Journal of Agricultural and Resource Economics, 18(1): 57–69

On Modeling Systems of Crop Acreage Demands

Barry T. Coyle

This article presents an alternative approach to the specification of systems of crop acreage responses. Derived demands for acreages of individual crops are specified as conditional on total crop acreage, and related separability and dynamic specifications help to reduce the effects of multicollinearity in the system. A simple econometric model of crop acreage demands for Western Canada illustrates the methodology.

Key words: crop acreage demands, econometrics, systems.

Introduction

Agricultural economists often have favored modeling crop production decisions in terms of acreage responses rather than output supplies. The standard argument has been that acreage planted is essentially independent of subsequent weather conditions and hence may provide a closer proxy to planned production than does observed output. Most of these acreage response studies have adopted the basic framework of the Nerlove partial adjustment and adaptive expectations model (Nerlove 1956, 1972; Askari and Cummings). More recent studies have modified this framework by incorporating (*a*) alternative specifications of price expectations (e.g., Chavas, Pope, and Kao; Shideed and White); (*b*) the role of government programs (Houck and Ryan; Lidman and Bawden; Morzuch, Weaver, and Helmberger; Lee and Helmberger; McIntosh and Shideed); and (*c*) risk (Behrman; Just; Lin; Traill; Nieuwoudt, Womack, and Johnson; Chavas and Holt). The Nerlove model also has been criticized from the viewpoint of rational expectations and more general models of supply response (e.g., Muth; Nerlove 1979; Eckstein 1984, 1985; Burt and Worthington). Problems in econometric specification and estimation of Nerlove models have been widely discussed (e.g., Griliches; Waud; Doran and Griffiths; Jennings and Young; Braulke; Diebold and Lamb).

However, there have been relatively few papers extending the Nerlove model or other acreage response models to a system of multiple crops (e.g., Colman; Binkley and McKinzie; Krakar and Paddock; Bewley, Young, and Colman), and these studies have not integrated acreage demands into an economic model of production. In this respect, acreage response models have been decidedly inferior to output supply models based on duality theory. A dual approach to the specification of a system of output supplies and factor demands has well known advantages over estimation of a single output supply or acreage response equation. The dual system approach permits (*a*) incorporation of contemporaneous covariance of disturbances across equations, (*b*) specification of symmetry/reciprocity restrictions on coefficients across equations implied by hypotheses of competitive profit maximization (or cost minimization), and (*c*) recovery of the underlying technology (e.g., Fuss and McFadden; Shumway; Shumway, Alexander, and Talpaz). In contrast, present

---

The author is an assistant professor in the Department of Agricultural Economics and Farm Management at the University of Manitoba.

Financial support for this research was provided by Agriculture Canada.

The comments of D. Kraft, M. Faminow, R. Josephson, S. Jeffrey, Y. Surry, the *Journal* editor, and two anonymous reviewers are greatly appreciated. V. Punyawadee, G. Toichoa Buaha, and C.-J. Xu provided able research assistance.

models of crop acreage response systems have addressed multicollinearity by adopting extremely restrictive functional forms (e.g., overlooking many cross-price effects) rather than by adopting restrictions on coefficients implied by fundamental behavioral theory. Moreover, it is difficult to infer anything about technology from such models.

The article presents an alternative approach to the specification of systems of crop acreage responses. Derived demands for acreages of individual crops are specified as conditional on total crop acreage, and related separability and dynamic specifications further reduce the effects of multicollinearity in the system. Reciprocity restrictions and duality relations also are noted. Econometric results for a simple model of crop acreage demands for Western Canada are presented. The proposed methodology and its advantages over standard models is illustrated. These econometric results are used to illustrate the advantages of a systems approach to modeling the impacts of policy interventions on acreage demands.

Models of Conditional Crop Acreage Demands

Preliminaries

Consider a multioutput firm with a fixed amount of total farm land $\bar{z}$ that can be allocated between M enterprises, and, for the purposes of illustration, assume static competitive profit maximization. Then the firm's decision problem is

$$(1)\qquad \max_{(y,x,z)\in T(K)} \sum_{j=1}^{M} p^j y^j - \sum_{i=1}^{N} w^i x^i = \pi(p, w, K, \bar{z})$$

$$\text{s.t.} \sum_{j=1}^{M} z^j \leq \bar{z},$$

where $y = (y^1, \ldots, y^M)$ is a vector of outputs for the M enterprises, $z = (z^1, \ldots, z^M)$ is a vector of acreage allocations to the M enterprises, total acreage is $\bar{z}$, and $x = (x^1, \ldots, x^N)$ is a vector of the total levels of the N variable inputs employed over the M enterprises. $T(K)$ denotes the feasible set of combinations of land allocations z and variable input/output vectors (x, y) conditional on the firm's technology and level of quasi-fixed capital inputs K; $p = (p^1, \ldots, p^M)$ and $w = (w^1, \ldots, w^N)$ denote corresponding output and input prices, and $\pi = \pi(p, w, K, \bar{z})$ denotes the firm's dual profit function corresponding to (1).

In order to focus on acreage allocation decisions, it is convenient to define the following dual profit function conditional on an acreage allocation vector z:

$$(2)\qquad \max_{(y,x)\in T(K,z)} \sum_{j=1}^{M} p^j y^j - \sum_{i=1}^{N} w^i x^i = \pi(p, w, K, z),$$

where $T(K, z)$ denotes the feasible set $\{(y, x)\}$ conditional on K, z. The profit function (1) can be defined in terms of (2) as

$$(3)\qquad \max_{z\geq 0} \pi(p, w, K, z) = \pi(p, w, K, \bar{z})$$

$$\text{s.t.} \sum_{j=1}^{M} z^j \leq \bar{z},$$

with standard first order conditions for an interior solution,

$$(4)\qquad \partial\pi(p, w, K, z^*)/\partial z^j = \partial\pi(p, w, K, z^*)/\partial z^i \qquad i, j = 1, \ldots, M$$

(Chambers and Just).

The above general model formulation implies that each acreage demand is a function of all product prices, all variable input prices, levels of quasi-fixed capital, and the total amount of farm land:

$$z^j = z^j(p, w, K, \bar{z}) \qquad j = 1, \ldots, M. \tag{5}$$

Since total farm land is an allocatable fixed input, the acreage demand for farm enterprise j depends on the prices of all M products even if technologies for all enterprises are disjoint (Shumway, Pope, and Nash).

