Non-linear programming models for sector and policy analysis

Experiences with the Turkish agricultural sector model

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This paper examines the basic problems of the mathematical programming models used for agricultural sector and policy analysis. Experience with traditional programming models shows that a considerable improvement in performance is possible by adequately incorporating non-linear relationships. Particular emphasis will be given to the calibration and validation problems involved in this type of model. With the help of the Turkish agricultural sector model it will be demonstrated that an empirical specification of a non-linear programming model for the agricultural sector is possible even with poor statistical data and that an operational model version can be handled on a PC.

Keywords: Sector analysis; Non-linear programming models; Turkish agriculture

The contribution of the agricultural sector to GDP, employment and foreign exchange earnings is economically significant in most developing countries. The agricultural sector in these countries has been subjected to various direct and indirect policy interventions. The high degree of interdependence produced by the pursuit of multiple policy goals with multiple policy instruments limits the contributions of partial market and aggregated sector models. Isolated measurements and piecemeal analysis can lead to quite misleading policy conclusions.

This paper presents an overview of traditional sector models based on the mathematical programming approach and summarizes some serious problems in their sectoral application. On the basis of this evaluation we will discuss some modifications to the traditional programming approach. The introduction in particular of non-linear relationships to improve the performance of sectoral models will be emphasized. The points raised in the paper will be supported with results based on TASM (Turkish agricultural sector model), which is a non-linear mathematical programming model developed to provide an internally consistent, quantitative framework to evaluate the effects of policy interventions in Turkish agriculture.

Mathematical programming models in agricultural sector analysis

With advances in computer technology over the past decades mathematical programming models have become a common tool for applied economic analysis in general and for farm planning and agricultural sector analysis in particular (Heady and Egbert [12], Hazell and Norton [10]). Mathematical programming models provide a flexible tool for agricultural sector and policy analysis since they allow, in principle, an appropriate representation of the multiple input and output relationships of the agricultural sector. In particular, it is possible to introduce the complementary relationships (eg between milk and meat production) and the competitive relations (eg between wheat and barley), which are an important characteristic of agricultural production. The linkages between crop and animal production through feed supply and demand relationships are another feature of agriculture

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which, from among all the available methodologies, can best be modelled with a programming approach. Programming models allow for process specific representation of agricultural technology, which plays an important role in agricultural economics and agronomy. Finally, the programming approach to sector modelling offers various possibilities for the incorporation of policy instruments such as foreign trade policies, domestic agricultural price and intervention policies, quota systems, input subsidies and technology improvement measures in crop and animal production.[1]

Traditional programming models, however, produce a number of problems when used for agricultural sector analysis which are directly or indirectly mentioned in the cited studies and often solved by *ad hoc* assumptions. These problems are mainly due to the carrying over of microeconomic and farm based models to the sectoral level. The economic conditions faced at the agricultural sector level differ, however, in many aspects significantly from the farm level conditions (Bauer [4]):

(i) While input and output prices are normally given at the farm level (eg they cannot be influenced by the decisions taken in a single farm), at the sectoral level prices are determined by the market mechanism (aggregate supply and demand) and government interventions.

(ii) Serious aggregation problems exist at the sectoral and even at the regional level (Day [9]) since natural and economic conditions vary from one location to the other and even from one farm to the other. Given the natural and economic conditions individual farms may specialize in production which is consistent with their resource constraints and preferences. At the aggregated regional or sectoral level production appears to be more diversified and the resource rigidities are to some extent relieved even in short time periods. From this general observation it follows that the outcome of a sectoral programming model may not match the aggregate results of individual farm models. When additional restrictions are introduced for calibration purposes, the shadow prices of important resources are driven to zero.

(iii) Finally, the general purposes of a farm model and a sector model are different. The farm model is mainly used for planning purposes; consequently a normative objective function, which expresses the goals of the farm family, is appropriate to the task. The sector model, on the other hand, has to describe the actual reactions of farmers and their expected responses to changing economic and political conditions. In other words, it has to explain sectoral developments in positive economic terms. This brings with it the problem of how to properly model farmer behaviour in terms of sectoral aggregates.[2]

These problems have been treated in different ways in applied sector modelling. Most applied agricultural models have resorted to introducing *ad hoc* flexibility constraints (Day [9]), rotation activities (Norton and Solis [22]) and the modification of objective functions via downward sloping output demand functions and risk (Hazell and Scandizzo [11]). The implications of such assumptions are often not very clearly stated (Bauer [3]). Worse still, in the absence of generally accepted calibration and validation procedures, and given the limitations of econometric methods in generating the required model parameters and data, arbitrary and non-explicit adjustments in model parameters and data were resorted to in many instances as the final avenue (Kasnakoglu [15].[3]

However, in order to achieve methodological improvements, more thorough investigations into and explicit formulation of the theoretical assumptions seem necessary. We attempt below to contribute to that process on the basis of our experiences with the Turkish agricultural sector model.

The basic features of TASM

The updated and modified version of the Turkish agricultural sector model (TASM) is a static quadratic programming problem with price elastic domestic demand functions, price elastic factor supply functions and non-linear cost functions. The objective function maximized in the model is the sum of the consumers' and producers' surplus, plus net trade revenue. The consumer demand functions at the farm gate level are exogenous but the supply functions are endogenous in the model.[4]

[1] More insights into and experiences with problem specific applications of such models can be found in Hazell and Norton [10], Thomson and Buckwell [24], Kasnakoglu [14], Bauer [3], Colman [8], Norton and Schiefer [23], Bauer and Schiefer [6] and Kasnakoglu and Howitt [17].

[2] Of course it does not mean that sectoral models cannot attempt normative problems. After all, the policies which the sector models are constructed to analyse are themselves normative. However, in sector models these normative issues have to be augmented with positive behavioural and physical constraints.

