Factors Affecting Supply Response in Programming Models

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Abstract

Although econometric modelling is often the preferred methodology to describe farm supply response, occasionally mathematical programming models are used. This paper describes the main characteristics of programming models used in supply estimation, highlighting their advantages and deficiencies. The deficiencies of programming models in representing supply response are explored, in particular the influence of specification errors. A case study of wheat production in a region of Western Australia is used to illustrate the importance of specification errors in estimation of supply response. Specification errors are introduced by including or excluding various characteristics of production activities and other features of the farming system.

The examples of specification errors reveal large changes in wheat area and output elasticities are possible. In many cases the changes are due to the slope effect (dQ/dP) dominating the shift effect (P/Q) in the elasticity calculation. The main inference from results is that unless the farming system, with its array of production technologies, resources and enterprise alternatives, is described in some detail, it is highly likely that specification errors in programming models will noticeably bias estimates of supply response.

Advances in spreadsheet, database and solving algorithm software enable farming systems to be described in greater detail, and with greater ease, than has hitherto been possible. Even though the curse of dimensionality still is a problem in constructing mathematical programming models, a history of experimental evidence from agricultural scientists plus advances in computer hardware, software and economic theory, increasingly mean models can be built that more accurately describe farming systems. Hence, economists increasingly have fewer reasons to excuse themselves for knowingly building models that contain many specification errors.

Introduction

Although econometric modelling is often the preferred methodology to describe farm supply response, occasionally mathematical programming models are used (e.g.Wicks and Dillon, 1978; Hall, Fraser and Purtill, 1988). Mathematical programming models are included in a recent review (Just, 1993) of the current state of modelling of agricultural supply.

In reviewing supply response methods Just comments that "One of the major problems with microeconomic empirical work is specification of the variables to be included. Which input variables or prices are to be considered ? How are inputs to be categorized ? What is the set of related outputs ?" (p.18). He further adds that another problem is missing data. He says, "When data are simply unavailable for some prices, inputs, or competing outputs, a common practice is simply to ignore them. However, the role of missing variables can change the appropriate specification and interpretation of results." (p.18) One of his recommendations is for further research to understand the implications of missing data on supply response estimation.

This paper echoes Just's concerns by illustrating the impact on wheat supply response of specification errors in programming models. The paper describes the main characteristics of programming models used in supply estimation, highlighting their advantages and deficiencies. Specification errors in programming models are represented by including or excluding various characteristics of production activities and other features of the farming system. A case study of wheat production in a region of Western Australia is used to illustrate the relative importance of various specification errors in describing wheat supply response at a representative farm-level.

Mathematical Programming Models

Recent reviews by Just (1991,1993) examine the current state of modelling of agricultural supply and build on an earlier review of Coleman (1983). Both authors classify the various methodologies found in the literature into either programming or econometric approaches. They further sub-categorise methodologies within the econometric approach. Given that this paper focuses on the programming approach, the various econometric approaches will be over-looked here.

General Nature

Following Just (1993), the basic programming model to describe the supply behaviour of a region or representative farm, subject to prices, production alternatives and resource availability, in the often applied case of expected profit maximization, is as follows:

$$\max U(p,q,w,x,X,y,Y,z) = E(p'q) - E(w')x$$

subject to

$$q = f(X,Y,z)$$
$$Yc \leq y$$
$$Xc \leq x$$

where $q = f(X,Y,z)$ is the production function with q being a m–vector of outputs, X is a m x n matrix of allocations of n variable inputs to m production alternatives, Y is a m x k matrix of allocations of k fixed inputs to m production alternatives, and z is a h–vector of non–allocatable fixed factors and producer characteristics.
In $Ye \leq y$, y is a k–vector of farm–level allocatable resources and fixed inputs and e is a m–vector of ones. The inequality allows for some resources to not be fully utilised.
In $Xe \leq x$, x is a n–vector of farm–level input quantities that are purchased.
The expression $U(p,q,w,x,X,y,Y,z)$ describes the behavioural assumptions where p is a vector of output prices associated with q and w is a vector of variable input prices associated with y.

As is often reported in introductory operations research texts, most programming models assume prices and production are nonstochastic and the production technology assumed requires fixed proportions for commodity output (i.e. nonjoint Leontief technology). Hence, the production function $q = f(X,Y,z)$ is of unique form where only one observation defines the fixed input requirements for each unit of q_i for each commodity *i*.

