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Supply Response of Texas Field Crops: An Evaluation of The CET Linear Supply Model

C. Richard Shumway and A. Anne Chang

The constant elasticity of transformation (CET) linear supply model is adapted and evaluated in this analysis of short-run supply response of six Texas field crops. Cross-product supply elasticities are estimated and direct supply elasticities are derived. The sensitivity of estimated parameters to alternative specifications of variables inducing shifts in the production possibilities surface is examined. Shift variables considered include input level, technology, government programs, and weather. The effect of risk on supply response is also examined. The model's symmetry assumption is tested and not rejected. All of the own-price elasticities derived from the fully-specified supply model estimates have expected signs, but less than half of the alternative-product price elasticities do. Price parameter signs are quite stable, but the large number of significant risk parameters and unexpected price parameter signs challenges the general adequacy of the CET model for measuring Texas field crop supply response.

Powell and Gruen's CET linear supply model is adapted for analysis of short-run response of six Texas field crops (corn, cotton, hay, rice, sorghum, and wheat). All potentially relevant product price parameters are estimated for these crops that collectively account for nearly 95% of Texas harvested field crop acreage and value of production.[1] The sensitivity of estimated parameters to alternative specifications in model scope and in non-price proxy variables is also examined. The sensitivity analysis is conducted to determine whether the proportion of unexpected parameter signs estimated with the CET supply model is highly dependent on the number of commodities in the model or on the number and definition of non-price independent variables included. This analysis permits limited evaluation of both the stability of the empirical estimates and general performance of the supply model.

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[1]Some of these six commodity prices could legitimately be deleted from specific supply equations on the basis of strong *a priori* evidence of little competition for resources. However, in the initial model, all six product prices are treated as potentially relevant to the supply decision for each commodity. Livestock prices are excluded *a priori* on the basis of little competition for resources.

Neglect of Intercommodity Supply

Most prior supply response literature has focused on own-price effects of individual commodities and aggregates. Little attention, however, has been given to intercommodity supply effects. This is not a serious problem when estimating the aggregate agricultural supply function; the theoretical model justifies exclusion of alternative product prices from the set of independent variables on the grounds that there are really no important alternative uses of aggregate agricultural resources. Such is not the case, however, for individual commodities. While there are some commodity-specific resources (e.g., specialized harvesting equipment), most inputs can be used in production of several agricultural commodities.

Comprehensive sets of partial direct and cross-product demand elasticities have previously been estimated for agricultural commodities [e.g., Brandow; George and King], but no comparable study has been conducted on the supply side. Empirical estimates of partial supply response parameters are needed before general equilibrium analyses of supply and demand can meaningfully be carried out. Estimates are also needed by regions to permit examination of interregional competition. This paper is a consequence of research aimed at reliably estimating regional supply response, including partial cross-product effects, of major field crops.

Model Selection

The Powell and Gruen model is one of the few econometric models that has been used to estimate intercommodity supply relations in agriculture. It has important estimation appeal because: (1) it reduces the number of product price parameters requiring estimation in a k-commodity system from k^2 to $0.5k(k-1)$, and (2) it transforms the data so that the price parameters to be estimated are the symmetrical elasticities of transformation and are assumed constant.

Symmetry and homogeneity of degree zero in prices are implied for firm supply by the assumption of perfect competition. At the industry level, homogeneity is an empirical question. However, it is a maintained hypothesis of the Powell and Gruen model and is not tested. Their model further estimates only input-constant partial price parameters of supply, which implies homogeneity in product prices alone.

Constant elasticities of transformation and a local correspondence at the variable means between the CET production possibilities surface and a linear supply function are also assumed. The latter assumption means that the change in quantity produced of i for a unit change from the mean in the price of j is the same whether measured along the production possibilities surface or measured with a linear supply function. These assumptions imply that the symmetrical elasticities of transformation are the product price parameters to be estimated. Constant-input cross-product elasticities of supply are computed from the elasticities of transformation and partial value shares, and the direct elasticities are derivable from the homogeneity assumption. Independent variables were added by Powell and Gruen to measure both neutral and biased impacts on the production possibilities surface caused by exogenous changes in input levels and technology.

