Automated model linkages: the example of CAPRI

Automatisierte Kopplung von Modellen am Beispiel von CAPRI

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Abstract

Increasing demand for policy impact assessment regarding social, economic and environmental aspects asks for combined application of different models and tools. The paper discusses concepts and challenges in linking models, taking CAPRI (Common Agricultural Policy Regionalised Impact) model as an example. CAPRI combines different economic models, spatial downscaling and interfaces to bio-physical components. 250 non-linear regional programming models with econometrically estimated costs functions cover the EU-27, Norway and Western Balkans. They are consistently linked to a spatial globally closed trade model, covering 60 countries / country blocks and 50 primary and secondary agricultural products. The link is based on sequential calibration: the market models prices drive the programming models whereas its supply and feed demand curves are calibrated to the programming models' results, iteratively repeated to convergence. CAPRI integrates projection results from other model systems in the baseline generation and calibrates the supply models to econometric estimations or the supply response from other models as in SEAMLESS. The spatial down-scaling component breaks down the regional EU-27 results regarding cropping shares, crop yields, animal stocking densities and fertilizer application rates to about 140 000 1x1 km pixel cluster and links these results to a statistical meta model of the bio-physical model DNDC.

Keywords

model linkage; linking economic and environmental models; policy impact assessment

Zusammenfassung

Die steigende Nachfrage nach Politikfolgenabschätzung in Bezug auf soziale, ökonomische und Umweltgesichtspunkte erfordert den kombinierten Einsatz unterschiedliche Modelle und Werkzeuge. Der Beitrag diskutiert Konzepte und Gesichtspunkte bei der Verlinkung von Modellen am Beispiel von CAPRI (Common Agricultural Policy Regionalised Impact). CAPRI kombiniert unterschiedliche ökonomische Modelle, Komponenten zur räumlichen Disaggregierung und Schnittstellen zu bio-physikalischen Komponenten. 250 nicht-lineare regionale Programmierungsmodelle mit ökonometrisch geschätzten Kostenfunktionen decken die EU-27, Norwegen und den westlichen Balkan ab. Sie sind konsistent mit einem räumlichen, globalen Handelsmodell gekoppelt, das 60 Länder oder Länderblöcke und 50 primäre und sekundäre Agrarprodukte abbildet. Die Kopplung basiert auf sequentieller Kalibrierung: Die Preise des Marktmodells treiben die Regionalmodelle, während das Angebotsverhalten und die Futternachfrage des Marktmodells auf die Ergebnisse der Regionalmodelle kalibriert werden. Der Prozess wird iterativ bis zur Konvergenz wiederholt. CAPRI integriert in seine Baseline Ergebnisse anderer Modellsysteme and kalibriert die Angebotsmodelle auf ökonometrische Schätzungen oder das Angebotsverhalten anderer Modelle wie in SEAMLESS. Die Komponente zur räumlichen Disaggregierung bricht die regionalen Fruchtartanteile, Erträge, Bestandsdichten und Düngergaben für die EU-27 auf ca. 140 000 1x1 km Pixelcluster herunter und koppelt diese Ergebnisse mit dem biophysikalischen Modell DNDC.

Schlüsselwörter

Verlinkung von Modellen; Politikfolgenabschätzung; Verbindung ökonomischer und ökologischer Modelle

1. Introduction

Linking models or usage of model chains for policy impact assessment is an established proceeding. Especially combined analysis of economic and environmental consequences of policy options has led since quite some time to development of model chains, e.g. parameterization of farm models by the help of bio-physical models (see e.g. ROEBELING et al., 2000). Recently, model linkage has also become fashionable in CGE-analysis regarding coupling with Partial Equilibrium (PE) or special trade models (JANSSON et al., 2008; BÖHRINGER and RUTHERFORD, 2006; or GRANT, HERTL and RUTHERFORD, 2006). The ongoing reforms in agricultural policy provide a further incentive by shifting the focus from market and farm income impacts to environmental and rural development ones. Expansion of existing impact assessment tools, either by enriching components or by adding new ones is therefore en vogue. In the following, model linkage in and around the CAPRI (Common Agricultural Policy Regionalised Impact) model (BRITZ et al., 2007) will be discussed, including the newly spatial down-scaling component (LEIP et al., 2008) and the CAPRI-DNDC meta model (BRITZ and LEIP, 2008). CAPRI is deemed an interesting example as it applies different options for model linkage such as response surfaces or sequential calibration.

