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Estimating feed input demand of the German Compound Feed Industry

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A Synthetic Non-Spatial Multi-Commodity Model as Market Component for CAPRI

1 Introduction **4**

2 Methodology **5**

2.1 Behavioural model 5

2.2 Estimation procedure 7

3 Data **8**

4 Results **8**

5 Annex **10**

5.1 Results from the first stage (instrumentation) of the 3SLS 10

5.2 Elasticities for the SUR system 12

6 References **12**

Abstract

In this paper the current solution for the market side of the CAPRI model is described: a non-spatial, synthetic multi-commodity regionalised at the level of the EU member states which determines for a given vector of supply quantities producer and consumer prices.

1 Introduction

Feed use accounts especially in cereals for large percentages of total demand, and given a relative high flexibility in substitution between different feedingstuffs, reacts easily to price changes whereas human consumption is relatively inelastic. Short and medium term changes in price and trade pattern for crops are therefore often to a large extent depending on feed use. Insofar, feed use is a key factor to model market mechanism in some politically sensible markets.

Three major approaches are applied to describe feed use in agricultural sector models:

1. programming solutions which describe feed use as a cost minimising problem under technological constraints.
2. so called "heuristic approaches" which use behavioural equations either sourced by assumptions and/or parameters taken from literature, as e.g. in SWOPSIM (Sullivan et.al, 1992) or WATSIM (Lampe 1997).
3. and econometric approaches (e.g. Surry 1989).

Feed use in the CAPRI model is up-to-now modelled based on a programming approach (Heckelei & Britz 1997, Nasuelli et.al. 1997) partially based on the feed sub-model of the SPEL/EU-Base Model (Wolf 1995). Requirement functions for individual animal activities determine mainly the energy, protein and protein/dry matter ratio need per head which must be satisfied by inputs of feedingstuffs. Given about 50 products in the CAPRI data base according to SPEL definitions, it would be a tremendous task to describe the feed input of each product to the 13 animal activities (13*50 feed activities per region). Therefore, individual raw and processed feedingstuff are mixed together to 7 bulk feedingstuffs as e.g. cereals according to the SPEL/EU-Data Base. However, the proceeding requires an additional methodological element which allows to describe how the individual components are mixed together to the bulk feedingstuff.

In order to test if heuristic or directly estimated econometric approaches could be used to complement the current feed sub-model of CAPRI, a duality based behavioral model for the German compound feed industry is estimated. The data do not stem from the SPEL/EU-Data base, but refer to monthly time series sampled from ZMP, a semi-official German statistical body specialising in agricultural markets.

Contacts to the German compound feed industry revealed that programming technics are used to determine cost-minimising mixtures for the standardised compound feeds marketed. The layout of these programming models is naturally a key production factor and therefore not accessible for outsiders. It is however sure from the definitions of the marketed compound feed that the constraints of these programming models must comprise beside energy, protein and energy density further requirements as minerals, vitamins etc.. A representation of these complex constraints in a sector models as CAPRI can be excluded. Instead, the resulting input demand the feed compound industry is estimated in here based on duality.

2 Methodology

2.1 Behavioural model

The compound industry is assumed to minimise costs for all kinds of compound feed produced based on a slightly modified Generalized McFadden unit cost function (Diewert & Wales 1987). The actual form estimated in here is a flexible functional form in the sense that it allows an approximation of the “true” (but naturally unknown) function up to second order terms at a specific point concerning prices of the ingredients. Test for second order terms in time and total output revealed that the related parameters were not statistically stable which led to simplified form shown below. The functional form is therefore not flexible in time and output quantities.

Let $p_I = \sum_{i=1}^{N} \theta_i p_i$ denote a price index for ingredients in compound feed with pre-selected weights θ_i. The costs function is then:

$$C(p,y,t) = \tfrac{1}{2}\, yt \sum_{i=1}^{N}\sum_{j=1}^{N} b^{p}{}_{ij}\, p_i p_j \Big/ p_I + \sum_{i=1}^{N}\sum_{k=1}^{M} b^{y}{}_{ik}\, p_i y_k + yt \sum_{i=1}^{N} b^{t}{}_{i}\, p_i t \tag{1}$$

with

C = costs

p_i = price of ingredient i, i = 1,...,N

yt = total quantity of compound feed produced: $yt = \sum_{k=1}^{M} y_k$

y_k = quantity produced of specific compound feed k, k = 1,..., M

t = a time variable subsuming other fixed factors such as labour and capital

The cost function (1) has two fundamental properties:

1. It is homogenous of degree one in prices as required by microeconomic theory.
2. It is linear in output quantities yk and yields therefore constant marginal costs for fixed input prices. Increasing marginal costs for the feed compound industry are therefore thought to result from the market mechanism in the feed ingredient markets: increasing output effects in higher demand for ingredients and therefore higher ingredient prices.