Programming models of the type outlined above are occasionally used to describe the supply behaviour of a region or representative farm. In the case where the supply of a particular commodity is being examined, the common approach is to record the model's optimal solutions over a range of prices of the commodity. The model can be either a regional model (Hall and Menz, 1985) or a representative farm (Sharples, 1969). To estimate an aggregate supply response based on regions (Wicks and Dillon, 1978; Hall, Fraser and Purtill, 1988) or representative farms (Sheehy and McAlexander, 1965) requires procedural steps outlined by Sharples.

Advantages

Although mathematical programming is rarely the preferred methodology to describe farm supply response, it does offer a few advantages. Firstly, it does not require long data series as do econometric approaches. It therefore avoids the problems of consistency and reliability in time series data sets and avoids untangling the historical effects of technology, resource quality and scale changes upon current supply response.

Secondly, it enables the cross effects of all input, output and technology options to be simultaneously included. Given *i* commodities and *j* inputs, then *i x i* effects of commodity prices on outputs can be considered, as well as *j x j* effects of input prices on inputs and *i x j* effects of commodity prices on input use. Hence, it allows the optimal level of outputs and inputs to be identified while taking full account of resource availability and the resource requirements and relative profitabilities of competing and complementary production alternatives.

Thirdly, the programming approach enables many technical factors that can effect supply response to be represented to a degree not easily possible in many econometric approaches. The growth in power and sophistication of database, computer spreadsheet and computer hardware technology in the last decade has allowed farming systems to be described in even greater detail in programming models than has hitherto been possible (e.g. Morrison *et al.*, 1986; Kingwell and Pannell, 1987; Abadi *et al.*, 1991; Kingwell *et al.*, 1992). Spreadsheet software enables various parts of farming systems to be described in detail and to be more easily checked and reviewed by relevant specialists, thereby lessening the problems of opaqueness (MacPherson and Bennett, 1979) and specification error (Pannell *et al.*, 1992) common in many large programming models. Spreadsheet linkages maintain the integrity and consistency of the models and further reduce the probability of introducing specification errors. These advances in technology enable more complete descriptions of the production options for a farm or agricultural region.

Further, advances in decision theory and optimization methodologies have enabled less restrictive specifications of managerial behaviour and production relationships. Hazell and Norton (1986) and Hardaker et al. (1991) review the current mathematical programming options that incorporate uncertainty. Quadratic risk programming (Freund, 1956), MOTAD (Hazell, 1971; Kennedy and Francisco, 1974), target MOTAD (Tauer, 1983; McCamley and Kleibenstein, 1987; Parton and Cumming, 1990), mean–Gini (Yitzhaki, 1982; Okunev and Dillon, 1988), utility maximization (Lambert and McCarl, 1985; Patten *et al.*, 1988), chance–constrained optimization (Charnes and Cooper, 1959; Wicks and Guise, 1978) and discrete stochastic programming (Cocks, 1968; Rae, 1971; Schroeder and Featherstone, 1990) are all examples of methodological refinements that more realistically describe the uncertain environment and risk behaviour within farming.

Disadvantages

A practical difficulty in constructing programming models is deciding upon the list of activities to include in the representative or regional farm. Supply responses generated by programming models are derived through parameterising prices. Farm activities considered within the models need to include production and technology alternatives that are realistic options at different output price levels. Unless the model builder is well-informed about the nature of the farming system or region, and the practical production options available to farmers, then the supply response may be mis–specified due to failure to represent feasible options.

Even when the production alternatives and resource availabilities of the representative farm are correctly specified, difficulties of aggregation bias remain (Buckwell and Hazell, 1972; Kennedy, 1975). Very stringent homogeneity criteria must be applied to the classification of farms to form representative farms whose supply functions are then aggregated to form a regional or aggregate supply function. Even when these homogeneity criteria are met, aggregation of supply functions (see Sharples for the procedural steps) may be misleading because the regional model may be better specified as a price–endogenous model rather than a summation of supply responses from price–exogenous models of representative farms.

The formation of aggregate or farm–level supply functions based on programming models generally lacks a statistical precision because the nonstochastic nature of coefficients makes t values meaningless (Hall and Menz, 1985). However, the coefficient of determination (R^2) does give an indication of goodness of fit of the estimated function to the data.