By imposing the homogeneity and symmetry constraints, a reduction is achieved in the multicollinearity problem that plagues estimation of multi-product supply models [Kmenta, p. 433]. As partial evidence of high multicollinearity in the alternative unconstrained linear model, the correlation matrix of own product price variables is reported in Table 1. It is perhaps through partial mitigation of the multicollinearity problem that the CET linear supply model performed in a superior manner to two alternative models in Whittaker's estimation of crop supply response in six multi-product regions of the U.S. The alternative models were unconstraind OLS and restricted least squares (with the homogeneity assumption imposed). Consistent with Powell and Gruen's earlier analysis of three and six-commodity Australian subsectors (see Gruen, et al. for the six-commodity analysis), each model gave a large proportion of unexpected signs. However, the CET supply model provided a larger proportion of estimates that were consistent with theoretical expectations. It also rendered the most accurate predictions.

The CET supply model is used in this study not because it appears to be a panacea for empirical estimation. In fact it is based on a set of very restrictive assumptions. But, it

TABLE 1. Correlation Matrix of Texas Product Prices

	Product					
Product	Corn	Cotton	Hay	Rice	Sorghum	Wheat
Corn	1.000	.590	.859	.897	.978	.897
Cotton		1.000	.523	.576	.606	.743
Hay			1.000	.816	.856	.836
Rice				1.000	.872	.882
Sorghum					1.000	.904
Wheat						1.000

does permit some relief from the collinearity problem, and its empirical results to date appear to be "least worse" of the previously applied options.[2] Unfortunately, it has not been used sufficiently to thoroughly evaluate its appropriateness for particular types of production systems.

It is modified in this study to permit an *ad hoc* test of the profit maximization hypothesis of perfect competition and to estimate output rather than acreage response. Risk variables are added to permit a partial test of profit maximization without altering any of the fundamental implications of that hypothesis. The adaptations imposed are similar to those made concurrently by Green in his study of U.S. field crop supply response.

Model Structure

One of the underlying assumptions of the CET linear supply model is that producers act like perfect competitors (which presumes profit maximization). However, with considerable evidence of risk-averse behavior among a large proportion of agricultural producers [Young, et al.], risk may also be an important behavioral variable. A utility function with arguments in price and risk can be specified, and the equilibrium conditions that would maximize utility can be derived in a straightforward manner. The problem faced here, though, is that even with the simple quadratic utility function and assuming zero covariances, a nonlinear estimation procedure would be required to estimate the risk aversion parameter of each CET linear supply equation.[3]

[2]Weaver has recently used the concept of duality to estimate the parameters of a multi-product supply, multi-input demand system via the indirect profit function.

[3]Let

$$\pi = PY - C$$

where π is profit, P is the product price vector, Y is the output vector, C is total cost and is treated as a constant. Under profit maximization, the first order condition for a price taker's optimal product combination is given by

$$\partial y_i / \partial y_j = -p_j / p_i,$$

where i and j are commodities.

Under utility maximization with uncertain prices and output, let

$$Y = Y^* \gamma$$

where Y^* is the expected output vector and γ is a multiplicative error term.

$$\pi = P'(\gamma Y^*) - C$$
$$= Y^{*\prime} (P\gamma) - C$$

Further, assume the quadratic utility function

$$U = P^{*\prime} Y^* - \frac{\lambda}{2} Y^{*\prime} \Sigma_{p\gamma} Y^* - C,$$

where U is utility, P^* is the expected product price vector, λ is the risk aversion parameter, and $Y^{*\prime} \Sigma_{p\gamma} Y^*$ is the variance-covariance matrix of total revenue (with zero off-diagonal elements, $\sigma_{i,j \neq i} = 0$). The first order condition for a utility maximizing price taker's optimal product combination is given by

$$\partial y_i^* / \partial y_j^* = (p_j^* - \lambda \sigma_{jj} y_j^* / (\lambda \sigma_{ii} y_i^* - p_i^*)$$

Consequently, risk is included in this supply model in an *ad hoc* fashion. Risk, measured as the variance in total returns, is added to the set of independent linear variables. Estimation of its parameters then is a simple test of the previous hypothesis that producers do operate as profit maximizers (given that each firm cannot affect prices by the quantity of products it sells or by the quantity of inputs it buys). This test is possible because the profit-maximizing supply model is a nested version of the model that exhibits no supply response to risk. Thus, if the risk parameters are significantly different from zero, the profit maximizing hypothesis is suspect.

