EXPAMOD: A methodological Tool for Linking Farm and Market Models by Means of Econometric Response Functions

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Abstract— **Technical change at the farm level or changes in input prices often entail that the firm's supply function changes. These changes can take place in numerous ways. This paper presents a methodology that increases the consistency in supply responses across various sets of agricultural products and farm types with a market model based on a statistical response function approach. Since most farm simulation models are limited to a subset of regions and farm types, the linkage to an aggregated model requires a procedure for expanding these results to non sample regions, so that full regional coverage is achieved. This paper addresses theoretical aspects related to the consistency between micro and market level models. Next it deals with some empirical findings related to the selection of different functional forms for extrapolation. We conclude with a critical reflection on applicability of this method in addressing further needs on up-scaling of other economic as well as non-economic indicators.**

Keywords— **farm models, market models, extrapolation.**

I. INTRODUCTION

Technical change at the farm level or changes in input prices often entail that the firm's supply function changes. These changes can take place in numerous ways and their aggregated response and their interaction may have profound impacts in agricultural markets, which in turn influence commodity prices. In providing a consistent integration between the farm and market level models it is possible to transmit the endogenous farm level supply behaviour from farm models (which are linked to technology and farm management) to a market model.

Different methods have been employed in natural sciences to estimate systems responses across scales or levels. The simplest approach is the extrapolation of results obtained at a detailed level to a higher level [1]. In social sciences, linking micro and market level models has been done for quite some time in the estimation of consumer demand (see [2] for an early review). [3] using an iterative approach, develop a method in which a regional equilibrium model incorporates farm type characteristics as well as the equilibrium equations for product markets. Regional product supply in combination with the respective product demand curves faced by producers in the region, determines market clearing equilibrium prices for products. In turn, these newly determined prices form the input of subsequent partial model runs for each farm type. This procedure is repeated until product prices deviate less than 1% from corresponding prices determined in the previous iteration. The approach of [3] bears close similarities with what is further presented further in this paper. This methodology, although focusing on economic issues, similarly offers a view on the up-scaling of supply, thereby providing a framework of consistent linking of economic models available at two different scales.

This paper presents a methodology based on an econometrically estimated response function that enhances consistency in the supply responses of these two models for the main agricultural products. The specific objective of this response function is to extrapolate the farm model results from a selected sample of regions and farm types to the EU27, enabling a full and consistent coverage of farm types in the EU while requiring a restricted amount of data (sample). For this extrapolation exercise, the most relevant variables affecting the supply estimates of farm simulation models are selected, so that a good statistical fit of results can be achieved. This approach currently considers 19 farm models based on an intensive survey-based data set in 4 representative regions of the EU27. This farm models are selected within the most important farm types in those regions as a combination of economic size, specialization and intensity variables, as three main categories in the specification of farm types [4]. The empirical illustration in the current version of the manuscript is provided for four selected regions in Germany, Spain, the Netherlands and France and should be expanded to another 15 to 20 representative regions, where surveys are currently being carried out.

II. MOTIVATION TO LINK FARM AND MARKET MODELS

Bio-economic farm models are particularly important as they provide a link between biophysical and economic models. Farmers try to achieve their objectives by choosing from a set of agricultural practices. The available set of practices is largely determined by economically feasible technology, and the specific biophysical environment. In turn, the chosen practices also impact on the biophysical environment.

Farms are the basic decision units in agriculture, and therefore influence market outcomes, land use, and the environment. Since each farm's production is small compared to the total production in society, each farmer perceives prices as given. Farm level optimization models take the same perspective. As long as the policies investigated are such that market prices stay reasonably constant, the error made from this simplification is negligible. However, policies affect multiple farmers and the aggregated response from these farmers and their interaction may have profound market impacts, and hence in turn influence agricultural commodity prices. The following figure reflects an upward shift of the firm's supply curve (decrease of supply for a given price) due to a technology change or a change in the structure of the farm.