Let B^P be symmetric. By Hotelling's Lemma, derivatives of (1) with respect to the ingredient prices p_i result in the following **input demand functions for the ingredients** to be estimated:

$$\begin{aligned} \frac{\partial C}{\partial p_h} = x_i = {} & yt \sum_{j=1}^{N} b^{p}{}_{hj}\, p_j \Big/ p_I - \tfrac{1}{2}\, yt\theta_h \sum_{i=1}^{N}\sum_{j}^{N} b^{p}{}_{ij}\, p_i p_j \Big/ p_I{}^{2} \qquad \forall h = 1,\dots,N \\ & + \sum_{k=1}^{M} b^{y}{}_{hk}\, y_k + ytb^{t}{}_{h}\, t \end{aligned} \tag{2}$$

It should be noted that the parameters in (2) are defined per unit of output. Differentiating (1) for the individual compound feed yields their marginal costs which are used in the **estimation equation for the output prices**:

$$(3)\quad mc_h = \frac{\partial C}{\partial y_h} = \tfrac{1}{2}\sum_{i=1}^{N}\sum_{j}^{N} b^{p}{}_{ij}\, p_i p_j \Big/ p_I + \sum_{i=1}^{N} b^{y}{}_{ik}\, p_i + \sum_{i=1}^{N} b^{t}{}_{i}\, p_i t \quad \forall h = 1,\ldots,M$$

By assuming a fix span b^m between the market price for each of the compound feed and marginal costs, the following estimation equation for the output prices is derived:

$$(4)\quad pc_h \equiv \frac{\partial C}{\partial y_h} + b_k^m = \tfrac{1}{2}\sum_{i=1}^{N}\sum_{j}^{N} b^{p}{}_{ij}\, p_i p_j \Big/ p_I + \sum_{i=1}^{N} b^{y}{}_{ik}\, p_i + \sum_{i=1}^{N} b^{t}{}_{i}\, p_i t + b^{m}{}_{h} \quad \forall h = 1,\ldots,M$$

In the following, theoretical restrictions reducing the number of parameters to be estimated are derived.

Differentiating (2) again with respect to the individual prices margins yields:

$$(5)\quad \begin{aligned} \frac{\partial C}{\partial p_h \partial p_g} = {} & ytb^{p}{}_{hg} \big/ p_I - yt\theta_g \sum_{j=1}^{N} b^{p}{}_{hj}\, p_j \Big/ p_I^2 \\ & - yt\theta_h \sum_{j=1}^{N} b^{p}{}_{gj}\, p_j \Big/ p_I^2 + yt\theta_g\theta_h \sum_{i=1}^{N}\sum_{j=1}^{N} b^{p}{}_{ij}\, p_i p_j \Big/ p_I^3 \end{aligned} \qquad \forall g,h = 1,\ldots,N$$

(5) shows that the postulated symmetry of B^P is necessary to identify the parameters based on the *Symmetry* of second derivatives:

$$(6)\quad b^{p}{}_{ij} = b^{p}{}_{ji} \quad \forall\, i,j = 1,\ldots,N$$

Due to the fact that each of the gross margins is linear dependent on all other prices and the price index, the b^p parameters can only be identified if the following restrictions are introduced

$$(7)\quad \sum_{i=1}^{N} b^{p}{}_{ij} = 0 \quad \forall\ j = 1,\ldots,N$$

The theoretically required *concavity* of the cost function with respect to prices is given, if the appropriate matrix of second partial derivatives of the cost function (1) is negative semidefinite. It can be shown that this is fulfilled if B^P is negative semidefinite (cp. KOHLI p. 247). Consequently, the curvature restriction holds globally, i.e. independently of the variable values, in this case.

Price elasticities $\varepsilon_{ij} = \frac{\partial x_i}{\partial p_j}\frac{p_j}{x_i}$ can be calculated as: $\varepsilon_{ij} = \frac{\partial C}{\partial p_j \partial p_i}\frac{\partial p_i}{\partial C} p_j$ from (2) and (5) which gives some nasty terms not reported in here.