Due to multicollinearity between prices, crop acreage demands are seldom estimated as in (5), where each demand depends upon prices for all crop and noncrop enterprises competing for farm land. Instead, crop acreage demands are usually misspecified as a function only of prices for crop enterprises: $z_A^j = z_A^j(p_A, w_A)$ $(j \in A)$, where p_A, w_A are vectors of output and input prices, respectively, for crops. Due to multicollinearity problems, crop acreage demands commonly are misspecified further by omitting various crop output prices and input prices. For example, Burt and Worthington omit prices of all alternative crops from an acreage response equation for wheat due to high collinearity between prices. They note that the estimated price elasticity indicates the joint impact of the price of wheat and correlated changes in other prices over the sample period. Thus results of such studies are of limited use in assessing impacts of changes in policy regarding the covariance of prices.

In contrast, Bewley, Young, and Colman specify a system of crop acreage demands conditional on all crop output prices and total crop acreage using a multinomial logit model (Colman, and Krakar and Paddock adopted a similar approach). However, there is little discussion of behavioral foundations for a system of acreage demands (e.g., there is no discussion of separability as a means of simplifying model structure or of the links between acreage demands and a behavioral model such as competitive profit maximization). Binkley and McKinzie also specify a system of crop acreage demands and briefly consider behavioral matters, but there are serious limitations to this study. For example, there is no discussion of separability, adding up, duality, or assumptions necessary for reciprocity in acreage demands (although reciprocity restrictions are stated).[1] These matters are addressed next.

Separability Between Enterprises

Acreage allocation decisions provide an obvious basis for formulating two-stage aggregation models in agricultural production. For example, consider the relatively unrestrictive assumption of weak separability between broad groups of enterprises A and B (crops and livestock):

$$T(y, x, z) = T^*(T_A(y_A, x_A, z_A), T_B(y_B, x_B, z_B)), \tag{6}$$

where $T(y, x, z) = 0$ is the transformation function for the firm, or

$$\pi(p, w, z) = \pi^*(\pi_A(p_A, w_A, z_A), \pi_B(p_B, w_B, z_B)), \tag{7}$$

where all functions are linear homogeneous and π^* is increasing in π_A, π_B. Under the stronger restriction that technologies of the enterprise groups A, B are disjoint, $\pi(p, w, z) = \pi_A(p_A, w_A, z_A) + \pi_B(p_B, w_B, z_B)$ (strong separability).[2]

This weak separability restriction is necessary and sufficient for stage 2 of a two-stage procedure where total acreage $\bar{z}$ is budgeted between the broad enterprise groups A and B in stage 1. Sufficiency is obvious. Given the first-stage allocation $(\bar{z}_A, \bar{z}_B)$ of $\bar{z}$ and weak separability, the full profit maximizing allocations $z^* = (z_A^*, z_B^*)$ solving (3) also must solve the second-stage maximization problems:

$$\max_{z_A \geq 0} \pi_A(p_A, w_A, z_A) = \pi_A^*(p_A, w_A, \bar{z}_A) \tag{8a}$$

$$\text{s.t.} \sum_{j \in A} z_A^j = \bar{z}_A,$$

(8b)
$$\max_{z_B \gtrsim 0} \pi_B(p_B, w_B, z_B) = \pi_B^*(p_B, w_B, \bar{z}_B)$$
$$\text{s.t.} \sum_{j \in B} z_B^j = \bar{z}_B.$$

Otherwise z^* does not solve (3). Necessity can be proved by standard methods (Deaton and Muellbauer, pp. 127–28). The second-stage allocation problems (8) imply that acreage demands within an enterprise group can be expressed as functions of prices of outputs and inputs for the group and the total amount of farm land allocated to the group:

(9a)
$$z_A = z_A(p_A, w_A, \bar{z}_A),$$

(9b)
$$z_B = z_B(p_B, w_B, \bar{z}_B).^3$$

Adding-up, Dynamics, and Reciprocity

A system of acreage demands for M' crops can be defined as conditional on total crop acreage $\bar{z}_A = \Sigma_{i=1}^{M'} z_A^i$:

(10)
$$z_{At}^i = z_A^i(p_{At}, w_{At}, K_{At}, \bar{z}_{At}, \bar{z}_{At-1}) + e_t^i \qquad i = 1, \ldots, M',$$

where $p_A = (p_A^1, \ldots, p_A^{M'})$ is a vector of crop output prices, w_A is a vector of input prices for variable inputs in crop production, and K_A is the related stock of capital. In principle, variable input and investment decisions are made jointly, so that crop acreage may be a function of $(K_A, \bar{z}_A)$ and their rates of change. Thus a one-year lag on $(K_A, \bar{z}_A)$ was initially included in (10), but K_{At-1} was insignificant. Assuming weak separability between crop and other enterprises, prices for only crop outputs and inputs are included in the conditional demands.

The rationalization for including $\bar{z}_{At-1}$ (or equivalently, the rate of change in total crop acreage) in individual crop acreage demand equations can be elaborated upon as follows. Given that some crops may be substituted into rotations more easily than other crops, the rate of change in total crop acreage may have different impacts on different crop acreage allocations. This simple model of the dynamics of individual crop allocations can be contrasted with other common models. An acreage demand equation for a single crop may incorporate lagged acreage for only the single crop (e.g., Burt and Worthington), or a system of crop equations may incorporate a nondiagonal matrix of partial adjustment coefficients for lags of all individual crops (e.g., Bewley, Young, and Colman). The system of individual crop acreage demands specified here relates demands to lags in adjustment of the overall crop rotation while preserving the simplicity for estimation of a lag in a single acreage variable.