[3] A more detailed review and evaluation of validation and calibration procedures used in agricultural sector models can be found in Kasnakoglu and Howitt [16] and Kasnakoglu and Howitt [17].

[4] For a complete algebraic specification of the model see Bauer and Kasnakoglu [5] and Kasnakoglu [14]. Earlier versions of the model can also be found in Kasnakoglu and Hawitt [16] and Le-Si, Scandizzo and Kasnakoglu [20].

Agricultural output is broken down into 55 commodities. There are 120 production activities. Special consideration is given to the level of mechanization (animal power or tractor based technology), to dry and irrigation farming and to the plant production system (annual crops, multiple crops, crop–fallow rotation systems). Some commodities like wheat can be produced by alternative activities (factor substitution), other commodities like sheep meat and sheep milk are produced in a fixed proportion (complementary products). The model considers eight different land categories, quarterly labour and machinery constraints as well as fertilizer and seed inputs.

There are several constraints which present internal linkages: feed can be supplied from pasture and fodder crops (competition with marketable crops), as byproducts of agricultural processes (straw) and of processing activities (concentrates) as well as grain, which can be used for feeding animals. Feed demand is broken into several categories to ensure proper feed ratios. The livestock and crop sectors are also linked by the supply and the use of animal power.

Commodity balances ensure that total supply matches total demand. Besides domestic supply, certain commodities can be imported at a given import price and/or import quota (policy variable). On the demand side there is domestic demand for human consumption, generated through the demand curve, cereal demand for feeding animals and export demand in raw and processed forms.

Computational aspects

The package program GAMS-MINOS, developed by the World Bank and Stanford University, has been used to solve the non-linear version of TASM. The model, which contains about 300 variables and 250 constraints, can run on a PC-XT and PC-AT. Total running time on a PC-AT with a mathematical coprocessor is about 15 minutes. One-third of this time is for compilation, matrix generation and execution respectively. The program package also allows a report facility for model results eg aggregated results, comparison of results with given statistical data and a restart option from a previous base solution.

Introduction of non-linear relations in programming models: the case of TASM

Some of the critical points raised above in relation to aggregated sector models can be handled at least partially by introducing appropriate non-linear relations. On many occasions scepticism has been expressed about the possibility of estimating meaningful non-linear relations, since the specification of linear relations, (input–output coefficients, model restrictions, objective function) already constitutes a heavy task. We think that the difficulties are exaggerated. The experience with TASM is that even if the data are poor and do not permit the construction of a detailed set of linearized coefficients and data, the introduction of non-linearities can be justified once the main theoretical relationships (discussed below) have been accepted.

Price responsive demand functions

In standard linear programming models, either demand quantities or product prices are assumed to be given exogenously, which means that a completely elastic or inelastic demand function is assumed. This leads for a single product market to the price–quantity schema shown in Figure 1. The segmented supply results from parametrization of a linear programming model. Given initial market equilibrium, it is obvious that supply response to a price change (a) depends on the initial position. The same is true for (b) as far as the equilibrium price response to changed demand is concerned. These price–demand interactions can in fact highlight the characteristics of certain markets. Case (a) is relevant if the market price is completely determined by government interventions. Case (b) corresponds to the situation of a strict quota system. However, because of the general existence of markets, in which prices are highly determined by demand and supply, an improved sector model should include domestic price–demand relations. Specific government intervention policies can easily be incorporated into this approach by introducing constraints on the functioning of the market mechanism.

As in many developing countries, no farm gate demand data are available in Turkey. In order to overcome this problem the following approach has been employed:

(i) Farm gate demand for domestic consumption has been calculated as a residual as follows:
   Domestic production − export of raw products + import of raw products − export of processed products (raw equivalent) + import of processed products (raw equivalent) − agricultural use (seeds, feed, waste) +/− stock change = domestic demand at farm gate level

(ii) Price elasticities of demand are estimated from income elasticities based on consumption surveys using the Frisch method (Le-Si, Scandizzo and Kasnakoglu [20]), since no direct econometric estimates are available for most of the products considered. For a given base year the parameters of a linear demand curve can then be derived

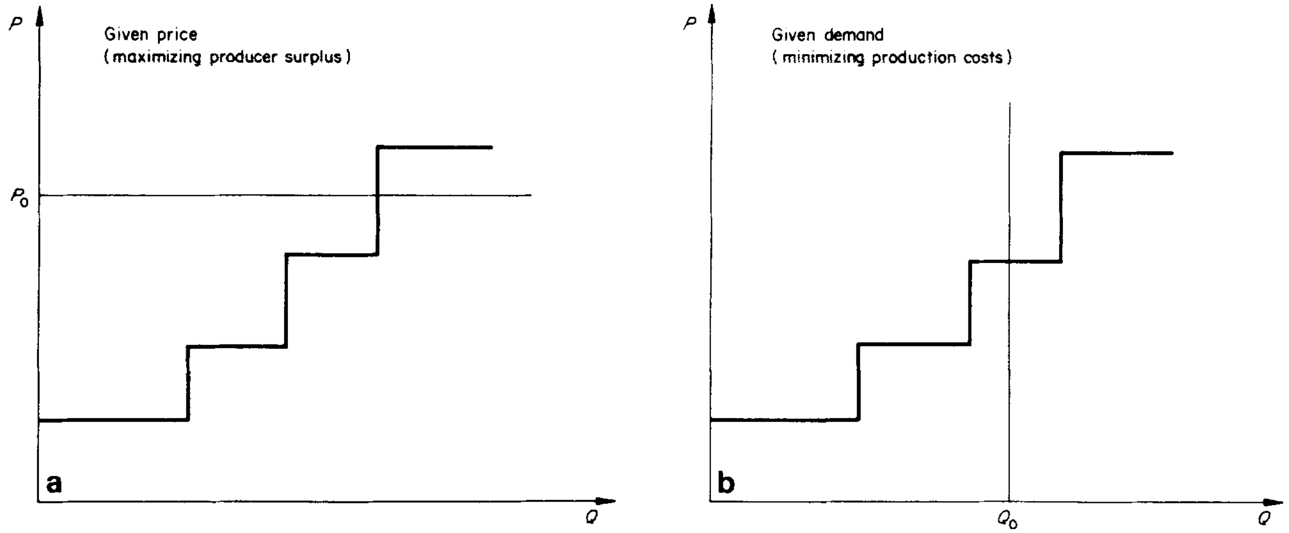

Figure 1. Price–quantity relations in a standard linear programming model.