The main arguments for linking models rather then building super-models are twofold. Firstly, to allow for differences in methodological and technical solution, parameterization and underlying data sources thus increasing flexibility in model development, application and maintenance. Secondly, by doing so, to exploit the comparative advantages of different model types and implementations, regarding result quality, coverage or resolution, or regarding response times.

2. Types of model linkage

Model linkage is seen here from the perspective of models providing data to and using data generated by other models. It is then useful to make a distinction between:

1. *Model chain without calibration*: one model is shocked with data by another one without calibration. That is the oldest and perhaps most often found application. Classical examples are the usage of prices stemming from PE models in programming models (e.g. BERTELSMEIER et

al., 2003), or using macro-economic simulation results from CGE in PE or micro-simulation models (see examples above). That will typically lead to inconsistencies in the common outputs. Defining the production possibility set of farm level programming models by the help of bio-physical models or coefficient generators may be seen as one special case of such a model chain (e.g. APES-FFSIM in SEAMLESS, see ITTERSUM et al., 2008), but in that case, the common output is typically empty, and no consistency issue arises. So called "soft linkage" where only some major outputs are passed in an ad-hoc way to another model or component are less vulnerable compared to an automated linkage where development and maintenance of the components or models is often distributed to different desks and institutions, and development of specialised versions e.g. for a specific project is combined with general model improvement / maintenance.

2. *One-way calibration*: one model is calibrated to results generated by another one. That solution may be found in bottom-up and in top-down approaches. Bottom-up examples are behavioural equations of market models being calibrated to the simulation response of econometrically estimated micro-models. Top-down approaches are typically more challenging as the more disaggregated result or even response behaviour at the bottom must be harmonized to the result or response behaviour at the top. An example will be discussed below for the site-specific calibration of the meta-model from DNDC.
3. *Sequential calibration*: both models act as users and providers. That is the solution used in CAPRI to link the regional programming models and the market part, and is currently also under investigation for a CAPRI-GTAP link (JANSSON et al., 2008). Here, both models are acting as data providers and users, and both are calibrated. The solution is discussed in more detail below. Sequential calibration requires iterations over components, so that interfacing between the models is complex and the response time of the linked system is typically much higher compared to stand-alone applications of the single components. That may either trigger refactoring of the components or lead to the development of response surfaces to ease integration and speed up processing.

3. CAPRI as a system of linked models

3.1 Overview[1]

The CAPRI model is an agricultural sector economic model covering the EU-27, Norway and Western Balkans based on non-linear regional programming models consistently linked with a global agricultural trade model (see BRITZ et al., 2007). Its principal aim is to analyse impacts of changes in EU (or international) agricultural policies and markets on European agriculture and global agricultural markets, mostly at the medium term (8-10 years ahead). Technically, it is a static, partial equilibrium model consisting of four interconnected modules covering (1) regional agricultural supply for EU-27, Norway and Western Balkans, (2) global and EU markets for major primary and secondary agricultural products including bi-lateral trade, (3) EU markets for young animals and finally (4) premium schemes and other policy instruments of the Common Agricultural Policy (CAP).

The supply module comprises about 50 crop and animal activities for each of the around 250 regions (at the so-called NUTS-2 level). Each independent model maximises regional agricultural income at given prices and subsidies, subject to constraints on land, policy variables and feed und plant nutrient requirements in each region. Income is defined as the gross value added (GVA) at producer prices plus direct subsidies (premiums). Costs neither included in the GVA nor covered by the restrictions[2] in the NLP models are captured by a quadratic costs function, whose slope terms are either estimated from time series analysis (JANSSON, 2007) or derived from exogenous elasticities. The cost functions' constant terms let the models calibrate to a given vector of technical coefficients, levels of the production activities, prices and subsidies.

The global market module covers regionally all countries, either individually as e.g. for the single EU member states, US, Canada, Japan, China, India or as block of countries as e.g. for the African, Caribbean and Pacific (ACP) countries with preferential access to EU markets. It covers all tradeable primary agricultural products from the supply module plus major secondary ones such as dairy commodities, vegetables cakes and oils. The market module incorporates bilateral trade flows based on the Armington-assumption (ARMINGTON, 1969), covering major agricultural trade policy instruments such as (bilateral) tariffs, tariff quotas, and subsidised exports. Its parameters are collected from other modelling systems as the FAO's World Food Model (e.g. FROHBERG and BRITZ, 1994), while trend forecasts on prices, yields and other economic variables are based on long-term outlook reports on agricultural markets from the EU-COMMISSION (2004) and the Food and Agriculture Organization of the United Nations (FAO, 2002).