Assuming that individual crop acreage demands depend on lags in adjustment of the overall crop rotation, crop acreage demand equations $z_{At}^i = z_A^i(p_{At}, w_{At}, \bar{z}_{At}, \bar{z}_{At-1})$, as in (10), can be motivated more formally as follows. Define the following discrete time calculus of variations problem (abstracting from accumulation of capital K):

(11)
$$\max_{(\bar{z}_0, \ldots, \bar{z}_T)} \sum_{t=0}^{T} \pi(p_t, w_t, \bar{z}_t, I_t)/(1 + r)^t$$
$$\text{s.t. } \bar{z}_0 = \bar{z}_0^*,$$

where $I_t \equiv \bar{z}_t - \bar{z}_{t-1}$ and

(12)
$$\pi(p_t, w_t, \bar{z}_t, I_t) = \max_{(y,x,z) \in T(I_t)} \sum_{j=1}^{M} p^j y^j - \sum_{i=1}^{N} w^i x^i$$
$$\text{s.t.} \sum_{j=1}^{M} z^j \leq \bar{z}_t.$$

The modified profit function (12) and separability imply crop acreage demand equations of the form

$$(13) \qquad z^i_{At} = \tilde{z}^i_A(p_{At}, w_{At}, \bar{z}_{At}, \bar{z}_{At} - \bar{z}_{At-1}) \qquad i = 1, \ldots, M',$$

or (10). In principle, total crop acreage decisions $\bar{z}_A$ can be specified in terms of a Euler equation, but this would require a more fully developed specification of a dynamic model (11).

The disturbances $e^1, \ldots, e^{M'}$ in the conditional acreage demands (10) are linearly dependent; total crop land $\bar{z}_A$ is generally endogenous in (10); and linearity of (10) in $\bar{z}_A$ generally implies consistency of standard instrumental variable methods of estimation (LaFrance). Consequently, $M' - 1$ of these M' conditional acreage demands (10) can be estimated jointly by three-stage least squares (3SLS) when these equations (10) are specified as linear in total crop land $\bar{z}_A$.[4]

Since (10) is defined as conditional on the total crop acreage demand $\bar{z}_A$ for these M' enterprises, equations (10) must satisfy the following adding-up restrictions:

$$(14) \qquad \sum_{i=1}^{M'} \partial z^i_A(v, \bar{z}_{At})/\partial v^j = 0 \qquad j \in v$$
$$\sum_{i=1}^{M'} \partial z^i_A(v, \bar{z}_{At})/\partial \bar{z}_{At} = 1,$$

where $v \equiv (p_{At}, w_{At}, K_{At}, \bar{z}_{At-1})$. These restrictions are satisfied automatically for OLS or 2SLS estimators of linear versions of equations (10) which are conditional on $\bar{z}_A$ and have identical regressors (Denton; Bewley).

Acreage demands often are expressed as functions of crop revenues per acre, $q_A = (q^1_A, \ldots, q^{M'}_A)$ (or net returns per acre), rather than crop output prices p_A, on the assumption that yields are predetermined and provide additional information about technologies (e.g., Bewley, Young, and Colman). The above discussion of adding-up, dynamics, and separability applies here. In addition, assuming predetermined yields, static competitive profit maximization implies reciprocity restrictions

$$(15) \qquad \partial z^i_A(q_A, \ldots)/\partial q^j_A = \partial z^j_A(q_A, \ldots)/\partial q^i_A \qquad i, j = 1, \ldots, M',$$

or equivalently,

$$(16) \qquad \partial s^i_A(q_A, \ldots)/\partial q^j_A = \partial s^j_A(q_A, \ldots)/\partial q^i_A \qquad i, j = 1, \ldots, M',$$

where $s^i_A \equiv z^i_A/\bar{z}_A$. This can be demonstrated simply as follows. Static competitive profit maximization implies the standard reciprocity conditions for output supplies (e.g., Varian), $\partial(yd^i z^i)/\partial p^j = \partial(yd^j z^j)/\partial p^i$, where yd^i, yd^j are yields for crops i, j. This is equivalent to (15) if yields yd are predetermined: $\partial(yd^i z^i)/\partial p^j = yd^i \partial z^i(q, \ldots)/\partial q^j \cdot \partial q^j/\partial p^j = yd^i yd^j \cdot \partial z^i(q, \ldots)/\partial q^j$, since $q^j \equiv p^j yd^j$.[5] Then reciprocity restrictions can be employed in order to reduce the effects of high collinearity between crop output prices.

Duality

Following Chambers and Just, acreage demands can be incorporated into a duality model of output supplies and variable input demands by postulating a multioutput profit function, $\pi(p, w, z)$ (2), conditional on the allocation vector z of total crop land or farm land. Output supply and variable input demand equations conditional on z are obtained by Hotelling's lemma, and acreage demands are implicit in the first order conditions (4).[6]

Duality between the profit function $\pi(p, w, z)$ and multioutput technology $T(y, x, z) = 0$ can be established by adapting standard arguments (McFadden; Epstein). Here we outline a proof of duality for the Chambers–Just profit function $\pi(p, w, z)$. Define the transformation function $T(y, x, z) = 0$ as $y^0 = f(y^I, x, z)$, where y^0 is an arbitrary numeraire output and y^I is the vector of other outputs (Diewert), and define an implicit technology f^* as

(17) $$p^0 \cdot f^*(y^I, x, z) = \min_{(p^I, w) \in P'} \pi(p^0, p^I, w, z) - \{p^I y^I - wx\} \qquad (p^0, y^I, x, z) \in S',$$

where

(18) $$\pi(p^0, p^I, w, z) = \max_{(y^I, x) \in S(z)} p^0 \cdot f(y^I, x, z) + p^I y^I - wx \qquad (p^0, p^I, w, z) \in P.$$

Compactness of S and continuity of $f(y^I, x, z)$ imply that $\pi(p^0, p^I, w, z)$ is defined and continuous, by the maximum theorem (Berge). Denote a solution to (18) as $y^I = y^I(p^0, p^I, w, z)$, $x = x(p^0, p^I, w, z)$. Similarly, compactness of P' implies that $f^*(y^I, x, z)$ is defined and continuous.