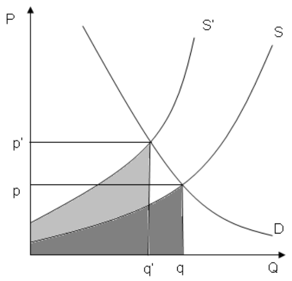

Fig. 1: Price impact from a supply shift when the demand curve is unchanged

This shift in supply (from S to S') implies a new setting of prices and quantities and also leads to a new vector of price-supply elasticities. Supply and prices are variables available in both farm management models and aggregate market models, and should be shared in order to integrate their responsiveness to shocks in other specific variables. Market models, like CAPRI [5], consider prices as endogenous variables and are able to capture price effects from simulated policies. Their relative weaknesses compared to farm level models, which consider prices as exogenous, are their lack of detail in modelling agricultural production and hence insufficient integration with biophysical models. The primary reason for this is that most aggregate models derive the supply behaviour on the basis of representative cost or profit functions. This has several benefits in terms of reducing model complexity and enabling an easier empirical specification of model parameters. The downside is that much of the technological detail that goes into primal models (with explicit formulation of technology) becomes less visible as they are embedded in parameters of the cost or profit function.

III. A QUANTITATIVE TOOL FOR LINKING FARM LEVEL AND MARKET LEVEL MODELS

The basic principle of the selected procedure (EXAPMOD) with respect to model linking is to parameterize market model using the simulated response behaviour of the farm model developed in [6]. This approach is an alternative for a full or “hard link” where one more detailed model substitutes fully for the endogenous simulation of variables in a more aggregate model. The soft link comes at the cost of approximation, but may significantly reduce the computation time of the application. This is particularly advantageous in applications that will be run multiple times.

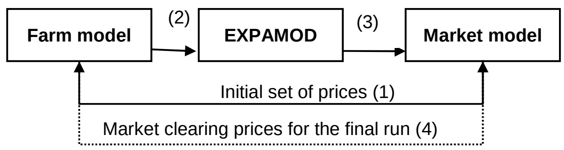

Fig. 2: Flow of prices (1, 2 and 4) and price-supply elasticities (3) between models

In order to map the supply behaviour of the farm simulation models to the market model, the EXPAMOD methodology comprises the following sequence of steps (see figure 2):

Step 1: The market model performs a calibration of the baseline scenario and estimates an optimal set of prices for the agricultural commodities.

Step 2: This price vector is mapped on the farm model product disaggregation and used to run the existing farm type models. With this parameterization, several price shocks relative to the prices delivered by the market model in step 1 are introduced for each farm model product in the farm type models;

Step 3: With the information on supply responses coming from step 2, EXPAMOD estimates by means of an econometric approach regional supply response functions depending on price variations, farm characteristics, and regional soil and climate conditions. These supply responses are extrapolated to other farm types and regions, and finally aggregated to match the regional disaggregation found in the market model (in this case NUTS2 administrative units) and product categories (inverse mapping as determined in step 2);

The regional price-supply elasticities in the market model are calibrated to the aggregated supply responses coming from EXPAMOD. Finally, the farm models are run with market clearing prices from the market model, resulting in the final consistent specification at the farm level.

EXPAMOD is an econometric meta-model that describes the price-quantity responses of farms given specific farm resources and biophysical characteristics that are available EU-wide. A meta-model in this context is an approximation of the input-output behaviour of the underlying simulation model, i.e. it describes the principle relationships between key FSSIM variables and the supply of products. Thus, the meta-model is estimated using simulated price-quantity data for farm types in regions for which farm models exist and then applied to project supply responses of other farm types and regions (extrapolation concept).

IV. EMPIRICAL MODEL

A. Generation of pseudo-observations

As mentioned above, the farm models are the main provider of information to EXPAMOD. The price impacts from supply changes in these (template) models generate information that can be interpreted as ‘pseudo-observations’ for the econometric estimation of EXPAMOD. The current simulation design implements varying one-price-at-a-time. The level of prices for each scenario is kept at the 100% level to the initial prices levels obtained from the market model. Currently, price-quantity vectors for 4 different price shocks in the farm models are considered (-40%; -20%, +20% and; +40% from the initial price, as delivered by the CAPRI model). These scenarios generate information on own and cross-quantity effects. In most cases, the price changes are likely to be far smaller; however, sufficient variation of prices is needed to stabilize the estimates of the price related coefficients. In future versions of EXPAMOD, a systematic cross variation of prices will be considered to render the price-quantity surface of the simulations denser. The following table 1 shows how this information enters the model as input data (two crop activities, one farm type and one region).