The price index p_I was defined by using the sample mean of the input demand costs as weights:

$$(8)\quad \theta_i = \frac{\sum_t x_{it}\, p_{it}}{\sum_t \sum_{i=1}^{N} x_{it}\, p_{it}}$$

2.2 Estimation procedure

In the equations to estimate (2) and (4) the same parameters occur in several equations which makes a system estimation necessary to impose these parameter restrictions across equations.

The error terms of the estimated input demand functions are most likely contemporaneously correlated, because of the interrelatedness of the input demand determination. In that case, the Seemingly Unrelated Regression (SUR) estimator would be an efficient estimator and was employed for the cash crop system.

Additionally, prices for the ingredients and output quantities could be the source of simultaneous equation bias of the parameter estimates. In that case, the error term is correlated with the endogenous variables and SUR is not an efficient estimator and 3-Stage Least Squares (3SLS) should be used by replacing the endogenous variables by estimates based on variables which are not suspect to simultaneity.

In our case, lagged prices of the ingredients, lagged demand for them and the trend were used as instruments. Results from the first stage can be found in the annex (5.1). It should be noted that the fit of the prices was close to unity. One may argue that an instrumentalisation cannot heal a possibly equation bias. However, an 3SLS estimation where only the prices were instrumentalized using first lags revealed already large differences in the parameter. It was therefore concluded that the instrumentation was sucessful. In the case of the input demand for ingredients, the fit of the first stage is relatively low. A better instrumentation would here lead to a lot of additional data mining and eventually lead to still better fit for the prices.

In order to test for simultaneity, typically the Wu-Hausman (Wu 1973, Hausman 1978) test is applied (Wahl & Hayes 1990). Let b_{SUR} and b_{SLS} denote the parameter estimates from the SUR and a 3SLS estimator and V_{SUR} and V_{SLS}. their estimated covariance matrices. The test statistic

$$(9)\quad W = \left(b_{3SLS} - b_{SUR}\right)^{\prime}\left[V_{3SLS} - V_{SUR}\right]^{-1}\left(b_{3SLS} - b_{SUR}\right)$$

where

M = is a chi-square distribution with n degrees of freedom

N = the number of parameters in b that are directly affected by the correction for endogenity.

If M is greater then the chi-square value, the Null-hypotheses that b_{SUR} and b_{3SLS} are drawn from the same sample are rejected. The probability to reject H_0 increases with increasing differences between the two sets and smaller differences in the variances. The problem of the test consists in the possible non-definiteness of the matrix of covariance differences. Tests for earlier version of the models revealed that the probability for equality of the parameter sets from a SUR and 3SLS estimation was very close to zero. It was however not possible to repeat test for the final version of the estimated system due to mentioned problems with non-definiteness.

However, the interpretation of the test regarding exogeneity is naturally depending on the accuracy of the instrumentation. If poor instruments are used, the parameter estimates from 3SLS become inaccurate and the test (9) looses partly its significance as an indicator for exogeneity. Insofar, as so often, subjective opinion plays a rule. As mentioned above, the instrumentation of the output quantities y_i is an especially crucial point because all parameters are defined per unit of output. Poor instrumentation of the output quantities will therefore most likely lead to overall bad parameter estimates. Tests for instrumentation of the quantities alone showed that price elasticities were not influenced much by the instrumentation.

Finally, the residuals showed a relative high serial autocorrelation so that an first order autoregressive term was introduced. Technically, EViews 3.1 was used for the econometric work.

3 Data

The statistical material was provided by ZMP (Zentrale Markt- und Preisberichterstattung) in Bonn, a semi-official statistical body specialising in agricultural markets. Most data are compiled from statistics sampled by the German Agricultural ministery. Data were aggregated to monthly observations by ZMP and span the years from from 1987/88 to 1996/97. However, data missings in some of the series reduce the number of observations to 62.

4 Results

The following tables shows the R squared and the Durbin-Watson where the parameter estimates are based on the instruments and the test statistics are calculated based on the observed values of the endogenous variables. Low R^2's in the case of maize gluten and fish meal - the later coupled to a high Durbin-Watson statistic - are the price for both the instrumentalisation and the system estimation. Using SUR instead, the R^2 are all as high as 70%.

