data from another model without considering any further feedback between the interlinked models. The established linkage for AGLINK-AGMEMOD and to a certain extent also GLOBIOM-CAPRI and MAGNET-GLOBIOM-CAPRI fall in this category. The linkage consists of using a certain set of macro/market simulation results from one model and apply them as exogenous information source in another model. One-way calibration is achieved when one model is calibrated to results generated by another model. In the top-down approach, one calibrates the more-disaggregated results or the response parameter to the results and to the response parameter of the top level. This applies to the approach described in the linkage AGLINK-AGMEMOD, where we link and harmonize the model parameter of MITERRA with results from economic models AGMEMOD. The third approach, which is based on sequential calibration each model uses and produces its own results, there is iterative feedback among the models. One example is the linkage of the partial equilibrium model of CAPRI and IFM-CAP. Iterative algorithms can achieve market equilibrium even in multi-dimensional and highly interdependent product settings (Britz, 2008). The IFM-CAP - CAPRI linkages builds upon this approach. The market module determines the equilibrium prices and supply quantities by solving the interaction of supply and demand functions, whereas the supply module solves for output quantities by taking the output prices as given. Linking the market and supply modules requires exchanging quantities and prices between the two modules in a sequential iterative process.
This deliverable describes the enhancements achieved in SUPREMA with respect to the above-mentioned model linkages. We present chapter-wise the linkages between the models and document the applicability of the linkage with different simulation shocks. Where applicable, we show the advance, achieved with the linkage, compared to stand alone simulation.

This report is structured in three chapters. Chapter one gives a short introduction. Chapter two describes the linkages of the SUPREMA models employed. In chapter two, each subchapter describes one model linkage. Chapter 3 finally presents the conclusions.

2 Current linkages and potentials for further developments of the different models

2.1 Model linkage IFM-CAP-CAPRI

2.1.1 Introduction

A feasibility study in 2015 supported the development of a linkage between the Individual Farm Model for the Common Agricultural Policy (IFM-CAP) and the market model component from the CAPRI model. The main challenge was to achieve a reasonable execution time, crucial for re-running, debugging and validation. Furthermore, a linkage requires that all regions in the EU are covered. As IFM-CAP run at the time of the feasibility study only for selected regions in the EU, the CAPRI supply response was required, to cover regions missing in IFM-CAP. This is also the case for products not represented in IFM-CAP. These requirements resulted in a model linkage architecture where IFM-CAP was embedded in CAPRI. In the SUPREMA project we reworked based on the experiences the linkage. First, we simplified the IFM-CAP model such that we could run different tests to improve the performance of the model, with respect to loading performance, compilation time, execution time and model structure, without changing its simulation behaviour. The resulting version consists of one file without any complex include structure. The version was tested by the IFM-CAP team and they confirmed that this simulation engine runs as the original version of IFM-CAP. Afterwards we tested different approaches to estimate supply elasticities for each farm to calibrate the market model for a fast convergence. However, since the last linkage project IFM-CAP changed from an NLP to a mixed integer programming problem (MIP), which did not allow to use the scenario solver (GUSS) for a fast simulation of programming models. Test to run standard simulation shocks for all farms and product proofed that a simulation exercise is not possible. We then extended the GAMS Graphical Interface Generator, in particular its batch execution facility (Britz, 2016) to interlink in a transparent way both models and at the same time to allow a user-friendly debugging and tracking the execution of the linkage. To test the model linkage, we used an analysis of yields and costs between organic and non-organic farms for four countries, namely Germany. Belgium, Ireland and Denmark derived from the European farm accounting data network (FADN) to shock IFM-CAP, assuming that non-organic farms will operate with yields and costs of observed organic farms. The section starts with explaining the methodology how the linkages is implemented from the economic point of view. For we shortly introduce the reader to the two models. Afterwards we present the technical implementation, present the scenario application and show results, by comparing effects with and without an application of the linkages. We finally conclude and point at directions to further improve the model linkage.

2.1.2 Methodology

The IFM-CAP model is a farm-level model designed for the economic and environmental analysis of the European agriculture. The main advantage of IFM-CAP is that it models a large sample of individual farms in the EU, which allows capturing the farm heterogeneity to a degree sufficient to apprehend the impacts of the direct payments as introduced by the 2013 CAP reform. The micro level detail of IFM-CAP is important because direct payments are farm-specific and their magnitude dependents on the implementation approach applied by each MS (e.g. full versus partial convergence of direct payments). Further, farmers receiving direct payments need to adopt greening measures. The greening measures target land allocation at farm level implying that their adoption and impacts largely depend on farm-specific characteristics (size, specialisation, localisation, etc.). This poses challenges for policy evaluation and raises the need for the application of a micro model. The advantage of IFM-CAP compared to other models used for CAP impact analysis is that it combines an EU-wide geographical coverage and the use of individual farm data that allows simulation of policy impacts

across all EU farming systems and regions (Louhichi et al., 2017; Louhichi et al., 2018). The IFM-CAP model is a static positive mathematical programming model. The model assumes that farmers maximize their expected utility subject to resource (arable and grassland and feed) endowments and policy constraints such as CAP greening restrictions (Louhichi et al., 2018). Farmer's expected income is defined as the sum of expected gross margins minus a non-linear (quadratic) activity-specific function. The gross margin is the total revenue including sales from agricultural products and direct payments (coupled and decoupled payments) minus the accounting variable costs of production activities. Total revenue is calculated using expected prices and yields assuming adaptive expectations (based on past three observations with declining weights). The expected accounting costs include costs of seeds, fertilisers and soil improvers, crop protection, feeding and other specific costs (following the same approach as with expected revenues). The quadratic activity-specific function is a behavioural function introduced to calibrate the farm model to an observed base year, as usually done in positive programming models. This function intends to capture the effects of factors that are not explicitly included in the model, such as farmers' perceived costs of capital and labour, or model misspecifications (Paris and Howitt, 1998; Heckelei, 2002; De Frahan et al., 2007).
CAPRI consists of global market model for agricultural products (Britz, 2008). It is a global spatial multi-commodity model covering 77 countries or country aggregates in 40 trade blocks and approximately 50 products. The Armington approach (Armington, 1969), assuming that the products are differentiated by origin, allows the simulation of bilateral trade flows and of related bilateral and multilateral trade instruments, including tariff-rate quotas. The supply module currently covers all individual MS within the EU-28, Norway, Turkey and the Western Balkans. These MS are then broken down into approximately 280 administrative regions (NUTS2 level) that cover more than 50 agricultural products.
Iterative algorithms can achieve market equilibrium even in multi-dimensional and highly interdependent product settings (Britz, 2008). The IFM-CAP - CAPRI linkages builds upon this approach. The market module determines the equilibrium prices and supply quantities by solving the interaction of supply and demand functions, whereas the supply module solves for output quantities by taking the output prices as given. Linking the market and supply modules requires exchanging quantities and prices between the two modules in a sequential iterative process.

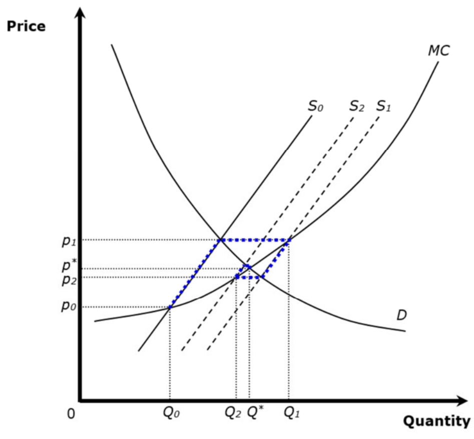

Figure 1. Sequential iteration between the market and supply modules (Britz, 2008)

Source(s): Own compilation.

Figure 1 shows the sequential model iteration between the supply and market modules. The implicit marginal cost curve (i.e. supply curve) of the IFM-CAP supply models is indicated by MC. To simplify the explanation, MC is assumed to remain constant in the iteration process. MC reflects how the farm model supply responds to different price levels. Note that because the parameters of the marginal cost curve are unknown, otherwise iterations are not necessary, and the optimal solution can be determined by solving the point of intersection between the demand and MC functions. In the first iteration, the supply model is solved at price p0 and yields a supply of Q0. In the next step, a hypothetical linear supply function that passes through the point (p0, Q0) is assumed. This function is used to solve for prices p1 in the market module, which are given by the intersection between the supply S0 and the demand D. In a second iteration, a new simulation with the supply module yields the supply quantities Q1, which are specified by the intersection of p1 with the MC curve. The supply curve is then shifted to S1 such that it crosses the demand curve at the point (p1, Q1). A new solution of the market model returns prices p2, whereas the supply module solution delivers supply quantity Q2. This process is repeated until the solution converges to the market equilibrium point (p*, S*) (Britz, 2008). IFM-CAP was built upon FADN which means that the total sector is not covered, and an exact sectoral consistency cannot be achieved. To overcome this inconsistency to the CAPRI market model we exchange the information in form of percentage changes (deltas of supply and prices). This allows a communication between the models without forcing one model to adjust to the other. Because FADN is a representative sample, we may assume that all products necessary in the market model are also represented in IFM-CAP under some heading. But a mapping is needed between the current product definitions in IFM-CAP and the CAPRI market model (see Annex). The sequential iteration approach presented in Figure 1 need to be adjusted to account for the exchange of deltas between the models. This is presented in the Figure 2. Here the sequential iteration approach using percentage changes of price and supply changes is presented for, IFM-CAP at the left and CAPRI at the right.

The baseline point of the CAPRI is obtained using information on trends and expert information (AGLINK) indicated in grey in the right. The changes of price between the baseline and the base year define the baseline scenario of IFM-CAP presented by the grey point on the left. The absolute supply quantity and the price differ between the models indicating differences in absolute values between the data bases. We assume that the unknown marginal cost curve (supply curve) of the IFM-CAP in the calibration point shifts rightwards due to a shock (decrease of marginal costs and hence an increase in supply). The aggregated farm model supply increases to given baseline prices from the calibration point to Q1. ΔQ1is defined as the changes between QBaseline and Q1. This information is included in CAPRI by adjusting the constant term of the MS supply function to pass through the blue point at S1 ($p_{baseline}$, Q1). The market module solves as described in Figure 2 at the green point on the supply function (p1, quantity not marked). The price drop in CAPRI from the baseline to p1 is implemented in IFM-CAP which defines supply Q2. The resulting ΔQ2 is introduced in CAPRI and solved at the green point on the supply function S2. The observed price p2 define Δp2 which again is introduced into IFM-CAP to calculate (Q3). This is repeated until the model converges.

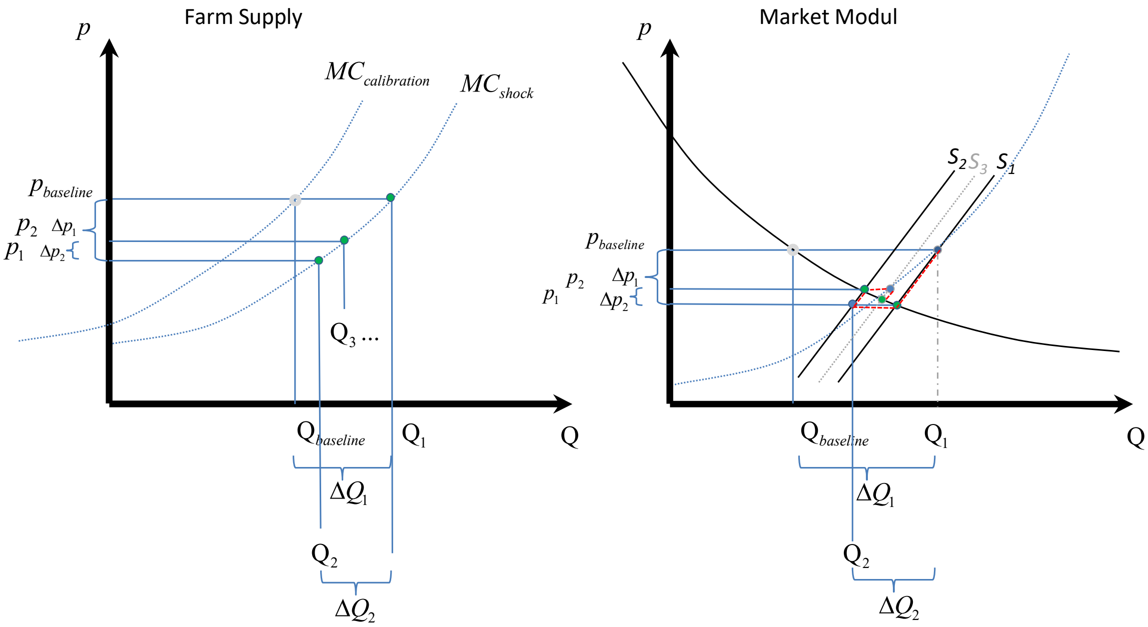

Figure 2. Sequential Calibration based on deltas

Source(s): Own compilation.

Figure 2 only depicts one commodity. The linkage approach needs to be operational for all commodities and feed demand in the countries covered by IFM-CAP as indicated in the Annex. In addition, in the annex the list of commodities of the market model in CAPRI is given and needs to be linked to the product list of IFM-CAP. Hereby feed needs to be mapped into the products.

2.1.3 Technical Implementation

A linkage of CAPRI and IFM-CAP is successful when the overall execution time, for at least some regions, allow sufficient repetitions to simulate robust and reliable results. To achieve this goal, we developed a "core" version of IFM-CAP, which consists only of i) the model formulation of the supply model (template model) and ii) the definition of the required parameters and sets of the supply formulation, ignoring other code and data parts required for calibration, baseline run or fodder consistency. With this we tested different ways to load data from the IFM-CAP database such that the execution time could be minimized and to run or divide the model in different units by farm, Nuts2. This separation allowed to make full use of parallel processing and at the same time to have a transparent way to debug the system. The developments have been committed to the SVN branch for SUPREMA[1]. Tests reveals that a full run of all models require less than 25 minutes. As the parallelization works by Nuts2 region, the minimum time is given by the regions with the higher number of farms, typically Denmark. Under suprema we agreed to run at 4 MS with the linkage, which means 47 Nuts2 region including Denmark as largest regions. To reduce the execution further we tested a random selection to reduce the farm number to let a sub-sample mimic the supply behavior of the full sample of farms in the Nuts2 region. Test for Denmark revealed that deviations are within +-22% and half of the changes are even less than +-5% compared to the case when all 1800 farms are simulated. We concluded that for receiving the price feedback from CAPRI the simulation with a reduced sample, particular for Denmark to further decline the execution time pays off. In the next table the differences between different sample sizes have been tested and reported:

[1] https://svn.jrc.es/repos/IFM-CAP/branches/Suprema

Table 1. Percentage changes in supply in dependence of the sample size

	supply change from yield and cost shock* in % using full sample 1,800 farms in DK compared to the baseline	Deviation in % to the % change with 1,800 farms for the scenario in 2.1.4 Farm sample: 200	:800	:1500
Soft Wheat	45	3.41	-2.58	-0.19
Rye	63	16.57	-3.18	-2.03
Barley	67	-11.69	-3.91	-1.61
Oats	64	-14.86	11.62	0.96
Grain Maize	62	-29.24	-21.22	11.24
Other cereals	70	-20.54	0.62	-0.03
Rape	31	19.61	-4.55	-0.79
Pulses	790	-20.00	-8.23	-1.19
Potatoes	119	-40.79	10.27	5.62
Sugar Beet	87	-72.87	1.50	3.00
Other industrial crops	351	-12.11	0.52	0.46
Other crops	157	-26.07	-16.63	-3.71
Tomatoes	676	14.91	-12.08	1.13
Other Vegetables	18	155.60	10.20	3.00
Apples Pears and Peaches	157	323.03	21.98	-6.95
Flowers	95	0.16	0.02	0.08
Fodder maize	114	1.53	1.68	0.88
Fodder root crops	379	51.50	-9.71	-17.29
Fodder other on arable land	119	6.87	3.31	3.11

Source: IFM-CAP, own calculations; * The scenario description of the shock can be found below in section 2.1.4

With respect to the execution time of the CAPRI: this model was already optimized in several ways. Parallel processes are standard in CAPRI. The market model in CAPRI requires several minutes before a feasibility had been found. Therefore, and more generally, to reduce solution time, pre-steps had been introduced. Those are based on the assumption that cross-price between certain groups of products are generally small, so that the overall problem can be portioned in groups solved independently, and once a solution is found for all of those groups, the full model can be solved must faster.

Furthermore, another important factor, which determines the overall execution time, is how long it takes to find an equilibrium between IFM-CAP and CAPRI. The interaction between the market and the supply module in CAPRI is based on sequential iteration, where the market models are calibrated against the latest points in the price / quantity space simulated with the supply models. Afterwards, the market models are solved. The supply models in IFM-CAP (or CAPRI for regions) simulate then again, a solution, at prices which are an average from the last iterations. The process is repeated until differences between the last two iterations both in prices and quantities fall beyond a small threshold. The speed of this process depends how well the supply and feed demand reactions in the market model mimic the behaviour of the supply models, in our case IFM-CAP. If we just look at an own price

effects and supply, differences in reactions root in differences in the (unknown) slope of the implicit marginal cost curve in the programming models and the slope used for the supply function in the market model. So far, the slope terms were derived from the CAPRI supply models in conjunction with the so-called scenario solver from GAMS, which can be used for sensitivity analysis with regard to prices. To run an elasticity experiments it means to solve the model for each farm for all products and increase the price by a certain amount. For the mixed integer approach in IFM-CAP, such an approach was not feasible. First, the current solver used in IFM-CAP does not support the scenario solver option in GAMS. We tested other MIP solver in combination with the scenario solver and an implementation as a loop over all product and farms, but for all cases the experiment took several days for just one region. Hence the conversion behaviour of the current linkage had to rely on the estimates of the supply models of CAPRI. Simulation tests turned out that even the considered shocks let both models converge within a reasonable number of iterations.
Finally, we assume to have a calibrated CAPRI baseline for a certain simulation year, which is the same for the baseline in IFM-CAP. The baseline in IFM-CAP is consistent to CAPRI baseline, i.e. using information and assumptions regarding trends from CAPRI in Task 3.3.
CAPRI works as the "master" model, which calls IFM-CAP with a vector of price changes provided using the batch execution facility of the GGIG (reference). For this the GGIG was adjusted that the GGIG batch file, normally executed within the GUI, can be independently called via a windows batch file, and such that it accepts arguments from outside, to pass information from CAPRI (GAMS) to the IFM-CAP GGIG batch file. The resulting call from CAPRI to run IFM-CAP looks like the following:

```
java jars\gig.jar de.capri.ggig.BatchExecution  ifmcap.ini ifmcap_default.xml batch\suprema_shock.txt step.tl YieldShockCostAll 800
```

We provide all setting of the IFM-CAP GUI via ifmcap.ini and ifmcap_default.xml and execute the GGIG batch file suprema_shock.txt passing information from the CAPRI on the iteration step.tl, the scenario to run (yieldshockcostall) and the maximal number of farm sample (800) allowed at Nuts2. The GGIG suprema_shock.txt batch file looks like:

```
* -----------------------------------------
*
* General settings for batch file mode
*
* -----------------------------------------

 gamsexe = D:\gams\win64\24.7\gams.exe

 output dir = D:\public\gocht\2020\IFM_CAP\GUI\batchoutput
 work dir = D:\public\gocht\2020\IFM_CAP\gams
 Res dir = D:\public\gocht\2020\IFM_CAP\results
 Restart dir = D:\public\gocht\2020\IFM_CAP\results\restart
 Dat dir = D:\public\gocht\2020\IFM_CAP\dat
 scratch dir =D:\public\gocht\2020\IFM_CAP\results\temp

* --------------------------------
  task = Run IFM-CAP light Nuts2
* --------------------------------

  Print gams code to listing = offListing
  Symbol list = offSymList
  Symbol list with cross references = offSymxRef
  Include file listing = onInclude
  Solprint = Off
  Additional result type identifier = %1
  Limrow = 0
  Limcol = 0
  Scenario = %2
  max farm sample size in Nuts2 = %3

  startParallel

        Countries   = DK000000
        Nuts2 = DK000000
        execute=gamsrun
```

Figure 3. Example scenario file

Source: Own compilation.

The placeholders, like %1, are replaced with the argument passed to the GGIG batch file. The advantage is that CAPRI and IFM-CAP are clearly separated, and the parallelisation is obtained by IFM-CAP rather than by CAPRI. In addition, it allows a transparent way to debug IFM-CAP using the batch output with the HTML overview and the linked GAMS listing files. To follow the run during the CAPRI run a popup windows similar to the window when executing a batch file in the GGIG GUI appears and closes when the run is over as directed:

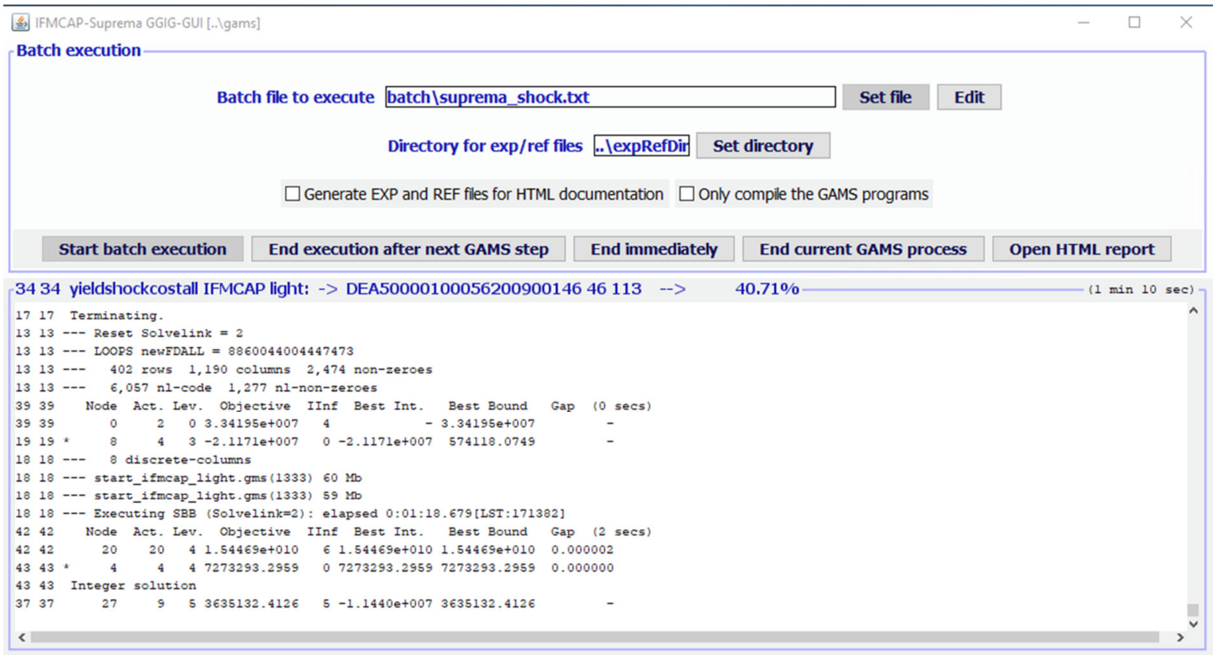

Figure 4. Popup windows to inspect the IFM-CAP run called from CAPRI

Source: CAPRI GUI.

The linkage is therefore achieved by running a scenario (or baseline scenario) in CAPRI defining all relevant option for IFM-CAP and calling independently IFM-CAP during each iteration in CAPRI.
The following sequence of steps are conducted

1. CAPRI runs the supply models for all regions including regions not covered by IFM-CAP.
2. CAPRI calls IFM-CAP to simulate the supply in the regions covered by IFM-CAP. During the first iteration CAPRI prices are not changed, however, other parameters due to the policy scenario in IFM-CAP.
3. To calculate the percentage differences, we also run during the first iteration the baseline of IFM-CAP.
4. The changes in supply from the first iteration are applied to the production (products and feed) at MS level for the market model.
5. The market model is solved with the new supply changes to receive a new vector of prices.

Step 1-5 is repeated as long as the total change in prices is less than a certain threshold (total sum of quantity changes is less the 0.05%). After we explained the general settings in the CAPRI GUI, we discuss the different steps.

Table 2. Iteration report on price changes and convergence

	Number of iteration															
Region	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S1 6
WBA	86	66	17	7	3	1	1	0	0	0	0	0	0	0.0	0.0	0.0
EU-WEST	197	166	72	32	12	8	5	3	2	1	0	0	0	0.1	0.0	0.0

EU-EAST	164	169	99	112	30	42	20	5	7	5	2	2	1	0.1	0.1	0.0
EU	197	169	99	112	30	42	20	5	7	5	2	2	1	0.1	0.1	0.0
TOT	197	169	99	112	30	42	20	5	7	5	2	2	1	0.1	0.1	0.0

Source: Own compilation.

Notes: %change to the iteration for the scenario run below; Numbers are sum of price changes compared to the iteration before

2.1.4 Scenario “conversation of agriculture to organic farming”

We apply a yield and cost changes observed in FADN conventional (non-organic farms) and organic farms to all conventional farm in IFM-CAP for the regions Denmark, Germany, Belgium and Ireland and solved IFM-CAP using price feedback from the market model in CAPRI as discussed above.
The scenario assumes that all conventional farms in IFM-CAP now operate with yields and costs as their organic counterparts in the regions. So, we simulate a complete conversion of farm to organic agriculture, applying the % yields and cost differences observed in FADN. The reduction of yields for the scenario are estimated at national level for cereals, soft wheat, milk from dairy cows, Sugar beet, group, fruits, grass production, maize, oils, permanent and vegetable crops. The estimated yields differences are mapped to the main product of the IFM-Cap and corresponding production activities[2]. The cost differences between organic and non-organic farms have been estimated for arable crops for the categories: fertilizer, seeding, pectizes and other costs at MS level by farm type. The magnitude of the yield and costs changes applied by crops at MS level are presented in the following tables. All results are compared to the SUPREMA baseline for market effects using CAPRI for supply and income effects using IFM-CAP baseline.

Table 3. Costs per ha aggregated for all farms and crops in the scenario and percentage difference to baseline

Country	Mineral fertilizer	Seeding	Plant protection	Other costs including machinery
Belgium	126	148	94	90
	-37%	-37%	-44%	-30%
Denmark	94	151	74	91
	-50%	-15%	-45%	-38%
Germany	124	106	75	70
	-32%	-11%	-40%	0.7%
Ireland	63	29	12	15
	-59%	38%	-52%	11%

Source: Own compilation.