Finally, adding relevant shifters to the production possibilities surface results in the following CET linear commodity supply model:

$$(1) \quad y_{i,t} = \alpha_{i,o} + \sum_{j \neq i}^{k} \tau_{i,j} z_{i,j,t} + \alpha_{i,1} v^*_{i,t} + \sum_{m=1}^{4} \alpha_{i,m+1} s_{i,m,t} + \mu_{i,t}$$

$$(2) \quad \tau_{i,j} \equiv \{d(y_i/y_j)\} \, (\partial y_i/\partial y_j)/\{d(\partial y_i/\partial y_j)\} \, (y_i/y_j)$$

$$(3) \quad z_{i,j,t} \equiv (\bar{y}_i \bar{w}_{i,j}) \, \{(p^*_{j,t}/\bar{p}^*_j) - (p^*_{i,t}/\bar{p}^*_i)\}$$

$$(4) \quad \bar{w}_{i,j} \equiv \bar{p}^*_j \bar{y}_j/(\bar{p}^*_j \bar{y}_j + \bar{p}^*_i \bar{y}_i)$$

where $y_{i,t}$ is supply of commodity i in year t, $\tau_{i,j}$ is the estimated elasticity of transformation parameter between commodities i and j, z is the transformed expected price variable (for its derivation see Powell and Gruen, pp. 319-21), v^* is the expected risk variable, s is a set of four production possibilities surface shift variables, μ is the error term, p^* is expected price, $\bar{p}^*$ is the mean of expected prices, $\bar{y}$ is the mean of quantities supplied, $\bar{w}_{i,j}$ is the share of j in total returns of i and j at the output and expected price means, and other terms in equation (1) are estimated parameters.

The vector of parameters τ in equation (1) is designed to measure output response along the production possibilities surface to changes in relevant price ratios. Expected prices affect the slope of the iso-revenue line. The defined shift variables directly affect the position of the production possibilities surface. Because there is a yield response as well as an acreage response to product price changes [Houck and Gallagher], this study is concerned with output response. The shift variables selected, therefore, include variables designed to reflect input levels, technology, agricultural commodity policies, and weather.

Expected Prices

Expected price are defined following Powell and Gruen as geometric lag functions of past prices, truncated on pragmatic grounds at seven years.

$$(5) \quad p^*_{i,t} = a_i \beta_i \sum_{\ell=1}^{7} (1-\beta_i)^{\ell-1} p_{i,t-\ell} + \varepsilon_{i,t}$$

where β is the coefficient of price expectation, a is the weighting factor to adjust the weights on the seven lagged price observations to sum to 1.0, and ε is the error term.

Also following Powell and Gruen, the coefficient of price expectation (β_i) is estimated for each commodity independently of all other model parameters. However, the estimation procedure used in this study differs. The β_i are parameterized from 0.1 to 1.0 in 0.1 increments. β_i is selected on the basis of minimizing the sum of squares between expected and actual prices over the data period.

While it is possible to obtain a local linear approximation of supply response under profit maximization, no linear approximation can be obtained at any point if this simple utility function is to be maximized.

Risk

The risk measure is variance in own-commodity total returns per acre defined following Just as a geometric lag function of past variance:

$$(6)\quad v^*_{i,t} = \phi_i \sum_{\ell=1}^{\infty} (1-\phi_i)^{\ell-1}(r_{i,t-\ell} - r^*_{i,t-\ell})^2$$

where ϕ is the coefficient of risk expectation, r is returns per acre, and r* is expected returns per acre which in turn is a geometric lag function of past returns:

$$(7)\qquad r^*_{i,t} = \Theta_i \sum_{\ell=1}^{\infty} (1-\Theta_i)^{\ell-1} r_{i,t-\ell}$$

where Θ is the coefficient of return expectation.

Like expected price, subjective risk as defined by Just is an unobserved variable and must be estimated. Following his procedure, subjective risk is partitioned into two parts which he labels unobserved and observed risk. The first is really initial risk which in this study is defined as a function of variance in returns during the seven years prior to the first observation of other model variables (i.e., 1946). The second is a subsequent risk variable and is a function of return variance for each year from 1946 to $t-1$.

The annual returns per acre series and the parameters ϕ and Θ fully define the subjective risk variables. The parameters are obtained as maximum likelihood estimates using OLS. To secure the greatest efficiency in estimation, the risk variables are defined while estimating other parameters of the model. This is accomplished in a three-pass procedure:

a. The system of equations (1) with the symmetry constraint on the τ's constitute a case of seemingly unrelated regressions [Kmenta, p. 517]. Thus, generalized least squares (i.e., a two-stage Aitken estimator) is used to estimate the parameters of equation (1) excluding risk.
b. The symmetric τ parameters thus estimated are treated as known structural constants, and parameters defining risk are obtaind as maximum likelihood estimates using OLS.
c. With the risk variables defined, all parameters of equation (1), including $\alpha_{i,1}$, are re-estimated.