The third module, the market module for young animals, is based on the derived supply response of the non-linear programming models. Subject to constraints linking supply and demand of the different types of young animals exchanged between the animal production activities as piglets or calves, it determines market clearing prices for young animals. The policy module finally, calculates the different CAP pillar I subsidies subject to ceilings in values or physical units derived from the results of the regional programming models.

Major outputs of the global market model include trade flows, market balance positions and producer and consumer prices for the products and countries and country blocks, whereas the supply module delivers for each NUTS II region crop levels and animal numbers with their associated revenues, costs and income at the regional level as well as information about feeding practice and nutrient management. CAPRI is thus unique in its ability to show the regional impact on EU agriculture of global changes in agricultural markets and policies, in a closed and consistent way. Developed since 1996 and operational since 1999, it has been gradually expanded and enhanced in many pro-

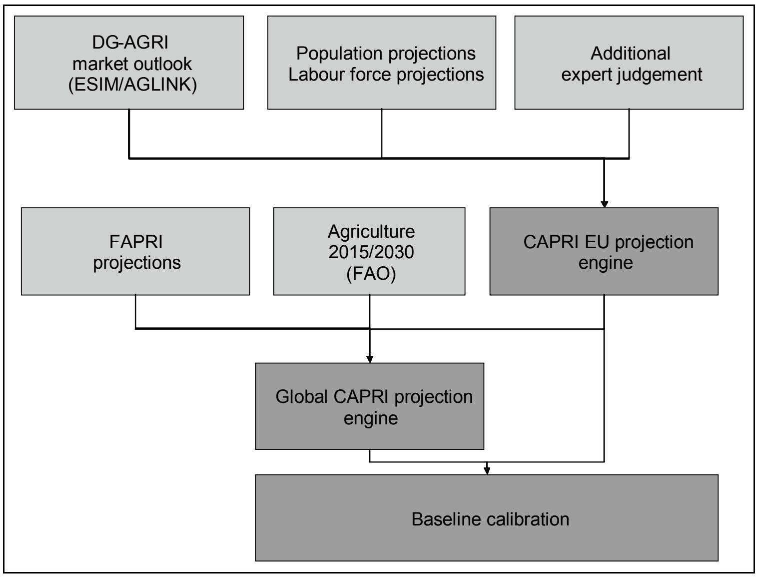
[1] The short overview is in parts taken from BRITZ and LEIP, 2008.

[2] Land availability, feed requirements and policy variables (like milk quotas) are modelled as restrictions.

jects and studies, and was and is regularly applied for policy impact assessment.

Around the economic core of CAPRI, components had been added over time which integrate results of other models or are models of their own as discussed in the following. They are providing data, projections results or information sourcing the parameterization of the different components, or perform post-model analysis based on the results of the supply and market parts. It is the combination of an economic core combining a highly detailed global model for agricultural markets with the regional programming models allowing for environmental impact assessment which explains the success story of CAPRI in the last decade, which manifests itself in a range of policy relevant projects (as e.g. CAPRI, CAP-STRAT, CAPRI-DYNASPAT, EU-MEDAGPOL, EU-MERCOPOL, SEAMLESS, SENSOR) where CAPRI is applied.

Figure 1. Other models as data provider to the CAPRI baseline process



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3.2 Integration of results from other models in the CAPRI baseline

Policy impact assessment requires in many cases the application of tools to (a) future point(s) in time, and thus shifts of the behavioural function according to technical progress, changes in farm structure and practise, changes in tastes, population size or GDP per head, as well as the incorporation of policy changes. Most baseline exercises around agricultural markets models as FAPRI (2006), OECD (2006) or the "Agriculture: Towards 2015/2030" exercise of FAO (2002) rely on a mix of model results, trend analysis and expert judgement. Instead of trying to provide yet another expert judgement, the CAPRI baseline process builds on trend projections and results from various other studies as the ones described above, integrated by a Highest Posterior Density estimator (BRITZ et al., 2007: 63-72). The supply and demand components of CAPRI are calibrated to the combined and reconsolidated content of the baseline results of those systems (figure 1).