Table 4. Absolute yields in tons per hectare in the scenario and applied changes to the non-organic farms

Crops	Belgium	Denmark	Germany	Ireland
Soft wheat	5.48	4.09	4.27	4.71
	-43%	-40%	-44%	-53%
Rape	2.14	2.63	1.69	2.07

[2] CERE.DWHE,RYEM,BARL,OATS,OCER, SWHE.SWHE, FRUI.APPL,OFRU,CITR,TAGR; GRAS.PGRA,RGRA; MAIZ.MAIZ; MILK.DCOW; OILS.(RAPE,SUNF,SOYA,OOIL); PERM .(OLIV,TABO,TWIN,NURS,FLOW,NECR); SUGB .SUGB; VEGE .(TOMA,OVEG)

	-52%	-43%	-58%	-48%
Pulses	6.1	3.65	3.13	6.99
	1%	7%	1%	-4%
Potatoes	47.49	36.35	40.46	27.72
	-1%	-1%	-3%	-14%
Sugar Beet	104.86	60.8	80.23	
	-2%	-11%	-3%	
Other Vegetables	22.99	70.72	29.32	
	-45%	0%	22%	
Apples Pears & Peaches	18.14	13.18	15.73	6.71
	-50%	-35%	-51%	-64%
Fodder maize	48.95	12.54	19.15	18.48
	0%	-1%	6%	0%
Fodder other on arable land	26.7	8.73	11.17	25.1
	0%	2%	0%	0%
Dairy Cows	7.82	10.29	8.14	6.45
	-19%	-10%	-19%	-14%

Source: Own compilation.

2.1.5 Results

We first analyze the market balance of the EU for products mostly effected in the scenario and show that for most products imports into the EU increase and exports decrease. This is triggered by higher prices due to decline production in the regions with extensification. We further analyze the price changes for the products in countries where organic yields and costs are applied to non-organic farm. To highlight the advantage of the model linkage, we compare production and land use received for IFM-CAP with and without the linkage. The results were obtained with 16 iterations between IFM-CAP with the market module in CAPRI to receive an equilibrium for supply and demand, equivalent to four hours of computational time as IFM-CAP requires to run per iteration for in about 15 min for 1 iteration.

The extensification scenario reduced supply in Germany, Denmark, Belgium and Ireland and resulting supply and price changes are not compensated by other EU regions but also by an increase in imports from outside of the EU. We only present commodities with a deviation of more than 5% from the baseline. The market balance for the EU shows that particular wheat production is reduced by 10% and exports reduced 25% and imports increased by 26%. Close substitutes to wheat are also increased namely other cereals, barley by additional imports and reduced exports. Oats and Pulses, which hat only smaller yield reduction in non-organic farms, get a comparative advantage and increase with 5-6% in the EU. Higher fodder prices for pork meat production let the net production in the EU slightly decline by 2%, whereas human consumption does not change much, and the resulting demand gap is closed by addition imports 10% and reduced exports -7%. Beef production declines as a consequence of higher fodder costs and also reduced revenues from milk. Milk production increases slightly in the EU.

Table 5. Market Balance of the EU for selected positions in million tones

	Net production - [1000 t]	Human consumption plus losses [1000 t]	Imports without intra trade [1000 t]	Exports without intra trade [1000 t]
Wheat	134323	64963	3189	17863

	-10%	0%	26%	-25%
Barley	58298	11630	385	8345
	0%	0%	12%	-6%
Oats	10766	1360	478	431
	5%	0%	5%	1%
Grain maize	66516	7460	10984	2753
	3%	0%	6%	-8%
Other cereals	16587	1302	6278	35
	5%	0%	3%	-12%
Pulses	3492	1598	1839	399
	6%	1%	-3%	8%
Beef	6977	8130	1161	10
	-2%	-1%	6%	-11%
Pork meat	23904	20710	181	3186
	-2%	0%	10%	-7%

Source: Own compilation.

The price effects for the countries affected in the scenario is given in the next table. The price changes without the linkages results from an aggregation effects when applying the scenario different farm production and hence aggregated prices at country level are obtained. With the market model interlinked all prices increase. For pork meat and rye we observe the highest price increases up to 20% in the equilibrium point.

Table 6. Aggregated producer price changes (min and max) for the four countries: Germany, Denmark, Ireland and Belgium with and without a linkage to the market model for all farms in IFM-CAP

	Price changes without linkage compared to the baseline		Price changes with linkage compared to the baseline	
	max	min	max	min
Soft wheat	0%	-1%	10%	9%
Rye	-1%	-3%	20%	15%
Barley	0%	-1%	12%	11%
Oats	1%	-1%	16%	13%
Grain maize	4%	0%	7%	6%
Other cereals	9%	0%	20%	10%
Rape seed	-1%	-4%	13%	11%
Sunflower seed	8%	8%	15%	15%
Soya seed	-3%	-3%	6%	6%
Pulses	3%	-1%	6%	-1%
Tomatoes	5%	5%	6%	1%
Apples pears and peaches	2%	2%	8%	6%
Other fruits	2%	-9%	4%	-8%
Other industrial crops	5%	-5%	5%	-5%
Fodder maize	3%	0%	8%	4%
Beef	2%	-2%	9%	7%
Pork meat	1%	1%	20%	3%

Sheep and goat meat	-7%	-7%	8%	7%
Eggs	0%	-5%	0%	0%
Young male calf output	9%	-4%	10%	1%
Young female calf output	9%	-4%	10%	1%

Source: Own compilation.

Similar to the table above we can present the supply change compared to the and without the linkage. Here we present the effect of the two large countries Germany and Belgium.

Table 7. % percentage change in supply in IFM-CAP for the extensification scenario with linkage to the market model compared to without the linkage

	Belgium	Germany	Ireland
Rye and Meslin	2.26%	18.90%	-
Oats	16.84%	31.07%	31.86%
Other cereals	0.43%	4.43%	4.76%
Pig fattening	1%	0%	2.67%

Source: Own compilation.

2.1.6 Summary and Conclusion

Over the past decade, a considerable amount of literature on model linking in the broader context of (agricultural) land use and commodity markets was published (e.g. Britz, 2008; Britz & Hertel, 2011; Britz et al., 2011; Ewert et al., 2011; Leip et al., 2008; Rosenzweig et al. 2013; Schönhart et al. 2011). The push for model integration across scales or disciplinary boundaries is driven by increased awareness of complex interactions and their relevance for successful policy design when trying to address challenges such as loss of biodiversity, nutrient emissions, food security or climate change (e.g. Liu et al. 2015). At the same time, advances in computing power and modelling techniques continuously push the frontiers of modelling with respect to scope and detail improving quality and lowering cost of more integrated approaches. Initial moves towards technically fully integrated quantitative assessment of approaches (van Ittersum et al. 2008) were discarded in favour of more flexible linking as we proposed in this section. The market models of CAPRI provide price feedback for the farm level models in IFM-CAP, whereas the farm level model returns the agricultural supply as information to the market model. The interlinked models improve the analysis when the farm supply model catches more realistically the production opportunity set of the farm, normally closely linked to the specialization, the natural condition and the policy.

However, for an interlinkage of farm level supply models and product market models there exists no standard procedure as existing approaches differ depending on the models and the analysis. IFM-CAP is developed by IPTS EU-Commission, CAPRI is developed within the CAPRI consortium, independently of each other. Although both models are programmed in GAMS, an independent institutional structure requires a model linkage which operates without the need of coordinating both model developments together. It requires a way which reduces the changes in the models to a minimum but provide an interface which still allows to run the link in a transparent and robust way. This prohibits the option of a direct inclusion of program code of one model in another. Although such a link has many advantages (debugging and application) particular during the developing process of the linkage, the disadvantage is that changes in the respective models are often not reintegrated in the main version and lost. To avoid such a situation a well-defined, applicable and well-known interface is required. In the case of the linkage between CAPRI and IFM-CAP we employed a facility of the GGIG-GUI: The batch execution facility. The GGIG has a batch facility to run the model. This facility allows to define all settings, e.g. options, parallelisation, setting, scenarios and regions, task, gams versions, in a compact manner independently of the linkage in the batch text file. So far, this facility was applicable via the GUI of GGIG and no automatization in form of a shell process possible. This was changed and further developed in SUPREMA such that the batch text file can be called from another GAMS process (or Windows CMD) and that information can be passed as arguments to the batch file, when required. This allows to keep settings and options, not related to the linkage, in the initial environment (batch file of the GGIG) and pass only a minimum set of information from the market model of CAPRI to the batch execution of the IFM-CAP model. This setup allows that the models can be independently tested to ensure error free execution before sharing the model versions to establish the link. With this setup we ensure that each model's identity is maintained (no mix of concepts, indicators, shared code snippets) and that the link follows a clear and transparent workflow with the possibility to check the model run using the tracking facility (HTML output), part of the batch facility.

The scenario application showed that the feature of organic and non-organic farming systems in IFM-CAP and the product market model in CAPRI can be linked to yield a quite realistic simulation of a highly relevant scenario that is not amenable to similar analysis in any of the two unlinked models. However, we admit that the current application is still a didactic approach, rather than a proof of the concept, and needs further elaboration. The scenario was certainly an extreme shock to test if the model-linkage converges. The scenario needs to be fine-tuned, means less drastic conversion rate and a brother coverage of regions. In addition, more indicators for income and environmental analysis derived from IFM-CAP are required to present and analyse the effects of the shock on the population of different farming types and economic size classes.

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2.1.8 Annex

Table 8. Linking products and activities between IFM-CAP and CAPRI

Products for feeding in IFM-CAP	Output from IFM-CAP activities	Product List IFM-CAP	Feed aggregates in CAPRI	Description	Link to CAPRI
x	x	SWHE	FCER	Soft wheat	SWHE
x	x	DWHE	FCER	Durum wheat	DWHE
x	x	RYEM	FCER	Rye and meslin	RYEM
x	x	BARL	FCER	Barley	BARL
x	x	OATS	FCER	Oats	OATS
x	x	MAIZ	FCER	Grain maize	MAIZ
x	x	OCER	FCER	Other cereals	OCER
x	x	RAPE	FOTH	Rape seed	RAPE
x	x	SUNF	FOTH	Sunflower seed	SUNF
x	x	SOYA	FOTH	Soya seed	SOYA
x	x	OOIL	FOTH	Other oil	OOIL
	x	OIND		Other industrial crops	OIND
	x	NURS		Nurseries	NURS
	x	FLOW		Flowers	FLOW
	x	OCRO		Other crops	OCRO
x	x	MAIF	FMAI	Fodder maize	MAIF
x	x	ROOF	FROO	Fodder root crops	ROOF
x	x	OFAR	FOFA	Fodder other on from arable land	OFAR

x	x	PARI	FCER	Paddy rice	PARI
x	x	OLIV	FOTH	Olive oil	OLIV
x	x	PULS	FPRO	Pulses	PULS
x	x	POTA	FOTH	Potatoes	POTA
	x	SUGB		Sugar beet	SUGB
x	x	TEXT	FOTH	Flax and hemp	TEXT
	x	TOBA		Tobacco	TOBA
x	x	TOMA	FOTH	Tomatoes	TOMA
x	x	OVEG	FOTH	Other vegetables	OVEG
x	x	APPL	FOTH	Apples pears and peaches	APPL
x	x	OFRU	FOTH	Other fruits	OFRU
x	x	CITR	FOTH	Citrus fruits	CITR
x	x	TAGR	FOTH	Table grapes	TAGR
x	x	TABO	FOTH	Table olives	TABO
	x	TWIN	FOTH	Table wine	TWIN
x	x	PGRA	FGRA	Permanent grassland	GRAS
x	x	RGRA	FGRA	raw grasing	GRAS
x	x	STRA	FSTR	Straw	
	x	OANI		Other animals output	OANI
	x	YCAM		Young male calf	YCAM
	x	YCAF		Young female calf	YCAF
	x	YPIG		Young piglet	YPIG
	x	COMI		Milk for sales	COMI
x	x	COMF	FCOM	Milk for feeding	
	x	BEEF		Beef	BEEF
	x	PORK		Pork meat	PORK
	x	SGMI		Sheep and goat milk	SGMI
x	x	SGMF	FSGM		
	x	SGMT		Sheep and goat meat	SGMT
	x	POUM		Poultry meat	POUM
x		WHEP	FMIL	Whey powder	WHEP
x		CASE	FMIL	Casein	CASE
x		WMIO	FMIL	Whole milk powder	WMIO
x		SMIP	FMIL	skimmed milk powder	SMIP
x		FRMI	FMIL	Fresh milk products	FRMI
x		RICE	FCER	Rice milled	RICE
x		SUGA	FOTH	Sugar	SUGA
x		RAPO	FPRO	Rape seed oil	RAPO
x		SUNO	FPRO	Sunflower oil	SUNO
x		SOYO	FPRO	Soya oil	SOYO
x		RAPC	FPRO	Olive cake	RAPC
x		SUNC	FPRO	Sunflower cake	SUNC
x		SOYC	FPRO	Soya cake	SOYC
x		DDGS	FPRO	Distillers Dried Grains with Soluble	DDGS
x		FENI	FENE	??	FENI

Source: Own compilation.

2.2 Model linkage GLOBIOM-CAPRI

2.2.1 Background

The collaboration of CAPRI and GLOBIOM team goes back to a service contract on behalf of DG CLIMA in support of the 2011 EU Commission "Roadmap for moving to a competitive low carbon economy in 2050" that was prepared, among other work, by a "Model based assessment of EU energy and climate change policies for a post-2012 regime"[3] involving PRIMES, GAINS, GLOBIOM, and CAPRI. That project prepared the main interface currently used to pass on GLOBIOM baseline information to CAPRI.
This project was followed up by several others that partly involved an update and improvement of this main channel of interaction (e.g. most work under the EUCLIMIT projects). In addition, other channels have been explored

- detailed comparisons of the data base and projections at the country level were performed in the context of a model-based quantitative assessment of the economic, environmental and social impacts of an inclusion of the LULUCF sector in the EU greenhouse gas reduction commitments in 2011. These comparisons have been partly repeated in subsequent work, usually triggering database improvements
- a tightened link of CAPRI to GLOBIOM scenarios was developed under the FP7 AnimalChange project
- systematic comparisons of CAPRI, GLOBIOM, MAGNET and IMAGE projections according to the AgMIP template were carried out under the AgClim50 projects, yielding new insights
- under the EUCLIMIT-II project an approach has been developed to implement a coordinated carbon price scenario in CAPRI and GLOBIOM that could achieve given total mitigation targets for the combined agriculture and LULUCF sectors
- exogenous changes in CAPRI of forest areas and forest management per ha carbon effects (potentially taken from GLOBIOM) have been explored under the EcAMPA-3 project.
- In the context of long run mitigation efforts (mostly covered in SUPREMA WP3.3), a sensitivity analysis has been set up to investigate the effects of model linkage between MAGNET, GLOBIOM and CAPRI (described in another section of D2.2).

This section covers the well explored model linkage between CAPRI and GLOBIOM in the baseline context.

2.2.2 Technical and methodological linkage solution

Conceptually, the baseline should capture the complex interrelations between technological, structural and preference changes for agricultural products world-wide in combination with changes in policies, population and non-agricultural markets. Given the complexity of these highly interrelated developments, baselines are in most cases not a straightforward outcome from a model but developed in conjunction of trend analysis, model runs and expert consultations. In this process, model parameters such as e.g. elasticities and exogenous assumptions are adjusted in order to achieve plausible results, close to expert projections by the European Commission or FAO.
The GLOBIOM baseline has still many elements of a forward simulation, meaning that exogenous inputs like GDP and population growth are compiled, together with other exogenous assumptions like crop yield developments and their input intensity, feed conversion efficiency, or consumer

[3] See http://www.eurocare-bonn.de/projects/ghg_carbon/post2012regime/post2012regime.htm

preferences with respect to diets, and then the model is applied as in any policy scenario that differs from the baseline. Nonetheless some of these exogenous parameters are set to come close to external projections. Examples are dietary preferences or yields.
In the case of the AgLink / COSIMO modelling system of OECD/FAO, questionnaires are sent out to the OECD / FAO Member States covering all endogenous and exogenous variables of AgLink/COSIMO. The constant terms in behavioural equations are modified to reproduce the Member state expectations and the model is rerun, possibly repeatedly, until an accepted outcome is achieved.
Given its frequent link to other modelling systems the CAPRI system has not been designed to give a "stand alone" baseline like GLOBIOM or AgLink. Instead it takes external ("expert") forecasts as inputs, together with trend forecasts using data from its database, these are merged in a statistical procedure in several steps:

- Step 1 involves independent trends on all series, providing initial forecasts and statistics on the goodness of fit or indirectly on the variability of the series.
- Step 2 imposes constraints like identities (e.g. production = area * yield) or technical bounds (like non-negativity or maximum yields) and introduces specific expert information given on the MS level
- Step 3 includes expert information on aggregate EU markets, currently from AgLink and GLOBIOM. Because this requires some disaggregation to single MS but also because it often the key information steering the outcome, it is treated in a step distinct from (2).
- Depending on the aggregation level chosen the MS result may be disaggregated in subsequent steps to the regional level (NUTS2) or even to the level of farm types.

AGLINK currently features results at EU-15 and EU-13 level whereas GLOBIOM may directly offer results at the MS level, at least if the EU version of GLOBIOM is used. To make use of AgLink information the CAPRI trend projection tool includes a scaling mechanism where the country level results of step 2 are adjusted proportionally to give target values for step 3 that are consistent with the AGLINK results. However, as the AgLink information is only introduced in the form of target values, deviations are still possible.
Another difficulty relates to the fact that AGLINK projections currently run to 2030 while climate related applications require longer time horizons, perhaps to 2070, such as is provided by GLOBIOM. We should also note that by design AgLink will be quite reliable in the medium run perspective while GLOBIOM has a clear long run orientation. To make use of both sources CAPRI first computes a conservative, logistic extrapolation of AgLink to the long run. This extrapolation is then averaged with the GLOBIOM information with the weight for Aglink (extrapolation or original) declining over time to obtain the target values for the CAPRI baseline. The gradual change in the weights reflects our changing trust in AgLink vs. GLOBIOM information for longer time horizons. The fact that the weights are only changing gradually prevents jumps in the target values even in the case of Aglink and GLOBIOM projections moving in opposite directions.
Evidently this approach is quite removed from economic modelling. Instead it tries to synthesize the existing projections from various agencies, each specialised in particular fields and time horizons, in a technically consistent and plausible manner.
In essence the idea of merging with gradually changing weights is also applied for non-European countries that are not covered by the CAPRI trend projection tool. Due to the CAPRI focus on Europe this is happening in the context of another CAPRI module and in a simpler technical form. However, the bottom line is that CAPRI combines its own database with growth rate information adopted from Aglink and GLOBIOM to produce its own baseline.

2.2.3 Further developments foreseen in SUPREMA

Several options to further improve the linkages between GLOBIOM and CAPRI have been considered at the outset of SUPREMA. Some of them have been addressed in the context of the mitigation runs with model linkage, others had to be postponed to future work.

- An improved comparison of database, also considering the supply side parameterization, and projections is prepared with the mapping file developed under Task 2.1, yielding the AgMIP style enhanced Suprema template at the country level. These comparisons have been part of the scenario work under WP2.2 and WP3.3 and included bilateral trade results.
- A more ambitious undertaking would be to also perform comparisons at subnational level, for example NUTS2. In practice this would be ambitious for at least two reasons: (1) At least CAPRI does not use a standard NUTS2 classification in order to make use of certain data sets, such that the regional mapping issues are non-trivial (2) It may be expected that differences will be large at the regional level because the data bases are different (Eurostat vs grid information). Given the focus on other topics this option has not been pursued under SUPREMA.
- In view of the foreseen CAP and climate related scenarios additional co-ordination may be considered in the following areas: forest areas, forest management carbon coefficients, irrigation technologies and use. Including forest area information from GLOBIOM in CAPRI was part of the scenario setting together with MAGNET, while comparisons of carbon coefficients have been postponed to future work and the irrigation version of CAPRI has not been used to focus on the LULUCF extensions (described under WP2.3).
- GLOBIOM could use AgLink projections, and try to align with them up to 2030 to potentially avoid abrupt changes in trends when transitioning in the CAPRI system from AgLink baseline to GLOBIOM baseline, which is currently taken care off through the above described weighting procedure. This linkage has also been postponed to future work because resource constraints in the end did not permit a participation of GLOBIOM in the "mid-term exercise" of WP3.2.

2.3 Model linkage AGMEMOD-AGLINK

2.3.1 Background

This section describes the underlying method to align AGMEMOD EU Member States' results to aggregated outcomes of the AGLINK model as published by the EU Commission (EC, 2019) in the Medium-Term Outlook on an annual basis. In preparing the approach, the EU Commission supplies in a first step a set of assumptions for the general economic developments in EU Member States which comprise historical data and projections on population, GDP, inflation, and exchange rates. Also, the EU Commission provides regular updates and projections of the policy variables and budgetary allocations to ensure that those variables are in-line with AGLINK's outlook assumptions (EC, 2019). In the linked version world market prices of AGLINK are introduced as assumptions.
Note that, for convenience sake, it is assumed that the external outlook (here AGLINK outcomes) provides the 'correct values' for the projections in the whole projection period, to which the AGMEMOD quantities are matched. The approach discussed below primarily focuses on volumes or quantities (e.g. production, use, area) rather than prices. The basic mechanics comprise a flexible and workable procedure, which is running as post-simulation process and aligns the AGMEMOD outcomes for EU Member States so that the AGLINK outcomes are met at the aggregate EU level of the Medium-term Outlook (MTO) (EC, 2019).

2.3.2 Technical and methodological linkage solution

2.3.2.1 Requirements for AGMEMOD-AGLINK mapping

A list of variables of variables (see Table 9) has been defined for which outcomes are aligned and this will be done, where possible, on EU-15 (now 14) and EU-13 level whereas a number of criteria has to be fulfilled:

- Quantities of area use, animal stocks, yields, production, domestic use, per capita consumption should match as well on sub-region level i.e. EU-15 (EU-14) and EU-13 as on total EU level.
- Chosen procedure should be as simple and transparent as possible and at the same time as flexible as possible.
- Flexibility is required to enable in-depth analysis for Member States and certain markets which gain special attention during projects.
- Inconsistencies should be avoided which might cause problems in solving the model.
- Matching quantities should not affect the underlying calibration to the world market price provided by AGLINK.

2.3.2.2 Method and solution

To align outcomes of AGMEMOD with the Medium-Term Outlook results (EC, 2019), a scaling procedure was developed to match results at the EU-15 (EU-14) and at the EU-13 level in a stepwise approach:

1) AGMEMOD's unscaled results of the considered variable on certain variables like for example domestic use, production or area at Member State level are aggregated to EU-15 (EU-14) and EU-13 values;
2) These unscaled AGMEMOD values are compared to the respective values of the MTO of the EU Commission based on AGLINK;
3) Individual scaling factors are calculated so that AGMEMOD's unscaled results match demand, supply, area and animal numbers of the MTO;
4) In case of large differences parameters of behavioral equations in AGMEMOD are re-estimated for those products and activities which depict large difference in results;
5) In AGMEMOD an automatized procedure is run which calculates the scaling factors and applies to AGMEMOD's original outcomes to guarantee a match between AGMEMOD and AGLINK results at aggregated EU-15 (EU-14) and EU-13 level.

Table 9. Products and Activities in AGMEMOD to be aligned with AGLINK

Products	Activities
Soft wheat	Area
Barley	Animal numbers
Corn	Production
Rape seed	Domestic use
Sunflower seed	Food
Sugar beet	Feed
Sugar	Slaughtering
Cattle	
Beef	
Pigs	
Pork	
Poultry	
Milk	
Drinking milk	
Butter	
Cheese	
Skimmed milk powder	
Whole milk powder	

Source(s): Own compilation.

For the applied scaling mechanism, it was considered to implement a weighting procedure which may regard the quality of the underlying data and/or country specific estimates. A possible weighting procedure could alter the uniform approach for Member States where projection results are more reliable than for others. This approach, however, would require a detailed ex-ante analysis of all markets in all Member States. Preliminary experiments with a more sophisticated approach led to a momentarily turn-down because scaled outcomes on Member State level depicted a number of inconsistencies and implausible outcomes. As the outcomes of the scaling process additionally face a validation procedure with Member States based market experts at regional workshops these problems would lead to unnecessary discussions.

Instead, unified scaling factors are applied, i.e. if AGMEMOD results differ in the area use for soft wheat at the EU-15 level by +5% compared to AGLINK results, all soft areas in EU-15 Member States would be reduced by 5% (Salamon et al, 2017). Implemented as an ex-post model calculation, the scaling factors are then considered as an ex-post shift in the model-results, without affecting the equilibrium (Salamon et al, 2017).

Figure 5 (Salamon et al, 2017) displays a typical outcome when running the AGMEMOD model (variables have subscript A) and comparing its results to the external outlook (variables have subscript O). In the Figure the differences between the models can be seen already when looking to the different slopes (implying differences in response of suppliers and users-consumers between the models). But also, the 'location' of the curves in the price quantity-space is likely to be different. As a result, the endogenous equilibria as calculated from both models are likely to be different. For the case displayed in Figure 1 it can be noted that the AGMEMOD model relative to the external outlook overestimates the EU supply and underestimates EU demand. As a result, also the excess supply (or trade or exports) estimated by the AGMEMOD model is overestimated relative to the external outlook (e.g. QES-A > QES-O). As already mentioned, this outcome of AGMEMOD is already based on the same world market price level as for AGLINK. In Figure 5 this is indicated by expressing the 'equilibrium' price of AGMEMOD with an associated price level as projected under the AGLINK outlook, e.g. PA= f(PO) (Salamon et al, 2017).

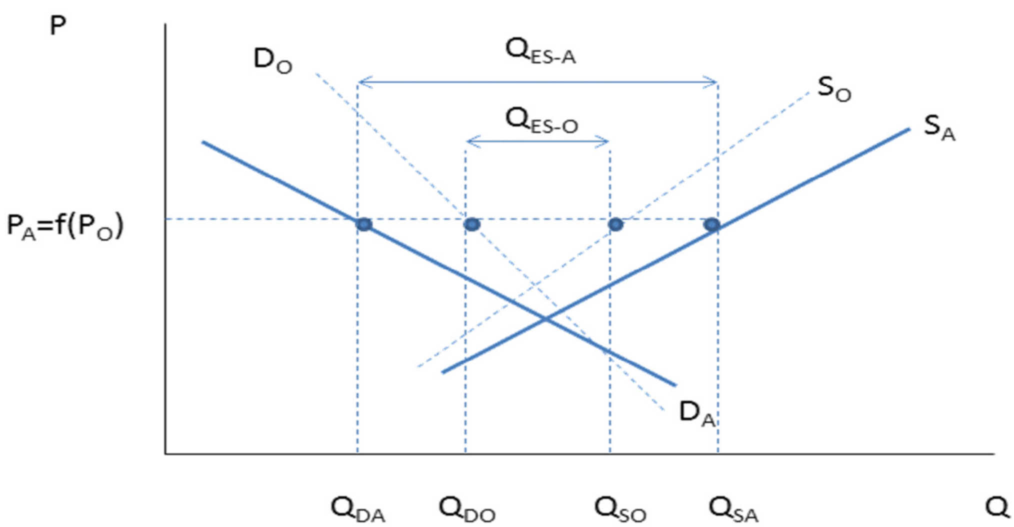

Figure 5. Comparing outcomes from two different market outlook models for a specific country or region

Source(s): Own contribution.