Input Level

Perhaps the most obvious variable determining the location of the production possibilities surface is the quantity of inputs available. A proxy for the aggregate level of inputs, i.e., acreage used in the production of the six field crops, is defined as the first shift variable.

Technology

The second major variable that shifts the production possibilities surface over time is technology. Following Powell and Gruen, we use lagged output as a proxy for the capacity measure. The coefficient of adjustment reflects technological stickiness in the adjustment of supply.

Goverment Policies

Agricultural commodity policies directly affect the supply of most crops included in this analysis: corn, cotton, rice, sorghum, and wheat. The policy variables used follow Houck and Ryan. Two variables are defined: weighted diversion payment and weighted support price. Weighted diversion payment can be conceptualized either as the price of another product, i.e., no production, or as a non-neutral shifter of the production possibilities surface due to removal of land inputs. With the first approach, the diversion payment parameter is considered in computing direct supply elasticities based on the homogeneity condition [e.g., Whittaker]. With the second approach it is not. For full specification with the former, the symmetry condition warrants estimation of an extra supply equation for diversion. Without an unambiguous criterion for choosing one assumption over the other, the more easily-implemented assumption is made here. That is, weighted diversion payment is added as the third variable in each equation shifting the production possibilities surface. In the results section, however, the direct elasticities implied by the first assumption without full model specification will also be noted. Finally, the higher of weighted support price and expected price is included in the model as the price assumed to be relevant for supply decisions.

Weather

Because this study is concerned with output supply response rather than acreage response, weather is a relevant shift variable and is included as the last independent variable in the model. The weather proxy variable used is an adaptation of Stallings' index.

Hypotheses

If the market is efficient and all commodities are strictly competitive for a given set of resources, all $\tau_{ij}<0$. Powell and Gruen anticipated these conditions so strongly that they not only hypothesized negative τ's but also constrained all positive τ's $= 0$ in deriving direct elasticities. Negative τ's are hypothesized in this study also. However, positive τ's (which imply convex production possibilities curves) may actually occur in the real world. Increasing returns to scale in two technically independent commodities is the most likely condition for such occurrence, but other possible conditions will also produce positive τ's. Whether τ is negative or positive depends on the shape of the multiproduct production function and is explained by the signs and relative magnitudes of the first and second partial derivatives of the production function.

The hypothesis that $\tau_{ij}<0$ implies hypotheses that constant-input cross-product supply elasticities are less than zero and derived direct supply elasticities are greater than zero.

Hypotheses for non-price variable parameters are:

$\alpha_{i,1} = 0$. If producers are risk neutral, product supply will be unrelated to own-product risk. However, if they are risk averse (preferers), product supply will decrease (increase) as risk increases. Actually, two risk parameters are estimated, on observed and on unobserved risk. Both parameters are expected to be zero if producers are risk neutral.[4]

$\alpha_{i,2}>0$. As the input level increases, the production possibilities surface shifts outward and product supply should increase.

$\alpha_{i,3}>0$. As technology develops as implied by lagged product supply, the production possibilities surface shifts outward and current product supply should increase.

$\alpha_{i,4}<0$. As the diversion payment for crop i increases, the incentive to decrease the acreage used in its production also increases.

$\alpha_{i,5}>0$. Since the weather index is a ratio of observed and expected yield, the higher the index, the further outward is the production possibilities surface and the higher is product supply.

Empirical Results

Initial CET Results

Parameter estimates of the initial CET model are reported in Table 2. Unexpected

[4]Gardner and Chavas [pp. 9-10] argue that non-neutral supply response to risk is not unambiguously implied by significant parameters estimates on risk variables. They document that under various conditions expected returns may decrease as production variability increases although no change in expected price and output occurs, thus giving rise to a decision to decrease supply in apparent response to an increase in risk even under risk-neutrality. An anonymous reviewer further suggests that risk neutrality is not necessarily implied by nonsignificant parameter estimates on risk variables. "If the estimated risk parameters are zero, all that can be said is that either producers are profit maximizers *or* researchers cannot model risk."