In order to establish duality, we make the following standard assumption:

(A.1) $$\forall\ (\bar{y}^I, \bar{x}) \in S(z)\ \exists\ (\bar{p}^0, \bar{p}^I, \bar{w}), \text{ where } (\bar{p}^I, \bar{w}) \in P', \\ \text{such that } \bar{y}^I \in y^I(\bar{p}^0, \bar{p}^I, \bar{w}),\ \bar{x} \in x(\bar{p}^0, \bar{p}^I, \bar{w}),$$

i.e., any $(\bar{y}^I, \bar{x}) \in S(z)$ can be obtained as a solution to a particular problem (18) for an appropriate choice of $(\bar{p}^0, \bar{p}^I, \bar{w})$. (A.1) is implied by the following restrictions on technology: $\{(y, x)\} \in T(z)$ is closed, nonempty, and convex; $f(0, 0, 0) = 0$; and inputs are freely disposable (McFadden). Given (A.1), it can be shown that $f^*(y^I, x, z) = f(y^I, x, z)$ $\forall\ (y^I, x) \in S(z), z$ (e.g., simply adapt the arguments of Epstein, theorem 1). This establishes that the technology $T(y, x, z) = 0$ can be recovered from the profit function $\pi(p, w, z)$.[7]

Data

A four-crop model (wheat, barley, rapeseed, and "other" crops) was specified for Western Canada over 1961–84 using annual data for the region. Expected prices for crops covered by the Canadian Wheat Board (including wheat, barley, and oats) were defined as the sum of the most recently observed components of Canadian Wheat Board payments at planting time: current initial payments, plus adjustment and interim payments for crop marketed in the previous year, plus final payment for crop marketed two years previously (Canadian Wheat Board). Expected prices for crops not covered by the Board and for livestock were defined as market prices plus government payments in the previous year (Statistics Canada 1986b). Divisia price indexes were calculated for "other" crops and for livestock.

Input price indexes were obtained for hired labor, machinery and equipment, variable inputs (e.g., fertilizer) for crops, and variable inputs for livestock (Statistics Canada 1986a). An index of the stock of physical capital in the crop sector was calculated as the current value of machinery and equipment (Statistics Canada 1986b) deflated by its price index. Crop acreages were defined as the estimated area of various crops sown annually for harvest (Statistics Canada 1986c).

Results for Conditional Acreage Demands

A linear system of crop acreage demands conditional on total crop acreage was defined as

(19) $$z^i_{At} = a_i + \sum_{j=1}^{4} a_{ij}(p^j_A/w^1_A)_t + a_{i5}(w^2_A/w^1_A)_t + a_{i6}K_{At} \\ + a_{i7}\bar{z}_{At} + a_{i8}\bar{z}_{At-1} + a_{i9}t + e^i_t \qquad i = 1, \ldots, 4,$$

where $p_A = (p^1_A, \ldots, p^4_A)$ is a vector of crop output prices, w^1_A is the price of variable inputs for crops, w^2_A is the wage rate for hired farm labor, K_A is the stock of machinery and equipment, $\bar{z}_A$ is total crop acreage, and t is a time trend.[8] A one-year lag in capital (K_{At-1}) was insignificant in the model.[9] Acreage demands are homogeneous of degree zero in prices; $i = 1, \ldots, 4$ refers to wheat, barley, rapeseed, and "other" crops, respectively. Since the disturbances in equations (1)–(4) are linearly dependent in spite of the endo-

Table 1. Estimates of Linear Model (19)

	A (All Coefficients)		B (− Insignificant Coefficients)		C (− $\bar{z}_A$, Adding-up)	
Parameter	Estimate	t-Ratio	Estimate	t-Ratio	Estimate	t-Ratio
$A1$	−1.317	4.40	−1.218	5.05	.019	.03
$A11$	.159	2.10	.143	2.38	.085	.39
$A12$	−.096	1.59	−.078	1.91	−.037	.22
$A13$	−.006	.10	—	—	−.002	.01
$A14$	.098	1.67	.069	1.52	.060	.36
$A15$	−.071	.73	−.102	1.42	−.389	1.58
$A16$	.342	2.73	.322	3.39	.437	1.23
$A17$	2.171	6.70	2.162	7.85	—	—
$A18$	.646	3.37	.606	4.18	1.051	2.02
$A19$	−.026	4.59	−.025	5.58	−.008	.55
$A2$	1.435	1.87	1.576	3.62	1.373	2.48
$A21$	−.062	.32	—	—	−.058	.31
$A22$	.273	1.76	.266	3.03	.270	1.81
$A23$	−.253	1.54	−.259	1.73	−.253	1.59
$A24$	−.151	1.00	−.226	1.98	−.149	1.02
$A25$	.325	1.29	.288	1.68	.340	1.59
$A26$	−.604	1.88	−.657	2.74	−.609	1.97
$A27$	−.102	.12	—	—	—	—
$A28$	−1.498	3.04	−1.635	4.58	−1.517	3.35
$A29$	.048	3.34	.048	4.92	.047	3.86
$A3$	1.727	1.22	1.130	1.75	.701	.81
$A31$	−.554	1.54	−.558	3.07	−.496	1.71
$A32$	.073	.26	—	—	.028	.12
$A33$	.448	1.49	.444	2.19	.445	1.80
$A34$	−.212	.77	—	—	−.183	.81
$A35$	−.169	.36	—	—	.075	.22
$A36$	−.140	.24	—	—	−.212	.44
$A37$	−1.667	1.09	−1.751	2.00	—	—
$A38$	−.344	.38	—	—	−.654	.93
$A39$	.049	1.83	.047	4.93	.035	1.82
Equation	D–W	R^2	D–W	R^2	D–W	R^2
Wheat	2.555	.953	2.353	.953	2.051	.594
Barley	1.721	.888	1.921	.884	1.726	.887
Rapeseed	1.911	.767	1.850	.747	1.632	.832

geneity of total cropland $\bar{z}_A$, equations (1)–(3) were estimated jointly by iterative three-stage least squares (I3SLS). A livestock price index and interest rate were used as additional predetermined variables in estimation of (19).[10,11]

Estimates of crop acreage demand equations (19) for wheat, barley, and rapeseed are presented in table 1. All variables (except for the time trend t) were normalized to 1 for 1984, so that coefficients can be interpreted as elasticities circa 1984. Column A reports 3SLS (or equivalently, 2SLS) estimates of (19). Eight coefficients were judged to be insignificant using the Gallant and Jorgenson joint test statistic T^0, which is approximately a chi-square under the null hypothesis.