easily. For inverse demand function

$$P_i = a_i - b_i X_i$$

it follows that

$$-b_i = X_i / P_i (1/E_i)$$

and

$$a_i = P_i + b_i X_i$$

where

P = given price
X = given (derived) demand
E = estimated price elasticity

(iii) In the case of competitive equilibrium, it has been shown (McCarl and Spreen [21]) that maximizing the sum of consumer and producer surplus leads to a market equilibrium. In our case the sum of the producer and consumer surplus is equal to the area under the demand curve minus the production costs implied by the programming model. For the domestic demand activities the integral over the inverse demand curve

$$a_i X_i - 0.5 b_i X_i^2 \text{ (area under demand curve)}$$

therefore enters into the objective function. As long as the area under the demand curve is defined, it is also possible to use other functional forms, instead of the linear one. Figure 2 illustrates this approach for a single commodity market.

(iv) For policy analysis, and especially for future projections, changes in the demand curve have to be taken into account. This can either be done by adding additional arguments (like income and population) to the above mentioned demand function or by shifting the parameters of the price–demand function directly. For TASM we have applied the latter. Having derived the parameters a and b for a time series, the changes in these parameters over time can be estimated as follows. An increase in income leads to a shift of demand. The changes in preferences can be approximated by a trend variable. The relation to be estimated is therefore:

$$a_{it} = f_i(I_t, t)$$

where

I = income
t = trend

Changing population mainly influences the slope of the demand curve. Adding another variable, the following relation is obtained:

$$b_{it} = f_i(P_t, t)$$

where

P = population
t = trend

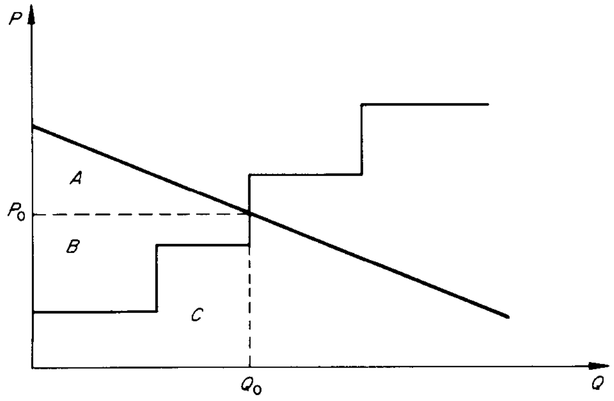

Figure 2. Price responsive demand function in a programming model.

A = consumer surplus; B = producer surplus; C = production costs; $A + B + C$ = area under demand curve.

Price responsive factor supply

Factor supply in conventional programming models – analogous to domestic demand – is assumed to be completely elastic or inelastic. Depending on the time span considered (short or long term), the composition of fixed and variable factors change. Certain factors, like available agricultural land, are in fact nearly fixed at the sectoral level. For some variable factors, like fuel, of which only a small share is demanded by the agricultural sector, it can be assumed that prices are exogenous. Special agricultural inputs, like fertilizer, may, however, be characterized by price responsive supply functions, at least if there are no market interventions. If such a supply function can be estimated, it can easily be included in a non-linear programming model of the agricultural sector.

A critical point in most aggregate programming models is related to the factors which are in principle fixed (in the short term) but are not fully employed and which do not hit the corresponding resource constraints. In this case their shadow prices become zero and no factor costs are computed by the model. This often happens with labour and machinery inputs. If this is the case the model can lead to quite misleading results and responses. One reason for the model outcome of underemployment lies in the aggregation error mentioned above. But disguised unemployment, especially of labour, can also occur at the farm level, if the traditional firm model is applied, although it seems unrealistic to assume that the farm family is willing to work at a zero or very low return to labour. A theoretical explanation can be found in the household–firm model (Becker [7]), which assumes a given amount of disposable time for the farm family, which can be spent on farming or leisure. The utility, which is maximized, is a function of leisure and income. The

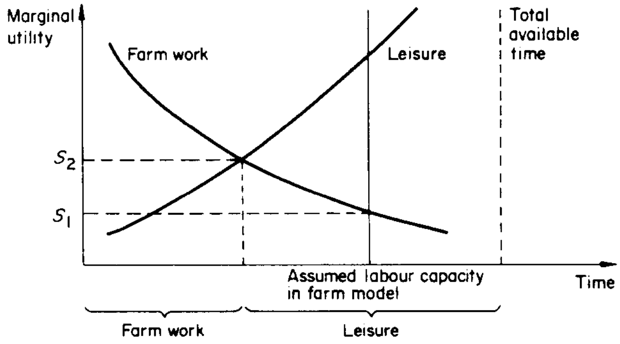

Figure 3. Household–firm model.

S_1 = shadow price of labour in a farm model; S_2 = shadow price of labour in a farm–household model.

optimal allocation of labour use for farming and leisure is given when the marginal utilities of leisure and farm work are equal. According to this broader view of the household–firm model the optimal labour use can be well below the capacity assumed in the traditional farm model. As Figure 3 demonstrates, the shadow price will not be zero in this case.