Factors usually considered in farm–level programming models

Programming models of farm–level supply response include explicit managerial goals, most commonly profit maximization (e.g. Hall *et al.*, 1988) or maximization of expected utility (Barton, 1987; Chavas and Holt, 1990; Kingwell (in press)). Although not often identified usually these models also include implicit managerial behaviour. The construction of the model involves including certain activities, constraints and coefficients that often imply the farm manager has additional preferences relating to conservation, leisure and animal welfare.

The main enterprises of the region or representative farm are typically included in a programming model, as are the prices of commodities and intermediate products produced by the region or representative farm. Most programming models of supply response consider the main technology options and often concentrate on the financial flows rather than biological detail of the farming system.

Factors usually overlooked in farm–level programming models

There are several factors often overlooked in farm–level programming models. Many assume risk neutrality (e.g. Morrison *et al.*, 1986; Hall *et al.*, 1988) rather than considering a range of risk attitude specifications (Chavas and Holt, 1990). Most are strategic models and ignore the contribution of tactical decision–making (Schroeder and Featherstone, 1990; Kingwell *et al.*, 1993).

Often farm–level programming models consider only a few soil classes and enterprise technology options. In addition, complementary and adverse interactions between enterprises are often overlooked or are considered in a gross way. However, features such as enterprise inter–dependencies are known to be important features of farming systems (e.g. Pannell, 1987). Further, changes in the relative profits of enterprises influence the choice of technology, and technologies differ across rotation phases and soil classes (Pannell and Bathgate, 1991; Abadi *et al.*, 1991). Curvilinear response functions or even linear segmented approximations of such functions are often not represented in these models leading to possible bias or error in selection of activities or technologies.

The Relative Importance of Some Factors in Programming Models

The relative importance of some factors often excluded from farm–level programming is investigated using a farming system model named MIDAS (Kingwell, 1987a; Pannell and Bathgate, 1991).

The Model

The model named MIDAS (*M*odel of an *I*ntegrated *D*ryland *A*gricultural *S*ystem) is a mathematical programming model of the farming systems of the eastern wheatbelt of Western Australia. Early versions of MIDAS are described in detail by Morrison *et al.* (1986) and Kingwell (1987a) and recent versions are described by Morrison and Young (1991) and Pannell and Bathgate (1991).

The model is based on expected values and therefore assumes certainty of knowledge about prices, costs and input–output relationships. It is a steady–state model founded on an expected weather–year and assumes the farm manager is profit–maximizing, although other managerial goals and behaviour are implicitly accounted for in the structure of activities. For example, the leisure preferences of the farmer are captured by the need to finish harvesting in early January. Also soil conservation attitudes are reflected in restrictions on the degree to which feed can be removed by the grazing of sheep and animal welfare considerations are reflected in not allowing sheep liveweight condition to fall to a level that would cause the sheep to be classed as being in poor condition. Output from the models is a set of profit–maximizing enterprise and rotational activities as well as shadow price information about the marginal value of farm resources and alternative enterprise or rotational options. In the model farm profit is calculated as a net return to capital and management. This return equates to monies left over from production receipts after deducting all operating costs, overhead costs, depreciation and opportunity costs associated with farm assets (exclusive of land).

As explained by Kingwell (1987b), the model has been developed in consultation with farmers, researchers, advisers and farm management consultants and it emphasizes the interdependencies of crop and livestock enterprises. The model comprises a matrix of around 470 columns (or activities) with around 300 rows (or constraints). The model's framework is a single period equilibrium structure, inclusive of inter-year effects.

Broadly, the model describes:

- the production alternatives on up to 7 soil classes. Up to 20 rotation options are described for each soil class. The crop options include wheat, oats, barley, white lupins, triticale and field peas. The production of over 25 classes of merino sheep based on a self-replacing flock are depicted and allow for a myriad of flock sizes and structures. The type and quantity of wool produced by each sheep class is recorded along with their liveweight and wool sale prices. Pasture production on each soil class and in each rotation phase is also described. The non-linear yield responses of cereals to applied nitrogen on each soil class are described using the Duloy-Norton (1975) approximation.
- enterprise interdependencies. The effects on cereal yields of previous leguminous pastures or legume crops are depicted. The increased weed burden in crops due to previous pastures is described as is the deleterious effect of cropping on subsequent pasture production.
- the various sources of feed for livestock; green and dry pastures, grain stored on-farm or bought in and crop residues including spilt grain as well as feeding restrictions on lupin stubble because of lupinosis risks. The effect of stocking rate on pasture production is outlined in the model. Also represented on a monthly basis are the energy requirements and appetite of each sheep class and energy sources and feed qualities within the farming system.
- current farming technology. The model represents the range of current farm management technology insofar as the types of tillage practices, machinery complements, herbicides used and rates applied, tasks contracted and crop and livestock options considered are all consistent with those used or being canvassed by leading farmers of the region. The maintenance of the model allows changes in farming technology to be incorporated in up-dated versions of the models.
- constraints on farm operations. These constraints include the physical limits imposed by farm size and areas of different soil classes. The limited supply of family labour and working capital are depicted as is the limited work capacity of farm machinery.