The required scaling factors on the demand and supply side will lower the supply in the AGMEMOD model and increase the demand in AGMEMOD until the excess supply under AGMEMOD will match with projected excess supply in AGLINK (Salamon et al, 2017).The choices during developing the matching procedure have been carefully selected. The 'unscaled' market balances for the key commodities have served as a guide for selecting those variables where scaling is required. While the scaling mechanism itself is programmed as an automatic procedure, the necessary choices have to be taken manually. Here it is strongly recommended to keep this 'semi-automatized' procedure, because final checks should be done 'outside' the model by the modeller and in particular market experts. The procedure of scaling is kept as simple as possible, because the main aim of this matching procedure is to use AGMEMOD as a 'downscale tool' for variables at EU sub-region level to individual Member States. The validation conducted by the market experts at Member State level may also feed back into the AGLINK outlook for the upcoming outlook process of the following year as the market experts are often more familiar with the Member State results than with the overall EU projections (Salamon et al, 2017). The market experts are provided with market balances in Excel format for those products which are of importance for the EU agro-food sector. Market balances are presented for all EU Member States (Belgium and Luxemburg are aggregated). Further a tool is made available which depicts the scaled and unscaled values to provide additional insights about the possible deviation attributed to the scaling process (Salamon et al, 2017; AGMEMOD Consortium, 2020).

2.3.3 Effects of the scaling procedure

In the following, the effects of the linkage are depicted in more detail. To achieve the linkage, average differences between the original AGMEMOD results and the AGLINK outcome are calculated separately for EU-15 and EU-13 for the period 2020-2030. As a base the outcomes of the MTO 2019 (EC, 2019) are compared to the AGMEMOD regional results of the AGMEMOD Outlook Workshop in Brussels 2020 which are based on the same assumptions (AGMEMOD Consortium, 2020). Negative values indicate that AGMEMOD outcomes are overshooting AGLINK's. In the following the scaling differences are described for certain product groups. A detailed description of the Mnemonics can be found in the following Table 10:

Table 10. Overview of Mnemonics in AGMEMOD

Product/Activity	Description	Product/Activity	Description
WS	Soft wheat	DC	Dairy cows
BA	Barley	CC_KTT	Total cattle slaughter
CO	Corn	HP_KTT	Total pigs slaughter
RS	Rapeseed	DC_CCT	Total dairy cows ending
UF	Sunflower seed	YPC	Yield per cow
PK	Pork	SPR	Production
BV	Beef	UDC	Domestic use
PO	Poultry	UPC	Per capita consumption
CD	Cheese	AHA	Area harvested
BU	Butter	YHA	Yield (crops)
CM	Cow milk		

Source(s): Own compilation.

Average differences with respect to crop area (AHA) and crop yields (YHA) are depicted in Figure 6. AGMEMOD results for the EU-15 tend to be slightly above the AGLINK results for most crops. Especially for yields AGMEMOD projections overshoot AGLINK's for all crops presented. Also, for cereals in the EU-15 areas projections are slightly higher for AGMEMOD. Somewhat higher differences can be observed for rape seed (RS) and sunflower seeds (UF). Thus, AGLINK shows a more conservative projection for the development of the EU rapeseed yields and area development. This is partly counterbalanced for oilseeds as sunflower area in AGLINK projections are higher.

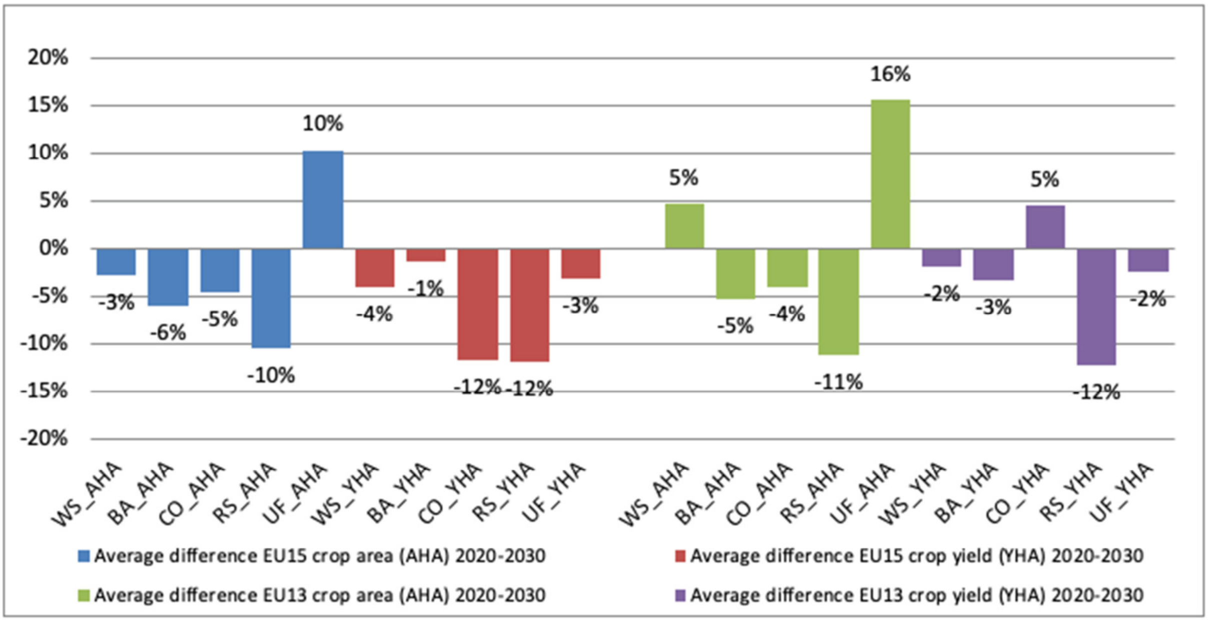

Figure 6. Average differences for crop area (AHA) and yields (YHA) in the EU-15 and EU-13

Source(s): Own compilation.

Comparing the differences to the EU-13, they do not reflect such homogeneous pattern. Hence, yield projections for crops are, in general, higher in AGLINK than in AGMEMOD. In contrast, the variations in area projections for the EU-13 are more markedly with barley, corn and rapeseed whereas AGMEMOD surpasses AGLINK while for soft wheat and sunflower it is the other way around.

Higher differences in outcomes of smaller products like sunflower seed between AGLINK and AGMEMOD may be a consequence of the different aggregation levels in both models. Here, AGMEMOD delivers more detailed area information on MS level. Thus, an overestimation in area of a rather small product like sunflower might easier occur under AGLINK. For the more important and bigger product like soft wheat it can be assumed that data availability is more precise leading to smaller differences between AGLINK and AGMEMOD data. When interpreting these results, it seems that AGMEMOD is more conservative regarding the EU-13 countries, since the share of countries with a positive scaling difference is higher in this EU group.

When domestic use (UDC) is compared, it appears that average differences for the EU-15 are somewhat lower than for the EU-13 (Figure 7). Deviations are in particular marked with barley with negative difference for the EU-15 and a positive for the EU-13, indicating a quite high divergence in the feed use of both regions. In case of wheat and corn projections of AGMEMOD and AGLINK, models are quite close for the domestic use of the EU-15. In contrast, also the use of wheat and corn deviates between AGLINK and AGMEMOD with respect to the EU-13. In principle, one can state that the EU-13 aggregate is more difficult to be reflected as developments and conditions across the EU-13 Member States are more diverse. Additionally, a lack of robust long-term data may jeopardise projections' quality in general and in the case of domestic use in particular as this variable is used to close balances and stocks or stock changes are only sparsely available.

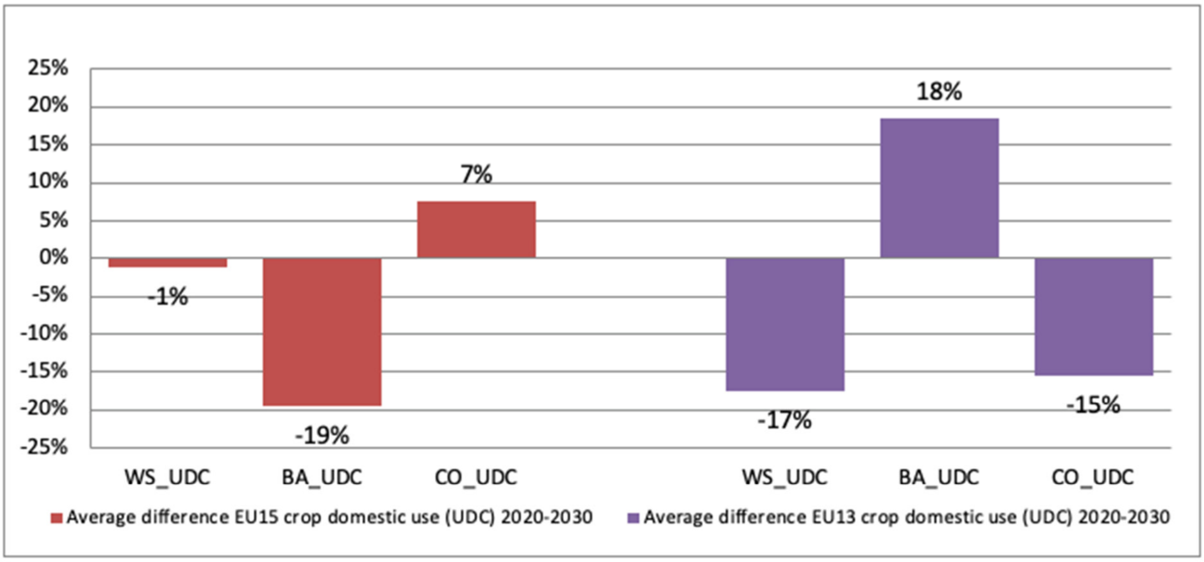

Figure 7. Average differences for crop production (SPR) and domestic use (UDC) in the EU-15 and EU-13

Source(s): Own compilation.

Additionally, a lack of robust long-term data may jeopardise projections' quality in general and in the case of domestic use in particular as this variable is used to close balances and stocks or stock changes are only sparsely available.

With respect to the animal sector, cattle and pig slaughtering (KTT) is to be found in Figure 8, where the average difference between AGLINK and AGMEMOD for the EU-15 and the EU-13 are limited. While the average AGMEMOD outcomes for the EU-15 have to be reduced to match with AGLINK, they have to be scaled up in the case of EU-13 cattle slaughtering. In this context, the development in live trade of animals between EU Member States has to be considered as well, which is not covered in AGLINK and therefore impedes the overall picture of slaughtering across Member States. In total AGMEMOD seems to be slightly more positive about the number of future slaughtering.

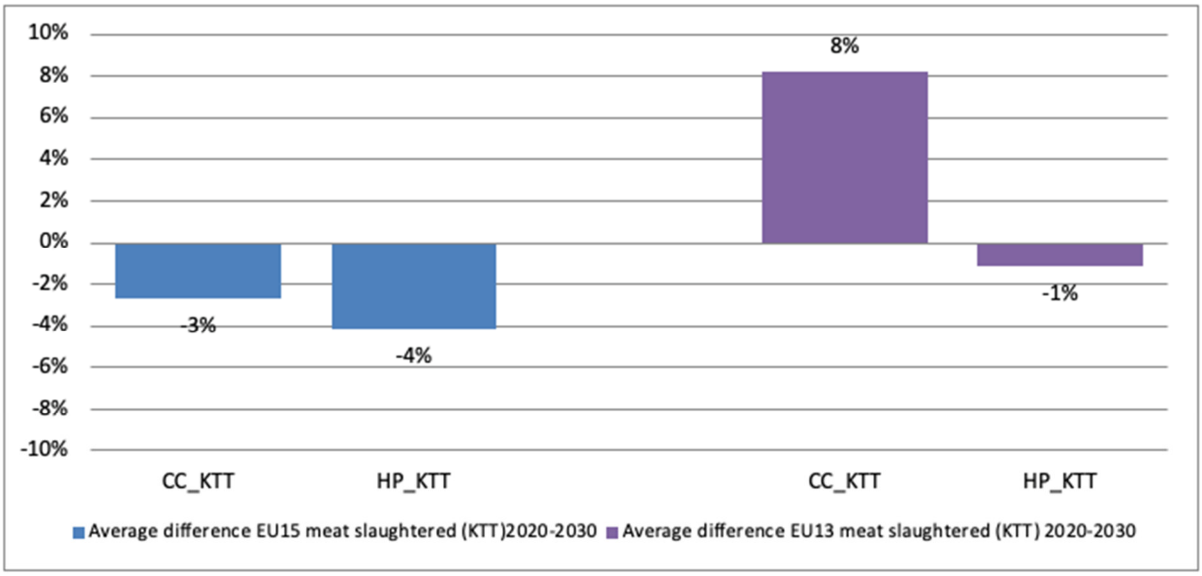

Figure 8. Average differences total animals ending (CCT) and meat slaughtered (KTT) in the EU-15 and EU-13

Source(s): Own compilation.

When projections of production (SPR) and domestic use (UDC) on meats are compared (see Figure 9), AGLINK outcomes are normally higher on average in the time period 2020-2030. Most results need to be upscaled, whereas for EU-15 the average deviations are relatively small. Only production of beef depicts a negative deviation indicating that AGMEMOD figures would need to be reduced to match AGLINK. The deviations are even a bit lower compared to the slaughtering which would reflect differences for the average slaughter weights of AGLINK.

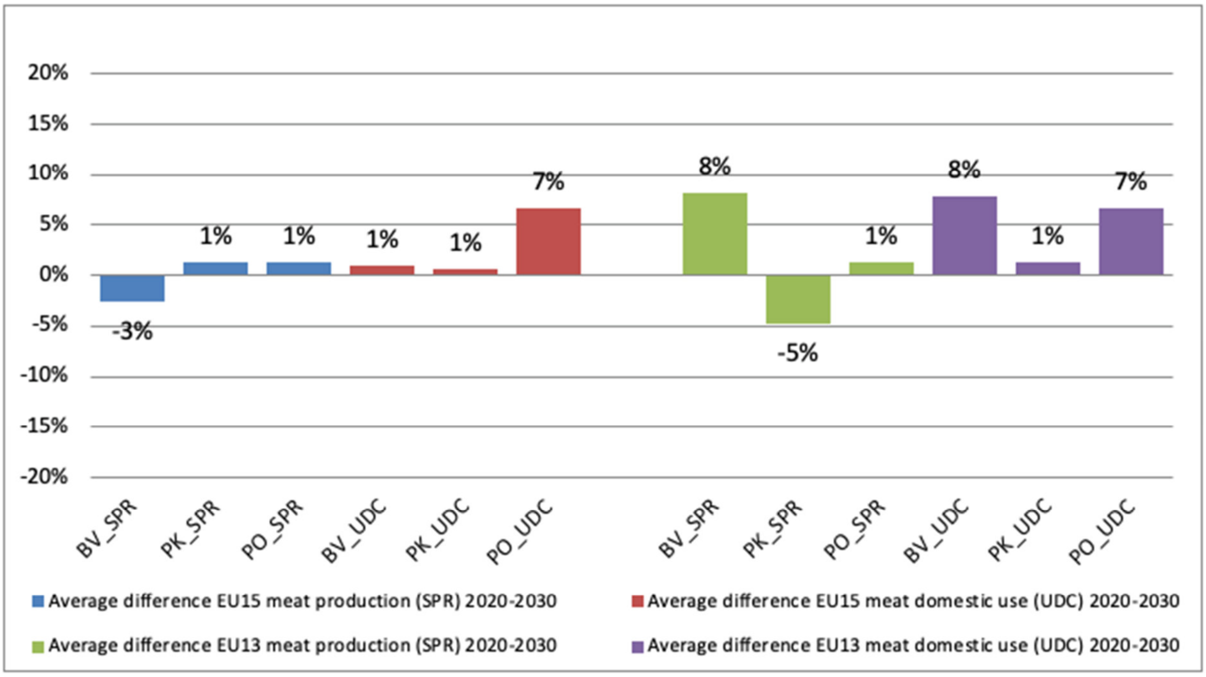

Figure 9. Average differences in meat production (SPR), meat domestic use (UDC) and meat per capita use (UPC) in the EU-15 and EU-13

Source(s): Own compilation.

Hence, for meats in the EU-15 AGMEMOD is more pessimistic concerning the prospects in the domestic use of poultry (PO_UDC). Here, AGMEMOD shows a somewhat bigger deviation from the overall AGLINK outcome for the EU-15. Nevertheless, still there is a tendency of a bit higher scaling requirements in most cases for in the aggregated EU-13 results of AMEMOD. Except for pork production (PK_SPR) the average deviation is positive and thus, depicting a requirement to increase production and use of AGMEMOD to make results equal to AGLINK's. In particular, domestic use needs to be adjusted, whereas pork is less affected than beef and poultry. Especially the demand for beef in most EU-13 countries is very weak.

The last sector which is considered in this section is the dairy sector. First of all, the average differences of dairy cows (DC_CCT), yield per cow (CM_YPC) and cow milk production (CM_SPR) in the time period of 2020-2030 is represented in Figure 10. Compared to the other sectors descripted previously, the graphic shows only minor differences after scaling the AGMEMOD outcome to AGLINK results for the EU-15. Since there is no strong growth in this sector in the EU-15 and since it is generally more static after transition period of the quota abolition and the implementation of environmental restrictions no huge changes in production are expected which could lead to bigger differences in model projections. In contrast is the situation in EU-13, where dairy cow herds are also relatively stable, while growth in yields per cow are stronger and thus differences in model outcomes are more likely. Therefore, higher scaling differences can be observed (+11 %) especially for milk yield per cow resulting also in a required increase in cow milk production of +8 % for the EU-13.

Figure 10 depicts the deviations between AGLINK and AGMEMOD for butter (BU) and cheese (CD) for production (SPR), domestic use (UDC) and per capita consumption (UPC) in the time-period 2020-2030.

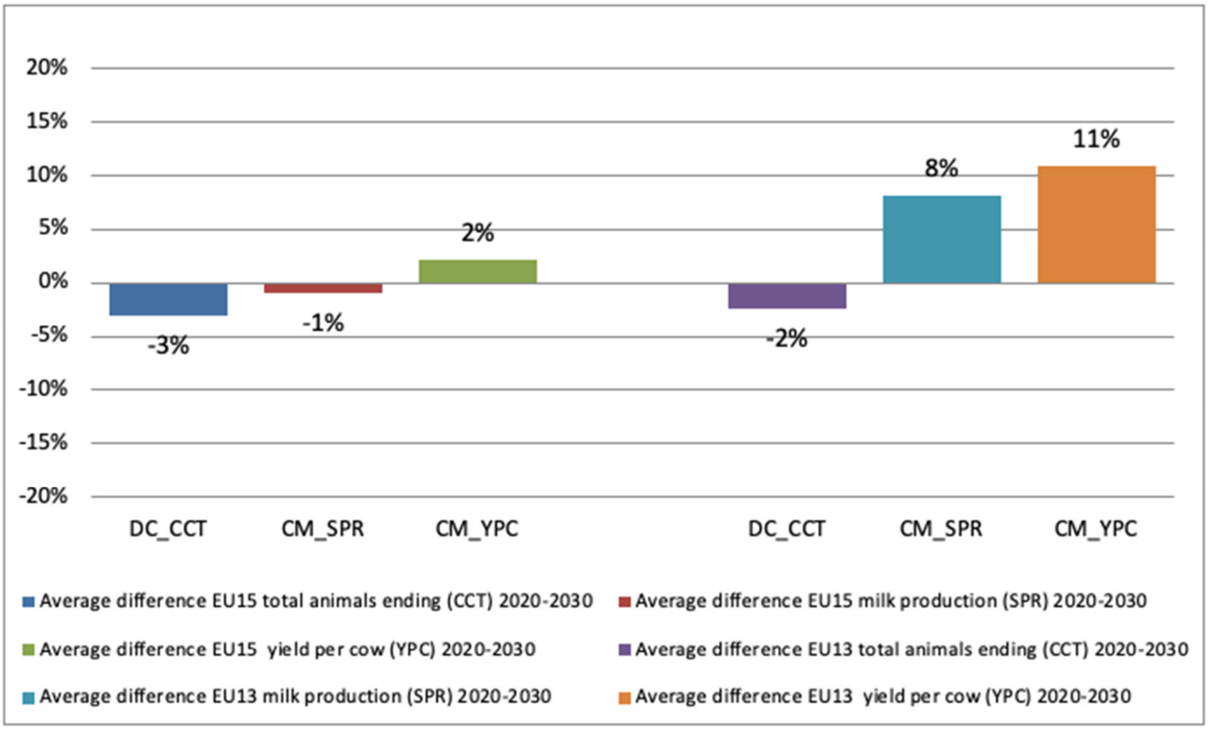

Figure 10. Average differences in cow milk production (SPR), numbers of dairy cows (CCT) and yield per cow (YPC) in the EU-15 and EU-13

Source(s): Own compilation.

In contrast to the animal herd sizes and developments in the yield per cow, the observed differences after scaling show more variation. Again, it becomes obvious, that the EU-15 scaling differences are only minor compared to the differences in the EU-13. However, scaling adjustments still result in a difference of above 5% for the results in the products considered. Again, the EU-13 results of AGMEMOD for butter and cheese are required to be scaled up in general, resulting from to conservative projections in AGMEMOD. In total the milk sector as a whole seems to be projected less optimistic than the AGLINK projection is. In the case of butter, both models show a constant difference in model results for production and domestic use; the differences between the EU-15 and the EU-13 are not significant.

2.3.4 Conclusion and Summary

The linkage of AGMEMOD to AGLINK is a useful process to obtain detailed member state results for based on aggregated EU results of the EU medium-term outlook. During the process AGLINK respectively the EU Commission provides a set of macroeconomic variables of the Medium-term outlook applicable in the AGMEMOD model. In a second step AGMEMOD results will be scaled to the to the AGLINK outcomes, by aggregating the AGMEMOD model results to two groups comprising the EU-15 (EU-14) and the EU-13 respectively and subsequently applying a scaling factor to align model results. Individual member states specific scaling factors per product and activity is renounced and one scaling factor per product and activity is used over all countries. A single member state approach would require a detailed ex-ante analysis of all markets in all Member States. In contrast, as stated above, the scaling factors implemented as an ex-post model calculation, are considered as an ex-post shift in the model-results, without affecting the equilibrium. For further details of the scaling procedure refer to Salamon et al. (2017). In case of significant deviations the related behavioural equations are revised and re-estimated. Scaled outcomes are in the end are validated by member states as well as by market experts and discussed. This process may lead also to revisions of AGLINK in the upcoming new outlook process.

In general, results indicate that AGMEMOD often provides more conservative model outcomes for the EU-13 than AGLINK. Most results have to be scaled up to meet the AGLINK results. As expected, it can be seen that the variations for scaling are less variable for the animal sectors compared to the crop sector, where the magnitude of scaling is higher. Especially for area and yield results the AGMEMOD output needs to be adjusted in a higher degree. In contrast, in the animal sector an especially in the meat sector, scaling of AGMEMOD to AGLINK are less pronounced which may be due to more severe restrictions in the markets which allow less flexibility with respect to the future development. Only exceptions in this context are production and use for milk products for which require somewhat higher scaling adjustment. Hence, here exit also some differences in data as aggregated member state data and EU data may differ. It turned out, that AGMEMOD delivers more conservative results for both the EU-15 and the EU-13.
The section above gives first insights into the associated linkage effect between the AGMEMOD and the AGLINK model and illustrates the ability how models may be aligned with a quite simple approach. Thus, both models can be used to either gain insight into more member state specific results (AGMEMOD) or EU aggregated results (AGLINK) while ensuring a harmonised level of results for both models. The approach can certainly be improved by (a) applying weights reflecting country specific data quality or (b) quality of behavioural equations, or (c) an entropy approach. But such results again will be subject to validations by markets experts. A further option might be to include a feedback loop via prices.

2.3.5 References

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2.4 Model linkage AGMEMOD-MITERRA

2.4.1 Description of the linkage

By linking the AGMEMOD (Chantreuil et al., 2011) and MITERRA (Velthof et al., 2009; Lesschen et al., 2011) models a tool which combines the strengths of two well-established models is developed. More specifically, such a tool can support policy makers with providing scenario analysis and (ex-ante and ex-post) impact assessments with respect to climate action and nutrient flows related policy measures.
As farmer behaviour is represented by AGMEMOD (which drives activity choice and levels) a one-way-causality between AGMEMOD and MITERRA can be assumed. This allows for the creation of a simplified (hard) model-linkage which will not require iterations between both models.
There are plans for further developing a technical and methodological linkage solution. It is foreseen to develop this in a two-step procedure, with the aim to benefit from ‘learning while doing’.
Initiated by SUPREMA, on a first stage, a shortcut one-way linkage which feeds the MITERRA model with information on agricultural producer behaviour from AGMEMOD has been established. The

connectedness could be best characterized as hard linkages. Special attention had to be given to these cases where variables and/or variable definitions in both models were differing because then a one-to one-matching is not possible. In such cases for linkage a conversion factors or parallel percentage change approach was used. The linkage of the feed parts in both models needs still further development and improvement.
The linkage allows MITERRA to take into account the current and/or the expected future market (outlook) and policy context by running a baseline or a particular policy scenario. The second step involves the development of a refined model-linkage methodology which accounts for potential interaction and feed-back effects between both models.
Figure 11 shows the linkage of AGMEMOD and MITERRA and also includes the role of a 'policy optimisation tool' that could be used as a 'bridge' between the two models and make operational the feed-back between AGMEMOD and MITERRA. In the context of Lesschen et al. (2020), which focused on climate, N and P policies, this approach has been proven as a successful one, using the policy optimisation tool to steer the two models and support the process of designing the policy scenarios (see, Figure 12 for a description of the tool). This is particularly relevant in cases where there is a complex of policy measures and regulations applying to farmers (e.g. Nitrates Directive, Ammonia ceiling, Phosphate ceiling). These different regulations may interact and could overrule each other, where the most binding one is the one which effectively curtails farmer behaviour and should be taken into account in the modelling. In modelling such policy environments, rather than looking to individual measures, an integrated policy approach is needed, which tries to recover 'the envelope' of the complete set of measures and regulations applying to farmer behaviour and then 'translates' this into proper signals for economic as well as agronomic models in a consistent way. In addition, the tool turned out to be useful to develop scenario's with interactive stakeholder involvement, where it contributed to enlighten trade-offs and helped stake holders with conflicting interests to better understand their bargaining space and thus the room for compromise-solutions with respect to scenario design.