Another critical point are the Durbin-Watson-Statistics for the output price equations. Serial autocorrelation was here attacked by a parameter which was kept constant across all equations. Naturally, the problem could be reduced if different parameters would be used in the equations. However, the solver used inside of EViews to determine the parameters did not converge in that case. Using different parameters for input demand equations and the output price equations lead in the latter case to some negative b^m parameters: the output price would lay in the average of the period *below* marginal costs.

It should be noted that the instrumentation of the output quantities is overall not really statisfying (see reported results in the annex for details). However, limited time did not allow for further data mining in order to get, e.g. output prices and quantities for the animals as possible exogenous variables in the instrumentation of the compound feed quantities.

Table: Test statistics for the equations in the 3SLS-System

Equation:	R^2	Durbin-Watson Statistic
Input demand		
Wheat (1)	0.9453034	2.0746336
Maize (2)	0.8278762	1.3986777
Other cereals (3)	0.9119800	2.6055793
By-products of milling industry (4)	0.7623423	2.4650080
Maize Gluten (5)	0.2547069	2.1352591
Soybean cakes (6)	0.8799173	2.5033643
Tapioka (7)	0.9094154	2.0359746
Fish meal (8)	0.5496128	3.1010441
Output prices for compund feed		
Pigs (1)	0.9873976	1.6666454

Laying hens (2)	0.9153241	1.0755326
Poultry (3)	0.9288426	1.9161085
Calfs (4)	0.8831257	1.5377719
Beef (5)	0.8514568	0.7982799

The following elasticities were calculated based on the estimated parameters. High elasticities can be found in the cereals complex (as high as 4.8%) whereas soybean and fish meal are much less price reactive. Tapioka reacts with an elasticity around two to its own price, but shows little reaction to cereals, a somehow disturbing result. Gluten feed reacts mainly to its own price (-1.5%) and Tapioka (+1.52%).

According to a "conditional" Bayes approach, 1000 parameter samples were drawn from a multi-variate t-distribution based on the parameter point estimates and their covariance matrix Each sample was tested for concavity of the cost function. The positive result of the test is the fact that 82% of the samples had only negative elements on the diagonal of the elasticity matrix. However, the chance to draw a fully concave matrix was 0,7%, only, and concavity is therefore surely rejected by the data and the chosen functional form.

Estimated Elasticities

	Wheat	Maize	Other cereals	By-product of milling industry	Gluten feed	Soybean cakes	Tapioka	Fish meal
Wheat	**-3.757179**	0.678484	2.274349	-0.004109	0.610973	0.657558	-0.120014	-0.340062
Maize	1.595960	**-3.173825**	2.692523	-0.746404	-0.066972	-0.556655	0.162557	0.092816
Other cereals	2.605880	1.311518	**-4.790964**	0.927403	-0.338636	-0.312788	0.336036	0.261551
By-products of milling industry	-0.008377	-0.646840	1.649972	**-0.525239**	-0.194703	0.047506	-0.377089	0.054770
Gluten feed	1.041133	-0.048517	-0.503639	-0.162761	**-1.544926**	-0.295009	0.858130	0.655590
Soybean cakes	0.212943	-0.076636	-0.088406	0.007547	-0.056063	**-0.139846**	0.089334	0.051127
Tapioka	-0.365218	0.210301	0.892499	-0.562935	1.532457	0.839475	**-1.793286**	-0.753293
Fish meal	-0.511690	0.059373	0.343486	0.040429	0.578892	0.237559	-0.372472	**-0.375577**

5 Annex

5.1 Results from the first stage (instrumentation) of the 3SLS

Instruments used: lagged prices of ingredients, lagged input demand for ingredients, trend, square and cube of trend:

Equation: P1

Observations: 59

R-squared	0.998684	Mean dependent var	31.98390
Adjusted R-squared	0.998138	S.D. dependent var	5.138583
S.E. of regression	0.221713	Sum squared resid	2.015423
Durbin-Watson stat	1.988762		

Equation: P2

Observations: 59

R-squared	0.995814	Mean dependent var	32.43051
Adjusted R-squared	0.994078	S.D. dependent var	5.006186
S.E. of regression	0.385246	Sum squared resid	6.085007
Durbin-Watson stat	1.283458		

Equation: P3

Observations: 59

R-squared	0.998315	Mean dependent var	29.80915
Adjusted R-squared	0.997617	S.D. dependent var	4.933811
S.E. of regression	0.240854	Sum squared resid	2.378440
Durbin-Watson stat	1.840313		