TABLE 2. Initial CET Model Estimates

			CET Price Variables[a]						Risk[b]				Shift Variables			
									Variables		Parameters			Lagged	Weighted	
Commodity	Unit	Intercept	Corn	Cotton	Hay	Rice	Sorghum	Wheat	Unobservable	Observable	ϕ	Θ	Land Input	Output (Technology)	Diversion Payment	Weather Index
	(1,000)															
Corn	bu.	−32,968		−.957	.632	.081	.321	.080	−95,536	−5.416	.1	.3	1.177	1.130	−23,027	700
		(14,514)[c]		(.229)	(.289)	(.309)	(.500)	(.433)	(13,379)	(1.047)			(.773)	(.095)	(18,052)	(99)
Cotton	lb.	−388,936			.034	−.003	−.579	−1.252	−927,802	17.561	.5	.1	62.370	−.165	−4,409,032	13,640
		(275,898)			(.115)	(.096)	(.154)	(.151)	(130,540)	(7.746)			(11.107)	(.047)	(726,336)	(1,182)
Hay	ton	−1,248				−.486	.256	−.458	−2,445	−.038	.1	.3	.014	.529		35
		(654)				(.166)	(.225)	(.244)	(341)	(.015)			(.030)	(.117)		(5)
Rice	cwt.	−15,495					.020	−.313	−2,285	.005	.5	.3	.223	.587		185
		(4,632)					(.185)	(.257)	(1,146)	(.003)			(.138)	(.071)		(23)
Sorghum	bu.	−35,448						.312	−214,374	2.454	.1	.3	1.661	.052	−47,349	2,851
		(48,659)						(.321)	(33,656)	(1.209)			(2.721)	(.075)	(59,877)	(366)
Wheat	bu.	−106,702							8,502	5.869	.9	.1	2.956	.115	−9,188	1,064
		(12,723)							(7,422)	(2.889)			(.607)	(.054)	(5,609)	(64)

[a]The estimated coefficients of price expectation, β in equation (5), are .8 for cotton, .7 for rice, and 1.0 for all other crops. The parameter estimates reported in the price variable columns of this table are the estimated elasticities of transformation.

[b]The risk variables are defined by ϕ and Θ, estimated in the second pass, and by returns per acre. See Chang for details concerning the estimation procedure.

[c]Estimated standard errors are in parentheses.

signs are obtained on 24% of the estimated price and shift variable parameters, including 53% of the τ's and 5% of the shift variable coefficients. Of the parameters with expected signs, 61% have t-values ≥ 2.0 including 57% of the τ's. Of parameters with unexpected signs, only 22% have t-values ≥ 2.0, including 13% of the τ's. Although more than half the τ's have unexpected signs, all direct elasticities of supply are positive as expected.[5] Elasticity magnitudes are reported and evaluated in the final section of the paper.

Nine of the 12 estimated risk variable coefficients have t-values ≥ 2.0 and one more is nearly 2.0. Although this constitutes an imperfect test, the maintained hypothesis of the CET linear supply model that producers operate as though they were profit maximizers appears highly suspect. Five of the estimated coefficients are positive (implying risk preference), but only three have t-values ≥ 2.0. All seven t-values of the negative coefficients exceed 1.99. Consequently, the evidence supporting an alternative hypothesis that producers are risk average appears to be greater than evidence implying that they are either risk preferers or risk neutral.

To test the originally maintained hypothesis that the τ's are symmetric, the linear CET commodity supply model is re-estimated without the symmetry constraint on the price coefficients. The symmetry hypothesis is not rejected at the 95% level of significance by the test statistic, $F_{15,116} = 1.33$. Thus, opposite from Whittaker's findings, the data used in this study do not cause rejection of the symmetry condition of this expanded CET model.

The data period used in estimating the parameters of the model is 1946-76. Commodity supply for 1977 is predicted using the estimated coefficients. The predictive accuracy of this model is not particularly good. Percent error in prediction ranges from 4% to 45%, and Theil's U_2 inequality coefficient [Theil, p. 28] ranges from .30 to .59.

The symmetry test does not compel rejection of the linear CET commodity supply model as a valid descriptor of Texas field crop supply response. Unexpected signs cannot totally be ruled out on theoretical grounds. Further, a large proportion of unexpected parameter signs and values is consistent with the findings of prior multi-product supply studies. However, the risk-neutral hypothesis of the CET model is rejected. Further, the bases for the remaining parameter hypotheses are strong and give substantial reason to suspect spurious estimation of some parameters. Although the effects of multicollinearity are partially mitigated by imposing the restrictions, high collinearity among the variable data continues to limit efficient estimation of multi-product supply response. For example, nearly ⅕ of the computed variance inflation factors [Marquardt] are large enough to suggest poor estimates by Marquardt's rule of thumb. Therefore, the remainder of this paper is devoted to an evaluation of the sensitivity of unexpected parameter signs to alternative specifications and model scope.