A direct incorporation of this household–firm approach into an applied sector model fails because of the difficulties in estimating the utility function. But if we accept the underlying basic hypothesis, a simplified relationship between labour supply and the opportunity cost of labour may be used as a proxy. In the case of TASM we have first modelled the labour supply by assuming an exogenous wage rate (derived from the wage rate for hired labour). Additionally we have assumed a quadratic cost function

$$C = a_0 + a_1 L + 0.5 a_2 L^2$$

where

C = labour cost
L = labour use (modelled)

which leads to the following wage rate (opportunity cost) and labour use relation:

$$W = \mathrm{d}C/\mathrm{d}L = a_1 + a_2 L$$

For the first simulations we have assumed $a_1 = 0$, so that the remaining parameter a_2 can be calculated as $a_2 = W/L$. The same labour supply function in TASM is applied to quarterly restrictions, which leads to shadow price differentiation according to seasonal labour use, as illustrated in Figure 4.

A similar approach has been followed for the costs of using machinery. The rationale behind this is that, in addition to some variable costs like fuel, costs for

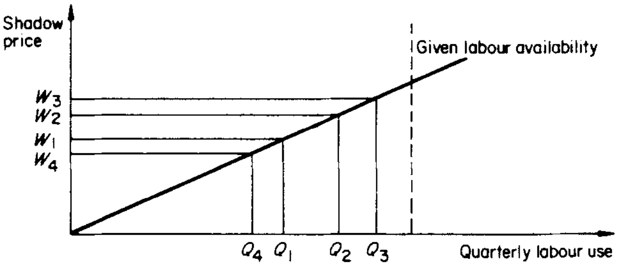

Figure 4. Shadow prices for labour in a non-linear programming model (TASM) with a quadratic labour supply function.

W_i = quarterly wage rates.

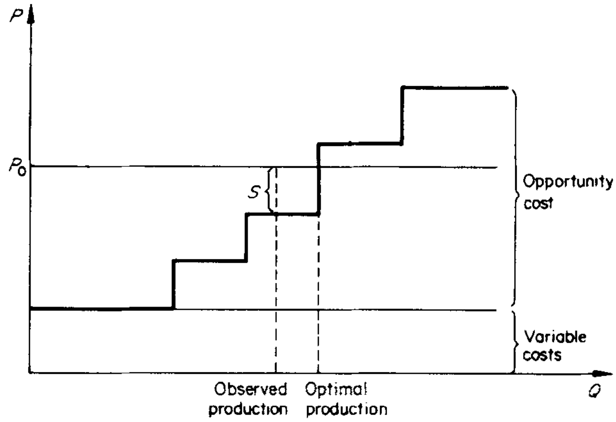

Figure 5. Principal problem of linear programming.

repair and maintenance, as well as waiting costs, may increase with the use of a given machinery capacity.

Introducing non-linear cost functions and model calibration

As already mentioned, programming models are known for their generally poor performance in validation with respect to observed levels in the base period. Furthermore, linear programming models may react too vigorously, because of the (stepwise) implied cost function. In practice, however, a more continuous cost increase at the aggregated level is expected. Additionally, a significant change may imply some adjustment costs. If we take the simple case of a linear programming model with given prices the principal problem may be illustrated as in Figure 5.

The cost structure for a certain commodity implied in the programming model contains the costs for variable factors (sum of the corresponding input coefficients multiplied by the given prices) and the opportunity costs of the fixed factors (input coefficients multiplied by the associated internal shadow prices). Given a certain commodity price, the modelled optimal production level may exceed the observed level in the base year. At the observed level it turns out that – staying within the profit maximizing assumption – costs S are not covered by the model. These costs can be covered exactly using an approach developed by Howitt and Mean [13], called positive quadratic programming (PQP). This approach introduces an additional quadratic cost component which covers costs S exactly, at the observed production level. The approach requires a two-step procedure for implementation:

(i) In the first step a conventional linear or non-linear programming model is extended by a set of calibration constraints, which serve as upper bound inequality constraints for the given production level X. If only one production activity per output commodity is considered, a small perturbation of the given production level (say $0.0001.X$) may be necessary in order to ensure that the relevant resource constraints are binding. The shadow prices for these additional constraints reflect costs S in Figure 5.

(ii) In the second step the shadow prices of the calibration constraints are used to derive the non-linear cost function parts which enter into the objective function. The calibration constraints of the first step are removed and it turns out that the model calibrates exactly with the given production levels.

The estimation of the non-linear cost function part is based on the following quadratic function:

$$C_n = aX + 0.5bX^2$$

where C_n is the non-linear part of total production costs. The first derivative of this function leads to

$$\mathrm{d}C_n/\mathrm{d}X = a + bX$$

which is equal to S at the point of the observed production level. Assuming that $a = 0$, the parameter b can be easily derived:

$$b = S/\bar{X}$$

If the programming model is applied to time series or cross section data, the parameter b can be subjected to econometric analysis to explain changes of the cost structure over time and space (Howitt and Mean [13]). The application of such an approach also allows for specifying and testing various functional forms. However, it has to be noted that such a non-linear programming model still follows the assumption of maximizing profits or, in case of an integrated demand function, the sum of the producer and consumer

Table 1. Estimated parameters of the quadratic terms of the cost functions for selected products in TASM ($/ton).