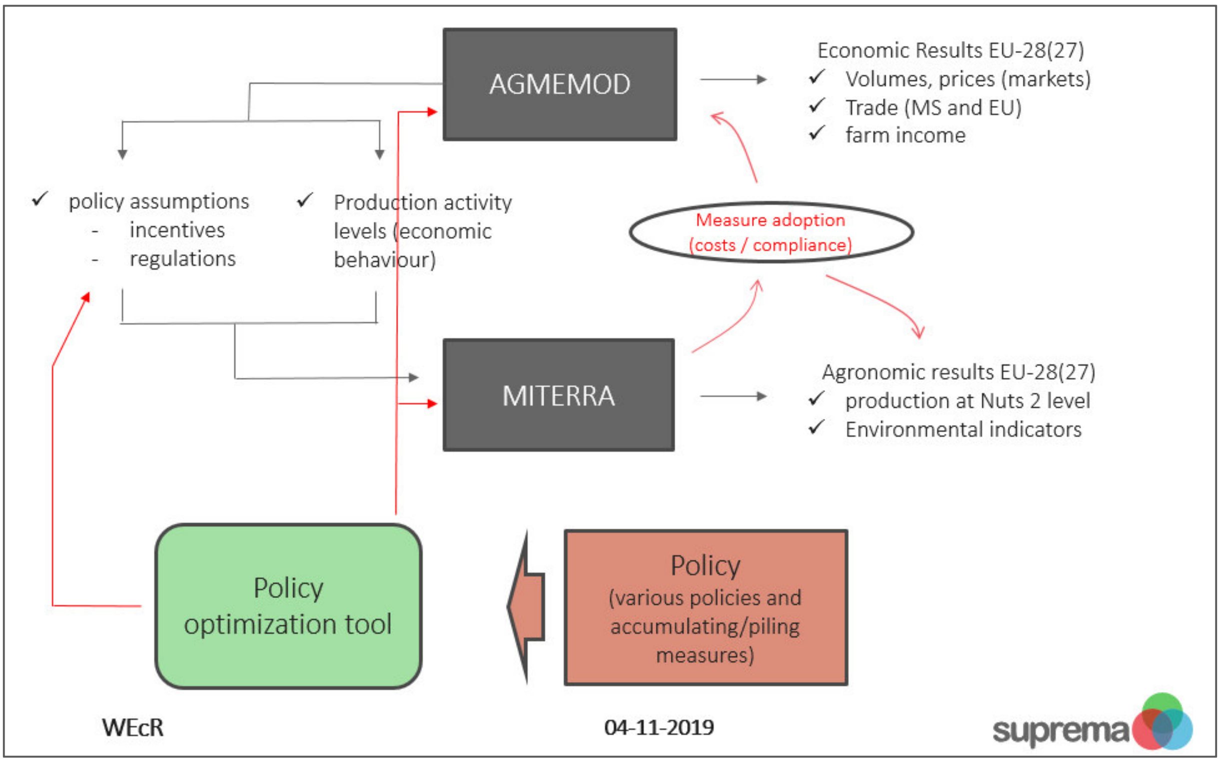

Figure 11. AGMEMOD-MITERRA linkage, including policy optimisation tool

Source(s): Own compilation.

Note(s): With regard to 'measure adoption', Figure 1 shows the feedback loop between AGMEMOD and MITERRA that was developed in the context of Lesschen et al. (2020). However, this mechanism was not 'active' in SUPREMA since it was not relevant for the scenario(s) modelled so far. This feedback mechanism will be further developed in the future; and could be 'activated' in the case of SUPREMA if needed.

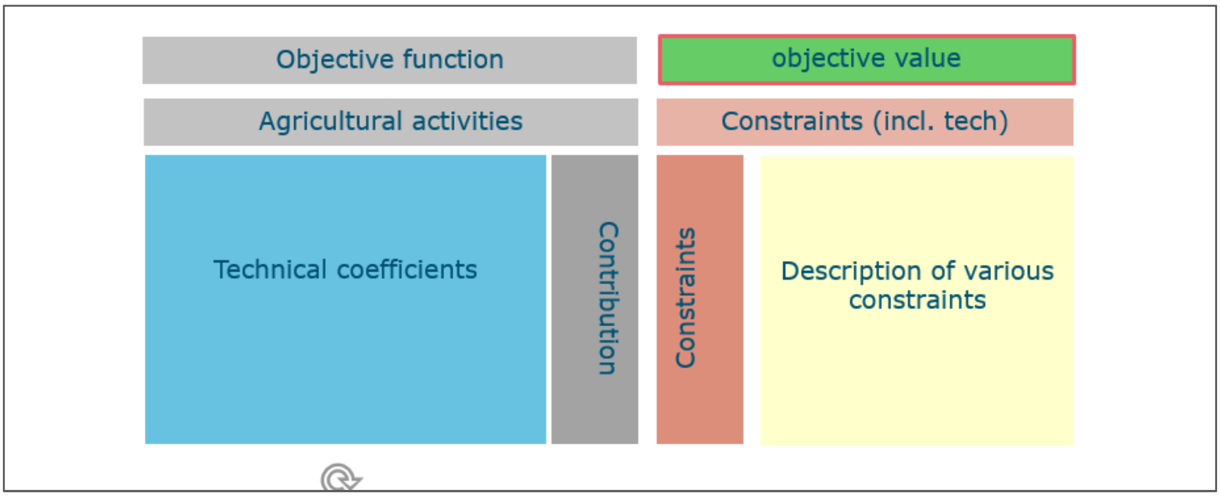

Figure 12. Structure of the policy optimisation tool

Source(s): Own compilation.

2.4.2 Additional features compared to individual models

The experience so far has proven that the AGMEMOD and MITERRA models are good complementary tools. The detailed modelling of the production of the agricultural sector that AGMEMOD offers can benefit from the calculation of environmental indicators and nutrient flows associated with that production, as delivered by MITERRA. At the same time, the MITERRA model can be used for projection purposes by building on the economic projections of AGMEMOD. Thus, this 'joint effort' permits AGMEMOD to provide indicators that go beyond the 'standard' AGMEMOD output, while it also permits MITERRA to be used for projections.

2.4.3 Illustrative simulation results with model linkage in place

In order to illustrate of the 'value added' of this exercise and additional results that are delivered by this linkage, Figure 13 present some maps to report on the simulation of GHG emissions of agriculture by 2030. These maps/indicators are provided by MITERRA based on the AGMEMOD baseline and represent an extension the standard AGMEMOD results.

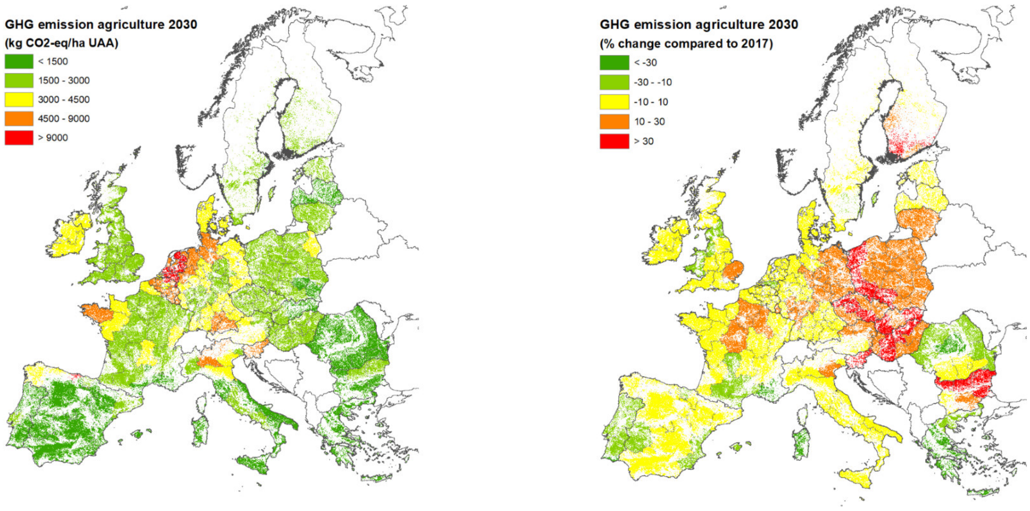

Figure 13. AGMEMOD-MITERRA linkage – results for GHG emissions from agriculture

Source(s): Own Compilation

2.4.4 Summary

By linking the AGMEMOD and MITERRA models a tool which combines the strengths of two well-established models is developed. More specifically, such a tool can support policy makers with providing scenario analysis and (ex-ante and ex-post) impact assessments with respect to climate action and nutrient flow related policy measures. The behavioral component is represented by AGMEMOD (which drives activity choice and levels). The environmental and climate impacts are generated by the biophysical MITERRA model, which has a detailed agronomic, agri-environmental and spatial representation of key mechanisms playing a role in agriculture and land use (including forestry). A hard linkage between both models has been developed. A one-way-causality between AGMEMOD and MITERRA has be assumed, and for this reason linkage does not require iterations between both models. A proof of principle of the results generated by the linked model application has been demonstrated by apply the tool to the medium-term CAP scenario assessments.

2.4.5 References

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2.5 Model linkage MAGNET-GLOBIOM-CAPRI linkage

2.5.1 General description

The general idea is that each model implements information from other models which is exogenous information if model is rune alone. So, MAGNET and CAPRI implements agricultural area afforestation form GLOBIOM and CAPRI and GLOBIOM implement energy price changes from MAGNET. The approach is illustrated by carbon price scenario run by all three models. Additionally, MAGNET test also MAGNET-GLOBIOM link for baseline.
The baseline scenario is constructed based on model specific interpretation of the Shared Socio-economic Pathway 2 (SSP2) story line (see for Frank et al., 2018 for more explanation) and uses SSP2 macroeconomic assumptions outside of EU (KC and Lutz W, 2017 and Dellink at al., 2017) and European Commission, 2018 assumptions for EU. In the carbon price scenario, we implement CO2 RCP1.9 prices on the top of baseline scenario (Rogelj et al., 2018).
GLOBIOM – MAGNET - CAPRI linkage is implemented as follows:

- All models run CO2 scenario independently
- GLOBIOM provides effects on forest and bioenergy plantation areas to MAGNET + CAPRI
- MAGNET rerun CO2 scenario with exogenous area information from GLOBIOM on forest and bioenergy plantation areas and provides adjusted effects on GDP and energy prices to CAPRI+GLOBIOM
- CAPRI+GLOBIOM rerun CO2 scenarios with MAGNET information on GDP and energy prices and forest/plantation areas for CAPRI

2.5.2 Implementation of the additional information in the single models

2.5.2.1 Afforestation and energy cop areas calculation in GLOBIOM

The area used for afforestation in GLOBIOM is determined by iterative runs between GLOBIOM and the Global Forestry Model (G4M), a geographically explicit agent-based model that assesses afforestation-deforestation-forest management decisions. Total forest area in GLOBIOM/G4M is calibrated according to FAO Global Forest Resources Assessments (FRA) and divided into managed and unmanaged forest utilizing a downscaling routine based on human activity impact on the forest areas (Kindermann et al., 2008). The available woody biomass resources are provided by G4M for each forest area unit and are presented by mean annual increments.
G4M uses projections of wood demand per country estimated by GLOBIOM to calculate total harvest iteratively. A 2000-2010 average wood production map (Verkerk et al., 2015) is applied to initialize wood production spatially. Afforestation and deforestation trends in G4M are calibrated to historical data for the period 2000-2013. G4M itself does neither represent forest markets nor other economic sectors, information which is provided by GLOBIOM (wood prices, land rents). As outputs, G4M produces estimates of forest area change, carbon sequestration and emissions in forests, impacts of carbon incentives (e.g. avoided deforestation), which in turn are applied in GLOBIOM.
Starting from calibrated afforestation and deforestation rates G4M projects the development of future forest area based on the development of basic drivers received from GLOBIOM, i.e. projections of land prices and wood prices. The potential value of forestry activities on a grid cell based on wood prices is compared to the opportunity costs of other land use options and a decision on afforestation or deforestation is taken by the model. Future demand for wood influences afforestation rates through the wood price estimated by GLOBIOM.
To ensure consistency in the total land area balance between GLOBIOM and G4M, GLOBIOM supplies G4M with the maximum area that can be afforested which excludes cultivated cropland or grassland necessary for food and feed production (e.g. fallow land, abandoned grassland and cropland, etc.) or areas not suitable. Once G4M has estimated afforestation areas, these are fed back and implemented in GLOBIOM for a final iteration.
Besides afforestation, large amounts of biomass will be required for the production of bioenergy in ambitious climate change mitigation scenarios. An increasing demand for biomass from the energy

sector, however, will reduce land that is available for other uses such as food production or nature conversation. To reflect these interdependencies between the land use and energy sector, bioenergy demand is calculated by an energy-system model and implemented into GLOBIOM to see the eventual impacts on the land use sector. GLOBIOM integrates bioenergy demand into the land use sector and in turn provides bioenergy supply and prices as a feedback to the energy-system model.
In GLOBIOM, biomass for energy production can come from residuals, by-products of the forest industry, or dedicated energy crops. The area used for the production of the latter is referred to as "energy crop area". Short rotation tree plantations are covered in GLOBIOM in the form of energy crop plantations, dedicated to produce wood for energy purposes. Plantation yields are based on net primary production (NPP) maps and model's own calculations, as described in Havlík et al. (2011). Plantation area expansion depends on the land-use change constraints and economic trade-offs between alternative land-use options. Land-use change constraints define which land areas are allowed to be changed to plantations and how much of these areas can be changed within each period and region (so-called inertia conditions). Permitted land-cover types for plantations expansion generally include cropland, grassland, and other natural vegetation areas, and they exclude forest areas, with more specific constraints for certain regions. Within each land-cover type the plantation expansion is additionally limited by land suitability criteria based on aridity, temperature, elevation, population, and land-cover data, as described in Havlík et al. (2011). The model also covers biomass production from grassy crops such as miscanthus or switchgrass simulated where productivities are simulated by the EPIC model.
In the work presented here, bioenergy demand and afforestation projections are based on scenarios run in combination with the energy demand model PRIMES for the EU-28 (reference and 1.5TECH scenarios in European Commission, 2018) and MESSAGE for the rest of the world (reference and SSP2-RCP1p9 scenarios in Rogelj et al., 2018).

2.5.2.2 Implementing afforestation in MAGNET

Land supply function in MAGNET specifies the relationship between total agricultural land supply and the real land price, given constraints related to biophysical availability (potential area of suitable land) and institutional factors (agricultural and urban policy, conservation of nature). These constraints are represented by an asymptote within the land supply function. The total land area suitable for agriculture includes the forest land which area is not modelled in MAGNET. Since agricultural land afforestation is considered to be important policy measure towards achieving climate mitigation goals, we modify agricultural land supply function in MAGNET to take into account:

1) that land supply is restricted due to exogenously assumed afforestation or
2) that there is an additional, exogenously given, demand for non-agricultural land (e.g. forest and) using land suitable for agriculture.

The implementation into MAGNET is explained in the following.

2.5.2.2.1 Restricted (agricultural) land supply (see Figure 14)

In the baseline, there is no distinction between Agricultural land supply (ALSB) and Total land supply (TLS) in count of growth in forest area. In Figure 14, both are shown by the same yellow curve. Land demand is denoted by LD. The baseline equilibrium is determined by the point of intersection of the two curves, giving total land supply (and demand) at LS. The land price is PB.
In order to implement afforestation scenario, we now distinguish the Agricultural land supply (ALSS) and Total Land Supply (TLS), where the difference is accounted for by forests. In applications, IMAGE model (Stehfest et al. 2014) provides the desired reduction in Agricultural Land use in order to accommodate afforestation. This information is used to restrict the agricultural land supply in the afforestation scenario. This restricted agricultural land supply is shown by ALS. Restricted Agricultural supply however means that the land price now increases to PS. At a higher price (PS), agricultural land demand falls accommodates the supply restriction. At the same time total land supply at price PS, is

given by TLS. The difference between the total and agricultural land supply (TLS - ALS) is the forest. With afforestation we see higher land prices, lower land use in agriculture but higher total land demand on account of growth in forest area.

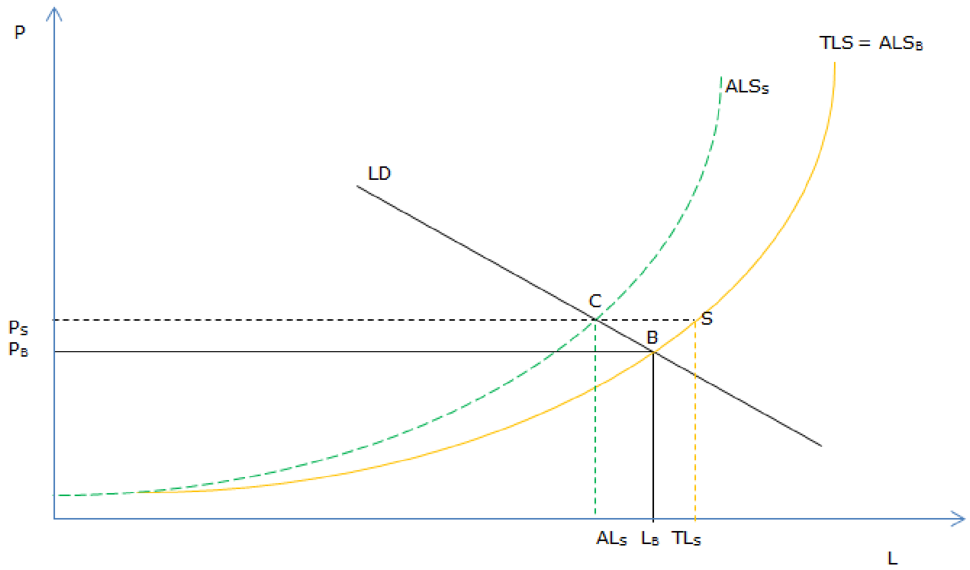

Figure 14. The Land Market with and without Afforestation (land supply approach)

Source(s): Own compilation.

2.5.2.2.2 Additional demand for (forest) non-agricultural land suitable for agriculture (see Figure 15)

An alternative way to implement the forest growth in the modelling is to introduce changes on the demand side in the land market. Instead of distinguishing between agricultural land supply and total land supply, agricultural land demand and total land demand, the difference being the forest land is differentiated. In the baseline, the equilibrium point B provides the land price PB and the land supply/demand LB. At this initial equilibrium price, we now need to sequester land for forests. Again, the information from IMAGE is used to calculate this demand for forest land (in km sq.). Graphically this means that the total demand (TLDS) for land is agricultural demand (ALDS) plus the demand for forest (distance BF). The new demand curve intersects the land supply curve (TLS) and generates the new land price (PS). A higher price also means higher land supply (TLS), of which a part (illustrated by the distance CS) is set aside for forests and the remaining (ALS) is used as agricultural land.
Like in other approach, we get higher land price and lower agricultural land use with afforestation.

The magnitude of land price and agricultural land changes differs across the two approaches. The difference is illustrated in Figure 15. Without any forests, we start with a land supply curve S and land demand curve D; land price is P_B and land demand and supply is L_B. At this initial price we can introduce forests in two ways by restricting land supply to agriculture by a given amount or by introducing the demand for forests as a new source of demand. To be able to compare we construct the figure in a way such that the increase in forest demand (BM) at the initial equilibrium price P_B is the same as the reduction in agricultural land supply (NB) at the same price. Following the forest demand approach, land demand at initial price increases to M (shift of demand curve D to D_A). However, this is more than the land supply available at that price, so market forces drive up land price and new equilibrium is found at point A. Even at the new price the forest land set aside remains the same (AD=BM) and the remaining supply (D) goes to agriculture. The equilibrium moves from B to A through M. The approach can be seen as finding a new equilibrium in land market and dictating the forest demand and residual is agricultural land. With the agricultural land supply restriction (A_L) approach (represented by artificial shift and twist agricultural land supply curve from S to S_L), the new equilibrium is found at point L (moving from B to N to L). With this approach the forests are determined as residual supply after agricultural market reaches an equilibrium at point L. Note that with this approach, we see a greater reduction in agricultural land use and higher land prices. This in turn implies that forest area with this approach (LC) exceeds that with the demand approach (DA) (in which forest demand is shocked).

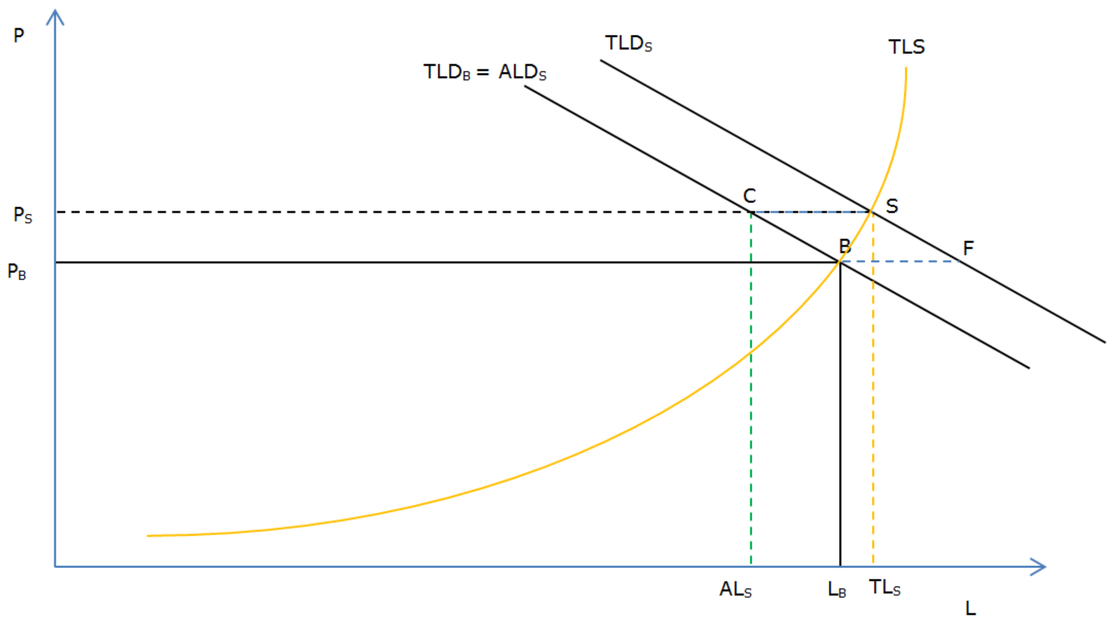

Figure 15. The Land Market with and without Afforestation (land demand approach).

Source(s): Own compilation.

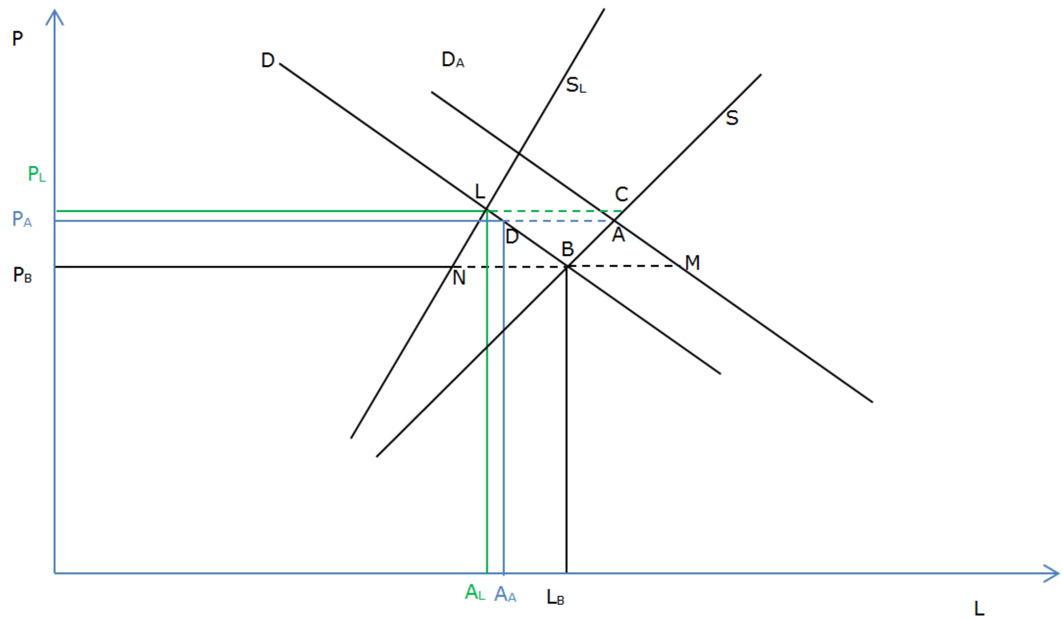

Figure 16. Difference between the agricultural land afforestation and higher demand for forest land.

Source(s): Own compilation.

2.5.2.2.3 Technical implementation in MAGNET and link with GLOBIOM

To implement this, the agricultural land afforestation and higher demand for forest land in MAGNET we modify land demand equation by adding demand for non-agricultural land (e.g. forest land) component. The modifiers equation is:
LANDSUPPLY(r)*p_landsupply(r) = AGLANDSUPPLY(r)*p_aglandsupply(r)+100*d_lfor(r)
were r is region index and:

LANDSUPPLY(r)	- supply of land suitable for agriculture
p_landsupply(r)	- percentage change of LANDSUPPLY(r)
AGLANDSUPPLY(r)	- supply of agricultural land
p_aglandsupply(r)	- percentage change of AGLANDSUPPLY(r)
d_lfor(r)	- supply of non-agricultural land (forest) using land suitable for agriculture.

One of two right side variables in the equation above is exogenous and the second one endogenous depending on the exogenous shock implemented. In case of afforestation of agricultural land, p_aglandsupply is shocked exogenously and equation will be solved for d_lfor showing related forest area increase. In case of additional supply shock for land suitable for agriculture coming outside of agriculture, d_lfor is exogenous and p_aglandsupply is calculated endogenously.

In model linking exercise, we are getting information from GLOBIOM model about additional land demand from energy crops as well as changes of agricultural area caused by afforestation. We use these changes and 2011 MAGNET agricultural areas to calculate MAGNET agricultural land projections according to GLOBIOM. We use share of energy crops in total agricultural land in GLOBIOM to calculate energy crops areas projections for MAGNET. In baseline, there is no agricultural land afforestation foreseen by GLOBIOM so the only additional shocks which MAGNET implements is shock related to energy crop area increase which is implemented by shocking of d_lfor. In the scenario, we shock agricultural land supply (p_aglandsupply). We assume that agricultural land in MAGNET will

follow the development pattern of GLOBIOM for regions where agricultural land area according to GLOBIOM is lower than in MAGNET and we assume that this difference is caused by afforestation and increase of for energy crops[4]. In the scenario, in regions where agricultural land area in MAGNET is lower than in GLOBIOM, we implement only energy crop area changes.
The implementation of GLOBIOM based information about energy crop area and afforestation has the pronounced impact on agricultural sector development in MAGNET. Table 11 shows that afforestation 24.4% of agricultural land coming from GLOBIOM causes more than doubling agricultural prices.

Table 11. Impact MAGNET – GLOBIOM link for the world agricultural sector development

	2020	2030	2040
	Linked vs not-linked baseline % difference		
Production	-0.4	-0.4	-1.1
Output price (real)	2.7	3.4	9.8
Land used	-0.9	-1.0	-1.9
	Linked vs not-linked scenario % difference		
Production	-0.4	-1.4	-5.8
Output price (real)	3.0	9.8	53.6
Land used	-2.0	-3.9	-13.7

Source(s): Own compilation.

