Dairy Supply and Factor Demand Response to Output Price Risk: An Econometric Assessment

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The model of production decision making for the expected utility maximizing firm under output price uncertainty is applied to a panel Pennsylvania dairy operators. The model generalized duality implemented in this paper has the advantage of generating a system of supply and variable factor demand functions that consistently account for the presence of output price risk. The application to Pennsylvania dairy operators indicates that output price risk measured by the second and third moments of individûal operators' historical output price series is not an important factor in production decision making. In addition to not maximizing expected utility, these operators are not expected profit maximizers.

The U.S. dairy industry has been regulated by price supports and marketing orders since the 1940's. The involvement of government in the marketing and pricing of milk spurred considerable research on the supply and demand characteristics of the markets for milk. On the supply side, most aggregate supply response and policy analyses have failed to account for the possible output supply and input demand responses to risk.

This article focuses on an econometric investigation into dairy farmers' risk attitudes in the presence of output price uncertainty. It is assumed that the variability in output resulting from random environmental effects (e.g., weather, pests) or random quality levels of purchased inputs is insignificant. Although the variability in milk prices has not been great in the past, attention to dairy farmers' risk response is considered interesting for two reasons. First, the federal dairy program has undergone several significant changes in its fifty-year history (LaFrance and DeGorter). Elimination of the dairy price support programs has been advocated for the last decade. Empirical studies indicate that there is a short-run cobweb type of variation in milk price and this variability would be increased in the absence of price supports (LaFrance and DeGorter, Hallberg). In such an era of strict government controls and strong government influence, uncertainty in output price driven by the uncertainty of government programs being continued at the same levels (e.g., changes in price support levels, deregulation of milk markets) still justifies a maintained hypothesis that dairy farmers in the 1980's face output price uncertainty. Second, milk has no forward market. Since dairy farmers cannot transfer price risk to the futures market the impact of output price risk may be significant.

The theoretical literature on firm behavior under output price risk has focused on the implications of expected utility maximization for the risk averse competitive firm. Much of this effort was initiated by Baron, Sandmo, and Batra and Ullah. The primary results are: (a) the presence of risk aversion biases the certainty results regarding the factor demands and output supply derived from the *ex ante* profit function (Pope, 1978), (b) the reciprocity conditions of symmetry and monotonicity do not generally hold (Pope, 1980), and (c) homogeneity does not hold (Pope and Kramer). More recently, attention has focused on developing the necessary and sufficient conditions to restrict the expected utility maximizing risk averse firm to satisfy reciprocity and homogeneity (Chavas and Pope; Paris).

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Econometric models incorporating risk response can follow three approaches: primal, dual, and differential. The primal approach has the advantage of explicitly estimating risk aversion coefficients. Recent examples are Antonovitz and Roe and Antle. Such models are complex for even simple technology specifications and must be aware of the simultaneity of production and risk preference coefficients.

While the dual approach has been exploited to develop some comparative static propositions, the primary barrier to econometric estimation is the demanding data requirements. The dual functions depend on all of the moments of the output-price distribution. Hence, a considerable time-series, cross-sectional data set is required. Applied studies have focused only on supply response and have approximated the presence of output price risk by focusing on only the first two moments. Incorporation of the risk variables in econometric models involves measuring subjective price and risk expectations. Since risk is usually defined as some function of the deviation from an expected output price in Nerlovian-type adaptive expectations models, the functional form of the deviation is of major concern. Behrman's study of the crop-supply response in Thailand specifies risk as a fixed-length moving average of the squared deviation of output price with arbitrarily chosen weighing parameters on the risk structure. To present a more general method of evaluating farmers' response to output price risk, Just constrained the subjective weighing parameters of the risk variable to follow a geometric distribution which is estimated by a two-dimensional maximum likelihood search procedure. Traill develops an alternative iterative estimation procedure that improves upon previous work in its ease of application and its flexibility in specifying a precise functional form of the risk variables.

The differential specification has its foundation in the production theory analog to the Rotterdam model originally proposed by Theil and entails estimating a Slutsky-type condition involving compensated and uncompensated components of the input-output ratio. While this approach has been advocated by Chavas and Pope and Paris, it has not been econometrically implemented to date.

The goal of this paper is to econometrically test if expected utility maximizing firms are risk neutral or not using the dual model of production decision making under output price uncertainty. This model is briefly reviewed and the econometric implementation is presented. The model is then applied to a group of Pennsylvania dairy farm operators and the presence of risk neutral versus risk nonneutral behavior is assessed via statistical hypothesis testing. Dairying in Pennsylvania is typical of production patterns in the Northeast. The region as a whole consistently supplies over 20% of the U.S. production and Pennsylvania consistently supplies approximately 35% of the Northeast regional production (USDA).