For a detailed exposition of the nature and structure of the model, readers are referred to Morrison *et al.* (1986), Kingwell (1987b) and Pannell and Bathgate (1991).

The Analysis

To examine the impact on farm-level supply response of some factors often over-looked or poorly represented in programming models, various factors were altered or removed in MIDAS to see how farm wheat supply was altered. Wheat supply was selected as the subject of the investigation because it is the principal crop grown in the eastern wheatbelt of Western Australia, plus MIDAS is constructed to represent in some detail the biology and economics of wheat production.

The impact on farm-level wheat supply response of changes in various factors is assessed by parameterising the on-farm wheat price ($10 per tonne increments in the range $90 to $200 per tonne), solving the model at each price increment and fitting a quadratic ($Q_w = f(p_w, p_w^2)$) equation to the generated supply response. The elasticity of supply is calculated at the mean wheat price and a coefficient of determination (R^2) is calculated.

Interpreting changes in the price elasticity of supply is aided by considering two facets of price elasticity. Commonly, price elasticity of supply (ε) is expressed as:

$$\varepsilon = \frac{dQ.P}{dP.Q}$$

The determination of ε depends firstly on the (dQ/dP) portion which is the inverse of the slope or responsiveness of supply to price change at sample means and secondly, upon (P/Q) which describes the shift position of the supply response. The price elasticity of supply can increase (decrease) by either an increase (decrease) in slope (dQ/dP)[1] or a leftwards (rightwards) supply shift (P/Q) or some combination of both. In analyses reported in this paper the mean price of wheat is identical so changes in elasticities are due to changes in Q at the mean price and changes in the slope dQ/dP.

❑ *Soil Classes*

Often farm-level programming models consider only a few soil classes. However, farms or regions usually comprise several soil classes or land management units (Lantzke, 1990, Kubicki *et al.*, 1992; Wells and King, 1989). To investigate the effect of failure to represent all soil classes, the MIDAS model with its 7 soil classes (Stoneham, 1992) was re-specified to have only 3 soil classes as shown in table 1.

The seven soil classes were amalgamated according to their main structural characteristic being either a sand, clay or a duplex soil. Hence, the sandy soil classes S1 to S3 became a single S2 soil class, S4 was unchanged as a duplex soil and the clay soil classes S5 to S7 were represented by the S6 soil class. The effect of the amalgamation on wheat supply elasticity is shown in table 2. Elasticity of response with respect to wheat area and production and slope and shift factors are reported.

The results in table 2 indicate that failure to fully represent the range of soil classes substantially reduces both the area and output elasticity estimates. The area elasticity falls from 1.95 to 1.27 while the output elasticity falls from 2.00 to 1.46. The reduction of elasticities is almost all due to a reduction in slope (dQ/dP). At wheat prices less than $130 per tonne more area is sown to wheat and wheat production is greater in the 3 soil class case. At these low wheat prices wheat is only grown in rotation with lupins. The S2 soil class is particularly suited to lupin-wheat rotations, whereas the S1 in particular is not suited to these rotations. Hence, more area is sown to wheat when the S1 soil class is overlooked, as occurs in the 3 soil class case. At wheat prices above $140 per tonne less area is sown to wheat and wheat production is less in the 3 soil class case. At these higher wheat prices, wheat dominant wheat-field pea rotations are the preferred option for soil class S7. Failure to include this soil class in the 3 soil class case means pasture-wheat rotations are initially selected on the S6 soil class with the wheat phases being less dominant

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[1] An increase in the factor (dQ/dP) corresponds to a decrease in the slope of supply curves as usually drawn in economic texts because dQ/dP equals the inverse of the slope of these supply curves (Tisdell, 1974).

in these rotations. The alteration in rotations causes the wheat area and wheat production to be less in the 3 soil class case at wheat prices above $140 per tonne.