Products	1980	1981	1982	1983	1984	1985	1986
Wheat	0.003	0.004	0.004	0.003	0.004	0.004	0.003
Corn	0.101	0.117	0.096	0.063	0.066	0.047	0.040
Rye	0.051	0.058	0.065	0.063	0.088	0.096	0.089
Barley	0.012	0.011	0.009	0.009	0.010	0.008	0.007
Rice	1.474	1.790	1.202	1.005	1.253	1.301	2.580
Chick pea	0.604	0.480	0.546	0.419	0.438	0.556	0.355
Dry bean	3.348	2.675	4.845	3.735	2.078	1.325	4.368
Lentil	0.869	0.674	0.197	0.141	0.208	0.307	0.272
Potato	0.045	0.038	0.027	0.026	0.033	0.032	0.017
Onion	0.276	0.156	0.072	0.083	0.136	0.106	0.052
Green pepper	0.386	0.309	0.182	0.142	0.185	0.205	0.439
Tomato	0.042	0.042	0.020	0.025	0.027	0.032	0.037
Cucumber	0.332	0.353	0.256	0.211	0.196	0.180	0.345
Sunflower	0.096	0.146	0.140	0.126	0.146	0.155	0.118
Olive	0.301	0.336	0.215	0.471	0.398	0.630	0.382
Groundnut	10.506	4.723	3.641	4.213	7.357	5.130	6.095
Sesame	24.355	17.434	19.150	19.607	11.347	11.634	15.404
Cotton	0.107	0.252	0.246	0.449	0.334	0.189	0.274
Tobacco	0.012	1.203	1.911	1.250	0.287	0.750	3.307
Tea	0.366	0.000	0.390	0.430	0.348	0.326	0.897
Citrus	0.132	0.155	0.120	0.089	0.056	0.180	0.140
Grape	0.085	0.064	0.057	0.062	0.059	0.061	0.078
Apple	0.093	0.071	0.080	0.059	0.052	0.066	0.077
Peach	0.947	1.084	0.955	0.612	1.267	1.231	0.939
Apricot	0.987	2.510	1.816	0.910	1.559	1.373	1.010
Cherry	1.038	1.883	3.668	3.087	4.177	1.401	1.782
Wild cherry	1.162	1.170	2.880	0.384	3.043	1.484	0.007
Melon	0.034	0.030	0.020	0.018	0.023	0.014	0.028
Strawberry	25.854	35.378	62.178	53.440	60.658	22.350	27.119
Banana	51.113	60.726	81.717	89.913	76.724	37.938	47.094
Quince	2.981	3.248	3.074	2.615	2.805	3.470	2.754
Hazelnut	0.197	0.987	0.395	0.803	0.138	0.206	1.728

surpluses. We have also to point out that this approach requires a careful specification of the input and output coefficients; otherwise all the errors are incorporated in the non-linear cost function part. Finally, the weakness of the approach is that the costs implied in the non-linear part cannot explicitly be attributed to specific production factors. Nevertheless, this approach allows for an operational calibration method which has proved to be useful in the applications of TASM, with a relatively large number of commodities, to practical policy analysis.

Some demonstrations with TASM

In order to carry out projections and policy analysis based on future scenarios, the model is solved and tested for the base periods 1980 to 1986. Since the model calibrates exactly with the base period, the conventional procedures of comparing simulated and observed values become irrelevant. However, the base period model runs present some insights into the past development process which have to be analysed carefully before further policy runs are carried out.

As a first step in evaluating sectoral programming models in general, and a non-linear model like TASM in particular, the shadow prices generated by the model provide a vital criterion. We wish to elaborate only on these results below and therefore refer those interested in more conventional results to Kasnakoglu and Bauer [18] and Bauer and Kasnakoglu [5].

In Table 1 the shadow prices of the calibration constraints divided by the level of production (the parameter b of the quadratic cost function part) are given for selected commodities. The structure of these parameters remains relatively stable over the years. This result suggests that yearly yield and price variations are fully reflected in the associated shadow prices. In fact there is a high correlation between the short-term fluctuation of the parameters and the yearly yield variations. Compared to the results of conventional linear programming models and earlier versions of TASM, the shadow price structure of the present version contains relatively less instability simply because of the model structure itself. The results are also encouraging for the possibility of predicting the quadratic cost function terms for policy runs of future scenarios. We intend to carry out and evaluate simple

Table 2. Shadow prices for selected resources in TASM.

Resources	1980	1981	1982	1983	1984	1985	1986
Irrigated land (US$/ha)	124.141	129.682	103.009	85.262	80.285	80.056	86.921
Labour (US$/h)							
Quarter 1	0.355	0.300	0.245	0.219	0.210	0.209	0.206
Quarter 2	0.576	0.480	0.406	0.381	0.376	0.384	0.377
Quarter 3	0.721	0.600	0.506	0.476	0.487	0.486	0.472
Quarter 4	0.464	0.390	0.323	0.294	0.300	0.293	0.282
Tractors (US$/h)							
Quarter 1	3.525	3.100	2.255	1.967	1.888	1.878	1.850
Quarter 2	8.432	8.210	5.731	5.107	4.292	4.104	4.735
Quarter 3	9.999	9.990	7.384	6.461	5.211	5.110	6.005
Quarter 4	8.848	9.050	6.007	5.211	4.363	4.231	4.872
Animal power (US$/h)							
Quarter 1							
Quarter 2	0.315	0.382	0.203	0.168	0.090	0.065	0.134
Quarter 3	0.356	0.450	0.285	0.218	0.083	0.073	0.176
Quarter 4	0.407	0.520	0.298	0.257	0.166	0.159	0.233
Animal feed (US$/t)							
Atraw	−3.067	−1.065	−1.711	−1.972	−3.015	−3.276	−2.247
Concentrate	−97.991	−31.980	−26.528	−24.690	−24.708	−24.830	−24.231
Cereals	−152.109	−183.720	−148.249	−131.521	−151.192	−137.915	−134.100
Pasture	−97.991	−31.980	−26.528	−24.690	−24.708	−24.830	−24.231
Oilseeds	−171.401	−203.368	−169.741	−144.919	−156.342	−149.597	−146.001

Table 3. Relative share of the shadow prices of the calibration constraints in total costs (1986 summary statistics).