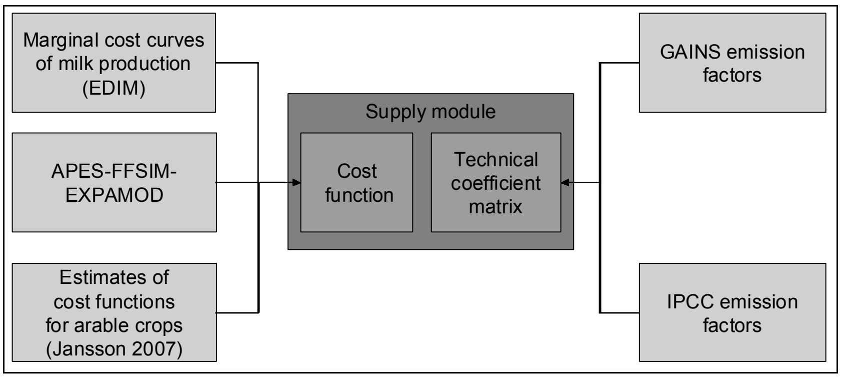
3.3 Calibration of the supply response

One way to link CAPRI to other models consists in updating the supply *response* of the regional programming models (figure 2). Strictly speaking, the different approaches to estimate non-linear cost functions in CAPRI (HECKELEI and BRITZ, 2000; JANSSON, 2007) may be summarized here as well, as the estimations did only cover arable crop activities, and selected constraints such as a land balance. The integration of the estimated cost function parameters for those arable crops in the total framework of the supply models thus requires modifications of the estimated parameters, both to allow for calibration and to ensure plausible supply behaviour.

There are two recent examples for the integration of micro model simulation behaviour into the regional programming models. The first example is the integration of micro estimation results from EDIM (SCHOKAI, 2005) in an on-going project for JRC-IPTS, relating both to milk quota rents and the slope of the marginal cost function. The estimation was originally not targeted towards CAPRI, and consequently, typical problems in model linkage as for example mismatches in base years or regions were encountered.

The second example relates to the linkage between the farm type layer in SEAMLESS called FSSIM and CAPRI, and is the outcome of a somewhat clearer structured exercise. EXPAMOD (BEZLEPKINA et al., 2007) as a component in SEAMLESS estimates a response surface from FSSIM simulation experiments to project own and cross-price elasticities for regions without FSSIM models. The regional supply programming models in CAPRI are then calibrated to these elasticities by adjusting the cost function parameters. In a somewhat wider context, using estimated or statistical data on resource prices to generate shadow prices for quotas (in the case of sugar beet: ADENAEUER, 2005) may also reported here, as they indirectly impact on the supply response, and the integration of emission factors as e.g. from the GAINS model or IPCC may be mentioned as well.

Figure 2. Other models/data sources as providers for the CAPRI supply module



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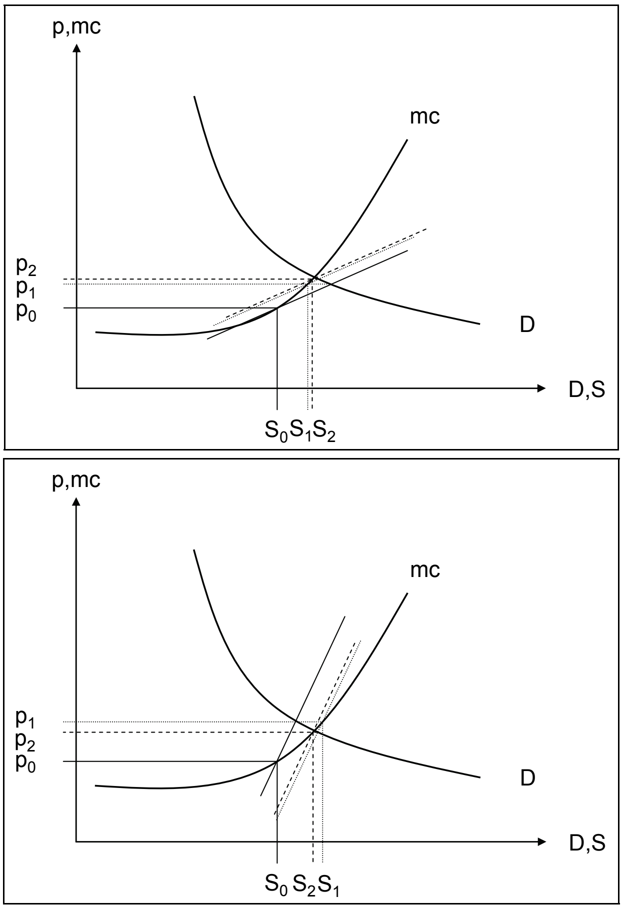
3.4 Sequential calibration of market modules