Sensitivity to Reduced Model Scope

The two crops with smallest harvested Texas acreage, rice and corn, are deleted from the model and the remaining parameters re-estimated. Reducing the number of commodities in the model by 33% reduces the number of price coefficients (τ's) requiring estimation by 60%, i.e., from 15 to 6. A much smaller proportion of parameters estimated with this reduced model have unexpected signs (14%) than parameters estimated with the initial model (see table 3, model 2). The proportion of unexpected τ signs is substantially reduced (33%) while the

[5]The direct elasticities are not estimated but are derived from the estimated τ's since the supply equations are presumed to be homogeneous of degree zero in product prices. The supply elasticity of product i with respect to the price of j at the means is $(\partial y_i / \partial p_j)(\bar{p}_j / \bar{y}_i) = \tau_{ij}\bar{w}_{ij}$ since, from equations (1) and (3), $\partial y_i / \partial p_i = (\partial y_i / \partial z_{ij})(\partial z_{ij} / \partial p_j) = \tau_{ij}(\bar{y}_i\bar{w}_{ij} / \bar{p}_j)$.

proportion of unexpected shift variable coefficients is approximately the same (7%).[6]

Sensitivity to Alternative Risk And Shift Variable Definitions

Although the generic variables included in the model can be strongly defended on conceptual grounds, the specific working variables selected to represent each concept are less defensible. In this portion of the sensitivity analysis, three variables are re-defined one at a time and all model parameters are re-estimated.

With risk re-defined as a three-year moving standard deviation of total returns per acre (model 3), the percent of unexpected parameter signs is the same as with the initial model (24%). This includes 33% of the τ's and 18% of the shift variable coefficients. A substantial improvement in expected signs is obtained among the τ's.

Because acreage represents only one input used in agricultural production, an alternative variable, index of total inputs used for agricultural production in Texas and Oklahoma [Durost and Black], is substituted in model 4. Estimation of this model results in more unexpected signs (27%), but with the same improvement in estimated τ's (33% with unexpected signs).

The justification for lagged output as a proxy variable for technology is perhaps the most tenuous variable in the specified model. Substituting time as the technology proxy (model 5) results in the same proportion of unexpected parameter signs as in the initial model (24%) but with minor reduction in unexpected τ's (47%).

Re-defining any one of these three variables results in improvement in the proportion of expected τ signs (with the alternative risk and input variables providing much improvement). There is no improvement in the shift variables. Overall, the proportion of unexpected parameter signs changes little.

Sensitivity to Deletion of Risk and Shift Variables

The final sensitivity analysis focuses on removing alternative combinations of the risk and shift variables. With each of these seven models (models 6-12), the percent of unexpected τ estimates is lower than in the initial model, ranging from 20 to 40%. However, unexpected shift variable parameters are greater in all cases (11 to 38%), and the percent of all parameters with unexpected signs varies in both directions (19 to 35%).

Evaluation of Sensitivity Analysis

The initial model gives the largest percent of unexpected τ signs. Reducing model scope, re-defining variables, and deleting combinations of selected variables improves those results, but does not always increase the proportion of expected signs on other model parameters.

Reference to Section A of Table 3 identifies 5 estimated τ's (cotton-rice, cotton-sorghum, cotton-wheat, hay-rice, and hay-wheat) that are negative in all 12 model specifications. Two more are almost always negative (positive in only one model); three are generally negative (positive in four or five models); two are generally positive (negative in three or four models); two are almost always positive (negative in only one model); and one is always positive. It is, therefore, concluded that estimated τ signs are generally quite stable to a wide variety of alternative model specifications. These results appear to provide strong evidence that at least the elasticities of transformation between corn and hay, between rice and sorghum, and between sorghum and wheat are positive. However, the large proportion of unexpected parameter signs estimated by each alternative challenges the adequacy of the CET

[6]Three of the estimated parameters of the deleted price variables have t-values ≥ 2.0. Although corn and rice are excluded in this alternative model on the *a priori* grounds that they use relatively few land resources, some of their t-values empirically imply that the supply of the remaining crops is interrelated with their supply in important ways.