Relative share (%)	Products
< 30	Cotton
30–50	Wheat, rye, dry bean, groundnuts, sugarbeet, tobacco
50–60	Barley, potato, sunflower, hazelnuts
60–70	Chick pea, lentil, soybean, sesame, cherry
70–80	Corn, onion, grape, apple
> 80	Rice, green pepper, tomato, cucumber, tea, peach, apricot, melon, strawberry, banana, quince, pistachio

trend forecasts and econometric estimations (influence of prices and yields) of these critical model parameters.

Table 2 contains selected shadow prices (in US$) of selected resources employed in the agricultural sector. As far as agricultural land is concerned the only restricting factor is the irrigated area. The associated shadow price (marginal value of irrigated land) reflects a tendency to decrease, as a result of the pressure on real agricultural prices (unfavourable sectoral terms of trade), limited domestic and foreign demand potentials and productivity increases in agriculture.

The other endogenous factor prices share the same tendencies. The shadow prices for labour and tractor use, influenced by the implied supply function, reflect a tendency to decrease in real terms in the reported period. At the same time the relative unemployment of these factors is increasing in agriculture. The shadow prices for animal power and feed reflect the economic importance of linkages (intermediate input supply and demand) between crop and animal production.

These shadow prices and the associated input and output coefficients of the activities present the basis for the internal calculation of opportunity costs, which constitute, in addition to costs for purchased input, an important component of total costs. As mentioned above, the residual between output prices and these cost items is exactly represented by the shadow price of the calibration constraint. In Table 3 we have grouped the commodities according to the shares of the calibration shadow prices in total costs. It becomes clear that for most commodities less than half of the total cost can be explained by the costs of purchased inputs and opportunity costs. However, there are large differences between individual commodities. Three conclusions, which will influence our future work on TASM, emerge:

(i) The non-linear cost function part is important in TASM. Further investigations concerning the estimation and forecasting of this cost part (functional forms, econometric estimation of the influence of economic factors) are required.

(ii) The higher the share of the quadratic cost part, the smaller the economic interaction between the different production sectors ie the implicit cross price supply elasticities. If the opportunity cost shares are relatively large, which is particularly the case in the livestock sector, multicommodity modelling is more appropriate.

(iii) A detailed examination of the implicit relative cost structure of the various model activities is an important step prior to policy applications. Such an analysis may also lead to a re-examination of the various model assumptions and the estimates of model coefficients.

Finally, we should note that information such as that presented in Tables 1–3 must be a part of the standard output in all sector model reports, to allow the readers and users to properly evaluate the reliability of model outcomes.

Appendix

The TASM model

Indices

a	Animal power
area	Area sown
b	Area
bc	Cereal area
bf	Fallow area
*b*1	Fodder production
*b*2	Fodder area
d	Seeds
dprod	Domestic production
e	Production costs
enegr	Energy supply of grains
exp-q	Raw export quantity
f	Fertilizer
factor	Processing factor
fallow	Fallow
fcoef	Fallow area coefficient
*g*1	Feed (straw and hay)
*g*2	Feed (concentrates)
*g*3	Feed (grains)
*g*4	Feed (oilcakes)
*g*5	Feed (green fodder and high quality hay)
imp-q	Raw import quantity
ir	Crop activities
j	Livestock production activities
jc	Livestock activity and commodity correspondence
lm	Labour and tractors
mingr	Minimum grain in feed
O	Output
*O*1	Crop outputs
*O*2	Livestock outputs
Oal	All outputs (including feedcrops)
pastuse	Pasture activity
pastfeed	Feed yield of pasture activity
*pqp*1	Quadratic cost parameters for crops
*pqp*3	Quadratic cost parameter for livestock
pqpcer	Quadratic cost parameter for cereal area
pqpfal	Quadratic cost parameter for fallow area
1*q*	First quarter
2*q*	Second quarter
3*q*	Third quarter
4*q*	Fourth quarter
quant	Quantity of resource available
s	Basic land types
t	Production techniques
tcoef	Technology coefficient
tconcen	Total concentrate
te	Total energy
tf	Total feed supply
tfodd	Total fodder
tgrain	Total grain
tgrconoil	Grain, concentrates and oilcakes
tgroil	Grain and oilcakes
toil	Total oilcakes
tpast	Total pasture feed supply
tradeq	Processed net trade quantity
tprice	Trade price of processed products
ts	Subgroups of energy requirements
tstraw	Total straw

Breakdown of indices

Basic land types
- Dry land with high or low rainfall
- Dry land with high rainfall
- Irrigated land with high or low temperature
- Irrigated land with high temperature
- Tree area
- Pasture land

Fertilizers

Nitrogen	Phosphate

Seeds

Wheat	Corn	Rye	Barley	Soybeam
Chick pea	Dry bean	Lentil	Potato	Onion
Tomato	Green pepper	Cucumber	Sunflower	Groundnut
Cotton	Tobacco	Sugarbeet	Melon	Pistachio
Rice	Sesame	Alfalfa	Fodder	

Crop outputs

Wheat	Corn	Rye	Barley	Rice
Chick pea	Dry bean	Lentil	Potato	Onion
Green pepper	Tomato	Cucumber	Sunflower	Olive
Groundnut	Soybean	Sesame	Cotton	Sugarbeet
Tobacco	Tea	Citrus	Grape	Apple
Peach	Apricot	Cherry	Wild cherry	Melon
Strawberry	Banana	Quince	Pistachio	Hazelnut