CAPRI comprises two market modules: the global multi-commodity model and an aggregated programming model for young animal markets, both sequentially calibrated to the supply models. Figure 3 depicts the sequential calibration process. The implicit marginal cost curve (= supply curve) of the regional supply models is depicted with *mc*, and assumed to remain constant during the solution sequence. That is usually not the case, as changes in cross-prices or policy instruments will shift the *mc*-curve as well over iterations. The upper part of the figure refers to a situation with over-estimated, and the lower side to a situation with under-estimated supply reactions in the market part.

Figure 3. Sequential calibration



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

3.5 Linkage to bio-physical models and spatial down-scaling

Since 2004, a top-down link from CAPRI to a bio-physical down-scaling component is realized which includes an interface (LEIP et al., 2008) to the DeNitrification-DeComposition (DNDC) computer simulation model (LI et al., 1994). It allows generation of a fully consistent layer of 1x1 km grid cell results for EU-27[3] covering cropping shares, animal stocking density, crop yields and input coefficients including mineral and organic fertilizer application rates. Those results then drive DNDC. Recently, a statistical meta model consisting of regression functions of selected output variables has been developed from DNDC (BRITZ and LEIP, 2008) which is transparently integrated into the down-scaling component, allowing to estimate per crop different nitrogen components and elements of a soil-water balance. The response surface is calibrated automatically for each site-crop combination by inverting the regression function for the yield by a matching potential yield (BRITZ and LEIP, 2008). By doing so, it is guaranteed that the down-scaled yields are replicated by the meta-model, which ensures that also crop nutrient removals are consistently downscaled.

4. Summary and conclusions

CAPRI provides examples of different types of model linkage: sequential linkage between the regional programming models and the market models, but also the more standard application where outputs from one model are passed as inputs to another one. The latter solution is used extensively in the CAPRI projection engine, but also to dis-aggregate the regional results to 1x1 km clusters. The examples based on CAPRI show that the increasingly complex aims of agricultural policies termed "multi-functionality" and policy questions e.g. around Global Warming or replacing fossil fuels require more and more the combined application of different types of models in impact assessment. The research community seems to answer to the challenge mostly by linking existing models or components in order to decrease development costs or to profit from the trust and client relations built over years with existing tools while remaining flexible in methodological and technical implementation of the components. Large-scale projects as SEAMLESS or SENSOR as well as CAPRI's history underline a shift towards more formalized approaches in model linkage. Appropriate technical and methodological solutions seem to evolve rapidly. However, some of the examples are still rather novel and their long-term sustainability remains to be seen, especially regarding the balance between maintenance and update costs and funds generated from application. The survival of CAPRI may in parts root in the fact that it evolved almost naturally as a club good, and that a balance was achieved between research oriented projects concentrating on model expansion and methodological improvement which contributed at the same time to maintenance and updates, and policy oriented applications which proved its usefulness to major clients. Another lesson learned from CAPRI and other successful networks as GTAP is the importance of building up and keeping human capacity. Further on, for model linkage, enforcing centripe-

[3] Data for Malta and Cyprus are currently missing.

tal impetus by generating and marketing outputs which are only possible with the linked system may be significant, backed up by common training and conferences, but also by providing tools shared across components e.g. for model and data base maintenance, simulation and exploitation. At the same time, centrifugal momentum must be avoided firstly by reducing model linkage costs, e.g. by defining clear interfaces while allowing freedom in implementation of the linked components. Secondly free-rider behaviour e.g. by teams continuously applying the model without contributing significantly to model maintenance and development, must be reduced e.g. by clear rules regarding the interaction between access to model data, code and results at the one hand and contributions at the other.

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