Column B reports I3SLS estimates when these coefficients are deleted. All own-price effects ($A11$, $A22$, $A33$) have a positive sign and are significant at the 95% level. With one exception ($A14$, which is the least significant), all cross-price effects have negative signs. The coefficients of total crop acreage $\bar{z}_A$ are positive for wheat, insignificant for barley, and negative for rapeseed ($\bar{z}_A$ is insignificant for both barley and rapeseed in table 1, column A). These results may be explained by the restrictive nature of Canadian prairie crop rotations, where there are considerable possibilities for additional planting of wheat but more limited possibilities for barley and especially rapeseed. The coefficients of the time trend t are negative for wheat and positive for barley and rapeseed. This is not surprising since management practices for barley and rapeseed presumably have improved over time relative to practices for wheat (alternatively, the coefficient for rapeseed simply may reflect the gradual increase in rapeseed acreage over time). On the other hand, the coefficients of capital stock K_A (positive for wheat and negative for barley) are somewhat surprising since capital requirements per acre are similar for these crops. Nevertheless, wheat presumably is somewhat more capital intensive than other crops in the sense that (under typical rotation practices) summerfallow is more closely associated with wheat than other crops, and summerfallow also requires capital expenditures. Deleting K_A from the model does not have a substantial effect on estimates of other coefficients.

Column C of table 1 provides SUR (or equivalently, OLS) estimates when total crop land $\bar{z}_A$ and the associated implicit adding-up restrictions are omitted from the acreage demand model (19). Comparing columns A and C, it is obvious that the specification of conditional acreage demands greatly reduces the variances of coefficient estimates in the acreage demand equation for wheat, which is the major crop (further omitting the lag of total crop acreage $\bar{z}_{At-1}$ from the model has only a minor effect on results). Of most importance, the t-ratio for coefficient $A11$ (the impact of wheat price on acreage demand for wheat) falls from 2.1 in column A to .39 in column C. This dramatic change in results for the wheat equation presumably reflects the significance of total crop acreage in this equation (see table 1, column A), and in turn this significance presumably can be explained by the relative ease of substituting wheat into crop rotations.

Alternatively, acreage shares, $s_A^i \equiv z_A^i/\bar{z}_A$ $(i = 1, \ldots, 4)$, were specified as linear functions of the same variables as in (19). Adding-up is implied by the restriction that the sum of shares is equal to one, and share equations (1)–(3) were estimated jointly. Estimated coefficients were similar in sign to table 1 but somewhat less significant. The significance of prices in the wheat acreage demand equation again fell dramatically when total crop acreage was omitted from the model.

The above models were respecified using revenues per acre $(q_A^1, \ldots, q_A^4)$ instead of crop output prices $(p_A^1, \ldots, p_A^4)$. Revenues per acre were defined as the product of expected prices as above and yields lagged one year. This is the most common specification of yields in acreage response studies (e.g., Bewley, Young, and Colman).[12] Assuming acreage demands are linear in normalized revenues per acre,

$$(20)\qquad z_{At}^i = a_i + \sum_{j=1}^{4} a_{ij}(q_A^j/w_A^1)_t + a_{i5}(w_A^2/w_A^1)_t + a_{i6}K_{At} + a_{i7}\bar{z}_{At} + a_{i8}\bar{z}_{At-1} + a_{i9}t + e_t^i \qquad i = 1, \ldots, 4.$$

The hypothesis of static competitive profit maximization and predetermined yields implies that standard reciprocity restrictions (15) can be placed on acreage demand equations:

$$(21)\qquad a_{ij} = a_{ji} \qquad i, j = 1, \ldots, 4.$$

Normalization of data implies a corresponding transformation of (21).[13]

Joint estimates of equations (1)–(3) for model (20) are presented in table 2. Columns A and B are calculated in a manner similar to columns A and C of table 1, respectively. Column C of table 2 reports joint I3SLS estimates of equations (1)–(3) for (20) when reciprocity is imposed on conditional acreage demands. Comparing tables 1 and 2, replacing crop prices with crop revenues per acre in the demand equations does not appear to have increased the general significance of coefficients. Indeed, coefficients of price in the key wheat equation (in particular $A11$) are somewhat less significant than before. Other results not reported here indicate that total crop acreage $\bar{z}_A$ and associated implicit adding-up restrictions have more impact on the significance of coefficients than do the reciprocity restrictions. Acreage shares also were specified as linear functions of the same variables as in (20). The significance of coefficients in the wheat equation was substantially reduced by replacing prices with revenues per acre.

Table 2. Estimates of Linear Model (20)

Parameter	A (All Coefficients) Estimate	A t-Ratio	B ($-\bar{z}_A$, Adding-up) Estimate	B t-Ratio	C (+ Reciprocity) Estimate	C t-Ratio
A1	−.833	3.43	.075	.17	−.825	3.46
A11	.107	1.47	.009	.05	.095	1.48
A12	−.074	1.33	−.042	.26	−.038	1.04
A13	−.044	.77	.038	.24	−.022	.57
A14	.056	.93	.122	.73	.035	.67
A15	−.178	1.76	−.456	1.93	−.198	2.12
A16	.404	3.02	.410	1.08	.391	3.15
A17	1.897	4.83	—	—	1.859	4.84
A18	.559	2.69	1.049	2.03	.587	2.90
A19	−.025	4.12	−.007	.49	−.025	4.22
A2	1.078	1.79	1.106	3.01	1.121	1.91
A21	−.092	.51	−.095	.57	−.143	1.04
A22	.260	1.88	.261	1.97	.316	2.69
A23	−.250	1.78	.248	1.91	−.184	1.84
A24	−.026	.17	−.024	.17	−.043	.34
A25	.422	1.69	.413	2.08	.363	1.58
A26	−.461	1.39	−.460	1.44	−.511	1.64
A27	.058	.06	—	—	−.119	.13
A28	−1.452	2.83	−1.436	3.32	−1.343	2.77
A29	.045	2.92	.045	3.92	.047	3.17
A3	.073	.07	−.070	.11	.004	.00
A31	−.184	.61	−.169	.60	−.092	.57
A32	−.008	.03	−.013	.06	−.205	1.84
A33	.564	2.39	.551	2.54	.421	2.32
A34	−.223	.89	−.223	.99	−.121	.57
A35	.132	.31	.176	.53	.262	.66
A36	−.623	1.12	−.624	1.17	−.531	1.00
A37	−.299	.18	—	—	.001	.00
A38	−.226	.26	−.303	.42	−.431	.52
A39	.047	1.82	.044	2.27	.045	1.75

Equation	A D–W	A R^2	B D–W	B R^2	C D–W	C R^2
Wheat	2.251	.955	2.157	.607	2.125	.953
Barley	1.841	.899	1.829	.899	1.711	.896
Rapeseed	1.779	.825	1.771	.826	1.714	.813

The hypothesis of reciprocity was tested (using the Gallant and Jorgenson joint test statistic T^0) for the linear model (20) where acreage demands depend on crop revenues per acre. Reciprocity was rejected at the 99% level when adding-up restrictions were imposed. This suggests that either (*a*) yields are not predetermined, or (*b*) equations (20) do not provide a reasonable approximation to acreage demands, or (*c*) acreage demands and production cannot be characterized in terms of static competitive profit maximization.