TABLE 1

Soil Classes in MIDAS

Soil class	Description	Soil area (ha) in Standard model	Soil area (ha) in Simple model
S1 (Acid sands)	Yellow, loamy or gravelly sands.	450	
S2 (Sandplain)	Deep, yellow-brown loamy sands.	500	1125
S3 (Gravelly sands)	Yellow-brown gravelly sands and sandy gravels.	275	
S4 (Duplex)	Grey, sandy loams, loamy sands, gravelly sands and sand over white clay with yellow or red mottles.	275	275
S5 (Medium heavy)	Red-brown, sandy loam over clay sub-soil.	425	
S6 (Heavy non-friable)	Dark red-brown, sandy clay loams.	450	1000
S7 (Heavy friable)	Previous S6 soil treated with gypsum.	125	
	Total	2500	2500

In short, the representation of fewer soil classes may give, as in this case, a false description of a farmer's responsiveness to changes in the wheat price. Including more soil classes widens the technical opportunities available to the farm manager to respond to changes in the wheat price. Failure to represent these opportunities may, as is the case here, underestimate the responsiveness of the farm's wheat supply to changes in the wheat price.

❐ *Crop Alternatives*

Some farm-level programming models consider only main production alternatives. For example, in a predominantly wheat-sheep farming region, only activities describing wheat and sheep production may be included in the farm model. Although the eastern wheatbelt region of Western Australia is such a region, the MIDAS model includes several crop options such as lupins, field peas, barley, oats and triticale rather than solely considering wheat. To examine the effect of representing only a few crop options, lupins and then peas are excluded as options and the subsequent effect on wheat supply response is observed.

Results in Table 2 show that if either lupins or peas is excluded as crop options then the generated supply response for wheat has a marked increase in its area and output elasticity. The increase in elasticities is due to mainly to a slope (dQ/dP) effect, although the shift (P/Q) effect has some influence in the case without lupins.

When lupins are excluded, the mean area and quantity of wheat selected over the range of wheat prices is slightly less than that which occurs when lupins are included. The reduction in mean values is due primarily to the much smaller areas planted to wheat when wheat prices are lower than $160 per tonne on-farm. At these prices most wheat is planted on the sandier soils in rotation with lupins. The exclusion of lupins necessitates a reduction in wheat area on some of these soil classes. At higher wheat prices continuous wheat rotations are selected on many of these soil classes with or without the option of lupins. Hence excluding lupins results in selection of smaller areas planted to wheat when wheat prices are low and the maintenance of wheat areas when wheat prices are high. Overall these changes increase the slope effect and slightly increase the shift effect.

For peas, the dominant effect on the wheat supply elasticities comes from the slope effect. At wheat prices greater than $170 per tonne, continuous wheat rotations replace rotations that normally include peas, causing an increase in the area planted to wheat. At wheat prices less than $120 per tonne the exclusion of peas does not effect the selection of wheat because wheat is mainly grown in rotation with lupins at these low prices. At wheat prices $120 to $160 per tonne, less wheat is sown because on the clay soils (S5 to S7) pasture-wheat rotations are selected rather than wheat dominant rotations that include some field peas, these latter rotations not being options. The overall effect of these rotational changes is that the average area sown to wheat is approximately the same in the with and without peas cases. However, the slope of the wheat supply curve is much greater in the case where peas are excluded.

TABLE 2

Effect of Model Changes on Supply Response

Model Characteristics	Area Elasticity	Slope Factor	Shift Factor	R^2	Output Elasticity	Slope Factor	Shift Factor	R^2
Standard	1.95	9.38	0.21	0.96	2.00	12.21	0.16	0.96
Only 3 soil classes	1.27	5.89	0.22	0.88	1.46	9.01	0.16	0.95
No peas	2.43	11.68	0.21	0.98	2.35	13.74	0.17	0.98
No lupins	3.01	13.59	0.22	0.96	2.96	15.68	0.19	0.96
No lupins & only 3 soil classes	3.73	15.16	0.25	0.95	3.56	16.97	0.21	0.94
No yield boost	3.15	14.24	0.22	0.93	3.22	15.40	0.21	0.93
Small machinery	1.97	9.06	0.22	0.97	2.05	12.00	0.17	0.97
Work-seed only	2.37	9.75	0.24	0.96	2.41	12.70	0.19	0.97

❐ *No Lupins and only 3 Soil Classes*

Often in farm-level programming models a combination of simplifications or oversights occur which together represent mis-specification of the true farming syst m.[2] The case of excluding lupins and considering only 3 soil classes is examined here a an illustration. Large increases in the wheat area and output supply elasticities are recorded for this case. The increases are due to slope (dQ/dP) and shift (P/Q) effects.