2.5.2.3 Implementing energy prices and GDP changes in GLOBIOM

In GLOBIOM, agricultural and forest biomass demand (for energy and non-energy uses such as food, feed, industrial uses) is based on the interaction of different drivers over time:

(i) Bioenergy demand growth
(ii) Population growth
(iii) GDP per capita growth (income elasticities)
(iv) Response to prices (own-price elasticities)

Drivers (i), (ii), and (iii) are exogenously introduced in the model while (iv) is computed endogenously. Bioenergy demand projections (i) are based on PRIMES biomass model for the EU-28 and MESSAGE for the rest of the world in the reference scenario context. Non-energy related demand increases linearly with population growth. GDP per capita changes (iii) determine non-energy demand variation depending on income elasticity values. For the agricultural sector the income elasticities area calibrated to mimic anticipated FAO projections of diets (Alexandratos and Bruinsma, 2012). Income elasticities for the forest sector are taken from Rametsteiner et al. (2007). The response of non-energy related demand to commodity prices (iv) is endogenously computed in GLOBIOM. Price elasticities for the agricultural commodities are taken from a global database from USDA (Muhammad et al., 2011) and for the forest sector from Rametsteiner et al. (2007). For the feedback scenario, relative changes in GDP as estimated by MAGNET are implemented in GLOBIOM within the described framework.
Energy costs of agricultural production in GLOBIOM are represented on a crop and energy carrier level. Different kinds of data from different sources are combined to estimate these energy costs. In a first step, energy cost shares of agricultural production calculated for several countries (USDA, 2018; FADN, 2018; CONAB, 2018; Indian Ministry of Agriculture and Farmers Welfare, 2018) and extrapolated to other countries are multiplied with production cost data in GLOBIOM to determine absolute energy costs. In a second step, energy carrier shares for the agricultural sector are calculated

[4] We assume that when agricultural land according to GLOBIOM is higher than in MAGNET than the afforestation required by GLOBIOM is already achieved in MAGNET. In such a case only a GLOBIOM based distribution of agricultural land between energy crops and another use needs to be achieved.

based on FAOSTAT and IEA world energy balances data. The respective shares are multiplied with energy prices (Jewell et al., 2018) to generate an average energy price per country. Then, the absolute costs from the first step are divided by the energy prices to calculate amounts of energy used per agricultural production unit. The latter again are compared to values from the Life Cycle Assessment (LCA) literature and corrected if not in a plausible range. A similar procedure is applied for livestock products.

Fertilizer production consumes large amounts of energy. To account for the impact of energy price changes on agricultural production costs via changes in fertilizer production costs, energy related costs from fertilizer are calculated per region and crop. Starting from the International Fertiliser Association database (Heffer 2009, 2013), we apply coefficients of the average energy use per produced fertilizer unit (GJ per ton of fertilizer) taken from the literature (Yara, 2017). The resulting aggregate amounts of energy used per crop and country are distributed among the crops produced in respective regions according to GLOBIOM data (regional fertilizer demands per crop in GLOBIOM are available - crop production systems are estimated by EPIC - but do not differentiate between natural and chemical fertilizer). Results are compared to LCA values from the literature and kept within a realistic range. The resulting GJ values are multiplied by prices (Jewell et al, 2018) to estimate energy costs in GLOBIOM. In a final step, the resulting energy cost estimates are compared to cost shares calculated from national input databases to ensure that costs are within a plausible range (based on Baffes (2009) we assume that 55% of fertilizer costs are going back to energy input costs).

To implement changes in energy prices from MAGNET for the feedback run, calculated energy costs are multiplied with the relative price changes of different energy carriers as estimated by MAGNET. In GLOBIOM, Leontief production functions with fixed costs per output are applied (except for endogenous land rental costs and water costs). Thus, the costs per unit are increased respectively to account for the increase in energy costs resulting from climate change mitigation scenarios (see Figure 17).

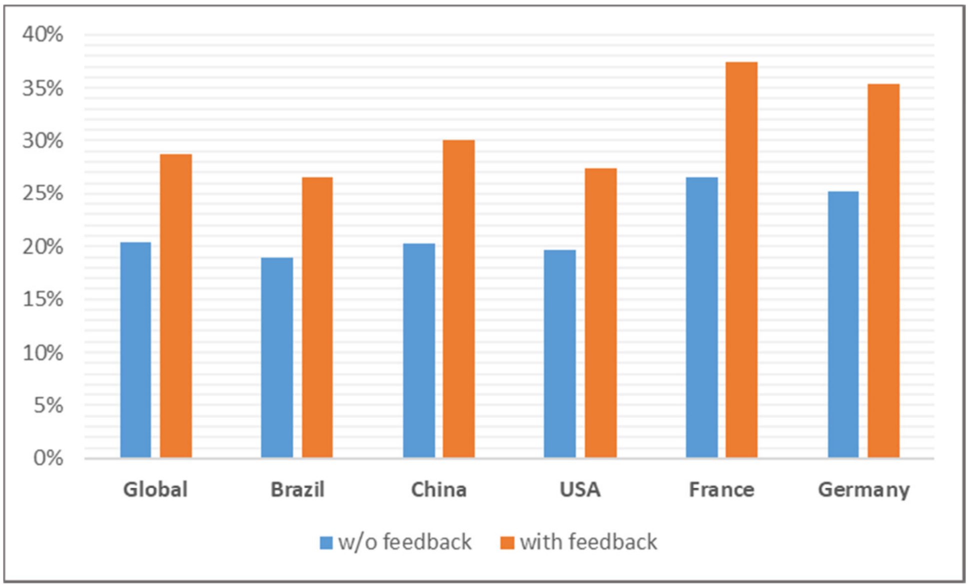

Figure 17. Energy costs for wheat as shares of initial total per-unit production costs in GLOBIOM for selected countries.

Source(s): Own compilation.

Notes: To improve visualization of the changes in energy prices, both (without and with feedback) values have been compared to the same initial production cost

2.5.2.4 Implementing energy prices and GDP changes in CAPRI

2.5.2.4.1 Implementing changes in forest areas

The background of the implementation of land use information from GLOBIOM in CAPRI is the revised specification of land markets in CAPRI as explained in SUPREMA Deliverable 2.3. Its final form may be recapitulated as follows.
Agricultural outputs i (barley, wheat, beef, ...) have land requirements LV_i derived from production of these outputs (via yields that respond to prices according to yield elasticities). We distinguish three major agricultural land types (LT_{ag}), fodder land (fd), temporary (non-fodder) crops (tc), and permanent (non-fodder) crops (pc). Each of these agricultural land types {tc, pc, fd } = ag are the sum of land requirements of single agricultural outputs related to them.

$$LT_{ag} = \sum_i LV_i(\boldsymbol{P}, \boldsymbol{R}_{ag})$$

Agricultural land demand depends on a vector of prices and agricultural rents $\mathbf{R}_{ag}$ (as a special type of input price). The previously shown balance is achieved by a scaling mechanism transforming temporary land requirements LV_i^* into final land requirements LV_i. Total agricultural land is just one of several land types (l) that together cover the complete country area:
l = {tc, pc, fd, fr, ur, ot, iw}, where
tc = temporary (non-fodder) crops
pc = permanent crops
fd = temporary fodder, permanent grassland and fallow land
fr = forest land
ur = settlements, industrial, built up md any other artificial areas
ot = other land
iw = inland waters (exogenous)
There is (so far) no explicit modelling of demand for non-agricultural land types. Instead they are treated as having an exogenous price.
For land supply we use a multinomial logit form covering of all major endogenous land types f = g = h = m = {tc, pc, fd, fr, ur, ot}:

$$LT_m = SH_m * T$$

where the area share of land type m is

$$SH_g = \frac{exp\left(\delta_{g0} + \sum_f \delta_{gf} R_f\right)}{\sum_m exp\left(\delta_{m0} + \sum_f \delta_{mf} R_f\right)}$$

and T is the country (land) area minus the area of exogenous inland waters. The parameters have been determined in a calibration process such that the differences to a set of prior land supply elasticities are minimised while at the same time reproducing the expected areas in the calibration point. The matrix of prior land supply elasticities has been derived based on an assumed matrix of transformation elasticities reflecting plausible assumptions on the relative responsiveness of areas. Basically, we assume that responsiveness increases in the sequence ur << pc < tc < fr ~ fd < ot. The elasticity assumptions have been revised in the course of the WP2.2 simulations as explained below.
Based on these specifications for land supply and agricultural land demand and given parameters δ_{g0} and δ_{gf} , there are three market clearing conditions for the agricultural land types that serve to determine the endogenous agricultural rents $\mathbf{R}_{ag}$, while non-agricultural rents, including those in forestry, are exogenous.
Exogenous shifts in forestry areas due to afforestation (as modelled in GLOBIOM) are introduced as shifts in land supply. However, unlike the graphical representation of such a shift in the MAGNET section (Figure 16) the shift is not calculated at the baseline price vector, but at the new equilibrium price vector. This means that forest land supply is shifted in such a way that, after all price adjustments being completed, the new forest land supply has increased exactly as planned. Technically this is achieved by fixing land supply of forestry and rendering the constant term associated with forestry in the MNL system (δ_{fr0}) a free variable.

In the carbon price scenario agricultural output prices are increased according to the GHG effects associated with agriculture (mostly from methane and nitrous oxide). As these price increases are partly passed on to consumers, they also share in the tax burden. In a similar manner the enhanced accounting of LULUCF effects in CAPRI (see 2.5.2.4.6) permits to value the carbon effects from LULUCF with the (same) carbon price to determine the subsidy or tax implied by these carbon effects. According to the CAPRI accounting the carbon benefits per ha, achieved when increasing the forest area by 1 ha, amounts to huge subsidies per ha (for example about 5000 Euros per ha in Ukraine). Given that initial rents in forestry are typically much lower (40 Euros per ha in Ukraine in our database) this would usually trigger an extreme reallocation of areas, even though the MNL form would eventually prevent a complete specialisation. With the initial land rent elasticities (own rent elasticity for forestry = 0.14) this would have triggered, for example, an increase of forest area of about 90% in Ukraine and similar in other regions, giving serious feasibility problems. These have been resolved by a very strong downscaling of land rent elasticities in CAPRI (at the Ukraine example from 0.14 to 0.0013) in order to strongly dampen the area reallocations (and preserve feasibility). With reduced land supply elasticities, a full set of result has been obtained that may be compared with the set of results when introducing the GLOBIOM information on forest area changes in the same scenario.

GLOBIOM has provided information on land types that may be mapped (approximately) to certain CAPRI land types. Only artificial land is not reported:

- FORE(CAPRI)~Forest(GLOBIOM) = forest land
- CRPR(CAPRI)~CrpLnd(GLOBIOM) = cropland (without temporary grass land and energy crops)
- NECR(CAPRI)~EneLnd(GLOBIOM) = land for (new) energy crops
- FODFAL(CAPRI)~GrsLnd(GLOBIOM) = productive grassland (and fallow)
- OLND(CAPRI)~NatLnd(GLOBIOM) = other (non-productive) areas

However, it is still frequent that some land types may be tiny in one model and non-negligible in the other such that transferring relative changes is risky. Therefore, to ensure that the imported changes are not extreme and inconsistent with the CAPRI land balance, they have been adopted in the form of absolute changes in total area shares. These changes in matched shares have been applied to the CAPRI total country area, after a scaling that ensures that the total country area is preserved by the sum of all changes.

The case of EU regions differs in some aspects strongly from the non-EU region (see also D2.3 of SUPREMA):

1. Land demand is derived from explicit (primal) maximisation of representative farmers at the NUTS2 level with detailed activities for cropland and productive grassland, rather than following from a behavioural function.
2. Land supply is represented by a two level system of behavioural functions (different from the MNL system used in non-EU regions). The top level represents total agricultural land supply (with an asymptote similar to MAGNET), considering regional land “availability for agriculture”. A second level disaggregates this agricultural land supply into land supply for cropland and productive grassland.
3. Non-agricultural land use that complements farm land to give the total region area is disaggregated into forestry, built up areas (urban or “artificial” land) and a remaining “other land” category. This disaggregation uses an ad-hoc scaling mechanism plus some assumptions on the responsiveness of areas (increasing in the sequence urban – forest – other).

The first approach to introduce changes in forest area was similar to the MAGNET solution: We shifted total agricultural land supply according to the planned change in forest area. This turned out insufficient in the context of the regional supply models as the scaling mechanism under point 3 above strongly counteracted the exogenous shift. As a consequence, the link to GLOBIOM was enforced in a

more direct way by switching off the endogenous land markets and running the scenarios with GLOBIOM input on forest land with exogenous total agricultural areas. This implies that the shifted total cropland and total productive grassland corresponding to the GLOBIOM results were exogenous in the CAPRI supply models. With exogenous total cropland and total productive grassland the programming models had only the freedom to use that given land in an optimal way for the disaggregate CAPRI activities.
Table 12 shows the impact of adding the GLOBIOM forestry information (“aglu_for”) in the described manner into the CAPRI simulation of the carbon price scenario in the agriculture and LULUCF sectors (“aglu”)

Table 12. Impact CAPRI – GLOBIOM link on forest area for selected regions and land types

	European Union			Russia			Non-EU		
	ref	aglu	aglu_for	ref	aglu	aglu_for	ref	aglu	aglu_for
Cropland (permanent or temporary crops)	114063.8	52749.5 -53.8%	109156.4 -4.3%	106323.3	104947.5 -1.3%	155174.2 45.9%	1852182.8	1813540.0 -2.1%	1820106.6 -1.7%
Fodder (permanent grassland or fodder on cropland) or fallow land	91407.8	95235.3 4.2%	84222.7 -7.9%	149431.4	145878.0 -2.4%	163238.8 9.2%	3312918.8	3264245.8 -1.5%	3178539.0 -4.1%
Temporary (arable) cropland: fodder or fallow	31719.6	14596.9 -54.0%	30032.0 -5.3%	29962.3	29249.8 -2.4%	32730.8 9.2%	209635.3	196491.2 -6.3%	197396.7 -5.8%
Productive grassland (permanent pastures and meadows)	59688.2	80638.5 35.1%	54190.7 -9.2%	119469.1	116628.1 -2.4%	130508.0 9.2%	3103648.2	3068732.0 -1.1%	2981278.0 -3.9%
Forest land	163907.9	190315.5 16.1%	165493.3 1.0%	811397.3	884142.0 9.0%	812528.5 0.1%	3638376.0	4029364.8 10.7%	4102881.2 12.8%
Artificial area (settlement area)	31602.1	35326.5 11.8%	32234.3 2.0%	17261.6	17199.5 -0.4%	25936.9 50.3%	220656.0	219225.8 -0.6%	223597.3 1.3%
Other land (than agricultural land, forest land, inland waters or artificial areas)	54248.3	64480.4 18.9%	62435.7 15.1%	583427.4	514961.6 -11.7%	513731.1 -11.9%	3140461.2	2824461.8 -10.1%	2827461.0 -10.0%

Source(s): CAPRI GUI, own compilation.

We like to focus first on the three rightmost columns (Non-EU region) as this is close to the global effect, given that the EU is globally just a small region. On this aggregate level (and measured in terms of the area reallocations) the impacts of linking appear moderate only: The largest increase is expected for forest land with 11% in CAPRI without linkage and 13% with linkage. The largest decrease is expected for “other land” with 10% without linkage and with linkage to GLOBIOM forest information. There are sign switches for the changes in total cropland and artificial land, but these changes are projected in any case to be small.
However next we might move to the effects in Russia as one region in the Non-EU aggregate to observe that the differences might be much stronger for single regions within this aggregate. While the changes in other land are again quite similar with or without linkage forest would hardly increase at all with the GLOBIOM information while it was expected to increase by 9% in the stand-alone version of CAPRI. This would be compensated by differences in other area changes, most importantly cropland. It should be mentioned that this increase in cropland is *not* the original GLOBIOM effect on cropland, but the endogenous effects in CAPRI of using only the GLOBIOM information on forest land. Finally, the first three columns show that the GLOBIOM information exerts a strongly moderating effect on EU projections, which featured a 16% increase in forest land on the stand-alone version, supplemented by strong changes in other areas, most importantly a 54% decline in cropland. The moderate increase in forest area in GLOBIOM reflects considerations of legal constraints to land conversions that have been ignored (so far) in CAPRI. Another reason for the extreme results might be rooted in the differences of land market specifications in the EU supply models as opposed to the market models (points 1 to 3 above), suggesting that this specification might be reconsidered (an element in the running EcAMPA-4 project).

2.5.2.4.2 Implementing changes in energy crop areas and combined effect of area information

Energy crop areas are (currently) entirely exogenous in CAPRI (like inland waters) and in the standard mode of application they are maintained at the reference run levels. Therefore, it is straightforward to include alternative settings such as the changes coming from GLOBIOM. The specification is again different in the details when considering the European supply models, but the key property is the same: New energy crop areas are exogenous and maintained at reference run levels in the stand-alone version of the carbon price scenario. By contrast, GLOBIOM expects increasing energy crop areas in most regions which should trigger other impacts as a consequence:

Table 13. Impact of the CAPRI – GLOBIOM link on energy crop areas for selected regions and land types

	European Union			Russia			Non-EU		
	ref	aglu	aglu_nec	ref	aglu	aglu_nec	ref	aglu	aglu_nec
New energy crops	2243.4	2243.4 0.0%	23245.9 936.2%			17213.0 inf.	81983.8	81983.8 0.0%	326634.6 298.4%
Cropland (permanent or temporary crops)	114063.8	52749.5 -53.8%	76076.2 -33.3%	106323.3	104947.5 -1.3%	104946.1 -1.3%	1852182.8	1813540.0 -2.1%	1813859.8 -2.1%
Permanent crops	13870.0	9930.5 -28.4%	31904.2 130.0%	420.5	414.6 -1.4%	414.6 -1.4%	131882.4	127822.4 -3.1%	128181.4 -2.8%
Temporary (arable) cropland: not fodder or fallow	68474.3	28222.1 -58.8%	29354.3 -57.1%	75940.5	75283.1 -0.9%	75281.7 -0.9%	1509914.9	1489005.6 -1.4%	1488954.9 -1.4%
Fodder (permanent grassland or fodder on cropland) or fallow land	91407.8	95235.3 4.2%	85845.9 -6.1%	149431.4	145878.0 -2.4%	145877.9 -2.4%	3312918.8	3264245.8 -1.5%	3264291.2 -1.5%
Forest land	163907.9	190315.5 16.1%	181419.7 10.7%	811397.3	884142.0 9.0%	884142.9 9.0%	3638376.0	4029364.8 10.7%	4029036.5 10.7%
Other land (than agricultural land, forest land, inland waters or artificial areas)	54248.3	64480.4 18.9%	61627.6 13.6%	583427.4	514961.6 -11.7%	514962.1 -11.7%	3140461.2	2824461.8 -10.1%	2824863.2 -10.0%

Source(s): CAPRI GUI, own compilation.

Starting again with the three rightmost columns for the non-EU region we see that the strong increase (by almost factor 4) of the energy crop area would be mostly accommodated within the crop sector alone, as other major land types like fodder, forest or other land are hardly affected at all. This also holds for single regions like Russia where the increase in new energy crop area would be 16% of the reference run cropland. This lack of sensitivity of broad land use results to exogenous shifts in new energy crop areas is not convincing. Presumably it is due to the above-mentioned scaling mechanism that is used to ensure consistency of single crop areas with temporary and permanent cropland as well as fodder and will be reconsidered in the future.

In the three columns for the European Union we see more intuitive results: The increase in energy crop area would result in a strong increase in cropland (in particular "permanent crops" where energy crops are accounted for in the EU supply models). This increase would be compensated by matching decreases in fodder, forest and other land (column 3 vs. column 2).

2.5.2.4.3 Implementing changes in energy related input prices CAPRI

The economy wide carbon price has general economy impacts that may only be captured in a CGE application such as the MAGNET simulations. Energy production, but also fertiliser production cause GHG emissions that are penalised by the carbon price and drive up prices for non-agricultural products serving as inputs to agriculture. These price changes are simulated for all MAGNET regions and prices affecting various agents in the CGE. For the linkage sensitivity analysis this information was aggregated to the EU and non-EU regions and input price changes were given for total agriculture as well as crop and animal sectors separately, together with matching cost shares in the MAGNET

database. Nine inputs were distinguished: primary factors (land, labour, capital), petrol, electricity, other energy, primary agriculture, processed feed, fertilizer, services, and other input. We also had information on the cost share of land (as part of the primary factor aggregate). As primary agriculture, feed and land markets are endogenous in CAPRI only the price changes for the other items have been used as exogenous inputs. The aggregate change in non-agricultural input prices into the crop and animal sectors in non-EU agriculture have been calculated to be 172% and 28% respectively. The crop sector is affected stronger due to the strong increase of fertiliser prices (about +400%).
The agricultural supply functions X_i in the CAPRI market model are linear in normalised prices (derived from a normalised quadratic profit function):

$$X_i(\boldsymbol{P}) = a_i + \sum_j b_{ij} \left(P_j - dC_j + PSE_j\right)/P_n$$

The prices are corrected for any exogenous cost change (term dC_i, introduced previously to handle crude oil price changes) and any potential agricultural support expressed in PSE (producer subsidy equivalent) form. To introduce the MAGNET input price changes into the CAPRI global market model the most straightforward approach would have been to change the numeraire price P_n which is intended to represent all non-agricultural prices. However, as there is only one numeraire price, it would have been impossible to make use of the crop and animal sector specific cost push information from MAGNET. Therefore, the second option of an explicit cost deduction from the output price (term dC_i) has been used in order to preserve the distinction of crop and animal sectors.
In the EU supply models CAPRI has a disaggregate representation of various non-agricultural inputs. Sometimes these may be mapped to the MAGNET items in a straightforward manner ("electricity") but most often CAPRI inputs like "plant protection inputs" will incorporate cost elements from various MAGNET sectors (labour, capital, petrol, electricity, services etc.). To make use of the magnet information the MAGNET sectors have been mapped to the CAPRI items with the following weights, giving the % price change as shown in the rightmost column:

Table 14. Weights of MAGNET items to determine the price change of CAPRI inputs and resulting price change as exogenous modelling input

	MAGNET items							
CAPRI inputs	labour, capital	petrol	electicity	other enrgy	fertilizer	services	other input	%CAPRI change
Seed	0.1	0.1	0.1	0.05	0	0.3	0.35	18.22
Plant protection	0.1	0.2	0.2	0.1	0	0.2	0.2	27.33
Maintenance materials	0.1	0.2	0.2	0.1	0	0.2	0.2	27.33
Maintenance buildings	0.1	0.2	0.2	0.1	0	0.2	0.2	27.33
Electricity	0	0	0.9	0	0	0.05	0.05	12.09
Heating gas and oil	0	0.45	0	0.45	0	0.05	0.05	50.25
Fuels	0	0.9	0	0	0	0.05	0.05	14.52
Lubricants	0.1	0.8	0	0	0	0.05	0.05	26.47
Other inputs	0.05	0.05	0.05	0.05	0	0.3	0.5	9.23
Services input	0.05	0.05	0.05	0.05	0	0.7	0.1	8.59
Pharmaceutical inputs	0.1	0.1	0.1	0.05	0	0.3	0.35	18.22
Nitrogen fertiliser	0	0	0	0	1	0	0	432.2
Phospate fertiliser	0.1	0.2	0	0	0.5	0.1	0.1	232.04
Potassium in fertiliser	0.1	0.2	0	0	0.5	0.1	0.1	232.04

Source(s): Own compilation.

In most cases we have assumed that a certain CAPRI input (like electricity) requires small shares of other complementary inputs (like services in the administration and distribution) to make the input available. In the case of fertilisers, we introduced a distinction of nitrogen from other fertilisers to reflect the particular energy and emission intensity of the former.
Entering the price changes as described in the CAPRI global market model as well as in the EU supply models yielded the following results.

Table 15. Market results from carbon price scenarios for selected regions with ("aglu_inp") and without ("aglu") CAPRI – MAGNET link via input prices

2050	Net production [1000 t]								
	European Union			Russia			Non-EU		
	ref	aglu	aglu_inp	ref	aglu	aglu_inp	ref	aglu	aglu_inp
Cereals	291529.0	148873.9 -48.9%	147345.3 -49.5%	160541.7	164945.9 2.7%	155063.7 -3.4%	2539475.0	2558086.8 0.7%	2440136.2 -3.9%
Oilseeds	37150.7	16453.8 -55.7%	14492.2 -61.0%	5794.8	6615.9 14.2%	6217.6 7.3%	586023.3	589055.6 0.5%	575154.5 -1.9%
Vegetables and Permanent crops	141791.7	127528.1 -10.1%	139505.1 -1.6%	23503.5	24187.9 2.9%	21513.9 -8.5%	1675659.8	1712524.0 2.2%	1572591.6 -6.2%
Meat	53094.1	52643.1 -0.8%	54696.6 3.0%	8336.2	8674.6 4.1%	8459.1 1.5%	318706.1	300528.2 -5.7%	293220.1 -8.0%
Dairy products	74738.1	75178.4 0.6%	75335.8 0.8%	26886.5	27559.6 2.5%	27667.0 2.9%	652173.1	671140.4 2.9%	671192.7 2.9%

2050	Producer price [Euro / t]								
	European Union			Russia			Non-EU		
	ref	aglu	aglu_inp	ref	aglu	aglu_inp	ref	aglu	aglu_inp
Cereals	261.7	552.9 111.3%	726.6 177.7%	252.1	300.9 19.4%	427.1 69.4%	319.1	333.5 4.5%	452.3 41.7%
Oilseeds	519.4	1058.7 103.8%	1362.5 162.3%	527.5	713.8 35.3%	967.0 83.3%	433.4	462.3 6.7%	640.3 47.7%
Vegetables and Permanent crops	517.0	641.3 24.0%	809.3 56.5%	940.6	990.4 5.3%	1442.9 53.4%	1188.1	1223.8 3.0%	1768.6 48.9%
Meat	3728.3	7407.0 98.7%	8039.3 115.6%	4281.9	5572.4 30.1%	7078.1 65.3%	3326.5	3587.3 7.8%	4585.3 37.8%
Dairy products	2264.7	2441.4 7.8%	2686.5 18.6%	1253.7	1422.4 13.5%	1630.2 30.0%	1329.3	1442.1 8.5%	1651.8 24.3%

Source(s): CAPRI GUI, own compilation.

As may be expected the cost push from the input side is partially passed on to output prices (lower part of Table 15). This happens as production decreases in most cases after including the MAGNET results on input prices (top part of Table 15). The MAGNET price information would have stronger effects on the crop sector. Within the animal sector dairy products are responding in a rather moderate way.
The EU and non-EU regions respond similarly to the increase input prices, considering that the reference point for these increases, the carbon price scenario without linkage ("aglu"), is quite different, with the EU much stronger hit than non-EU regions.

2.5.2.4.4 Implementing changes in GDP in CAPRI and combined effect of CGE information

The economy wide carbon price does not only drive up input prices, but also has a cost in terms of GDP losses. These are reducing final demand for agricultural outputs depending on the income elasticities of demand. The income losses simulated in MAGNET have been incorporated in relative form, yielding the following effects.