Model of Firm Decision Making Under Output Price Uncertainty

Pope (1980) offers a theoretical presentation of a generalized duality approach allowing for the presence of output price uncertainty within an expected utility maximization framework. A brief review of this model follows. Consider the single output firm that must make production decisions prior to the realization of the stochastic output price, p. The output price is radomly distributed with additive error, e,

$$p = \bar{p} + e \quad \text{and} \quad E\{p\} = \bar{p},$$

where E is the expectation operator. Firm variable profits are defined as

$$\pi = pq - r'x \quad \text{such that} \quad q = f(x, z),$$

where q is output, r is a m-dimensional vector of prices associated with the vector of inputs x, f(x, z) is a well-behaved production function and z is a n-dimensional vector of fixed factors of production. The utility of profit is denoted $U(\pi)$ and has the properties

$$\partial U/\partial \pi > 0 \text{ and } \partial^2 U/\partial \pi^2 \lesseqqgtr 0$$

as the firm is risk averse / neutral / prone.

The operator's objective is to maximize the expected utility of profit, $E\{U(\pi)\}$. The well-known first order maximization condition is (see Sandmo)

$$E\{(\partial U/\partial \pi)[\bar{p}(\partial f/\partial x_i) - r_i]\} = 0$$

or

$$(1) \quad (\partial f/\partial x_i)(\bar{p} + \sigma) - r_i = 0 \quad \text{for } i = 1, \ldots, m$$

where $\sigma = \text{cov}[(\partial U/\partial \pi), p]/E\{(\partial U/\partial \pi)\}$ is the covariance term associated with the marginal risk premium.

Using the indirect expected utility function, Pope (1980) demonstrates that the optimal input demand and output supply functions (x^* and q^*, respectively) can be solved using the first order conditions in (1). Thus, x^* and q^* are functions of all arguments taken parametrically; namely, input prices, the parameters of the output price distribution and the fixed factors of production. The output price distribution parameters can be represented by all of the moments relevant to the decision maker. The expected utility maximization analog to Hotelling's Lemma yields

$$(2) \quad \partial E\{U^*(\pi)\}/\partial \bar{p} = E\{(\partial U^*/\partial \pi)\}q^*(r, \bar{p}, t, z)$$

$$(3) \quad \partial E\{U^*(\pi)\}/\partial r_i = -E\{(\partial U^*/\partial \pi)\}\, x_i^*(r, \bar{p}, t, z) \qquad i = 1, \ldots, m$$

where t is a τ-dimensional vector of moments of the second order and higher. The challenge in implementing this approach is developing reliable data points of the higher order moments for a given operator.

Specification

Since a system of supply and variable factors demand functions are jointly estimated, both the supply and input responses to output price risk can be evaluated. The econometric specification of the *ex ante* variable profit function for the expected utility maximizing firm is

$$\pi^* = pq^*(r, \bar{p}, t, z) - r'x^*(r, \bar{p}, t, z),$$

and is specified as

$$(4) \quad \ln\pi = \alpha_o + \kappa \ln\bar{p} + .5\, \xi(\ln\bar{p})^2 + \sum_i^m \alpha_i \ln r_i + \sum_i^m \lambda_i \ln r_i \ln\bar{p} + .5 \sum_i^m \sum_j^m \alpha_{ij} \ln r_i \ln r_j + \sum_k^n \mu_k \ln z_k \ln\bar{p} + \sum_i^m \sum_s^\tau \delta_{is} \ln r_i \ln t_s + \sum_s^\tau \nu_s \ln t_s \ln\bar{p} + \sum_i^m \sum_k^n \gamma_{ik} \ln r_i \ln z_k,$$

where "ln" denotes natural logarithm and $\alpha_{ij} = \alpha_{ji}$.

Homogeneity (of *any* degree) in prices is neither necessary nor sufficient for expected utility maximization. Paris notes that past econometric studies have ignored the result that money illusion can occur. Hence, all prices used in estimation are in nominal terms.

The indirect expected utility function is specified as

$$(5) \quad E\{U^*(\pi^*)\} = \pi^{*^\theta}.$$

This implies that

$$(6) \quad E\{(\partial U^*/\partial \pi^*)\} = \theta E\{U^*\}/\pi^*.$$

The derivative of the expected utility with respect to the *ith* optimal input price is

$$(7) \quad \partial E\{U^*\}/\partial r_i = \theta \psi_i E\{U^*\}/r_i$$

$$\text{where } \psi_i = \alpha_i + \lambda_i \ln\bar{p} + \sum_j^m \alpha_{ij} \ln r_j + \sum_k^n \gamma_{ik} \ln z_k + \sum_s^\tau \delta_{is} \ln t_s.$$