The alternative specifications of acreage demand models in terms of crop prices and crop revenues per acre were compared using a *J*-test (Davidson and MacKinnon). Predictions of crop acreages from acreage demands (19) using prices were all significant at the 95% level when added to an acreage demand model (20) using revenues per acre, whereas all predictions of crop acreages from acreage demands (20) using revenues per acre were insignificant individually or jointly at the 90% level when added to an acreage demand model (19) using prices. This result favors the specification of acreage demands in terms of crop prices rather than crop revenues per acre, and this result is consistent with our priors that yields vary with the levels of variable inputs such as fertilizer. In turn, the rejection of reciprocity in model (20) may well be interpreted as a rejection of the assumption of predetermined yields rather than as a rejection of profit maximization.[14]

A Simple Application

The above econometric results can be used to demonstrate the importance of modeling a system of acreage equations for the purpose of policy simulations. The effects of policy interventions in Canadian agriculture often have been simulated using crop acreage response equations that exclude cross-price effects (e.g., Harling and Thompson), but this ignores the fact that these programs typically influence prices for multiple crops and that total crop acreage adjusts slowly (Paddock). Thus it is essential to consider cross-price effects in evaluating impacts of these programs on grains.

A major policy intervention in Canadian agriculture has been subsidies to rail transport of grain moving eastward from the Prairies in accordance with the Crow's Nest Pass Agreement and the Western Grains Transportation Act (WGTA). Estimates of the resulting farm gate output price subsidies for the major crops in the Prairies have been reported by Fulton, Rosaasen, and Schmitz, and by Xu. Using all coefficient estimates of the crop acreage model (19) (table 1, column B), the impacts on crop acreages of removing these subsidies for 1984 were calculated as follows: −.72% for wheat, −1.7% for barley, +4.15% for rapeseed, +1.65% for other crops, and 0% for all crops. Using only coefficient estimates for the own-price effects in the crop acreage model (19) (i.e., ignoring estimates of cross-price effects), the impacts on crop acreages of removing these subsidies for 1984 were calculated alternatively as follows: −1.42% for wheat, −2.21% for barley, −1.36% for rapeseed, −.12% for other crops, and −1.46% for total crop acreage. Thus, by ignoring cross-price effects in calculations of impacts of removing 1984 subsidies, there is a decrease in total crop acreage and a decrease in acreage for all categories of crops. In contrast, when cross-price effects are considered, removal of 1984 subsidies leads to a substitution from wheat and barley towards rapeseed and other crops. In sum, these calculations demonstrate the importance of incorporating cross-price effects into analyses of the allocative impacts of such policy interventions.

Conclusion

This article has modeled a system of crop acreage demands as conditional on total crop acreage, and related separability and dynamic specifications helped to reduce the effects of multicollinearity in the system. Econometric results were presented for a four-crop model of acreage demands for Western Canada, 1961–84. Results for the major acreage demand equation (wheat) were improved dramatically by specifying demands as conditional on total crop acreage. Within the context of revenue per acre models, reciprocity restrictions corresponding to the joint hypothesis of static competitive profit maximization and predetermined yields were rejected. Specification of acreage demands in terms of revenues per acre was rejected in favor of a specification using output prices.

[*Received November 1991; final revision received November 1992.*]

Notes

[1] In addition, the specified functional form for acreage demands in Binkley and McKinzie violates homogeneity (acreage demands are specified as linear functions of returns per acre in each crop rather than of relative returns, so homogeneity of degree zero in the vector of returns and Euler's theorem imply that acreage demands are independent of the vector of returns).

[2] Summerfallow is the primary rotation practice for increasing crop yields on the Canadian prairies, so summerfallow is not weakly separable from crop acreage decisions. An anonymous reviewer pointed out that, to the smaller extent that forage is included in rotations to increase crop yields, the assumption of weak separability between crops and livestock is somewhat restrictive. Since it is difficult to reestablish livestock range (e.g., Burt and Worthington), such an interaction between forage and crop yields is unlikely to play a major role in crop acreage decisions.

[3] More restrictive separability conditions also can be specified to rationalize omission of variable input prices from second-stage acreage allocation problems (Coyle).

[4] In contrast, Bewley, Young, and Colman treated total crop acreage as exogenous or predetermined in their multinomial logit model. The analogous assumption of exogenous income may be appropriate for common nonseparable allocation models of consumption, but exogeneity generally seems inappropriate for modeling crop acreage allocations (LaFrance).

[5] Binkley and McKinzie state without proof that a system of acreage demands, expressed as a function of expected profits per acre for each crop, satisfies reciprocity conditions under profit maximization. There is no mention that this depends on the restrictive assumption of predetermined yields (and, in their case where acreage demands are conditional on profits per acre, predetermined variable costs per acre).

[6] The first-order conditions (4) for optimal allocations z^* imply that the Chambers–Just duality model endogenizing acreage allocations is relatively complex. However, this model can be simplified somewhat by an appropriate transformation of the dual.

[7] Given that the allocation vector z also can be recovered from $\pi(p, w, \bar{z})$ (Paris), our argument can be extended to establish duality between $\pi(p, w, \bar{z})$ and the technology $T(y, x, z) = 0$.

[8] Alternatively, a multinomial logit functional form could be specified for acreage demands so that predicted shares are non-negative for all possible prices. However, other functional forms yield positive predicted shares over the sample period and this seems satisfactory in practice (e.g., note the popularity of translog share equations). Moreover, there are significant disadvantages to the choice of a multinomial logit (each logit equation must share a common term, coefficients in individual share equations are not identified, and any variable having a significant influence on one share must have a significant influence on all shares) (Theil; Bewley, Young, and Colman).

[9] The hypothesis that individual crop acreage demands depend on lagged total crop acreage rather than lags for each individual crop can be expressed in terms of a nondiagonal matrix of partial adjustment coefficients α_{ij} (for lag z^j_{t-1} in the ith demand equation) as the restrictions $\alpha_{ij} = \alpha_{ik}$ for all crops i, j, k. These restrictions were not rejected at the 99% level.