Table 16. Market results from carbon price scenarios for selected regions with ("aglu_gdp") and without ("aglu") CAPRI – MAGNET link via GDP

2050 — Human consumption plus losses [1000 t]

	European Union			Russia			Non-EU		
	ref	aglu	aglu_gdp	ref	aglu	aglu_gdp	ref	aglu	aglu_gdp
Cereals	96052.2	92351.7	92353.9	29668.7	29054.9	28813.2	962676.4	963913.0	955154.8
		-3.9%	-3.9%		-2.1%	-2.9%		0.1%	-0.8%
Oilseeds	1935.4	1774.2	1778.9	186.7	183.1	182.5	25648.2	24579.8	24422.2
		-8.3%	-8.1%		-1.9%	-2.2%		-4.2%	-4.8%
Vegetables and Permanent crops	145238.6	139312.5	138987.9	32738.0	33013.7	32234.6	1561940.1	1595466.4	1566492.5
		-4.1%	-4.3%		0.8%	-1.5%		2.1%	0.3%
Meat	44340.0	43091.9	42974.1	9640.6	9425.3	9111.8	324619.9	308739.9	303403.9
		-2.8%	-3.1%		-2.2%	-5.5%		-4.9%	-6.5%
Dairy products	64354.4	64734.6	64649.2	20376.2	20415.3	20189.8	543643.9	555692.8	547939.1
		0.6%	0.5%		0.2%	-0.9%		2.2%	0.8%

2050 — Producer price [Euro / t]

	European Union			Russia			Non-EU		
	ref	aglu	aglu_gdp	ref	aglu	aglu_gdp	ref	aglu	aglu_gdp
Cereals	261.7	552.9	547.9	252.1	300.9	298.8	319.1	333.5	326.4
		111.3%	109.4%		19.4%	18.5%		4.5%	2.3%
Oilseeds	519.4	1058.7	1047.9	527.5	713.8	710.4	433.4	462.3	456.4
		103.8%	101.7%		35.3%	34.7%		6.7%	5.3%
Vegetables and Permanent crops	517.0	641.3	633.2	940.6	990.4	971.5	1188.1	1223.8	1197.3
		24.0%	22.5%		5.3%	3.3%		3.0%	0.8%
Meat	3728.3	7407.0	7317.0	4281.9	5572.4	5365.5	3326.5	3587.3	3464.0
		98.7%	96.3%		30.1%	25.3%		7.8%	4.1%
Dairy products	2264.7	2441.4	2361.2	1253.7	1422.4	1372.9	1329.3	1442.1	1392.4
		7.8%	4.3%		13.5%	9.5%		8.5%	4.7%

Source(s): CAPRI GUI, own compilation.

As may be seen from Table 16 the CAPRI results from GDP effects simulated in MAGNET correspond to expectations: They are smaller in the EU than in non-EU regions (due to higher income in the former) and stronger in the animal sector when compared with crop products.

2.5.2.4.5 Implementing general economy changes in GDP and input prices according to MAGNET together with area information from GLOBIOM in CAPRI scenarios

Finally, Table 17 shows the effects form picking up both the general economy information from MAGNET as well as the area information from GLOBIOM.

Table 17. Impacts of linking CAPRI to GLOBIOM via area information and to MAGNET via economic information for selected regions and markets

2050 — Net production [1000 t]

	European Union					Non-EU				
	ref	aglu	aglu_glo	aglu_mag	aglu_glomag	ref	aglu	aglu_glo	aglu_mag	aglu_glomag
Cereals	291529.0	148873.9 -48.9%	243978.4 -16.3%	142978.9 -51.0%	224188.3 -23.1%	2539475.0	2558086.8 0.7%	2519810.8 -0.8%	2421812.5 -4.6%	2383784.2 -6.1%
Oilseeds	37150.7	16453.8 -55.7%	29828.6 -19.7%	14453.5 -61.1%	24795.7 -33.3%	586023.3	589055.6 0.5%	576959.6 -1.5%	570556.2 -2.6%	561212.0 -4.2%
Vegetables and Permanent crops	141791.7	127528.1 -10.1%	140219.1 -1.1%	138837.2 -2.1%	149881.8 5.7%	1675659.8	1712524.0 2.2%	1703614.1 1.7%	1546579.2 -7.7%	1539122.4 -8.1%
Meat	53094.1	52643.1 -0.8%	54329.1 2.3%	53891.6 1.5%	55966.4 5.4%	318706.1	300528.2 -5.7%	299822.7 -5.9%	288608.3 -9.4%	287462.5 -9.8%
Dairy products	74738.1	75178.4 0.6%	75054.4 0.4%	75206.1 0.6%	75067.1 0.4%	652173.1	671140.4 2.9%	669632.9 2.7%	661712.5 1.5%	660206.6 1.2%

2050 — Producer price [Euro / t]

	European Union					Non-EU				
	ref	aglu	aglu_glo	aglu_mag	aglu_glomag	ref	aglu	aglu_glo	aglu_mag	aglu_glomag
Cereals	261.7	552.9 111.3%	363.8 39.0%	722.0 175.9%	511.0 95.3%	319.1	333.5 4.5%	295.1 -7.5%	443.3 38.9%	402.0 26.0%
Oilseeds	519.4	1058.7 103.8%	711.9 37.1%	1348.6 159.6%	1007.1 93.9%	433.4	462.3 6.7%	444.2 2.5%	633.4 46.1%	619.2 42.9%
Vegetables and Permanent crops	517.0	641.3 24.0%	569.5 10.2%	800.9 54.9%	730.3 41.3%	1188.1	1223.8 3.0%	1227.7 3.3%	1744.4 46.8%	1749.4 47.3%
Meat	3728.3	7407.0 98.7%	7002.5 87.8%	7948.8 113.2%	7525.5 101.8%	3326.5	3587.3 7.8%	3496.2 5.1%	4456.9 34.0%	4358.5 31.0%
Dairy products	2264.7	2441.4 7.8%	2406.4 6.3%	2603.1 14.9%	2567.7 13.4%	1329.3	1442.1 8.5%	1423.6 7.1%	1599.7 20.3%	1581.0 18.9%

Source(s): CAPRI GUI, own compilation.

As may be expected the linkage effects of picking up two types of area information and two types of economic information are quite complex with the combined effects sometimes reinforcing each other and sometimes counteracting. As the non-EU regions give almost the global results it is useful to start here. We note that in terms of non-EU production small negative area effects from GLOBIOM and strong input price effects form MAGNET combine to modify the CAPRI effects on production of major output aggregates downward (compare columns "aglu_glomag" with "aglu"). For prices, the area information from GLOBIOM mildly counteracts the effects of the economic information from MAGNET. Overall it seems that the linkage via input prices gives the strongest modification of CAPRI results at the global level in this scenario.
For the EU the strongest effect comes from the moderation of area reallocations via GLOBIOM. The combined effects are complex and may differ in sign from the stand-alone CAPRI results (see the changes in production of permanent crops and meats). But there are also sectors like dairy where the external information did not significantly modify the "stand-alone" CAPRI results (in this scenario). The effects of model linkage may thus be sizable for some sectors and regions and very weak for others.

2.5.2.4.6 Annex: Review of expanded LULUCF accounting in CAPRI

The expansion of LULUCF accounting in CAPRI revision had to overcome the critical limitations of land use modelling in the former CAPRI global market model: no mapping from CAPRI land types to UNFCCC land types, no transition matrices and hence no carbon accounting according to IPCC default values. Fortunately the Ecampa-III study had prepared the key data work already such that we could proceed as follows:

The mapping of market model land types LT_l to UNFCCC land use LU_k may rely on the most recent historical shares φ_{kl} of UNFCCC land use k in CAPRI land type l (according to the expanded CAPRI database):

$$LU_k = \sum_l \varphi_{kl} LT_l$$

These shares are trivially zero or one in case that certain land types like "temporary non-fodder crops" (tc) and permanent crops (pc) are exclusively mapped to one UNFCCC category (cropland). The remainder to total cropland derives from temporary fodder and fallow land which is a fraction of total fodder area with the remainder being (productive) permanent grassland. The allocation of "other land" (ot) to grassland (φ_{glot}), wetland (φ_{wlot}) and residual land (φ_{rlot}) follows the procedures in the European database.

The next component needed for global carbon modelling and accounting is the land transition matrix describing how an initial allocation of land uses (either from the base year or from an intermediate simulation year) is transformed into the currently simulated one. The transition matrix may be expressed in terms of absolute areas from land use LU_j in the initial year s converted into another land use LU_k in the final year t or in terms of a transition matrix sh_{jk} giving the share (probability in a Markov chain) of initial land use LU_j converted into the final LU_k over the whole horizon of (t-s):

$$LU_{k,t} = \sum_j sh_{jk} LU_{j,s} = \sum_j L_{jk}$$

Where the shares (probabilities) have to add up to one:

$$1 = \sum_k sh_{jk}, \forall j$$

And the total areas converted from initial land use j into final land use k over the horizon (t-s) are denoted L_{jk} above. For those land transitions we would expect that the pattern of changes resembles that in the past, at least if total land uses LU_j change similarly as in the past. This expectation corresponds to the most likely land transitions maximising a Gamma density, giving for each transition a corresponding FOC:

$$(\lambda_{jk} - 1) L_{jk}^{-1} - \mu_{jk} + \tau_k + \tau_j^{initial} = 0$$

Where λ_{jk} and μ_{jk} are parameters related to the mode (determined from the database or baseline projection) and standard deviation (assumed = 1) of the Gamma density. The variables τ_k and τ_j are shadow values paired with the final year land use accounting from transition probabilities and the adding up condition for probabilities.

The original specification for land transitions as explored in the CAPRI supply models involved 6x(t-s) = 120 equations for a 20-year time horizon to represent a Markov chain of annual land transitions for each region. The advantage of this specification was that annual transitions were explicit model variables that could be used to compute annual carbon effects which were comparable to annual non-CO2 effect from running agricultural production. This was also acceptable from a computational viewpoint for the relatively small regional supply models of CAPRI (about 1500 equations). However, in the global market model all regions (about 80 with agents like farmers, consumers or landowners) have to be solved simultaneously such that the additional equations and variables for the extended land use modelling and carbon accounting (addressed in the following section) could increase solution time beyond critical limits. Given that the standard market model already includes about 80000 equations the above framework was adjusted to give the land transitions in one step for the change from the initial year s to the final year t, while still considering that we need annual carbon effects for comparability with the annual non-CO2 emissions. This has been achieved

- by respecifying the total land transitions sector as average transitions times, the projection horizon and

- by considering for the remaining class without land use change on the diagonal of the land transition matrix only the annual carbon effects per ha (for the case of gains via forest management).

This may be motivated as follows, starting from a calculation of the total GHG effects G over horizon h = t-s from total land transitions L_{jk} and carbon effects per ha for the whole period e_{jk}:

$$G = \Gamma \cdot h = \sum_{i,j} e_{ij} L_{ij}$$

Where Γ collects the annual GHG effects that correspond to the total GHG effects divided by the time horizon G / h. These annual effects may be calculated as based on average annual transitions and annual effects for the remaining class as follows:

$$\Gamma = \sum_{i,j} e_{ij} L_{ij} / h = \sum_{i \neq j} e_{ij} \Lambda_{ij} + \sum_i \varepsilon_{ii} L_{ii}$$

Where $\Lambda_{ij} = L_{ij} / h$ is the average land use change per year and ε_{ii} is the annual carbon effect on a remaining class (relevant might be an annual increase due to growing forests while this will be zero for most effects based on IPCC default assumptions).
Using these average annual transitions for true (off-diagonal) LUC we may compute the final classes as follows:

$$LU_{k,t} = \sum_j L_{jk} = \sum_{j \neq k} \Lambda_{jk} \cdot h + L_{kk}$$

While adding up of shares (or probabilities) of LUC from class I to k over all receiving classes k continues to hold as stated above. In this form LUC by CAPRI region and the associated accounting of carbon effects turned out computationally feasible even though the number of equations increased to about 85000. Apart from feasibility the format above also permitted to retain the typical CAPRI accounting identity that some total “quantity” (“GROF”) should be computable as the effects “per activity” times activity levels.

2.5.3 Linkage effect: differences of simulation results of the linkage in place and without linkage

In order to evaluate the effectiveness of the linkage, detailed analysis is required. Specifically, we are interested in whether the future scenario projections of the models exhibit comparatively less divergence post linkage implementation. We aim to evaluate this across multiple variables, items and regions. For each of these projections, we have three separate observations stemming from the CAPRI, GLOBIOM, and MAGNET models. In order to enable cross-variable and -item comparisons we focus our analysis on each models’ relative difference to 2010 (*rel2010*) and to their reference scenario (*relREF*), respectively. The focus should not solely lie on reducing the dispersion with regard to growth in 2010, but also on how much growth models predict from their respective baseline.
The presence or absence of the linkage effects is evaluated across fourteen products: Cereals (CER), Coarse grains (CGR), Dairy products (DRY), Energy crops (ECP), Fish (FSH), Non-ruminant meat (NRM), Oilseeds (OSD), Other crops (OCR), Plant based fibres (PFB), Rice (RIC), Ruminant meat (RUM), Sugar crops (SGC), Vegetables fruits & nuts (VFN), and Wheat (WHT). For each of these items the respective projections regarding Area, Consumption, Production, Total Emissions, and Producer Prices are evaluated. Moreover, the land-use in terms of Grass (GRS), Forestry Products (FOR), Natural vegetation (NAT), Other natural vegetation (ONV), Arable cropland (CRP), and Pastures (LSP) is evaluated. The indicators for land areas, as well as total GDP are used as an overall benchmarks of linkage evaluation, as these indicators were the main interfaces between the models.
The standard deviation of across models would appear as a natural choice to quantify their relative dispersion. One drawback of the standard deviation, however, is that it is unit dependent, therefore making cross item and variable comparisons difficult. Additionally, all variables under scrutiny (Area, Consumption, Production, Prices, Emissions, and GDP) are lower bounded by zero. Our measure of

dispersion should express this lower bound. For this purpose, we use the coefficient of variation (CV: defined as the standard deviation divided by the mean) as our main indicator variable to assess the performance of the linkage.

After calculating the CV for each item, variable, year, region, and scenario (linkage vs no linkage) combination across the three models, the difference of the CVs between results with and without linkage can be evaluated. This difference in CVs determines linkage effectiveness: a negative CV difference would indicate that the results from the linkage exhibit lower dispersion as without, while a positive CV difference is an indicator that the linkage of the models increased dispersion. With this measure we can do a basic comparison of how successful the linkage was across various regions and indicators.

We present a statistical framework, which is suitable to evaluate the linkage effectiveness across models. Such a statistical model would help us quantify where the linkage efforts were successful, and where improvements can be made. For this purpose, let us denote the CV difference between the linkage and no-linkage scenarios as y_i, related to observation i (where $i = 1, \dots, n$). Attempting to trace this back to specific item, regions and variables we can formulate the following model:

$$y_i = X_i' \beta + \varepsilon_i$$

where X_i is a K −dimensional matrix of a constant and item, variable and region-specific dummy variables β is a vector of regression coefficients of dimension $K \times 1$ and $\varepsilon_i \sim N(0, \sigma^2 \omega_i)$ is a Gaussian shock with variance $\sigma^2 \omega_i$. Note, that ω_i allows for observation specific heteroskedastic variances, in a sense, equivalent to a regression model with Student-t errors (see e.g. Koop, 2003).

This model can be easily estimated using maximum likelihood estimation. However, since one of the goals of this study is to analyze the impacts of various items, variables and regions on CV differences, we need a more flexible approach that allows to a.) assess uncertainty with respect to the underlying structural model and b.) enables robust estimation if the number of observations is small relative to the number of covariates K. The Bayesian approach allows, through flexible prior specifications, to control for model uncertainty and this entails estimating large models with only a moderate number of observations.

To set the stage, we assume that each element of β, β_j, arises from a mixture of Gaussians distribution. This prior, labeled the stochastic search variable selection (SSVS) prior (see George & McCulloch, 1993; 1997), is given by:

$$\beta_j | \delta_j \sim N(0, \tau_1^2)\delta_j + N(0, \tau_0^2)(1 - \delta_j),$$

whereby $\tau_1^2 \gg \tau_0^2$ denote prior scaling parameters, where τ_0^2 is specified to be close to zero and δ_j denotes an indicator variable that follows a Bernoulli distribution with prior inclusion probability p_0. In the empirical application, $\tau_1^2 = 10^2$ and $\tau_0^2 = 10^{-4}$ while $p_0 = 1/2$. This specification implies that if $\delta_j = 1$, a Gaussian prior with a larger prior variance is used for β_j with little weight attached to the prior information (i.e. exclusion of the corresponding element in X_i). This component of the mixture distribution is commonly referred to as the 'slab' distribution. By contrast, if $\delta_j = 0$, the prior variance is close to zero and the corresponding element in β_j is pushed to zero. We refer to this component as the 'spike' distribution. The δ_j can be used to infer what covariates determine CV differences.

The remaining priors are standard in the literature. On σ^2, we use an inverted Gamma prior specified to be weakly informative while we use a Gaussian prior with zero mean and a large prior variance on γ. For ω_i we use a hierarchical prior, as in Koop (2003).

Model estimation is carried out using a Markov chain Monte Carlo (MCMC) algorithm. This algorithm cycles between full conditional posterior distributions, iteratively sampling β_j from a Gaussian posterior density, σ^2 from an inverse Gamma posterior distribution, the indicators δ_j from a Bernoulli distribution. The posterior moments of all quantities except γ take standard forms and are, for the sake of brevity, not repeated here.

2.5.3.1 Global results

As a first step, we consider global aggregates of all items and variable combinations. While a detailed regional analysis will provide more insights, the global aggregates summarize the overall results well. To provide a first intuition, Figure 18 depicts the CV differences of all item-specific global aggregates from 2010 to 2050. In the left panel displays the CV differences are computed based on the relative growth of the observations to their 2010 values (rel2010), while the right panel relates to values in relation to their respective reference scenarios (relREF). The colored points correspond to the CV difference observations, while the color signifies the respective variable. The two control variables – namely, GDP and forest area – are highlighted as red lines. Observations below the zero line exhibit a lower CV post linkage, whereas positive valued observations indicate that the linkage has increased the CV.

This comparatively simple illustration already allows us to deduce a couple of key observations regarding the linkage exercise. First and foremost, the majority of the CV differences are not negative, thus the linkage had mixed success. It seems that while some variation between the models was reduced, in other cases the linkage caused a respective increase in variation. This is not necessarily surprising, as all involved models are highly complex, non-linear and built upon multiple sources of data dependency. Thus, a linkage exercise like the above can be expected to increase dispersion in some areas. This also motivates the necessity of detailed analysis of the linkage results, in order to trace for which items, variables and regions the linkage was statistically significant, and what its main impact was.

When we observe the temporal behavior of the CV differences we can observe that while over time some points exhibit higher CV differences, the majority remains concentrated around the axis. With the exception of prices (which post linkage has a higher dispersion, which increases over time) no clear increasing trends with regard to time can be seen in the CV differences.

The global CV difference aggregates of the control variables GDP and forest area lie overall below the zero line, indicating that the model projections post linkage are closer with regard to these variables, albeit the CV differences of forest area in relREF in 2050 is above zero (thus indicating a larger dispersion post linkage). The difference between rel2010 and relREF observations seems to be muted, with the post linkage scenarios in relREF exhibiting a slightly higher range of CV differences.

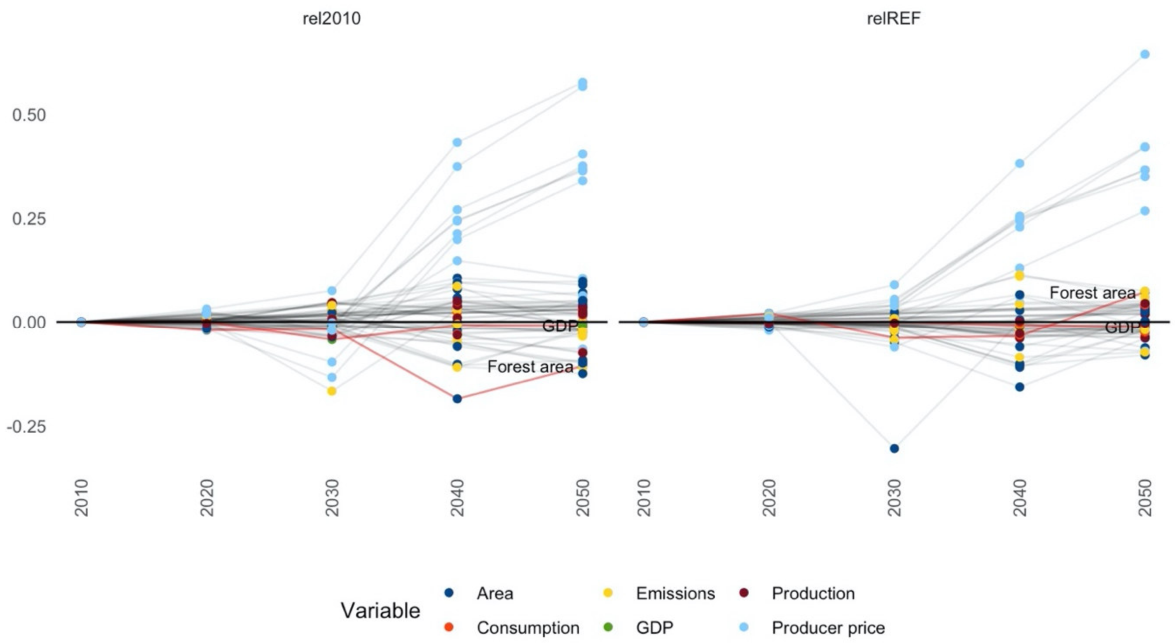

Figure 18. Difference of CVs pre and post linkage of global aggregates

Source(s): Own compilation.

Note: Left panel based on data relative to 2010, right relative to the reference scenario. Red colored lines correspond to the control variables GDP and forest area.

The colored differentiation of the variables in Figure 18, clearly allows us to distinguish that the producer prices post linkage exhibit a clearly higher variation as before the linkage. This trend seems to be also increasing over time. We cannot clearly discern trends with regard to the other variables, with areas, emissions, production, and consumption all giving both indication of convergence, as well as divergence past linkage.

To further analyze the results, we use our statistical model in Eq. (1) to estimate the marginal impact of each item category and variable type on the CV difference between linkage and non-linkage scenarios. Note, that in difference to the model, we drop the regional variable, as we are only exploring global aggregates at this stage. Table 18 shows the estimated marginal effects of each item and variable. The left panel denotes the model estimates when using observation from Rel2010, while the right relates to RelREF. Each panel contains the posterior mean and standard deviation estimates of the coefficients. Observations that are statistically significant under 95% confidence intervals are signified in bold. Note, that the result of both panels are similar in the significance of variables, as well as magnitude of estimates, confirming the graphical intuition based on Figure 18, that the results of the CV differences is similar, whether we look at the values relative to 2010 or relative to their reference scenarios. The low number of observations makes the variable selection in our model estimation framework clearly necessary, as otherwise we would lack the necessary degrees of freedom to arrive at statistically significant parameter estimates. The R^2 is reasonable for both models and a VIF test indicates that we have sufficiently captured heteroskedasticity (which was indeed present in the data).

Turning our attention to the parameter estimates, we can observe that most items, with the exception of CGR (and FOR in the RelREF panel) are negative, indicating an overall trend to CV convergence in the linkage scenarios. This trend, however, is not statistically significant in the majority of the estimates. Indeed, only CGR, which exhibits a small, albeit significant positive impact (i.e. increase in deviation past linkage), and RUM are significant. Note, that based on the statistical estimate, in the case of ruminants, the global averages of the models have clearly converged across all variables.

Table 18. Marginal effects on global CV differences

Coefficient		Rel2010		RelREF	
		Mean	Std. Dev.	Mean	Std. Dev.
Items	CGR	**0.092**	**0.044**	**0.094**	**0.040**
	CRP	-0.001	0.124	-0.005	0.123
	DRY	-0.025	0.061	-0.059	0.062
	ECP	-0.052	0.125	-0.095	0.119
	FOR	-0.164	0.126	0.031	0.125
	FSH	-0.085	0.085	-0.092	0.088
	LSP	-0.078	0.131	-0.065	0.126
	NAT	-0.050	0.120	-0.042	0.124
	NRM	-0.095	0.071	-0.080	0.065
	OCR	-0.088	0.096	-0.061	0.085
	ONV	-0.068	0.135	-0.052	0.130
	OSD	-0.021	0.056	-0.048	0.055
	PFB	-0.040	0.061	-0.044	0.056
	RIC	-0.028	0.062	-0.044	0.058
	RUM	**-0.109**	**0.062**	**-0.109**	**0.059**
	SGC	-0.013	0.056	-0.021	0.056
	VFN	-0.008	0.061	-0.028	0.059
	WHT	-0.094	0.060	-0.027	0.057
Variables	Area	-0.008	0.029	-0.009	0.026
	Consumption	0.005	0.042	0.013	0.037
	Emissions	-0.032	0.045	0.012	0.039
	GDP	-0.061	0.153	-0.046	0.118
	Producer price	**0.284**	**0.061**	**0.274**	**0.060**
	Production	0.007	0.043	0.016	0.039
	σ^2	0.007	0.003	0.007	0.002
	Observations	62		62	
	Adjusted R^2	0.397		0.382	

Sources(s): Own compilation.
Note: Results based on 20,000 draws, where the first 10,000 were discarded as burn-in. Convergence was checked using the diagnostic proposed by Geweke (1992). Bold numbers denote significance at the 95th percentile.

Looking at the average impact of variables, we can observe that our control variable GDP shows a decrease in CV differences (thus indicating model convergence past linkage), although this effect is not statistically significant. Indeed, divergence on average across variables is present in consumption, production (although both are comparatively small and not significant), and producer prices (which confirms the visual analysis above).

2.5.3.2 Regional results

Figure 19 provides an overview of CV differences per region in 2050 across items and scenarios. The left panel relates to the data based on their relative value to 2010 and the right panel to the respective model-specific reference scenario. Each grid cell of the figure corresponds to a CV difference for a given region, item, and variable. A positive value (divergence post linkage) is indicated with red shading, while a negative value (convergence post linkage) is shaded in blue. Stronger shading denotes a higher respective value, whereas values close (or equal) to zero are shaded in white. For some item/variable combinations there are no observation: these are shaded in grey. This is most notably the case for ECP in the left panel, as in two out of three models there are no areas for energy crops in 2010, thus no relative growth could be calculated.

The first observation underlines our global results, namely that the strongest and most persistent divergence can be observed with regard to producer prices. While some convergences exist (notably

OCR, and RUM, RIC, and DRY for selected regions), most producer prices either diverge or show no response to linkage across items and regions.