Table 1: Price-quantity vectors from one farm type* in Flevoland, the Netherlands

	Observa-tions	Price Variation	Soft Wheat		Potatoes	
			Price (Euro)	**Quantity (1000t)**	**Price (Euro)**	**Quantity (1000t)**
Change in Price of Soft Wheat	Obs2105	-40%	91.24	16.71	135.42	1769.35
	Obs2106	-20%	121.65	17.55	135.42	1758.81
	Obs2107	0%	**152.06**	**18.18**	135.42	1750.98
	Obs2108	20%	182.47	18.66	135.42	1744.98
	Obs2109	40%	212.88	20.32	135.42	1724.33
Change in Price of Potatoes	Obs2174	-40%	152.06	56.26	81.25	1241.77
	Obs2175	-20%	152.06	25.12	108.34	1614.94
	Obs2176	0%	152.06	18.18	**135.42**	**1750.98**
	Obs2177	20%	152.06	3.19	162.5	1986.44
	Obs2178	40%	152.06	0	189.59	2073.89

Note: price changes for one product at a time, other prices kept constant at the baseline level

*An arable farm type with specialised crops of large size and high intensity.

The estimation of quantity responses in EXPAMOD is done iteratively for single products (currently no panel data estimation), so that any of the observations shown in the previous table provide information to the model (farm model baseline and price shock scenarios).

B. Linear model specification

The basic idea, as presented above is to estimate regression functions based on simulated “observations” from existing farm simulation models. The general approach to be followed in the selection of variables is to promote their highest explanatory relevance and availability for all EU-farm types and regions. Following the linear functional form in equation (1), each farm model is developed for a particular farm type (z) in region (r). The notation for each estimation equation is denoted by the superscript + to emphasize the difference between estimation and extrapolation. The meta-model that is defined in the following way:

$$Q_{kzr^+} = \alpha_k + \sum_{k'} \beta_{k'} \cdot P_{k'lr^+} + \sum_w \gamma_w \cdot b_{wzr^+} + \sum_c \lambda_c \cdot c_{czr^+} + e_k \quad (1)$$

where:

- Q_{zklr^+} is the quantity of (supplied to the market) product *k* (k=1,…,K and K∈V_i vector of non-negative decision variables) estimated by a farm model $M_{z\,r}^{+}$ (model from specific farm type *z* and region r^+).

- $P_{k'lr^+}$ are prices of product *k'* (k'=1, …, V_j) at price level *l* in NUTS2 region r^+

- b_{wzr^+} is a vector (W_i x 1) of resource endowments from model M_{zr}+ (on farm type *z* in region r^+)

- c_{czr^+} is a vector (C_i x 1) of biophysical characteristics on farm type *z* in region r^+

- e_k is the error term

- $\alpha, \beta, \gamma, \lambda$ are the parameters to be estimated

The above specification is applicable only to regions for which farm models are applied, denoted with the subscript r^+ ("r-plus"). It is important to note that farm resources (b_{wzr^+}) such as economic size unit, area, machinery, labour, buildings as well as agri-environmental variables (c_{czr^+}) such as soil type characteristics (e.g. soil type), and climate zone characteristics (e.g. minimum and maximum temperature, precipitation, radiation) are needed for all European NUTS2 regions.