Equating (3) and (7) yields

$$-x_i^* E\{(\partial U^*/\partial \pi)\} = \theta \psi_i E\{U^*\}/r_i$$

and using (6) yields the optimal *ith* input share equation

$$(8) \qquad r_i x_i^*/\pi^* = -\psi_i.$$

Similarly, the optimal output share equation is

$$(9) \qquad \bar{p}q^*/\pi^* = \phi$$

$$\text{where } \phi = \kappa + \xi \ln\bar{p} + \sum_i^m \lambda_i \ln r_i + \sum_k^n \mu_k \ln z_k + \sum_s^\tau \nu_s \ln t_s.$$

Equations (4), (8) and (9) constitute the system to be estimated. Since the *ex ante* profit function is still a linear combination of inputs and output, one of the equations in this system must be dropped to avoid a singular error covariance. The simultaneity of risk preference and production decision is no longer an issue since the risk preference coefficient, θ, vanishes. The presence of risk neutral attitudes implies that only the first moment (the mean output price) enters the input demand and output supply functions; hence, firms may be maximizing expected profit. An econometric test for risk neutrality involves testing the hypotheses that the coefficients associated with t_2 equal zero or t_3 equal zero, or both sets of coefficients are equal to zero.

If the operator is risk neutral, then expected utility maximization is equivalent to expected profit maximization. The expected variable profit function possesses all of the properties of the deterministic variable profit function. In particular, the expected variable profit function is homogenous of degree one in $\bar{p}$ and r. Thus, risk neutrality implies homogeneity but homogeneity does not necessarily imply risk neutrality.

Estimation Results

Observations of 106 Pennsylvania dairy farms are available from 1977 to 1984 from the Pennsylvania Farmers Association survey providing data on the cost and quantity of hired labor, the quantity of family labor, the value of capital, the herd size of milking cows, the quantity of milk sold, and the price of milk sold. The value of capital is segmented into three components: machinery, land, and buildings. Herd size is defined as the average number of milking cows in the herd during the year. The Dairy Herd Improvement Association survey is available for these farms from 1982 through 1984 and provides data on the quantities and cost of feed. The cost of feed is the value of feed produced on the farm as well as purchased off the farm. The variable factors of production are hired labor (x_1), grain and supplements (x_2), quantity of pasture and silage (x_3), and hay (x_4). The fixed factors of production are herd size (z_1), land (z_2), buildings (z_3), machinery (z_4), and family labor (z_5).

The estimation involves the 1984 calendar year. Each operator's set of moments is calculated using the output price information from 1977 through 1983. In the interest of parsimony and ease of interpretation, the first three moments are used. The first moment is $\bar{p}$, the second moment is t_2 and the third moment is t_3. The coefficients of variation for $\bar{p}$, t_2, and t_3 for the sample period are 4%, 8.5% and 13.3%, respectively.

To avoid a singular system error covariance matrix, the output share and variable input shares equations (8) and (9) are jointly estimated using the nonlinear iterative Zellner procedure. All estimated coefficients are presented in Table 1.

Table 1. Coefficient Estimates for Expected Utility Maximizing Model

Coefficient	Estimate	Coefficient	Estimate
α_1	0.0044 (2.71)[a]	γ_{32}	−0.0002 (0.81)
α_2	0.0459 (4.59)	γ_{42}	−0.0001 (0.33)
α_3	0.0077 (2.13)	γ_{13}	0.000005 (0.81)
α_4	0.0205 (3.18)	γ_{23}	−0.0002 (0.45)
α_{11}	−0.0003 (3.14)	γ_{33}	0.0003 (1.31)
α_{12}	−0.0009 (2.57)	γ_{43}	0.0002 (0.43)
α_{13}	−0.0004 (2.17)	γ_{14}	−0.00002 (0.16)
α_{14}	−0.0004 (1.60)	γ_{24}	−0.0001 (0.15)
α_{22}	−0.0163 (7.44)	γ_{34}	−0.0002 (0.62)
α_{23}	−0.0033 (4.23)	γ_{44}	−0.0001 (0.27)
α_{24}	−0.0066 (4.95)	γ_{15}	−0.0007 (2.94)
α_{33}	−0.0019 (3.91)	γ_{25}	0.0007 (0.51)
α_{34}	−0.0014 (2.54)	γ_{35}	0.0005 (1.02)
α_{44}	−0.0083 (7.13)	γ_{45}	0.0008 (0.86)
λ_1	0.0003 (3.48)	κ	−0.0323 (3.72)
λ_2	0.0036 (6.37)		

If any of the higher order moments are present in the output supply or factor demand equations, the operator is not risk neutral. The test for risk neutrality implies that the coefficients associated with the second or third moments, or both, are equal to zero. This suggests three tests must be conducted to assess the operator's attitude toward risk: (a) the coefficients associated with the second moment equal zero, (b) the coefficients associated with the third moment equal zero, and (c) the coefficients associated with both the second and third moments equal zero. If all three tests are not rejected the operator is risk neutral. If at least one of the tests is rejected the operator is not risk neutral. The tests for risk neutrality using the likelihood ratio test (Gallant and Jorgenson) are reported in Table 2 and indicate that all three tests cannot be rejected at the .01 significance level.