Livestock outputs

Sheep meat	Sheep milk	Sheep wool	Sheep hide
Goat meat	Goat milk	Goat wool	Goat hide
Angora meat	Angora milk	Angora wool	Angora hide
Beef	Cow milk		Cow hide
Buffalo meat	Buffalo milk		Buffalo hide
Poultry meat	Eggs		

Feed (straw and hay)

Wheat	Corn	Rye	Barley
Pulses	Alfalfa	Fodder	

Feed (concentrates)

Wheat	Rye	Barley	Sugarbeet

Feed (grains)

Wheat	Corn	Rye	Barley

Feed (oilcakes)

Sunflower	Groundnut	Cotton	Soybean

Feed (green fodder and high quality hay)

Fodder	Alfalfa

Crop activities (i = irrigated; d = dry; f = fallow)

Wheat (d)	Wheat (fd)	Wheat (i)	Corn (d)
Corn (fd)	Corn (i)	Rye (d)	Rye (fd)
Rice (i)	Rice (fi)	Barley (d)	Barley (fd)
Chick pea (d)	Chick pea (i)	Dry bean (i)	Lentil (d)
Potato (i)	Onion (d)	Onion (i)	Green pepper (i)
Tomato (i)	Cucumber (i)	Sunflower (d)	Sunflower (i)
Groundnut (i)	Soybean (i)	Sesame (i)	Cotton (i)
Tobacco (d)	Melon (d)	Melon (i)	Sugarbeet (i)
Alfalfa (i)	Fodder (d)	Pasture	
Olive (d)	Tea (d)	Citrus (i)	Grape (d)
Grape (i)	Apple (i)	Peach (i)	Apricot (i)
Cherry (i)	Wild cherry (i)	Strawberry (i)	Banana (i)
Quince (i)	Pistachio (d)	Hazelnut (d)	

Livestock production activities

Sheep	Goat	Angora	Cattle
Buffalo	Mule	Poultry	

Livestock activity and commodity correspondence

Sheep meat	Goat meat	Angora meat	Beef
Buffalo meat	Poultry meat	Mule	

Area

Wheat	Corn	Rye	Barley	Rice
Chick pea	Dry bean	Lentil	Potato	Onion
Green pepper	Tomato	Cucumber	Sunflower	Olive
Groundnut	Soybean	Sesame	Cotton	Sugarbeet
Tobacco	Tea	Citrus	Grape	Apple
Peach	Apricot	Cherry	Wild cherry	Melon
Strawberry	Banana	Quince	Pistachio	Hazelnut
Alfalfa	Fodder			

Cereal area

Wheat	Corn	Rye	Rice	Barley

Fodder production

Fodder Alfalfa

Fodder area

Alfalfa Fodder

Production costs

Seed Fertilizer Capital

Parameters (data)

Macro	Macroeconomic variables and relations
Concent	Concentrate by product coefficient (per output unit)
Conoil	Oil seed by product coefficient
Dom	Observed production, area, yield and prices
Enec	Energy equivalent by products by product unit
Feedabs	Absolute feed requirements
Feedgrain	Minimum grain feed and energy yields
Labfed	Labour for harvesting and feeding straw
Feedreq	Feed requirements (energy per yield unit)
Pqplt	Quadratic labour and tractor costs
Runeap	Relative unemployment of labour and tractors
P	Crop production coefficients
Par	Price and income elasticities, processing costs and factors and quadratic cost parameters
Pcost	Crop production costs
Proctrade	Observed processed net trade quantities and prices and processing factors
Q	Livestock production coefficients
Qq	Index of livestock grain consumption
Qcost	Livestock production costs
Res	Resource availability and resource costs
Imprice	Import price
Trade	Observed export and import data
Exprice	Export price
Tcon	Consumption of raw products
Dpri	Demand curve prices
Alpha	Demand curve intercept
Beta	Demand curve slope
Impppind	Imported processed product index

Exppind Exported processed product index
Expindex Export index
Impindex Import index

Activities (variables)

PROFIT	Objective function
RELFAL	Relative fallow
PPTRADE	Trade of processed commodities
CROPS	Production of crops
PRODUCT	Production of livestock
PFERT	Purchase of fertilizer
PRCOST	Production costs
LATRUSE	Labour and tractor use
FEED	Feed use in animal production in energy units
FGRAIN	Composition of feed grain in product weight
TOTALPROD	Total production in raw form
TOTALCONS	Total consumption in processed form
IMPORT	Import of livestock and crops
EXPORT	Export of livestock and crops
CERAREA	Cereal area
FALAREA	Fallow area
TECH	Technology
TECHNOL	Relative technology

List of equations

Basic land constraints

$$\sum_{ir}\sum_{t}(P_{s,ir,t}*CROPS_{ir,t}) \leqslant Res_{s,quant} \tag{1}$$

for all s.

Labour and tractor constraints

$$\sum_{ir}\sum_{t}(P_{lm,ir,t}*CROPS_{ir,t})+\sum_{j}(Q_{lm,j}*PRODUCT_j) + Labfed_{lm}*FEED_{tstraw} = LATRUSE_{lm} \tag{2}$$

for all lm.

Animal power balances

$$\sum_{ir}\sum_{t}(P_{a,ir,t}*CROPS_{ir,t}) \leqslant \sum_{j}(Q_{a,j}*PRODUCT_j) \tag{3}$$

for all a.