The separate inclusion of only 3 soil classes lowers supply elasticities while the separate exclusion of lupins increases supply elasticities. However, their joint effect results

[2] There are some exceptions such as Easter and Paris (1983) who attempt to represent the stochasticity of some technical coeficients in a programming model. Kingwell et al. (1992) also incorporate the effect of weather-year variation within a programming model.

in larger increases in supply elasticities than is recorded for the separate exclusion of lupins. At prices at or below $120 per tonne, no wheat is sown. If lupins were an option then wheat would be selected on the soil class S2 in rotation with lupins. At prices at or above $170 per tonne more wheat is sown than occurs in the standard case where lupins and 7 soil classes are available. The extra area sown wheat is due in part to the introduction of continuous wheat rotations on the S2 soil class. This soil class is a sandy soil particularly suited to lupin–wheat rotations and continuous wheat. In the 7 soil class model there are 3 sandy soils, S1 to S3. The S1 soil is highly infertile and wheat is only grown on this soil class at very high wheat prices. The S3 soil is suited to lupin–wheat rotations and pasture production. Hence, continuous wheat rotations are also only selected on this soil class at high wheat prices. By excluding the soil classes S1 and S3 and solely including the S2 soil class the altered model apportions a greater area for wheat production at wheat prices at or above $170 per tonne.

The change in the area allocated to wheat production across the range of wheat prices results in an increase in the slope (*dQ/dP*) effect. Further, because the reduction in wheat areas at prices at or below $120 per tonne is greater than the increases in the wheat area at prices at or above $170 per tonne, the shift (*P/Q*) effect is also greater. The combination of the shift and slope effects lead to an increase in the price elasticity of wheat supply.

❑ *No Yield Boost Effects*

Some farm–level programming models fail to adequately consider the biology of the farming system. Gross assumptions are made about the way enterprises interact. These assumptions affect enterprise or activity selection and resource use, and may introduce bias or error in activity selection.. The example there is the beneficial effect on cereal yields provided by leguminous pastures and lupins grown in rotation with the cereals. The beneficial effects are the nitrogen fixation of the leguminous pastures and lupins and other yield–boosting effects (Lacey and McLeod, 1993).

These latter effects are due firstly, to leguminous pastures and lupins being break crops that reduce disease incidence in subsequent cereal crops (Chatel and Rowland, 1982). Secondly, the long tap root of lupins can act as a biological plough providing opportunities for the root systems of subsequent wheat plants to have improved access to soil water (Nelson and Delane, 1990). Thirdly, leguminous pastures and lupins provide an opportunity to control grass weeds that could be problems in future cereal crops. Together these factors enable wheat yields to be higher. Failure to represent these factors in a farming systems model may result in the incorrect identification of some activities as being optimal. The effect on wheat supply elasticities of failing to represent these factors is illustrated here.

The removal of yield boost effects (apart from nitrogen fixation) causes a marked increase in wheat supply elasticities, due mostly to an increase in the slope (*dQ/dP*) effect. At prices at or above $160 per tonne more wheat is sown than occurs in the standard case where all yield improving effects are considered. The increase in wheat area is due to other rotation phases (eg lupins or pasture) not being selected as strongly. The failure of legume phases of rotations to provide yield increases to wheat, reduces the profitability of the legume phase of the rotation and therefore discourages its selection.

At prices below $160 per tonne less wheat is sown than occurs in the standard case where all yield improving effects are considered. In this lower range of wheat prices the sheep enterprise is made relatively more profitable than the wheat enterprise (depending on soil type considerations) because the yield boosting effects of legumes are ignored. This change in relative profitabilities leads to more land being allocated to pasture and legume grain production than occurs when legume yield boost effects are considered.

The change in the area allocated to wheat production across the range of wheat prices results in an increase in the slope (*dQ/dP*) effect. Further, because the reduction in wheat areas at prices below $160 per tonne is slightly greater than the increases in the wheat area at prices at or above $160 per tonne, the shift (*P/Q*) effect is also greater. The slope effect, with some lesser influence by the shift effect, leads to an increase in the price elasticity of wheat supply.