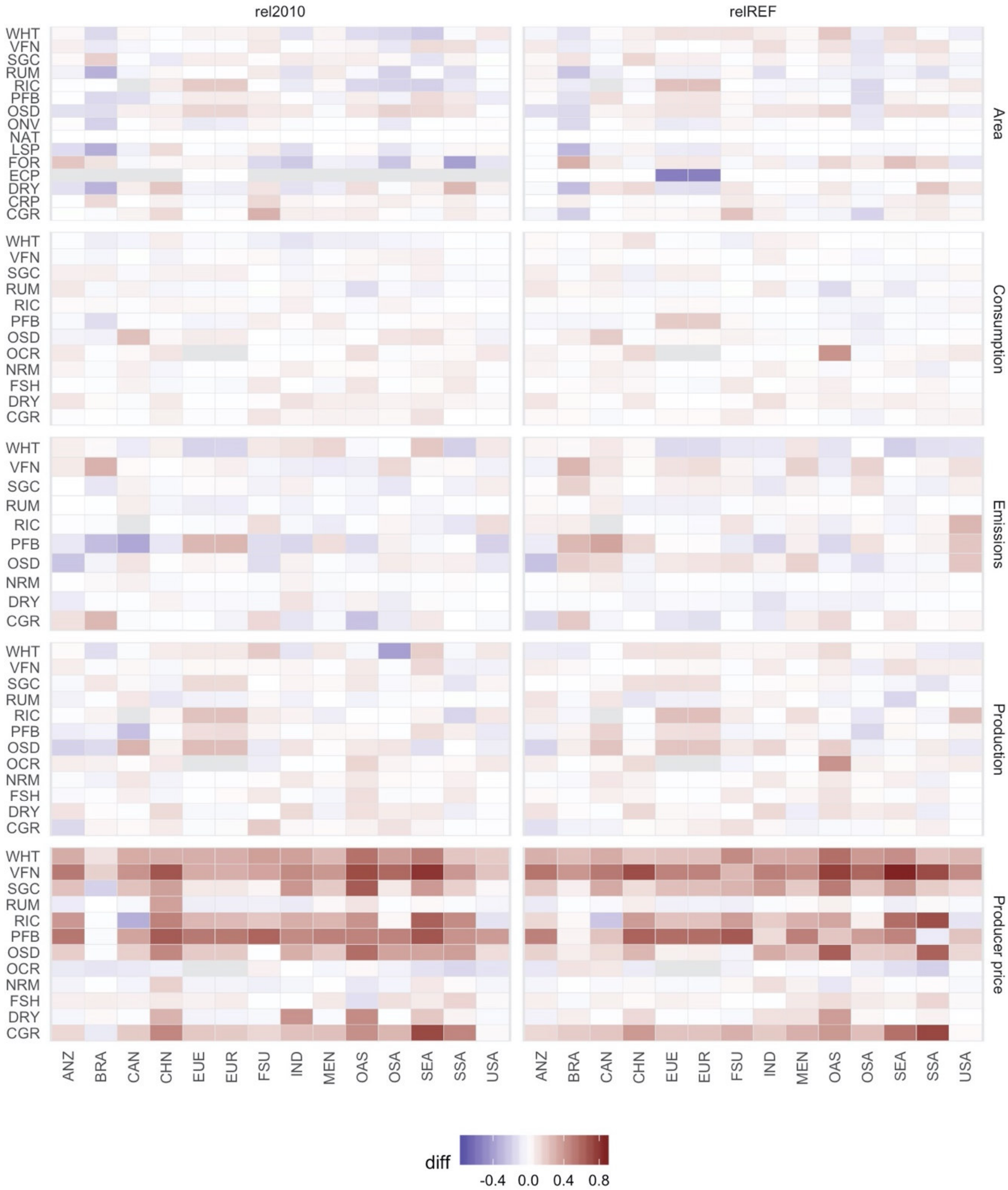

Figure 19. Difference of CVs pre and post linkage in 2050

Source(s): Own compilation.
Note: Left panel based on data relative to 2010, right relative to the reference scenario. Grey shaded areas denote missing observations.

For other variables there are mixed results, with Areas containing the strongest convergences, but also some divergence. With regard to regions, in the Rel2010 dataset, the Brazil region shows overall a trend towards convergence, but this is not as prominent in the RelREF dataset.
A statistical analysis using Eq. (1) is summarized in Table 19. Similar to Table 18, the left panel relates to the Rel2010, while the right relates to the RelREf dataset, respectively. The additional section of regions coefficients in the table summarizes the ceteris paribus average marginal impact of each

region. Note, the number of observations is much higher than in the global models, thus the more precise estimates and resulting higher number of statistically significant observations (under the 95th percentile).

Table 19. Marginal effects on regional CV differences

Coefficient		Rel2010		RelREF	
		Mean	Std. Dev.	Mean	Std. Dev.
Items	CGR	0.035	0.012	0.022	0.012
	CRP	0.002	0.027	0.007	0.025
	DRY	-0.027	0.017	-0.024	0.015
	ECP	-0.040	0.065	-0.020	0.026
	FOR	-0.078	0.035	0.045	0.030
	FSH	-0.056	0.018	-0.031	0.018
	LSP	-0.061	0.031	-0.042	0.027
	NAT	-0.030	0.026	-0.016	0.023
	NRM	-0.047	0.017	-0.038	0.016
	OCR	-0.060	0.023	-0.033	0.021
	ONV	-0.052	0.028	-0.036	0.026
	OSD	0.009	0.016	0.022	0.016
	PFB	-0.022	0.018	0.002	0.016
	RIC	-0.010	0.017	0.000	0.016
	RUM	-0.076	0.016	-0.065	0.015
	SGC	-0.015	0.016	0.009	0.015
	VFN	-0.002	0.016	0.025	0.017
	WHT	-0.008	0.018	0.015	0.016
Regions	ANZ	0.001	0.013	0.005	0.012
	BRA	-0.049	0.020	-0.015	0.018
	CAN	0.012	0.018	0.028	0.017
	CHN	0.032	0.018	0.018	0.016
	EUE	0.017	0.018	0.018	0.017
	EUR	0.018	0.018	0.019	0.017
	FSU	0.020	0.018	0.016	0.016
	IND	0.008	0.018	0.010	0.016
	MEN	0.006	0.017	0.018	0.016
	OAS	0.024	0.018	0.023	0.017
	OSA	-0.006	0.018	-0.027	0.017
	SEA	0.038	0.018	0.005	0.017
	SSA	0.012	0.019	0.010	0.016
	USA	-0.013	0.018	0.003	0.017
Variables	Area	0.006	0.011	0.005	0.010
	Consumption	0.009	0.011	0.006	0.010
	Emissions	-0.016	0.013	0.003	0.012
	GDP	-0.034	0.026	-0.023	0.024
	Producer price	0.146	0.017	0.134	0.013
	Production	0.022	0.012	0.023	0.011
	σ^2	0.007	0.001	0.006	0.000
	Observations	847		859	
	Adjusted R^2	0.334		0.331	

Source(s): Own compilation.

Note: Results based on 20,000 draws, where the first 10,000 were discarded as burn-in. Convergence was checked using the diagnostic proposed by Geweke (1992). Bold numbers denote significance at the 95th percentile.

Overall, the Rel2010 dataset indicates a higher and more significant average converge across regions and items than the RelREF dataset, although the average impacts of the variable coefficients are similar in magnitude and significance. Particularly, FOR, LSP, OCR, and ONV items, as well as the average impact of the BRA region trend more significantly towards convergence when they are measured relative to 2010. Moreover, the CHN region indicates a slightly higher, and statistically more significant divergence when looking at the Rel2010 dataset. The two datasets show differing results for the OSA and SEA regions, though in both cases the coefficient impacts are relatively small.
When looking at the average impact of items, we can observe a relatively strong and significant impact towards convergence on part of ruminants across all regions. Additionally, FSH and NRM both indicate small, albeit statistically significant convergence of CV differences post linkage. Coarse grains (CGR) are confirmed to have diverged across indicators and regions. Furthermore, the producer prices, as well as production are both statistically significantly diverging post linkage, though again the strongest effect is from the producer prices. The control variable GDP indicates a convergence, although it is not statistically significant from zero.

2.5.3.3 Conclusion

Our results indicate, that – not surprisingly given the overall model complexity – the models converged only partially across regions, items and variables. The model divergence has overall decreased for the harmonized variables GDP and forest area. For the meat markets (FSH, RUM, NRM) we can provide statistically significant evidence for convergence. In the BRA region, the models, relative to their 2010 values, have also converged post linkage. However, in terms of producer prices, the models exhibit post linkage a large and statistically significant divergence, which seems to increase over projected time.
In summary we presented a statistical evaluation framework for model convergence, which is based on a measure of CV difference between model outputs. The statistical model uses dummy observations, coupled with Bayesian model selection, and heteroskedasticity to flexibly assess whether variables across different levels of aggregation converged or diverged with a statistical significance. The presented framework could be a useful tool for the community to further benchmark harmonization efforts across the models.

2.5.4 References

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2.6 Model linkage MAGNET-AGMEMOD - Value chains and the marketing margin: the case of dairy - Some lessons for modelling and policy analyses

2.6.1 Introduction

In most agricultural policy models perfect competition and arm’s length pricing is assumed in all stages of the supply chain (McCorriston 1997). That implies that parties to the transaction are independent and prices are determined by aggregate supply and demand. The models typically use a 'representative firm' approach for agricultural production, as well as the food processing stage of the supply chain (e.g. AGMEMOD and MAGNET). Wholesale and retail stages are often modelled as inputs to the production sectors. The downstream part of the supply chain, i.e. beyond processing, is then modelled as a service (marketing services or wholesale and retail services) or a fixed mark-up rather than a separate stage in the value chain (e.g. MAGNET and other CGE models). And although some model versions allow increasing returns to scale or imperfect competition, these models are typically hard to implement in CGE settings due to a lack of data. Price transmission is either based on empirical estimations of elasticities of demand and supply or some exogenously determined price transmission equations (e.g. AGMEMOD).

The marketing margin is the difference between the farmer price and the consumer price (the farm-to-retail price spread) and has gotten much attention in agricultural market research over the past few decades (Wohlgenant 2001; Vavra and Goodwin 2005a). In the US, the farmer share of the food dollar has decreased from 41% in 1950 to about 21% in 1994 (Wohlgenant 2001). Similar decreases have been found in Europe. Between 1995 and 2011 the share of agriculture in the total value added of the EU food chain decreased from 31% to 21%[5]. For some reason the share of the primary sector in total value added of the food supply chain is decreasing. Wohlgenant (2001) asked the question whether these changing marketing margins have anything to do with the scale of production and marketing, whether concentration and market power have an effect on the margins, and how quickly changes in prices are transmitted through the chain. "The margin is influenced primarily by shifts in retail demand, farm supply, and marketing input prices. But other factors also can be important, including time lags in supply and demand, market power, risk, technical change, quality, and spatial considerations." (Wohlgenant 2001, 935)

Bakucs, Fałkowski, and Fertő (2014) list a number of reasons why imperfect price transmission is a concern to policy makers, and hence to economic modellers. Firstly, price changes have consequences for the welfare of consumers and producers and different model outcomes due to incomplete (or under certain conditions also more than proportionate) price transmission may have serious consequences for consumer and producer surplus. Secondly, prices convey information about scarcity. "As a consequence, investigating price movements along the marketing chain could be relevant to understanding whether resources employed in agro-food production are allocated efficiently." Thirdly, the analysis of price transmission from upstream to downstream stages in the chain can shed more light on the level of competition in the food sector and is therefore of interest to competition authorities (McCorriston 2002; Bakucs, Fałkowski, and Fertő 2014). Acosta, Ihle, and von Cramon-Taubadel (2019) add that "in the short-term, direct effects of this transmission on prices and the resulting incentives for supply and demand can affect food availability, access, price stability, and shift food use preferences. In the long term, domestic factors of production such as land, labour and capital can move towards new equilibria due to factor price adjustment, causing indirect dynamic effects on land use, production structures, dietary patterns, employment, and income. These issues have focused attention on price transmission (PT) analysis not only from researchers but also policy makers."

Deviations from perfect competition may significantly alter the modelling results with respect to price transmission between the various stages of the supply chain, and hence the responses of market actors (suppliers, processors, retailers, consumers) and the effects on producer and consumer surplus resulting from changes in agricultural policies (McCorriston 1997). Despite attempts to incorporate imperfect competition and the dynamics of price transmission into various economic models including equilibrium displacement models (Zhao et al. 2000; Harrington and Dubman 2008), there is still much work to be done to be able to clarify the effects of the value chain organization on price transmission and changing marketing margins.

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[5] European Commission own calculations based on Eurostat Data.

In this chapter, we briefly summarize some of the literature about price transmission with a specific focus on dairy products, showcase some of the issues of the dairy supply chain in the EU, and discuss the implications for price transmission. This choice has been made because of the limited budget available for this task which urged to also limit the scope of the assessment. It is our conviction that the insights derived from this dairy case can be generalized to many other sectors. Finally, we make suggestions for future research. We don't provide an extensive discussion of trade and value chains here (this aspect will be picked up in the Roadmap deliverable).

2.6.2 Literature on price transmission in the dairy supply chain

The literature on price transmission goes back to at least the late 1960s (Baltussen et al. 2019; Meyer and von Cramon-Taubadel 2004). Vertical price transmission between different stages or actors along the supply chain is distinguished from spatial price transmission between firms at different locations, regions or countries. Here, we focus on the first kind of price transmission, as it related to the functioning of supply chains; i.e. on the extent to which cost and/or price changes at one stage result in price changes at other stages.

Asymmetries in price transmission – generally meaning that cost increases are transmitted faster than cost decreases – are studied and found in numerous agricultural supply chains (Peltzman 2000; Meyer and von Cramon-Taubadel 2004; von Cramon-Taubadel 1998). Peltzman (2000) finds, in a study of 77 consumer goods and 165 producer goods, that for many products, both consumer goods and intermediate products, the "immediate response to a positive cost shock is at least twice the response to a negative shock, and that difference is sustained for at least five to eight months." In the longer term, Peltzman finds that prices do adjust and asymmetries are not sustained. Also, Peltzman finds contradicting effects of imperfect competition as measured by numbers of firms and concentration. Fewer competitors tend to increase asymmetry, while higher concentration ratios tend to decrease asymmetry. However, Peltzman concludes from this finding that there is no effect of imperfect competition without further investigating the two effects which are statistically significant in their own right. Furthermore, later research (e.g. Bonnet et al. 2013) suggests that other factors, such as vertical integration and contracting terms, as well as the increase of private labels of retailers has a significant effects on the relationship between concentration and margins. It is not only just the price margin that matters, but also the activities performed and the value added. It is important to note that Peltzman also finds markets in which prices tend to fall faster than they rise. He does further find that more price volatility leads to a lower degree of asymmetry in price transmission. This may suggest that unpredictability of future prices leads actors to arrange more flexible contract terms.

Whether imperfect competition is a cause of asymmetric price transmission and under what conditions is still being debated. Richards, Allender, and Hamilton (2012) study the relationship between price volatility, price transmission asymmetry and market power for potatoes and fluid milk. They find that for potatoes, both wholesale and retail market power decreases (increases) during periods of rising (falling) commodity prices. Price-cost margins "widen a substantially greater degree in response to negative shocks than margins narrow in response to positive shocks, indicating that commodity price volatility increases market power." Also for fluid milk they find that market power of downstream actors declines during periods of rising commodity prices; however, market power does not significantly change during periods of falling commodity prices, suggesting that commodity price volatility decreases market power. A report from the Commission of the European Communities (2009) summarizes that for most commodities price transmission is asymmetric in the sense that upward shocks are transmitted faster than downward shocks, while in the long run most price transmission is symmetric. Furthermore, margins were observed to increase to the benefit of processors in the Danish dairy chain.[6] On the other hand, another study on the Belgian dairy chain and a study on the French dairy chain found no evidence of pricing irregularities.[7]

Many different explanations have been given for the existence of incomplete or asymmetric price transmission. Market power has often been put forward as a reason for imperfect price transmission (McCorriston, Cw, and Aj 2001) as well as adjustment costs (Meyer and von Cramon-Taubadel 2004). The existence of market power or at least considerable concentration in food chains has been shown in many studies (eg. Lopez, Azzam, and Lirón-Espana 2002; Wann and Sexton 1992; Gohin and Guyomard 2000). "There is a growing literature that suggests that the food sector in developed countries is more appropriately characterised as being oligopolistic" (McCorriston, Cw, and Aj 2001). On the other hand, studies of the effects of market power on price transmission have led to varying outcomes. Regarding adjustment costs, factors like transaction costs (search costs), menu costs are often mentioned (Azzam 1999; Meyer and von Cramon-Taubadel 2004; Loy, Weiss, and Glauben 2016). Other explanations of asymmetric price transmission include e.g. information asymmetries, inventory management (stocks), expectations about inflation (e.g. Aguiar and Santana 2002).

A part of the (empirical) literature focuses on equilibrium prices at various stages of the supply chain and the effects of cost or price changes at the other stages, while assuming symmetry in the adjustments. Another part of the literature focuses on asymmetric price transmission, investigating whether the adjustment processes are different for increases and decreases of prices and the time lags involved.

2.6.2.1 Structural equations and equilibrium

There are several ways to model the 'intermediate food industry', comprising the processing, handling and distribution stages between primary production and final consumption. The standard approach to modelling retail/farm price linkage is based on the theory of derived demand, where consumer demand for the retail commodity generates a derived demand for the agricultural commodity (Gordon and Hazledine 1996; Jongeneel 2000). The retail price of the commodity will reflect the farm price plus the cost of marketing the commodity from the farm to the retail level. McCorriston, Cw, and Aj (2001) state that "the obvious framework to analyse this issue [of price transmission] is in the context of the equilibrium displacement model developed by Gardner (1975). However, the assumption of perfect competition in the food sector that is typically employed in these equilibrium displacement models does not appear to fit the facts". Most of the policy analysis models start from the assumption of perfect competition, and price transmission is typically assumed to be complete (not necessarily equal to 1), with the price transmission or cost pass-through coefficients generally being below one - depending on the nature of the aggregate demand curve. In a world without transport or transaction costs, without market power, or (government) policies restricting price transmission, cost increases would be fully transmitted.

Several studies use a one output/two inputs framework (Gardner 1975; Heien 1980; Wohlgenant 1989). The farm-retail linkage is then modelled as a single sector, with one final product output and an agricultural and a non-agricultural 'marketing' input. A simple condition to impose is that there is a fixed relationship between the farm product and the marketing inputs used in processing the product for the retail market. Also, it is often assumed that the supply of marketing inputs is perfectly elastic (Wohlgenant and Haidacher 1989). Holloway (1991) provided a 3-equation reduced form modelling approach, which was extended by Gordon and Hazledine (1996). The so modelled supply chain is often assumed to be characterized by perfect competition. Several other authors have added to this literature by accounting for different forms of imperfect competition (e.g. McCorriston (1997) or by extending the number of vertical stages in supply chains (Zhao et al. 2000).

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[6] Danish Competition Authority (2009), "Food prices: price developments for milk, butter and bread", cited in Commission of the European Communities (2009).

[7] SPF Economie, P.M.E., Classes moyennes et Energie, (2008), "Développements Récents dans l'Evolution des Prix et des Coûts de la Chaîne du Lait" ; FranceAgriMer, (2009) "Observatoire des Prix et des Marges – Filière Laitière", cited in Commission of the European Communities (2009).

Gardner (1975) set out the basic determinants of retail and farm level prices in a framework consisting of a six-equation model which determines (for some given commodity) the retail price and quantity, the farm price and quantity, and the price and quantity of other retail inputs (e.g., marketing services). The basic concept employed is a static equilibrium framework which assumes the equality of supply and demand in each of the three markets. Gardner develops a model of six equations, of supply and demand for farm outputs, marketing services, and retail food. This basic model assumes equilibrium of demand and supply in each market, and perfect competition. He finds that there is no simple mark-up rule (percentage mark-up, absolute mark-up, or combination) that can describe behaviour of farm-retail price spread. “Prices move together in different ways depending on whether the events that cause the movement arise from a shift in retail demand, farm supply, or the supply of marketing inputs”. Another finding is that events that increase the demand for food will reduce the retail-farm price ratio (and percentage marketing margin) if marketing inputs are more elastic in supply than farm products, but increase the spread if marketing inputs are less elastic in supply than farm products. Whereas events that increase (decrease) the supply of farm products will increase (decrease) the spread. Heien (1980) extends the model of Gardner to make a dynamic mark-up model of food pricing. In the Heien model, instead of looking only at the long-term equilibrium, the dynamic path of the price adjustments is described. The Heien model assumes a Leontief production function with zero substitution between farm output and marketing services, constant returns to scale, and ‘auction type competition’ at the farm level. The study finds no significant indication of asymmetric behaviour in price adjustments as the test for asymmetry (price increase passed on more complete than decrease) for the 22 product groups only show a significant coefficient with the right sign in five cases. The results for dairy suggest overshifting of price increases for milk, but undershifting of price increases for butter. More careful examination of the results, however, indicates that in seven cases the price transmission is also asymmetric with the opposite sign (overshifting), indicating the price increases are passed on more than price decreases. Most of these products seem to be packed and branded food products. Heien (1980) says nothing about the underlying market structure of the manufacturers or product differentiation.

Kinnucan and Forker (1987) study asymmetric price transmission in the dairy chain and apply the mark-up pricing model of Heien. They name a number of reasons for incomplete pass-through and stickiness: normal inertia related to storage, transporting, and processing; costs of repricing at the retail; market imperfections; the nature of price reporting. The authors hypothesize that market concentration and government intervention in the pricing of milk are affecting price transmission asymmetries. The existence of a government intervention system is thought to affect the expectations of retailers and wholesalers about the duration of periods of low prices. If actors believe that the government is going to intervene, they might (collectively) choose to wait a while before adapting prices, and avoid repricing costs. On the other hand, price increases as a result of increasing price support may be understood as permanent. For the current EU situation, the effect of government support may be less as price support has been substituted for by a safety net mechanism, which only becomes operational in case of extremely low prices.

Wohlgenant (1989) extents the equilibrium displacement model of Gardner to be more flexible and allow for input substitution between farm products and marketing inputs in the processing and retail industry. It shows that input substitutability can greatly increase elasticities of derived demand for farm products, in comparison with more traditional estimate derived from multiplying the elasticities of price transmission by elasticities of retail demand. “Thus, analysts should use reduced-form derived demand specifications for farm outputs in order to obtain more realistic estimates of derived demand elasticities.” (Wohlgenant 1989)

McCorriston, Cw, and Aj (2001) point to the role of the underlying cost structure. They show that if an industry is characterised by non-constant marginal costs, “there can be a significant impact on price transmission in the agro-food sector”. They show that the returns to scale in the industry cost function can considerably increase or decrease the degree of price transmission. In some circumstances, in industries with increasing returns to scale, price transmission may even exceed price transmission under conditions of perfect competition and constant returns to scale.

McCorriston, Morgan and Rayner (1998) have used imperfect competition in the equilibrium displacement framework to study price transmission. They find that market power in the food sector will reduce the degree of price transmission, but the results are subject to the functional form of the demand curve. Bonnet, Corre, and Réquillart (2015) explain that under perfect competition cost pass-through is lower than or equal to 1 and depends on the price elasticity of supply and demand. Under imperfect competition, cost pass-through also depends on the mark-up adjustments (i.e. strategic behaviour of firms). In that context the cost pass-through might be less than or greater than 1 depending on the form of the demand curve.

Bonnet et al. (2013) have pointed to the impact of the form of contracts between manufacturers and retailers on the extent of price transmission. This shows that the empirical results of many studies may be difficult to interpret if the market structure, the nature of the cost function, and the nature of the demand function are not fully accounted for. And it also suggests that taking market structure, contracts, and the nature of the cost function and demand function into account is very important for outcomes of price transmission and hence for the results of agricultural policy measures.

Bonnet, Corre, and Réquillart (2015) focus at the Dutch dairy chain with specific attention to fluid milk and dairy desserts. They study price transmission in a structural model, taking into account the vertical as well as the horizontal competition between manufacturers and retailers. Their model does not look at asymmetric price transmission, but only to what occurs in equilibrium. They first estimate a demand model, then compute cost-price margins based on the demand estimates, for a set of specific contractual relations between manufacturers and retailers and then select the best fitting model for simulations. They find that a 10% decrease in the milk price (farm price) causes a 2.60 euro per kilogram (1.91%) decrease in marginal costs of yoghurts, 3.66 euro (1.99%) decrease in the costs of cottage cheeses, a 1.34 euro (0.55%) decrease in the marginal costs of other dairy desserts, and a 1.77 euro (4.1%) decrease in the marginal costs of fluid milk. Consumer prices decrease by 1.1%, 1.3%, 0.3%, for yoghurts, cottage cheeses and other dairy desserts respectively, and by 1.81%, 1.92% and 3.36% for skimmed, semi-skimmed, and whole milk respectively. For semi-skimmed the cost pass-through was 1.11 and for whole milk even higher at 1.33, meaning that a decrease in costs to the industry leads to an even larger absolute decrease in retail prices. For desserts pass-through was generally found to be much lower at about 0.6 to 1.

The Bonnet, Corre, and Réquillart (2015) study shows that pass-through is larger for national brands in fluid milk and lower for private labels, whereas the situation is reversed for dairy desserts where pass-through is lower for national brands than for private labels. These differences may well be explained by the contracting arrangements. National brands may be able to increase their prices faster after an increase in the farm price than private label suppliers. Bonnet, Corre, and Réquillart (2015) also find that higher market shares of private labels lead to lower cost pass-through for national brands and higher pass-through for private labels. National brands manufacturers may be able to decide on the final resale price through the contracts that they have with retailers (Resale Price Maintenance). It seems that retailers are mostly competing on private labels while national brands attempt to avoid competition on prices. Retailers can use their private labels as a strategic tool in negotiations with brand manufacturers, mainly in the fluid milk market where private labels have a high market share. In the desserts market, brand manufacturers have a stronger position. The study also points to the impact of (or relation to) elasticities, which are higher for national brands than for private labels in the desserts market, and higher for private labels than national brands in the fluid milk market. Higher elasticities lead to higher demand responses after a price change and could therefore also explain the difference in pass-through. In any case, some of the changes in farm milk prices are not transmitted to consumers, while the dairy industry and/or the retailers adjust their mark-ups. The results show that contrary to the case of perfect competition, in the case of imperfect competition and strategic behaviour, both undershifting and overshifting of cost changes can occur. Extrapolation of the results to other industries is however not straight-forward. The structure of the upstream part of the supply chain plays a role, as well as the curvature of the demand curve, and the type of contracts. We may add to that, that product differentiation is probably also an explanatory factor.

Hong and Li (2017) also demonstrate that horizontal and vertical market structure including the role of private labels can influence cost pass-through, in a partial equilibrium model where large firms face a CES demand structure. "Accounting for the interaction of vertical and horizontal structure is important in understanding how market structure affects pass-through, as a reduction in double marginalization can raise pass-through directly but can also reduce it indirectly by increasing market share."