Feed supply (straw)

$$\sum_{ir}\sum_{t}\sum_{g1}(P_{g1,ir,t}*CROPS_{ir,t}*Enec_{g1}) \geqslant FEED_{tstraw} \tag{4}$$

Feed supply (concentrates)

$$\sum_{ir}\sum_{t}\sum_{g2}(P_{g2,ir,t}*CROPS_{ir,t}*Enec_{g2})*Concent_{g2} \geqslant FEED_{tconcen} \tag{5}$$

Feed supply (cereals)

$$\sum_{g3} (FGRAIN_{g3} * Feedgrain_{g3,enegr}) \geqslant FEED_{tgrain} \tag{6}$$

Feed supply (pasture)

$$\sum_{t} (CROPS_{pastuse,t} * P_{pastfeed,pastuse,t}) \geqslant FEED_{tpast} \tag{7}$$

Feed supply (oilcakes)

$$\sum_{ir} \sum_{t} \sum_{g4} (P_{g4,ir,t} * CROPS_{ir,t} * Enec_{g4}) * Conoil_{g4} \geqslant FEED_{toil} \tag{8}$$

Feed supply (alfalfa and fodder)

$$\sum_{ir} \sum_{t} \sum_{g5} (P_{g5,ir,t} * CROPS_{ir,t} * Enec_{g5}) \geqslant FEED_{tfodd} \tag{9}$$

Total feed balance

$$\sum_{tf} (FEED_{tf}) \geqslant \sum_{j} (Q_{te,j} * PRODUCT_j) \tag{10}$$

Minimum feed requirements by components

$$FEED_{tf} \geqslant \sum_{j} (Q_{tf,j} * PRODUCT_j) \tag{11}$$

Minimum grain concentrate and oilcake requirements

$$FEED_{tgrain} + FEED_{tconcen} + FEED_{toil} \geqslant \sum_{j} (Q_{tgrconoil,j} * PRODUCT_j) \tag{12}$$

Minimum grain and oilcake requirements

$$FEED_{tgrain} + FEED_{toil} \geqslant \sum_{j} (Q_{tgroil,j} * PRODUCT_j) \tag{13}$$

Minimum shares of individual grains in feed

$$FGRAIN_{g3} * Feedgrain_{g3,enegr} \geqslant FEED_{tgrain} * Feedgrain_{g3,mingr} \tag{14}$$

for all $g3$.

Purchased fertilizers

$$\sum_{ir} \sum_{t} (P_{f,ir,t} * CROPS_{ir,t}) = PFERT_f \tag{15}$$

for all f.

Production costs

$$\sum_{ir} \sum_{t} (Pcost_{e,ir,t} * CROPS_{ir,t}) + \sum_{j} (Qcost_{e,j} * PRODUCT_j) = PRCOST_e \tag{16}$$

for all e.

Commodity balances

$$\sum_{ir}\sum_{t}(P_{O,ir,t}*CROPS_{ir,t})*(1-Concent_O)*(1-Conoil_O)+\sum_{j}(Q_{O,j}*PRODUCT_j)+IMPORT_O*Impindex_O$$
$$=TOTALCONS_O+EXPORT_O*Expindex_O+Proctrade_{factor,O}*PPTRADEO. \quad (17)$$

for all O.

Cereal area

$$\sum_{bc}\sum_{ir}\sum_{t}(P_{bc,ir,t}*CROPS_{ir,t})=CERAREA \quad (18)$$

Fallow area

$$\sum_{ir}\sum_{t}(P_{fallow,ir,t}*CROPS_{ir,t})=FALAREA \quad (19)$$

Technology

$$\sum_{b}\sum_{ir}(P_{b,ir,t}*CROPS_{ir,t})=TECH_t \quad (20)$$

for all t.

Objective function

$$\sum_{O}(Alpha_O*TOTALCONS_O+0.5*Beta_O*TOTALCONS_O^2)+\sum_{O}(Exprice_O*EXPORT_O)-\sum_{O}(Imprice_O*IMPORT_O)$$
$$+\sum_{O}(Proctrade_{tprice,O}*PPTRADE_O)-\sum_{e}PRCOST_e-0.5*\sum_{lm}(Pqplt_{lm}*LATRUSE_{lm}^2)$$
$$-0.5*\sum_{Oal}Par_{Oal,pqp1}*\sum_{ir}\sum_{t}(P_{Oal,ir,t}*CROPS_{ir,t})^2-0.5*\sum_{j}(Res_{j,pqp3}*PRODUCT_j^2)-0.5*\sum_{t}(Macro_t*TECH_t^2)$$
$$-0.5*Macro_{pqpcer}*CERAREA^2-0.5*Macro_{pqpfal}*FALAREA^2=PROFIT \quad (21)$$

Calibration and base solution constraints only

Animal inventory

$$PRODUCT_j \leqslant Res_{j,quant} \quad (22)$$

for all j.

Import of crops and livestock

$$Impindex_O*IMPORT_O=Trade_{O,imp-q} \quad (23)$$

for all O.

Export of crops and livestock

$$Expindex_O*EXPORT_O=Trade_{O,exp-q} \quad (24)$$

for all O.

Trade of processed products

$$Expppind_O*PPTRADE_O=Proctrade_{tradeq,O} \quad (25)$$

for all O.

Production calibration

$$\sum_{ir} \sum_{t} (P_{Oal,ir,t}{*}CROPS_{ir,t}) = Dom_{Oal,dprod} \tag{26}$$

for all *Oal*.

Fodder area calibration

$$\sum_{ir} \sum_{t} (P_{b2,ir,t}{*}CROPS_{ir,t}) = Res_{b2,area} \tag{27}$$

for all *b*2.

Fallow in cereal area calibration

$$FALAREA - CERAREA{*}Macro_{fcoef} = RELFAL \tag{28}$$

$$RELFAL \leqslant 0 \tag{29}$$

Technology calibration

$$TECH_{animal} - TECH_{mechanized}{*}Macro_{tcoef} = TECHNOL \tag{30}$$

$$TECHNOL \leqslant 0 \tag{31}$$

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