Table 1. (Continued)

Coefficient	Estimate	Coefficient	Estimate
λ_3	0.0010 (4.66)	ν_1	0.0005 (0.02)
λ_4	0.0021 (5.90)	ν_2	−0.0024 (0.10)
δ_{11}	0.0034 (0.16)	μ_1	0.0005 (1.31)
δ_{21}	0.0017 (0.01)	μ_2	0.0001 (1.01)
δ_{21}	−0.0428 (0.91)	μ_3	−0.00002 (0.12)
δ_{41}	0.0247 (0.28)	μ_4	−0.00001 (0.27)
δ_{12}	−0.0034 (0.24)	μ_5	−0.0005 (1.42)
δ_{22}	−0.0016 (0.02)	ξ	0.0020 (2.46)
δ_{32}	0.02881 (0.91)		
δ_{42}	−0.0152 (0.26)		
γ_{11}	−0.0003 (1.45)		
γ_{21}	−0.0013 (0.96)		
γ_{31}	0.0001 (0.23)		
γ_{41}	0.0018 (2.01)		
γ_{12}	−0.0008 (0.95)		
γ_{22}	−0.0007 (1.25)		

[a] Absolute asymptotic t-ratio in parentheses.

Since the results suggest that Pennsylvania dairy operators are risk neutral, the next step is to determine if these operators are expected profit maximizers. The expected profit function is estimated for the operators in this study. The results indicate that convexity is violated in all of the 106 cases and the test for the homogeneity of the expected variable profit function in r and $\bar{p}$ is soundly rejected.[1] Using data from the same sources for 1982, Stefanou and Saxena find that Pennsylvania dairy operators are maximizing production rather than variable profits. The violation of convexity and homogeneity for the expected variable profit function along with the findings of Stefanou and Saxena suggests Pennsylvania dairy operators respond only to mean output price but they are *not* expected profit maximizers. However, there are a couple of caveats that should be mentioned. The first concerns the difficulty in measuring input quality. As the variation in the quality of inputs increases, operators may appear to apply inputs at levels inconsistent with profit maximization. The second focuses on the prospect that farmers face binding expenditure constraints in financing their variable production costs. Tauer and Kaiser find that credit-constrained profit maximization can lead to negative supply response for a sample of New York dairy producers.

Concluding Comments

The empirical investigation into the importance of output price risk in dairy farmers' production decisions is presented. An econometric evaluation of expected utility versus expected profit maximization is considered by implementing the model of generalized duality proposed by Pope. While this approach is demanding in terms of the data requirements, it

[1] The local evaluation of convexity is done by checking the sign of each principal minor for each data point. The likelihood ratio statistic for the homogeneity test yields $\chi^2 > 10{,}000$ with 11 degrees of freedom.

Table 2. Tests for Risk Neutrality

Test	χ^2 Statistic[a]	degrees of freedom	Critical χ^2 Statistic[b]
1. H_o: $\delta_{i1} = 0$, $\nu_1 = 0$ for all $i = 1, \ldots, 4$	2.76	5	15.09
2. H_o: $\delta_{i2} = 0$, $\nu_2 = 0$ for all $i = 1, \ldots, 4$	8.38	5	15.09
3. H_o: $\delta_{is} = 0$, $\nu_s = 0$ for all $i = 1, \ldots, 4$; $s = 1, 2$	15.85	10	23.21

[a] The test statistic is based on the likelihood ratio test presented in Gallant and Jorgenson.
[b] Significance level = .01.

has the advantage of generating a system of supply and variable factor demand functions that consistently account for the presence of output price risk. The application to Pennsylvania dairy operators indicates that output price risk measured by the second and third moments of individual operators' historical output price series is not an important factor in production decision making. This result is consistent with studies which find that output price risk has an insignificant impact on production decisions for activities that are strongly regulated by government programs (Just).

The finding of risk neutrality has important implications in the evaluation of alternative government programs and policies directed toward the stabilization of prices. Traditionally, one of the motivating factors leading to government intervention in agriculture has been the stabilization of farm prices and incomes. If farmers are risk averse, the measurement of benefits from price stabilization must account for the benefits that risk reduction generates through market adjustments (Brorsen et al., 1985, 1987). The findings of this study suggests that the additional social benefit from risk reduction is limited for the dairy industry. In evaluating alternative government programs, the price support program which has been previously regarded desirable for its risk reducing aspect may possess no such merits.

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