2.6.2.2 Time series models

The literature greatly expanded after von Cramon-Taubadel (1998) applied a new time series modelling approach to the study of price transmission. These analyses generally apply different specifications of the vector error-correction model (VECM/ECM) first introduced by Granger (1981) and Engle and Granger (1987). The number of papers increased significantly producing many estimates of price transmission speed, completeness and asymmetry. However, finding well-established causes for asymmetry or incompleteness of price transmission is still ongoing work. For an overview of studies see Meyer and von Cramon-Taubadel (2004); Bakucs, Fałkowski, and Fertő (2014); Frey and Manera (2007). Various determinants of (asymmetric) price transmission are tested. Baltussen et al. (2019) summarize them as follows:

1) "Market power is the most intuitive determinant of asymmetric price transmission. Supply chain actors with market power are assumed to pass through price changes in such a way that their margins are maintained or even increased. However, there are not many studies that explicitly test whether market power affects price transmission along food supply chains (Meyer and von Cramon-Taubadel 2004; Weldegebriel, Wang, and Rayner 2012). Since most studies only focus on one product without much variation in market structure it is often also not possible to test. Moreover, since pure monopolies/monopsonies are rare in food chains, market power is often materialised in oligopolies/oligopsonies for which strategic considerations (e.g. loss of market share, fear of price wars) and scale economies may prevent asymmetric price transmission.
2) Adjustment costs related to prices and quantities may differ between firms in different stages of supply chains. Both Meyer & Cramon-Taubadel (2004) and Vavra and Goodwin (2005b) note that retailers may abstain from raising consumer prices out of fear with respect to unsold stocks of perishable products, reputation loss of products with long shelf-life, or price wars. However, for each reason they only mention one supporting study, all from the 1980-1990's. E.g. against the perishability argument one could counter that farm price increases therein only arise in case of shortages, e.g. due to low harvests. However, in that case also retail may face shortages reducing the probability of unsold stocks. Moreover, with low income and price elasticities for food products it is not clear whether a consumer price increase would lead to a substantial decrease in demand. A more convincing argument seems to be fear of idle processing capacity for food processors, making farm prices sooner go up than down.
3) Inventory management may also lead to price asymmetries. In periods of low demand, processors may build up stocks instead of lowering retail prices, whereas in periods of high demand retail prices may be increased. Although this is a plausible argument explaining price asymmetries in retail, it is not discussed whether this also implies asymmetries between farm and retail prices.
4) Farm price support policies could make processors and retail reluctant in lowering their prices since they believe that lower farm prices will be compensated through these policies. Higher farm prices would be translated in higher retail prices though.
5) Differences in retail demand shocks and farm level supply shocks could also be a cause of price asymmetries, but only if their occurrence is unevenly distributed. M-CT suggest that this may have occurred in the European beef market during a sequence of various animal diseases leading to substantial demand shocks.
6) Asymmetric price information and biased price reporting by parties with vested interest is also suggested to be a determinant of asymmetric price transmission."

Most of the papers reviewed in Baltussen et al. (2019) test for the existence of asymmetries without explicitly testing what determines price transmission. Cutts and Kirsten (2006) look at maize meal, bread, sunflower cooking oil, and milk in South Africa. They confirm that differences in price transmission can be explained by market concentration. More concentration is associated with more asymmetric price transmission, but perishability of products is a confounding factor. Falkowski (2010) finds that retail market power in the Polish dairy supply chain leads to positive price transmission. Lass (2005) looks at the milk markets in Boston, Massachusetts, and Hartford, Connecticut in the US and specifically at two distinct periods: before and after the implementation of the Northeast Dairy Compact from July 1, 1997, to September 30, 2001, which established a farm price floor at $16.94 per hundredweight for fluid milk sold in New England. This study finds transmission rates are greater for the Compact period (100–120%) than the pre-Compact period (66–88%). Short-run asymmetries are also found, with retail prices responding more rapidly to farm price increases than farm price decreases. Sckokai, Soregaroli, and Moro (2013) find that retailers exercise market power towards processors of Italian cheese affecting price transmission.
Bakucs, Fałkowski, and Fertő (2014) apply a meta regression analysis to empirical results of other papers and find that asymmetric farm–retail price transmission is associated with sectors/countries with a more fragmented farm structure (i.e. less market power for farmers), higher governmental support and more restrictive regulations on price controls in the retail sector. "On the other hand, more restrictive regulations on entry barriers in the retail sector and the relative importance of the sector tend to promote symmetric farm–retail price transmission. The latter is also more likely in the presence of a strong processing industry." (Bakucs, Fałkowski, and Fertő 2014, 1) Moreover, with the increased market orientation of the CAP, the role of farm price support policies has weakened over time in the EU and seems no longer to be an explanatory factor, maybe except for cases of extremely low prices, when the safety net provisions could become operational.

2.6.2.3 Global Supply Chains

Global supply chain (GSC) trade is a new type of trade that has developed over the last 30 years. It is trade resulting from decisions by firms producing final goods (e.g. Apple iPhones) to allocate underlying tasks (e.g. design, component production and assembly) to dedicated facilities in different countries. These decisions create cross-border flows of products at various stages of completion. Exports from one country to another often involve complex interactions among a variety of domestic and foreign suppliers. Even more than before, trade is determined by strategic decisions of firms to outsource, invest, and carry out activities wherever the necessary skills and materials are available at competitive cost and quality (https://www.oecd.org/trade/topics/global-value-chains-and-trade/)

2.6.3 The dairy supply chain

Supply chains can show quite some heterogeneity even within one product and even though there is a Single Market in the EU. The EU dairy case may illustrate this. The total number of dairy firms in the EU (including ice cream) is about 13 thousand.[8] In the figure below the number of companies is plotted against the turnover in the industry. From this data it is shown that the average size of the companies differs greatly between MS. The number of dairy firms increases with the size of the country. Italy, Germany, Spain and Germany naturally have a large number of dairy firms. The total turnover of the industry also increases with the size of the country, but there are some exceptions. Especially the Netherlands and Denmark have a larger dairy industry than would have been expected in comparison to e.g. the number of inhabitants.

[8] The data are from Eurostat sbs. Luxembourg and Malta have no data reported. Missing data for Denmark and Italy was estimated from previous years and public information on the largest companies.

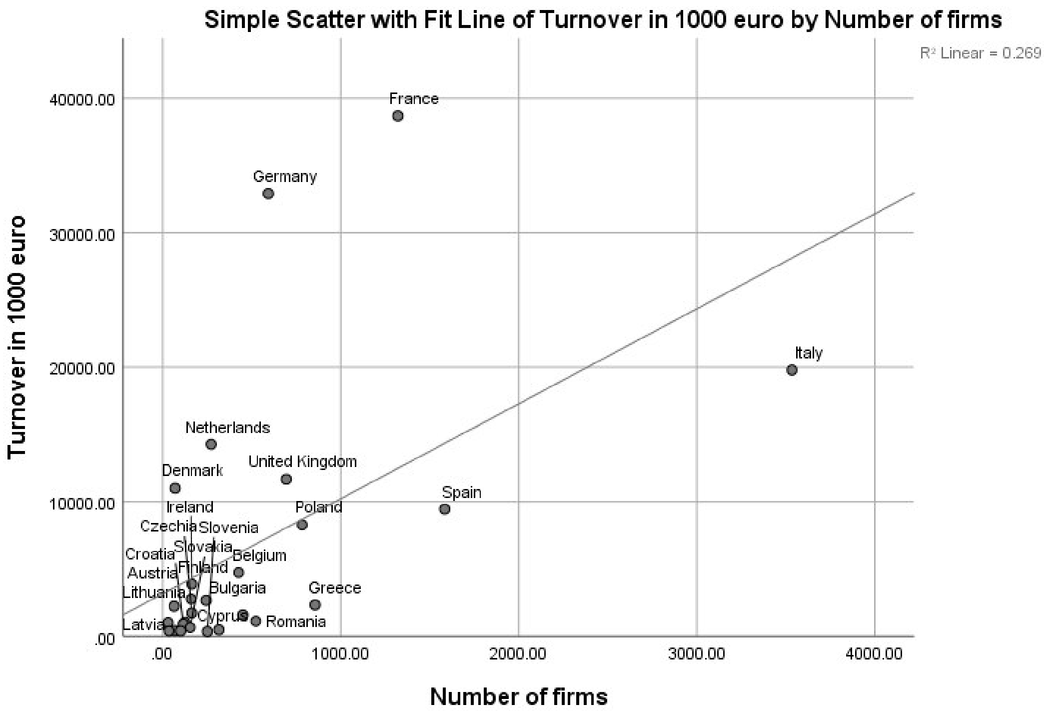

Figure 20. Number of dairy firms versus the total turnover in the industry, in EU countries.

Source(s): Eurostat SBS.

The Danish dairy sector, with Arla as the main producer, has just a small number of firms (71 in 2018) but a very large turnover resulting in a very high average turnover per firm (see Figure 21 below). Of these 71 firms, Arla is by far the biggest. From company accounting data it is estimated that the four largest dairy firms in Denmark have a market share of 98%. The Netherlands have 273 dairy processing firms but only about 20 have a turnover exceeding 10 million euro. The estimated concentration ratios are displayed in Figure 22.

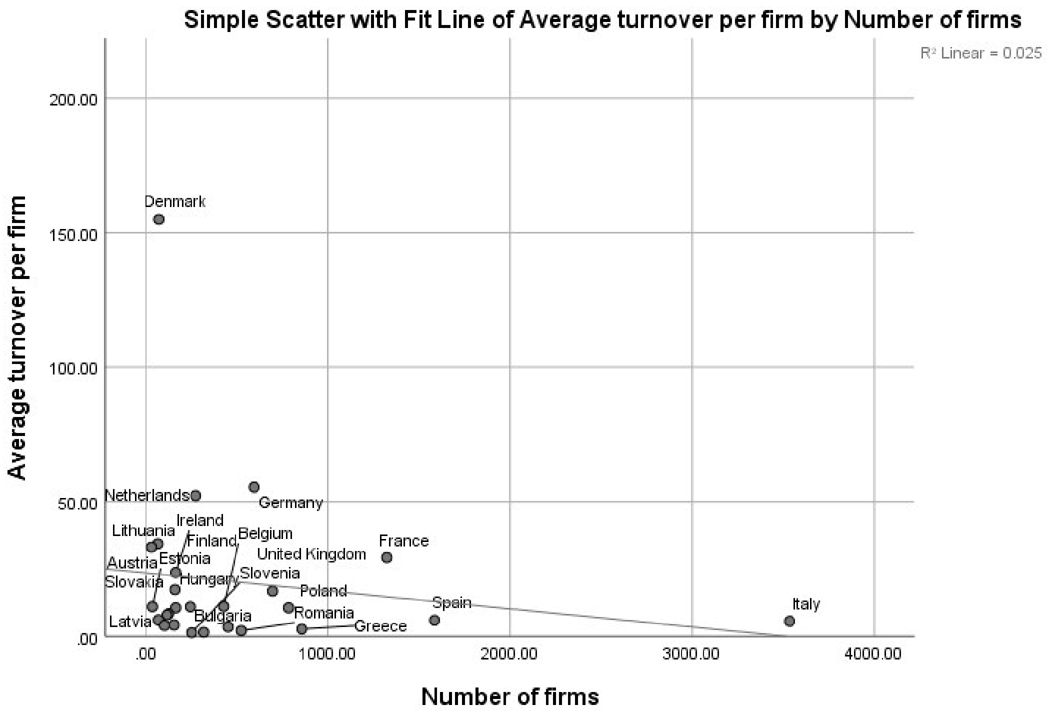

Figure 21. Number of dairy firms versus average turnover in the industry, in EU countries.

Source(s): Eurostat SBS.

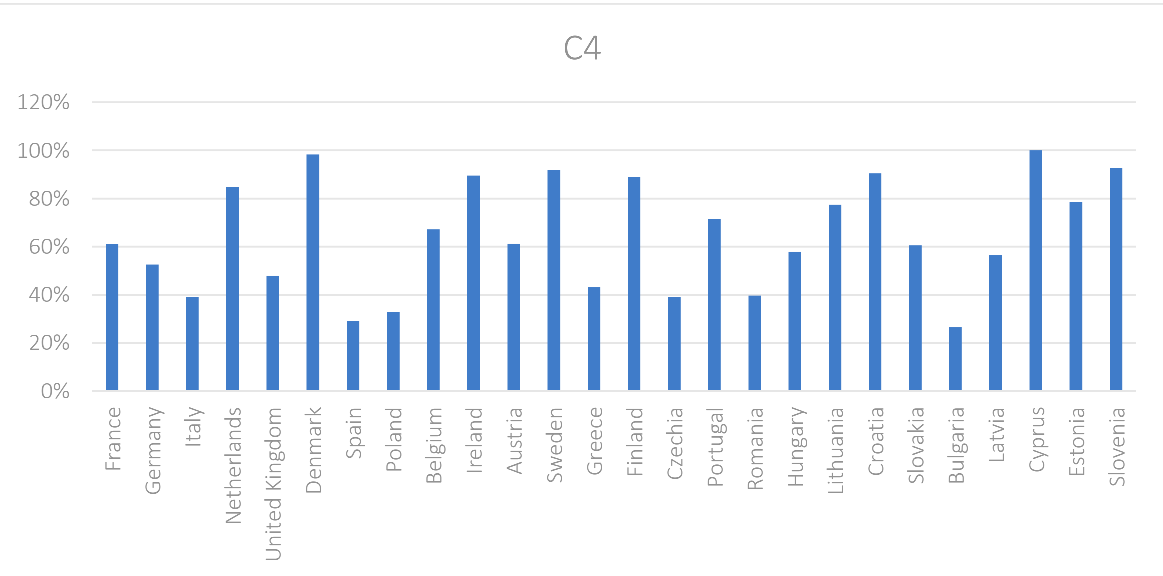

Figure 22. Concentration ratios, C4, in the dairy processing industries, in EU countries, 2016-2018 estimates.

Source(s): ORBIS Bureau van Dijk, calculations Wageningen Economic Research.

The dairy supply chain structure yields a differentiated picture of farm gate milk prices (see Figure 23; right axis). Also the share of (farmer owned) dairy processing cooperatives has been added to this graph, which shows quite some variation over Member States, more than the variation in C4 rates). Although some attempt has been made to link farm gate milk prices to the industry structure as comprised by the previously presented C4 concentration ratio's as well as an indicator expressing the share of cooperatives in dairy processing, this did not lead to clear results. For example, the hypothesis that a relatively high concentration ratio leads to a relatively lower farm gate milk price was not confirmed. Even in contrast, the C4 ratio showed a positive rather than a negative correlation with the milk price, although this was not significant. There could be also a rational for such a counterintuitive finding: a high C4 could point to an advanced dairy supply chain consolidation, including the utilization of economies of scale in processing and marketing, which may allow for higher farm gate milk returns, than in cases where the industry structure is still more dispersed and fragmented. Some evidence was found for the share of farmer owned-dairy cooperatives to positively relate with the farm gate milk price. However, on average the explanatory power of both variables appeared to be low and not significant.

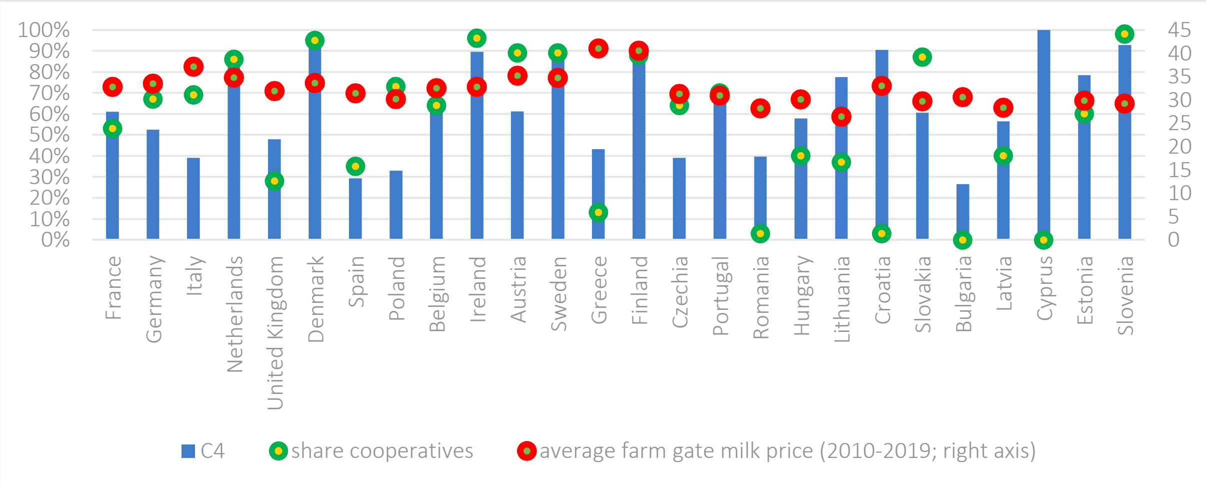

Figure 23. Prices of raw cows' milk actual fat content - prices in euro per 100 kg (2010-2019 average), concentration rates (C4) in milk processing and share of dairy cooperatives in milk processing

Source(s): authors: milk price data come from EU Milk Market Observatory (Dg-AGRI).

2.6.4 Conclusions and recommendations

An assessment has been made about the importance to understand supply chain phenomena and to see to what extent these are taken into account in the MAGNET and AGMEMOD modelling tools. It turned out that both the GE MAGNET model as well as the PE AGMEMOD model has a very poor representation of supply chains:

- GE models (MAGNET being a prime example of such a model) in principle cover the whole economy and thus supply chains and usually do this by adding ‘services’ to a primary product to create a transformed final consumer product. Usually this is done at a quite high aggregation level, which goes much beyond the level of individual products (e.g such as cheese, butter, fresh dairy products).
- PE models (AGMEMOD being a prime example of such a model) sometimes include selected processing stages (e.g. dairy processing, slaughterhouses, sugar beet processing, oilseed crushing) but omit others (e.g. retail sector).
- Both the MAGNET and AGMEMOD models rely on a so-called ‘representative firm’-assumption in modelling supply chain behaviour. This implicitly implies that a full competition-assumption is used.
- Both MAGNET and AGMEMOD include price transmission linkages. In MAGNET price transmission is consistent with a CES-type structure of substitution elasticities, which are usually calibrated and not empirically estimated. MAGNET exploits the so-called Armington assumption, according to which similar products from different regions are imperfect substitutes. As such the model allows for price differentials of the same product between regions.

- In AGMEMOD, which in contrast with MAGNET applies a homogeneous good assumption, the price transmission relationships have been empirically estimated, and can then be interpreted as reduced form expressions of complex price transmission mechanisms as these are operating in reality.
- No industry structure-variables, such as concentration ratio's or the share of cooperatives are included as explanatory variables in price transmission equations.
- Price transmission equations in both models are symmetric: price transmission is not dependent on the direction of the shock (upward, downward) disturbing the market.

As has been shown from the literature assessment, supply chain characteristics and the behaviour of different players in the supply chain is important for understanding the evolution of the farmer-retail price spread. The literature on mark-ups and price transmission has shown a rich variety of relationships. A general suggestion from the supply chain and price transmission literature is that competition is often characterized by some form of oligopoly/oligopsony rather than by full competition. As market and sector models, including MAGNET and AGMEMOD, do not explicitly model firms, nor take into account industry structure indicators as explanatory variables in empirically estimated (vertical) price transmission relationships, they are in general not suited to properly represent the actual industry dynamics, and especially short-term dynamics.
The 'approximation error' market or sector models make as a result of the poor representation of supply chains is difficult to define or to measure, as the results from the case studies done in the literature show a wide range of results depending on product, place, time, product-(des)aggregation level (e.g. distinguishing brands and private labels), and supply chain coordination and integration. AGMEMOD has an advantage that since they include empirically estimated 'reduced forms' of price transmission equations (at product and Member State level). AGMEMOD models can for that reason be argued to capture as best as possible the net impact, of what might be complex supply chain dynamics. However, even then it lacks the issue of price/mark-up asymmetries, even though the supply chain literature shows that price asymmetry is a phenomenon to be accounted for, at least in the short run. However, if the focus of the MAGNET and AGMEMOD model uses is on medium term assessments and on aggregate commodity levels (rather than detailed products and product qualities), such as for example in outlook studies and policy simulation analysis, these models still suffice.
When the focus of the analysis is on specific policy measures aimed at influencing industry behaviour or the position of farmers within the supply chain, such as the CAP measures with respect to producer groups, or on the leakage of support (e.g. direct payments) from farmers to other stages of the supply chain, as well as on the impact of certain ways of contracting or integration along supply chains on farmer earnings, the sector models are insufficient. When they are used is such occasions, they should be complemented by suitable supply chain models (e.g. by targeted equilibrium displacement models).

2.6.5 Further developments foreseen in SUPREMA

Although no additional developments were planned on MAGNET-AGMEMOD linkage within the context of SUPREMA, the discussions within the SUPREMA team, have being important in initiating a linkage between MAGNET and AGMEMOD. Moreover both the financial crises of 2008 and the COVID19 crisis, have strengthened the wish to be better able to link macro-economic developments that take place outside agriculture (e.g. bio-economy) and outside the EU (e.g. geopolitical developments with respect to trade, the worldwide recession linked to COVID) to EU agriculture. First steps in this regard have been made, which so far are mainly based on soft and indirect linkages.

2.6.6 Summary

An assessment has been made about the importance to understand supply chain phenomena and to see to what extent these are taken into account in the MAGNET and AGMEMOD modelling tools. It turned out that both the computable general equilibrium (CGE) MAGNET model as well as the partial equilibrium (PE) AGMEMOD model have a very poor representation of supply chains. Moreover they use different approaches: CGE models usually include supply chain stages by adding 'services' to a primary product to create a transformed final consumer product. Usually this is done at a quite high aggregation level, which goes much beyond the level of individual products (e.g such as cheese, butter, fresh dairy products). In PE models often only selected processing stages (e.g. dairy processing, slaughterhouses, sugar beet processing, oilseed crushing) are included, while others (e.g. retail sector) are omitted. However in neither case firms are explicitly modelled or accounted for in other ways (e.g. concentration ratios). This is a drawback as the literature shows that by this model specification the considered models will not be able to capture a number of important supply chain phenomena, including the distribution of remuneration along the chain and changes in this distribution as a consequence of shocks or policy changes. When the focus of the analysis is on specific policy measures aimed at influencing industry behavior or the position of farmers within the supply chain, such as the CAP measures with respect to producer groups, or on the leakage of support (e.g. direct payments) from farmers to other stages of the supply chain, as well as on the impact of certain ways of contracting or integration along supply chains on farmer earnings, the sector models are insufficient. When they are used is such occasions, they should be complemented by suitable supply chain models (e.g. by targeted equilibrium displacement models).

2.6.7 References

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3 Conclusions and recommendations

The different subchapters present various linkage activities in SUPREMA. This section collects short summaries and the main conclusions of the model linkages.

The IFM-CAP-CAPRI linkage concluded that the developed linkage is operational and applicable. They showed this using an extensification scenario. However, they admitted that the current application is still a didactic approach, rather than a proof the concept, and needs further elaboration. The scenario was certainly an extreme shock to test if the model-linkage converges. The scenario needs to be fine-tuned, means less drastic conversion rate and a brother coverage of regions. In addition, more indicators for income and environmental analysis derived from IFM-CAP are required to present and analyse the effects of the shock on the population of different farming types and economic size classes.

With respect to the GLOBIOM-CAPRI link: Several options to further improve the linkages between GLOBIOM and CAPRI have been considered at the outset of SUPREMA. Some of them have been addressed in the context of the mitigation runs with model linkage, others had to be postponed to future work. They conclude that GLOBIOM could use AgLink projections and try to align with them up to 2030 to potentially avoid abrupt changes in trends when transitioning in the CAPRI system from AgLink baseline to GLOBIOM baseline, which is currently taken care off through the above described weighting procedure. This linkage has also been postponed to future work.

The linkage of AGMEMOD - AGLINK is a useful process to obtain detailed member state results for based on aggregated EU results of the EU medium-term outlook. In general, results indicate that AGMEMOD often provides more conservative model outcomes for the EU-13 than AGLINK whereas scaling less pronounced for the animal sectors which may be due to more severe restrictions in the markets which allow less flexibility with respect to the future development. Hence, there exit also some differences in data as aggregated member state data and EU data may differ. The analysis gives first insights into the associated linkage effect between the AGMEMOD and the AGLINK model and illustrates the ability how models may be aligned with a quite simple approach. Thus, both models can be used to either gain insight into more member state specific results (AGMEMOD) or EU aggregated results (AGLINK) while ensuring a harmonised level of results for both models. Yet the outcomes of the linked models are subject to validation processes via market experts. The used approach can certainly be improved by (a) applying weights reflecting country specific data quality or (b) quality of behavioural equations, or (c) an entropy approach. A further option might be to include a feedback loop via prices. But such results again will be subject to validations by markets experts. All mentioned improvement possibilities require detailed analysis before they can be implemented.

By linking AGMEMOD and MITERRA models a tool which combines the strengths of two well-established models is developed. More specifically, such a tool can support policy makers with providing scenario analysis and (ex-ante and ex-post) impact assessments with respect to climate action and nutrient flow related policy measures. The behavioral component is represented by AGMEMOD (which drives activity choice and levels). The environmental and climate impacts are generated by the biophysical MITERRA model, which has a detailed agronomic, agri-environmental and spatial representation of key mechanisms playing a role in agriculture and land use (including forestry). A hard linkage between both models has been developed. A one-way-causality between AGMEMOD and MITERRA has be assumed, and for this reason linkage does not require iterations between both models. A proof of principle of the results generated by the linked model application has been demonstrated by apply the tool to the medium-term CAP scenario assessments.

The linkage for MAGNET-GLOBIOM-CAPRI indicate, that – not surprisingly given the overall model complexity – the models converged only partially across regions, items and variables. The model divergence has overall decreased for the harmonized variables GDP and forest area. For the meat markets (FSH, RUM, NRM) we can provide statistically significant evidence for convergence. In the BRA region, the models, relative to their 2010 values, have also converged post linkage. However, in terms of producer prices, the models exhibit post linkage a large and statistically significant divergence, which seems to increase over projected time. In summary we presented a statistical evaluation framework for model convergence, which is based on a measure of CV difference between model outputs. The statistical model uses dummy observations, coupled with Bayesian model selection, and heteroskedasticity to flexibly assess whether variables across different levels of aggregation converged or diverged with a statistical significance. The presented framework could be a useful tool for the community to further benchmark harmonization efforts across the models.

With respect to the model linkage for MAGNET-AGMEMOD an assessment has been made about the importance to understand supply chain phenomena and to see to what extent these are taken into account in the MAGNET and AGMEMOD modelling tools. It turned out that both the computable general equilibrium (CGE) MAGNET model as well as the partial equilibrium (PE) AGMEMOD model have a very poor representation of supply chains. Moreover, they use different approaches: CGE models usually include supply chain stages by adding 'services' to a primary product to create a transformed final consumer product. Usually this is done at a quite high aggregation level, which goes much beyond the level of individual products (e.g such as cheese, butter, fresh dairy products). In PE models often only selected processing stages (e.g. dairy processing, slaughterhouses, sugar beet processing, oilseed crushing) are included, while others (e.g. retail sector) are omitted. However, in neither case firms are explicitly modelled or accounted for in other ways (e.g. concentration ratios). This is a drawback as the literature shows that by this model specification the considered models will not be able to capture a number of important supply chain phenomena, including the distribution of remuneration along the chain and changes in this distribution as a consequence of shocks or policy changes. When the focus of the analysis is on specific policy measures aimed at influencing industry behavior or the position of farmers within the supply chain, such as the CAP measures with respect to producer groups, or on the leakage of support (e.g. direct payments) from farmers to other stages of the supply chain, as well as on the impact of certain ways of contracting or integration along supply chains on farmer earnings, the sector models are insufficient. When they are used is such occasions, they should be complemented by suitable supply chain models (e.g. by targeted equilibrium displacement models).