C. Logarithmic model specification

Here we alternatively estimate the production of product (k) of farm type (z) in region (r) by means of an exponential function. By selecting a Cobb-Douglas function, it is possible to apply ordinary least squares (as in the previous case) by taking the logarithms of the dependant and independent variables. The production function to estimate is the following:

$$Q_{kzr^+} = \alpha_k \prod_k P_{k'lr^+}{}^{\beta_{k'}} \cdot \prod_w b_{wzr^+}{}^{\gamma_w} \cdot \prod_c c_{czr^+}{}^{\lambda_c} \cdot e_k \quad (2)$$

This formulation is more convenient for the extrapolation of results, since it prevents the solver[1] from scaling problems. The same number of parameters as in the linear model has to be estimated (see table 2)

D. Polynomial model specification

In this third model specification, cross terms between the variables prices ($P_{k'lr^+}$), farm resources (b_{wzr^+}) and biophysical characteristics (c_{czr^+}) are introduced in the optimization in order to allow for more flexibility. A generalization of the Cobb-Douglas function (translog) is currently tested for the purpose.

$$Q_{klzr^+} = \alpha_k \prod_{k'} P_{k'lr^+}{}^{\beta_{k'}} \cdot \prod_w b_{wzr^+}{}^{\gamma_w} \cdot \prod_c c_{czr^+}{}^{\lambda_c} \cdot \prod_{w,k'} \left(P_{k'lr^+} \cdot b_{wzr^+}\right)^{\varphi_c} \cdot \prod_{c,k'} \left(P_{k'lr^+} \cdot c_{czr^+}\right)^{\delta_c} \cdot e_k \quad (3)$$

where:

- φ, δ are the additional parameters to be estimated

The motivation for this model specification is that prices and biophysical characteristics might present some correlation in specific regions (e.g. confluence of good soils and high prices for cereals). This formulation allows the recovery of this additional explanatory power, nevertheless, at the cost of degrees of freedom in the estimation, an important factor to take into account if the number of observations or the variance of the sample is low.

E. Econometric performance

The two exponential model specifications tested for EXPAMOD are presented in table 2 for the production activities observed in a farm type in one sample region. As we can see, the explanatory power of the different model specifications is quite high, even if the number of observations is low. This table hints at a fairly stable behaviour of the farm models considered for the analysis and, in the end, at a quite good fit of the response.

1. [1] EXPAMOD uses a nonlinear programming algorithm (NLP) for approaching the optimum. This option is chosen to facilitate the technical link between farm and market models, which are programmed in GAMS and are being part of the integrated modelling software.

Table 2: Results of different model specifications for one farm type* in Flevoland, the Netherlands

	Nobs	Npar	Mean	SST	Var	VarErr	R2Corr	R2
Cobb-Douglas function (Nobs=87,Npar=12)								
Soft Wheat	87	12	4.4	0.19	0	0	0.91	0.92
Maize for fodder	87	12	3.23	0.13	0	0	0.93	0.94
Onions	87	12	6.72	1.2	0.01	0	0.96	0.96
Sugar Beet	87	12	6.01	0.01	0	0	0.18	0.28
Potatoes	87	12	7.22	0.21	0	0	0.99	0.99
Polynomial function (Nobs=87,Npar=47)								
	Nobs	**Npar**	**Mean**	**SST**	**Var**	**VarErr**	**R2Corr**	**R2**
Soft Wheat	87	47	4.4	0.19	0	0	0.82	0.92
Maize for fodder	87	47	3.23	0.13	0	0	0.86	0.94
Other Vegetables	87	47	6.72	1.2	0.01	0	0.92	0.96
Sugar Beet	87	47	6.01	0.01	0	0	-0.55	0.28
Potatoes	87	47	7.22	0.21	0	0	0.98	0.99

*An arable farm type with specialised crops of large size and high intensity. Total observations in the sample= 2001 (for a potential maximum of 16 crops, 15 farm types and 4 NUTS2 regions)

where:

- $NObs = N$, number of observations in the sample (outcome of the price sensitivity analysis with the farm model at hand, see table 1), $NPar = p$ is the number of parameters to estimate in each model specification and $Mean = \overline{Q}$ is the mean of the whole sample.

- $SST = \sum_i \left(Q_i - \overline{Q}\right)^2$ is the square of the observed deviations against the mean, $VAR = \frac{\sum_i \left(Q_i - \overline{Q}\right)^2}{N-1}$ the square of the deviations between observations and the mean weighted by the number of observations in the sample and $VarErr = \frac{\sum_i \hat{\varepsilon}_i^2}{N-p}$ the square of the deviations between observations and estimations weighted by the number of observations minus the number of dependant variables.