❐ *Crop Machinery*

Farm-level programming models consider crop machinery either as a fixed resource that may limit the size of cropping programmes or as a component of enterprise variable costs or as a combination of both (e.g. Abadi *et al.*, 1991). In MIDAS machinery is treated as a fixed resource with its operating costs and depreciation depending on use, tillage method, soil type and crop. Introducing smaller machinery in MIDAS causes some changes in the shift and slope effects, but the changes are in opposing directions, cancelling one another. Hence, there is little change in the wheat supply area and output elasticities.

❐ *Tillage Technology*

The technology assumptions that underpin many farm-level programming models often represent a great simplification of farming technology. For example, the tillage method employed by farmers can differ across soil classes and within rotation phases. MIDAS represents all such tillage options (Pannell and Bathgate, 1991). However, what is the effect on supply elasticities of wrongly assuming a single tillage method ? The case of assuming all cereal crops are sown using a work-seed tillage method is examined here.

This assumption results in increases in the wheat area and output supply elasticities mainly due to shift (*P/Q*) effects. At all wheat prices used in the analysis, the area allocated to wheat is the same or often less than that which occurs in the standard case. Because there is little variation in the size of the area reduction across the range of wheat prices, a parallel shift in the wheat supply response occurs. This shift is due to the consequence of sole reliance on the work-seed crop sowing technology for wheat.

On some soils, and in some rotations, wheat can be more cheaply and quickly sown using direct sowing. Hence, the assumption of the work-seed technology results in less wheat being sown and overall increases the shift effect. Ultimately, the increase in the shift effect causes an increase in the supply elasticities.

So far this paper has illustrated the impact on farm-level supply elasticities of different specification errors. Many errors lead to supply elasticity estimates changing by over 40 per cent, and in the worst cases estimates change by over 80 per cent. Of course, the standard model is itself not free of specification error. There are many other important influences on supply elasticities not included in the standard model. The model assumes risk neutral management yet Kingwell (in press) identifies the importance of a farmer's attitude to risk and the effect of within-season tactical adjustment on wheat supply elasticities. Both factors are overlooked by most programming models. Pandey *et al.* (1982) also show how the period of data can affect elasticity estimates. They found short-run and long-run elasticities of aggregate agricultural supply in Australia increased over the period 1950-1 to 1975-6. Most programming models assume a single price, or at least a narrow range of current price forecasts.

When Adams (1988) reviewed five supply studies (Adams 1987; Dewbre *et al.* 1985; Fisher and Munro 1983; McKay, Lawrence and Vlastuin 1983; Wicks and Dillon 1978), he commented that the differences in the elasticity estimates were "indicative of the current lack of consensus concerning short-run supply elasticities for agricultural commodities in Australia."(p. 354). He concluded that the differences were due to the variety of approaches and data used in the studies. I would add that the structure of the models and the technical assumptions made about the farming systems would have contributed also to the differences between the estimates.

Conclusions

This paper describes the main characteristics of programming models used in supply estimation, highlighting their advantages and deficiencies. The main focus of the paper, however, is to illustrate the impact on wheat supply response of specification errors in programming models. These errors are represented by including or excluding various characteristics of production activities and features of the farming system. A case study of wheat production in a region of Western Australia is used to illustrate the relative importance of various specification errors in describing wheat supply response at a representative farm-level.

The examples of specification errors reveal that large changes in wheat area and output elasticities are possible and that in many cases the slope effect (dQ/dP) dominates the shift effect (P/Q). The main inference from results is that unless the farming system, with its array of production technologies, resources and alternatives, is described in some detail, it is highly likely that specification errors will noticeably bias estimates of supply response.

Advances in spreadsheet, database and solving algorithm software (e.g. Pannell, 1990) enable farming systems to be described in greater detail, and with greater ease, than has hitherto been possible. Mathematical programming practitioners need to utilize these technologies and more fully interact with agricultural scientists and farmers, if they are to reduce the specification errors in their farming system models. Even though the curse of dimensionality still reigns, a history of experimental evidence from agricultural scientists plus developments in computer hardware and software, increasingly mean this problem is a less credible excuse for economists neglecting to build models that better and more completely describe micro-economic supply response.

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