[10] We assume that the livestock price index and interest rate along with exogenous variables in (19) are included in the reduced form equation for total crop land $\bar{z}_A$; but other exogenous variables Q also presumably should be included in this reduced form equation. Then our truncated 3SLS estimator is consistent. It should be noted that the most efficient linear instrumental variable estimator for this system utilizes Q as well in specifying an instrument for total crop land $\bar{z}_A$ (e.g., Hausman). However, there is no concensus on these additional variables Q explaining total crop acreage in Western Canada.

[11] A crop growth weather index (GRODEX) (Dyer, Narayanan, and Murray), on-farm stocks of wheat and barley, exports of wheat and barley, and a dummy variable for the LIFT program also were included in the acreage demand models but were found to be insignificant. Alternative models of price expectations (including a simple ARIMA model of rational expectations) yielded poor results. Summerfallow is excluded from the version of the model reported here since there are few studies of the economics of summerfallow (Johnson and Ali); however, similar results were obtained with summerfallow included in the model.

[12] Yields are included in acreage demand equations such as (20) primarily in order to proxy differences in technology between crops. A simple one-year lag on yields (as here) is appropriate assuming static (regressive) expectations for technology and weather, but this assumption is questionable for weather. Although the simplest alternative is to calculate expected yield by regressing yield on a time trend, the resulting estimates of (20) did not appear to be any better than in the standard case of a one-year lag on yields. A simple ARIMA model of rational expectations also was used to calculate expected yields: yields were specified as model predictions of current yields in terms of lagged yield for the crop, lagged weather conditions (GRODEX), current variable input prices, expected crop output prices, and a time trend. However, poor results were obtained for (20) using these predicted yields.

[13] Normalization of acreages and revenues per acre in (20), i.e., $\hat{z}^i_t \equiv z^i_t/z^i_{84}$ and $\hat{q}^i_t \equiv q^i_t/q^i_{84}$ $(i = 1, \ldots, 4)$, implies that the reciprocity conditions (15) correspond to restrictions $\partial\hat{z}^i/\partial\hat{q}^j \cdot (z^i_{84}/q^j_{84}) = \partial\hat{z}^j/\partial\hat{q}^i \cdot (z^j_{84}/q^i_{84})$.

[14] A major reason for the common specification of crop acreage response models in terms of revenues per acre rather than prices presumably is that revenues per acre for different crops are often less correlated than crop output prices. However, our results suggest that such specifications are inappropriate and do not increase the significance of response coefficients within the systems framework adopted here.

References

Askari, H., and J. T. Cummings. "Estimating Agricultural Supply Response with the Nerlove Model: A Survey." *Internat. Econ. Rev.* 18(1977):257–92.

Behrman, J. R. *Supply Response in Underdeveloped Agriculture: A Case Study of Four Major Annual Crops in Thailand, 1937–63.* Amsterdam: North-Holland, 1968.

Berge, C. *Topological Spaces.* New York: Macmillan, 1963.

Bewley, R. *Allocation Models: Specification, Estimation, and Applications.* Cambridge MA: Ballinger, 1986.

Bewley, R., T. Young, and D. Colman. "A System Approach to Modelling Supply Equations in Agriculture." *J. Agr. Econ.* 38(1987):151–66.

Binkley, J. K., and L. McKinzie. "Improving Acreage Response Analysis with Multiple Equations." *N. Cent. J. Agr. Econ.* 6(1984):91–98.

Braulke, M. "A Note on the Nerlove Model of Agricultural Response." *Internat. Econ. Rev.* 23(1982):241–45.

Burt, O. R., and V. E. Worthington. "Wheat Acreage Supply Response in the United States." *West. J. Agr. Econ.* 13(1988):100–11.

Canadian Wheat Board. *Canadian Wheat Board Annual Report.* Canadian Wheat Board, Winnipeg, Manitoba, Canada, 1986.

Chambers, R. G., and R. E. Just. "Estimating Multioutput Technologies." *Amer. J. Agr. Econ.* 71(1989):980–95.

Chavas, J.-P., and M. T. Holt. "Acreage Decisions Under Risk: The Case of Corn and Soybeans." *Amer. J. Agr. Econ.* 72(1990):529–38.

Chavas, J.-P., R. D. Pope, and R. S. Kao. "An Analysis of the Role of Futures Prices, Cash Prices, and Government Programs in Acreage Response." *West. J. Agr. Econ.* 8(1983):27–33.

Colman, D. "Prairie Grain and Oilseed Acreage Response." Work. Pap. No. 7, Policy, Planning, and Economics Branch, Agriculture Canada, Ottawa, 1979.

Coyle, B. T. "Allocatable Fixed Inputs and Two-Stage Aggregation Models of Multioutput Production Decisions." *Amer. J. Agr. Econ.* 75(1993):367–76.

Davidson, R., and J. G. MacKinnon. "Several Tests for Model Specification in the Presence of Alternative Hypotheses." *Econometrica* 49(1981):781–94.

Deaton, A., and J. Muellbauer. *Economics and Consumer Behavior.* London: Cambridge University Press, 1980.

Denton, F. T. "Single-Equation Estimators and Aggregation Restrictions When Equations Have the Same Sets of Regressors." *J. Econometrics* 8(1978):173–79.

Diebold, F. X., and R. C. Lamb. "Why Are Estimates of Agricultural Supply Response So Variable?" Staff Pap., Dept. of Econ., University of Pennsylvania, 1992.

Diewert, W. E. "Functional Forms for Profit and Transformation Functions." *J. Econ. Theory* 6(1973):284–316.

Doran, H. E., and W. E. Griffiths. "Inconsistency of the OLS Estimator of the Partial Adjustment–Adaptive Expectations Model." *J. Econometrics* 7(1978):133–46.

Dyer, J. A., S. Narayanan, and D. Murray. "A Water Use Index for Crop Performance." *Can. Water Resour. J.* 9(1984):22–29.

Eckstein, Z. "The Dynamics of Agricultural Supply: A Reconsideration." *Amer. J. Agr. Econ.* 67(1985):204–14.

———. "A Rational Expectations Model of Agricultural Supply." *J. Polit. Econ.* 92(1984):1–19.