TABLE 3. Unexpected Parameter Signs, 12 Alternative Model Specifications

Variable	Model[a]											
	1. Initial	2. No Rice or Corn	3. Redefined Risk Variable	4. Redefined Input Variable	5. Redefined Technology Variable	6. No Risk, WDP,WI	7. No Risk, WDP	8. No Risk, WI	9. No WDP, WI	10. No Risk	11. No WDP	12. No WI
A. CET Price Variables:[b]												
Corn - Cotton		–			X							
Corn - Hay	X[c]	–	X	X	X	X	X	X	X	X	X	X
Corn - Rice	X	–	X			X	X	X			X	X
Corn - Sorghum	X	–		X	X						X	
Corn - Wheat	X	–	X			X	X	X		X	X	X
Cotton - Hay	X			X			X			X		
Cotton - Rice		–										
Cotton - Sorghum												
Cotton - Wheat												
Hay - Rice												
Hay - Sorghum	X	X		X	X						X	
Hay - Wheat												
Rice - Sorghum	X	–	X	X	X	X	X	X	X	X		X
Rice - Wheat		–			X							
Sorghum - Wheat	X	X	X		X	X	X	X	X	X	X	X
Percent Unexpected Price Parameters	53	33	33	33	47	33	40	33	20	33	40	33
B. Shift Variables:												
Input:												
Corn		–	X	X								
Cotton												
Hay			X	X		X	X	X		X	X	
Rice		–				X		X	X			X
Sorghum			X	X		X	X	X		X		
Wheat				X								
Technology:												
Corn		–			X							
Cotton	X	X	X	X	X				X	X	X	X
Hay												
Rice		–										
Sorghum												
Wheat												

Weighted Diversion Payment:												
Corn		–				–	–	X	–	X	–	X
Cotton						–	–		–		–	
Sorghum						–	–	X	–		–	
Wheat						–	–	X	–		–	X
Weather Index:												
Corn		–				–		–	–			–
Cotton						–		–	–			–
Hay						–		–	–			–
Rice		–				–		–	–			–
Sorghum						–		–	–			–
Wheat						–		–	–			–
Percent Unexpected Shift Parameters	5	7	18	23	9	25	11	38	17	18	11	25
C. Percent Unexpected Parameters, All	24	14	24	27	24	30	24	35	19	24	24	29

[a]WDP is weighted diversion payment; WI is weather index.

[b]The first CET price variable parameter measures the response in corn supply to a change in cotton price.

[c]Notation: X is unexpected parameter; – is a parameter not estimated.

model and/or the data series and consequently the reliability of this empirical conclusion.[7]

Evaluation of Profit Maximization Hypothesis

Estimated risk coefficients with t-values $\geq$ 2.0 are identified in Table 4 for each of the eight models containing risk variables. In six of the models, at least 2/3 of the coefficients are in this category. In none do fewer than 3/8 of the coefficients have t-values $\geq$ 2.0, thus challenging the hypothesis of profit-maximizing behavior, an underlying premise of the CET supply model. From all but one model, the evidence supporting risk averse behavior is substantially greater than that supporting the notion of risk preference.

Elasticities of Supply

For illustrative purposes, two preliminary sets of supply elasticities are reported in Table 5. The range is based on the initial model and model 9 estimates. The latter model is the one with the lowest percent of unexpected price parameter estimates. Among the six-commodity models, it also has the fewest unexpected parameters on all variables combined. It has two shift variables deleted from its structure, weighted diversion payments and weather.

Corn is the only crop with a negative derived direct elasticity estimate. Although a fifth of the elasticities reverse signs between the two models; 4/10 of the elasticities vary by less than a magnitude of 0.1. Another 3/10 differ by no more than 0.2 from each other. None vary by a magnitude greater than 0.8.

The rank order of direct elasticities is generally as expected on theoretical grounds. Higher elasticities are expected for those commodities that use the fewest resources and have the closest production alternatives. From Table 6 it can be observed that if the crops are divided into two subgroups (A: hay, corn, rice; B: sorghum, cotton, wheat), the elasticity and acreage rank orders are totally consistent within subgroups. On the basis of size of the major resource (i.e., acreage), we would expect most crops in subgroup B to have lower elasticities than those in A. Such is not the case. However, each of the crops in B have more and closer production alternatives than two of the crops in A. Consequently, except for corn, the relative magnitudes of the direct elasticities appear plausible when examined with respect to these two variables.

They are also plausible when compared with prior empirical work. Askari and Cummings report direct elasticity estimates from a large number of commodity supply studies conducted throughout the world. Prior work is reported by them for all commodities included in this study except hay. Our direct elasticity estimates all fall within the range of prior estimates for the particular crop. In addition, our hay estimates are very similar to the elasticity for hay computed from Whittaker's estimated CET model of the Southwest. Thus, although estimation approach and geography vary, the elasticities derived here are all within the limits of prior empirical estimates for the same crops.