A close look at the estimated parameters shows that most of the explanatory power is covered by the price variables (strictly positive for the own prices). The resource endowments and biophysical variables seem to play a minor role in the current data constellation used by EXPAMOD, as well as the cross-terms in the polynomial specification.

In table 3 the price-quantity elasticities for two farm types in one region and calculated with the Cobb-Douglas model specification are reported. Although the behaviour of the farm models seems to be correctly picked up by the estimation approach, the elasticities seem too low when compared to the literature.

Table 3: Price-quantity elasticities calculated with the Cobb-Douglas model specification for one farm type* in Flevoland, the Netherlands

		Soft Wheat	Fodder Maize	Onions	Sugar Beet	Potatoes
Specialised Crops	**Soft Wheat**	**0.1**	0	-0.5	0	-0.29
	Maize for Fodder	-0.01	**0.19**	-0.35	-0.01	-0.37
	Onions	-0.02	-0.01	**1.46**	0.01	-0.63
	Sugar Beet	0	0	0	**0**	-0.1
	Potatoes	-0.04	0	-0.38	-0.01	**0.59**
Arable Others	**Soft Wheat**	**0.43**	-0.02	-2.93	-0.01	-0.75
	Maize for Fodder	-0.02	**0.21**	-0.9	0	-0.32
	Onions	-0.04	0	**0.5**	0	-0.16
	Sugar Beet	0.01	0.01	-1	**0.08**	0.28
	Potatoes	0.48	-0.01	-5.1	0	**0.39**

*Both farm types of large size and high intensity

These findings are not only interesting as a feasible means of extrapolation to other regions/farm types, but can also help the further development/improvement of farm models. In the end, the data base for EXPAMOD is a detailed sensitivity analysis of the farm model behaviour with respect to price changes. In future versions of EXPAMOD shocks on the biophysical variables are also foreseen.

V. CONCLUSIONS AND FURTHER CONSIDERATIONS

This paper has presented a feasible conceptual approach for up-scaling economic results from the farm level to regional and EU levels with a first empirical illustration. The approach establishes a link between a bio-economic farm model operating at the level of a representative farm and an aggregate economic model for the EU27 with a market model component.

Several issues have to be addressed regarding the conceptual approach and the model specifications presented. The tests performed with flexible functional forms (equations (2) and (3)) show plausible results and a high explanatory power. Nevertheless, some poor predictions have been observed for estimations with a low number of observations and high number of parameters. This should be easily solved by generating a higher number of pseudo-observations. Additionally, a higher variance in the data (especially for products under a quota regime, such as sugar beet) and a closer link of results to the biophysical and farm management variables would be desirable.

In future versions of EXPAMOD, panel data estimation and non-parametric approaches (dealing with large number of variables in functional forms with higher order polynomials) will be considered. Moreover, future developments will address experimental meta-modelling designs that are appropriate given the underlying relationships whereas the current simulation design implements varying one-price-at-a-time. The explanatory variables need to cover variability in farm types and scales, soils and climates. It will be further checked whether the sole focus on production quantities already provides sufficient variation in production conditions and farm types. This is because regions specializing in different products likely do not coincide much in terms of biophysical characteristics and farm types.

The approach developed in this paper also allows for further research regarding the validation of the model specification selected. This will be done by running EXPAMOD for a sub-sample of the farm models and comparing the estimated results with the other part of the sample, i.e. to perform an out-of-sample projection of farm model results when more farm models become available at a later stage. A useful criterion for this could be the mean squared deviation of estimated and simulated elasticities.

ACKNOWLEDGEMENTS

The work presented in this publication is funded by the SEAMLESS integrated project, EU 6th Framework Programme for Research Technological Development and Demonstration, Priority 1.1.6.3. Global Change and Ecosystems (European Commission, DG Research, Contract No. 010036-2). We gratefully acknowledge all SEAMLESS participants who contributed to the development of SEAMLESS-IF.

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