Epstein, L. G. "Generalized Duality and Integrability." *Econometrica* 49(1981):655–78.

Fulton, M., K. Rosaasen, and A. Schmitz. *Canadian Agricultural Policy and Prairie Agriculture.* Ottawa: Economic Council of Canada, 1989.

Fuss, M. A., and D. McFadden, eds. *Production Economics: A Dual Approach to Theory and Application,* Vols. I, II. Amsterdam: North–Holland, 1978.

Gallant, A. R., and D. W. Jorgenson. "Statistical Inference for a System of Simultaneous, Non-Linear Implicit Equations in the Context of Instrumental Variable Estimation." *J. Econometrics* 11(1979):275–302.

Griliches, Z. "Distributed Lags: A Survey." *Econometrica* 35(1967):16–49.

Harling, K. F., and R. L. Thompson. "The Economic Effects of Intervention in Canadian Agriculture." *Can. J. Agr. Econ.* 31(1983):153–76.

Hausman, J. A. "Specification and Estimation of Simultaneous Equation Models." In *Handbook of Econometrics,* Vol. I, eds., Z. Griliches and M. Intriligator, pp. 392–448. Amsterdam: North–Holland, 1983.

Houck, J. P., and M. E. Ryan. "Supply Analysis for Corn in the United States: The Impact of Changing Government Programs." *Amer. J. Agr. Econ.* 54(1972):184–91.

Jennings, A. N., and R. J. Young. "Generalization of the Nerlove Supply Model Using Time Series Methodology: An Application to Potato Plantings in Great Britain." *J. Agr. Econ.* 31(1980):99–110.

Johnson, R. G., and M. B. Ali. "Economics of Wheat–Fallow Cropping Systems in Western North Dakota." *West. J. Agr. Econ.* 7(1982):67–77.

Just, R. E. "An Investigation of the Importance of Risk in Farmers' Decisions." *Amer. J. Agr. Econ.* 56(1974):14–25.

Krakar, E., and B. Paddock. "A Systems Approach to Estimating Prairie Crop Acreage." Work. Pap. No. 15, Marketing and Econ. Branch, Agriculture Canada, Ottawa, 1985.

LaFrance, J. T. "When Is Expenditure 'Exogenous' in Separable Demand Models?" *West. J. Agr. Econ.* 16(1991):49–62.

Lee, D. R., and P. G. Helmberger. "Estimating Supply Response in the Presence of Farm Programs." *Amer. J. Agr. Econ.* 67(1985):193–203.

Lidman, R., and D. L. Bawden. "The Impact of Government Programs on Wheat Acreage." *Land Econ.* 50(1974):327–35.

Lin, W. "Measuring Aggregate Supply Response Under Instability." *Amer. J. Agr. Econ.* 59(1977):903–07.

McFadden, D. "Cost, Revenue, and Profit Functions." In *Production Economics: A Dual Approach to Theory and Application,* Vol. I, eds., M. A. Fuss and D. McFadden, pp. 3–109. Amsterdam: North–Holland, 1978.

McIntosh, C. S., and K. H. Shideed. "The Effect of Government Programs on Acreage Response Over Time: The Case of Corn Production in Iowa." *West. J. Agr. Econ.* 14(1989):38–44.

Morzuch, B. J., R. D. Weaver, and P. G. Helmberger. "Wheat Acreage Supply Response Under Changing Farm Programs." *Amer. J. Agr. Econ.* 62(1980):29–37.

Muth, J. F. "Rational Expectations and the Theory of Price Movements." *Econometrica* 29(1961):315–35.

Nerlove, M. "The Dynamics of Supply: Retrospect and Prospect." *Amer. J. Agr. Econ.* 61(1979):874–88.

———. "Estimates of the Elasticities of Supply of Selected Agricultural Commodities." *J. Farm Econ.* 38(1956):496–509.

———. "Lags in Economic Behavior." *Econometrica* 40(1972):221–51.

Nieuwoudt, W. L., A. W. Womack, and S. R. Johnson. "Measurement of Importance of Risk on Supply Response of Corn and Soybeans." *N. Cent. J. Agr. Econ.* 10(1988):281–92.

Paddock, B. "The Economic Effects of Policy Intervention in Canadian Agriculture: Comment." *Can. J. Agr. Econ.* 32(1984):437–42.

Paris, Q. "A Sure Bet on Symmetry." *Amer. J. Agr. Econ.* 71(1989):344–51.

Shideed, K. H., and F. C. White. "Alternative Forms of Price Expectations in Supply Analysis for U.S. Corn and Soybean Acreages." *West. J. Agr. Econ.* 14(1989):281–92.

Shumway, C. R. "Supply, Demand, and Technology in a Multiproduct Industry: Texas Field Crops." *Amer. J. Agr. Econ.* 65(1983):748–60.

Shumway, C. R., W. P. Alexander, and H. Talpaz. "Texas Field Crops: Estimation with Curvature." *West. J. Agr. Econ.* 15(1990):45–54.

Shumway, C. R., R. D. Pope, and E. K. Nash. "Allocatable Fixed Inputs and Jointness in Agricultural Production: Implications for Economic Modeling." *Amer. J. Agr. Econ.* 66(1984):72–78.

Statistics Canada. *Farm Input Price Indexes 62-004.* Farm Income and Prices Div., Statistics Canada, Ottawa, 1986a.

———. *Farm Net Income 21-202.* Farm Income and Prices Div., Statistics Canada, Ottawa, 1986b.

———. *Field Crop Reporting Series 22-002.* Statistics Canada, Ottawa, 1986c.

Theil, A. "A Multinomial Extension of the Linear Logit Model." *Internat. Econ. Rev.* 10(1969):251–59.

Traill, B. "Risk Variables in Econometric Supply Response Models." *J. Agr. Econ.* 29(1978):53–61.

Varian, H. *Microeconomic Analysis.* New York: Norton, 1992.

Waud, R. N. "Misspecification in the 'Partial Adjustment' and 'Adaptive Expectations' Models." *Internat. Econ. Rev.* 9(1968):204–17.

Xu, C.-J. "Impact of the Crow Rate and the Western Grain Transportation Act on Western Canadian Grain Production." Unpub. M.Sc. thesis, Dept. Agr. Econ. and Farm Management, University of Manitoba, 1991.