Conclusions

With a large number of alternative model specifications examined in the sensitivity analysis, the percent of unexpected parameter signs ranges from 14 to 35%. The percent of unexpected τ's differs more, from 20 to 53%, (the former with model 9 and the latter with the initial model). Unexpected shift variable parameters range from 5 to 38%.

Based on consistency in sign estimation, it may be tentatively concluded that 1/5 of the elasticities of transformation are in fact positive. This leads to the conclusion that in the absence of aggregate input supply response, their cross-product supply elasticities are also positive. The direct supply elasticities de-

[7]Although not carried that far in this study, a positive elasticity of transformation implies some product specialization, which in turn is a testable hypothesis.

TABLE 4. Risk Variable Coefficients with t-values ⩾ 2.0, 8 Alternative Model Specifications

Risk Variable	Model[a]							
	1. Initial	2. No Rice or Corn	3. Redefined Risk Variable	4. Redefined Input Variable	5. Redefined Technology Variable	9. No WDP, WI	11. No WDP	12. No WI
Unobservable:								
Corn	–[b]	/	/	–	–		–	
Cotton	–	–	/	–	–	–	–	–
Hay	–	–	/	–		–	–	–
Rice		/	/	–	–	–	–	–
Sorghum	–	–	/	–		–	–	–
Wheat			/	+	+	–		–
Observable:								
Corn	–	/		–	+	+	–	+
Cotton	+		+		+		+	
Hay	–		+	+	–	+	+	+
Rice		/						
Sorghum	+					–		–
Wheat	+		+	+	–			
Percent summary:								
t < 2.0	25	62	50	25	33	33	33	33
t ⩾ 2.0								
Negative	50	38	0	50	42	50	50	50
Positive	25	0	50	25	25	17	17	17

[a]WDP is weighted diversion payment; WI is weather index. Models 6, 7, 8, and 10 are not reported because risk variables were not included.

[b]Notation: – is a negative parameter and + is a positive parameter, each with a t-value ⩾ 2.0; / is a parameter not estimated.

TABLE 5. Range in Short-Run Supply Elasticities Estimated by the Initial Model and the Model with the Smallest Percent of Unexpected Parameter Estimates

	Elasticity with Respect to the Price of [a]					
Commodity	Corn	Cotton	Hay	Rice	Sorghum	Wheat
Corn	−.10 to .15	−.85 to −.30	.34 to .95	0 to .05	−.45 to .26	−.10 to .05
Cotton	−.10 to −.04	.52 to .66	−.03 to 0	−.03 to 0	−.38 to −.20	−.22 to −.19
Hay	.29 to .81	−.19 to .03	.02 to .03	−.27 to −.16	−.25 to .20	−.28 to −.23
Rice	0 to .03	−.16 to 0	−.21 to −.12	.18 to .34	.02 to .37	−.27 to −.17
Sorghum	−.10 to .06	−.72 to −.38	−.07 to .05	.01 to .13	.17 to .58	.09 to .19
Wheat	−.05 to .03	−1.03 to −.86	−.18 to −.15	−.22 to −.14	.22 to .45	.84 to 1.10

[a]Even if diversion payment is treated as the price of another product, i.e., no production, the derived direct elasticities of supply change little: corn −.10 to .19, cotton .56 to .66, sorghum .19 to .58, and wheat .84 to 1.12. Direct elasticities for hay and rice are unaffected.

TABLE 6. Commodity Rankings[a]

Crop	Direct Elasticity	Acreage	Closeness of Production Alternatives
Corn	1	5	5
Cotton	5	3	3
Hay	1	2	2
Rice	3	6	1
Sorghum	4	1	5
Wheat	6	4	3

[a]The first and third rankings are in ascending order; the second is in descending order.

rived from the initial model are all positive. All but one derived from the model with the fewest unexpected parameter signs are also positive. Although generally smaller in absolute magnitude than the direct elasticities, the magnitudes of estimated cross-elasticities are often substantial, suggesting that alternative product prices play an important role in determining supply response.

The symmetry test does not compel rejection of the symmetry condition of the CET linear supply model as a valid specification of Texas field crop supply response. However, the large number of unexpected parameter signs are indicative of problems with the model and/or the data series. The estimated risk coefficients also challenge the hypothesis that producers act like profit maximizers, which in turn challenges the assumption that the CET linear supply model is appropriate for explaining supply response of Texas field crops.

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