Equation: P4

Observations: 59

R-squared	0.974584	Mean dependent var	24.25000
Adjusted R-squared	0.964046	S.D. dependent var	3.658964
S.E. of regression	0.693793	Sum squared resid	19.73532
Durbin-Watson stat	1.882373		

Equation: P5

Observations: 59

R-squared	0.948772	Mean dependent var	26.73780
Adjusted R-squared	0.927532	S.D. dependent var	3.882771
S.E. of regression	1.045240	Sum squared resid	44.79360
Durbin-Watson stat	1.874219		

Equation: P6

Observations: 59

R-squared	0.971391	Mean dependent var	38.98305
Adjusted R-squared	0.959528	S.D. dependent var	7.933086

```
S.E. of regression          1.595943   Sum squared resid       104.4284
Durbin-Watson stat          2.246828
=======================================================================
Equation: P7
Observations: 59
-----------------------------------------------------------------------
R-squared                   0.954069   Mean dependent var      28.27373
Adjusted R-squared          0.935025   S.D. dependent var      4.174857
S.E. of regression          1.064181   Sum squared resid       46.43171
Durbin-Watson stat          1.942479
=======================================================================
Equation: P8
Observations: 59
-----------------------------------------------------------------------
R-squared                   0.975824   Mean dependent var      80.27797
Adjusted R-squared          0.965799   S.D. dependent var      11.99138
S.E. of regression          2.217614   Sum squared resid       201.6302
Durbin-Watson stat          1.713059
=======================================================================
Equation: Y1
Observations: 66
-----------------------------------------------------------------------
R-squared                   0.810943   Mean dependent var      508.1864
Adjusted R-squared          0.759045   S.D. dependent var      65.84816
S.E. of regression          32.32299   Sum squared resid       53283.57
Durbin-Watson stat          2.296700
=======================================================================
Equation: Y2
Observations: 66
-----------------------------------------------------------------------
R-squared                   0.495088   Mean dependent var      191.5939
Adjusted R-squared          0.356484   S.D. dependent var      17.63974
S.E. of regression          14.15050   Sum squared resid       10212.07
Durbin-Watson stat          2.168226
=======================================================================
Equation: Y3
Observations: 66
-----------------------------------------------------------------------
R-squared                   0.733662   Mean dependent var      139.1818
Adjusted R-squared          0.660550   S.D. dependent var      25.99018
S.E. of regression          15.14248   Sum squared resid       11694.04
Durbin-Watson stat          2.162840
=======================================================================
Equation: Y4
Observations: 66
-----------------------------------------------------------------------
R-squared                   0.703615   Mean dependent var      39.28182
Adjusted R-squared          0.622255   S.D. dependent var      6.934349
S.E. of regression          4.261921   Sum squared resid       926.3624
Durbin-Watson stat          2.515508
=======================================================================
Equation: Y5
```

Observations: 66

R-squared	0.551729	Mean dependent var	634.5833
Adjusted R-squared	0.428674	S.D. dependent var	73.02669
S.E. of regression	55.19804	Sum squared resid	155388.0
Durbin-Watson stat	2.175316		

5.2 Elasticities for the SUR system

	Wheat	Maize	Other cereals	By-product of milling industry	Gluten feed	Soybean cakes	Tapioka	Fish meal
Wheat	**-1.353042**	0.756930	-0.049292	0.087517	-0.014153	0.356296	0.232565	-0.025420
Maize	1.686132	**-2.572835**	1.210634	-0.303403	0.170293	-0.603716	0.136568	0.211864
Other cereals	-0.063535	0.700499	**-0.851416**	0.202075	0.003086	-0.070200	-0.043434	0.152487
By-products of milling industry	0.176055	-0.273993	0.315382	**-0.348307**	0.000828	0.182528	-0.037858	0.063550
Gluten feed	-0.024139	0.130383	0.004084	0.000702	**-0.519294**	0.152686	0.143402	0.242091
Soybean cakes	0.116373	-0.088519	-0.017789	0.029636	0.029240	**-0.064267**	-0.016322	-0.050809
Tapioka	0.760471	0.200471	-0.110189	-0.061538	0.274937	-0.163410	**-0.699289**	-0.310107
Fish meal	-0.042000	0.157144	0.195469	0.052196	0.234526	-0.257024	-0.156692	**-0.490184**

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