Economía Agraria y Recursos Naturales, ISSN: 1578-0732, Vol. 2, 2 (2002), pp. 73-91

Scale, productivity growth and risk response under uncertainty

Jana Hranaiova
Anderson Schools of Management, University of New Mexico
Spiro E. Stefanou1
Dept. of Agricultural Economics, Pennsylvania State University

SUMMARY: This study focuses on the analysis of the production behavior and risk preferences in the presence of output price uncertainty. Following a theoretical model based on the assumption of maximization of expected utility of profits, the approach used in this study infers information about risk preferences from the production characteristics of the farm. In addition, the nonparametric method of estimating elasticity of scale and technical change eliminates the need to impose a uniform production or cost functions on individual producers. The approach is applied to a panel of dairy farms, which are evaluated for their elasticity of scale and the total productivity growth components of their operations. Estimates of farmers' risk attitudes represented by individual marginal risk premiums are also related to socio-economic attributes of farmers. Overall, farm size plays an important role in explaining productivity and scale differences and has the most significant negative effect on marginal risk aversion. The magnitude of the impact of additions to the farm's dairy herd increases with scale of operations.

KEY WORDS: Uncertainty, Risk Aversion, Productivity Growth

Escala, crecimiento en la productividad y respuesta al riesgo bajo incertidumbre.

RESUMEN: El objetivo de este trabajo es el análisis del comportamiento de la producción y en las preferencias ante el riesgo en condiciones de incertidumbre en el precio de salida. Siguiendo un modelo teórico basado en la asunción de maximización de utilidad de los beneficios, el enfoque empleado en este trabajo permite obtener información relativa a las preferencias ante el riesgo a partir de las características de la explotación. Además, el método no–paramétrico de estimación de la elasticidad de la escala y del cambio técnico elimina la necesidad de imponer una producción uniforme o funciones de precio sobre productores particulares. Este enfoque se aplica a un panel de explotaciones lecheras, que son evaluadas en función de los componentes relativos a su elasticidad de escala y al incremento total de la productividad de sus operaciones. Las estimaciones en torno a las actitudes de los productores ante el riesgo representadas por primas individuales por riesgos marginales están igualmente relacionadas con a los atributos socioeconómicos de los productores. En conjunto, el tamaño de la explotación es importante para explicar las diferencias en productividad y escala, y produce el efecto negativo más significativo sobre la aversión al riesgo marginal. La magnitud del impacto de nuevas incorporaciones de cabezas de ganado a los rebaños en

---

1 Professor Spiro E. Stefanou. Armsby Building. Pennsylvania St. University
Univ. Park, PA 16802 USA Phone: +1.814.863.8635 Fax: +1.814.865.3746 ttc@psu.edu

Recibido en julio 2002. Aceptado en agosto 2002

explotaciones lecheras aumenta con la escala de las operaciones.

PALABRAS CLAVE: Incertidumbre, Aversión al Riesgo, Incremento de la Producción
CÓDIGOS JEL: Q14

1. Introduction

Numerous applied and theoretical studies address the role of variability from both physical and market forces on agricultural production. One of the most common approaches to addressing the role of risk in decisions is the notion of the expected utility of profit maximizing operator. This model has its roots in Sandmo (1971) and relates the objective distribution of price and its subjective evaluation by the producer. Although theoretically appealing, methods used in the empirical analysis suffer from various shortcomings. The subjective influence of the presence of risk aversion on producer decision making may be the basis of variation in performance among firms employing a similar technology.

Based on Sandmo's model, Chambers (1983) derives the elasticity of scale and rate of technical change for a risk averse, competitive firm and finds generally no measures of scale elasticity or rate of technical change which can be derived from price and quantity observations unless information on either the production structure or the utility function is known. Flacco and Larson (1992) revisit the problem posed by Chambers and find elasticity of scale and rate of technical change measures that are observable from price and quantity data provided a measure of marginal cost can be developed nonparametrically. The result is not inconsistent with Chambers in that knowledge of the marginal costs implies knowledge of the structure of the production.

This study focuses on the analysis of the production behavior and risk preferences of a sample of dairy producers to output price uncertainty. The elasticity of scale, technical change, and total productivity growth for years 1987-92 for a panel data set are computed and risk preference estimates are related to farmers' attributes. A nonparametric approach to analyzing producer behavior and risk attitudes under output price uncertainty presented in Flacco and Larson (1992) is employed. The manipulation of the expected utility model developed in Flacco and Larson requires no knowledge of a producer's utility function in estimating risk attitudes. Sandmo's (1971) model finds that the risk averse firm selects output such that the marginal cost equals the expected output price plus the marginal risk premium. By generating firm-specific estimates of marginal costs, estimates of the marginal risk premium, elasticity of scale, and technical change under uncertainty can be calculated without explicit specification of a production function. The method eliminates problems resulting from the direct contact of the interviewer with producers and from the lack of producers' precise knowledge of their own risk preferences.

Specific characteristics of milk production and marketing can lead the dairy industry to be especially susceptible to price uncertainty and market imperfections. Perishability of milk and its inability to be stored in the raw form makes milk producers vulnerable to swings in prices as well as regional monopolistic practices of processors. The government through federal marketing order and price support programs establishes fair marketing practices, reduces price uncertainty in the dairy sector, and thus stabilizes farmers' incomes. Consequently, milk price is not free of variability. Ford, Musser and Yonkers (1993) suggest milk price risk has increased in the last decades. In addition, substantial increases in efficiency, excessive surpluses in the last decades, recent approval of the use of bovine somatotropin hormone, and the commitment of the U.S. towards freer trade under World

Trade Organization participation and North American Free Trade Agreement all place pressure on government policies to change and add to the uncertainty in dairy prices.

This study empirically tests the hypothesis that uncertainty has an output reducing impact on farms using a panel data set of dairy farms. We also investigate the magnitude of the impact on small- and large-scale farms as well as the effect of socio-economic economic factors on the degree of the output response to uncertainty.

A review of the theoretical model is presented developing the measures of the elasticity of scale, productivity growth and their nonparametric estimation. The panel data are then described and an application to dairy operators presents the empirical estimation of these concepts. With the deviation between expected output price and marginal cost being the marginal risk premium, the next section relates the estimates of the marginal risk premium to firm financial and socio-economic characteristics. The final section offers concluding comments.

2. The theoretical model

This section reviews the model developed in Sandmo (1971) and Chambers (1983) for the elasticity of scale and rate of technical change for a risk averse competitive firm. The measures in general require information on either the production structure or the utility function. We then present the measures of elasticity of scale and rate of technical change observable from price and quantity data that were developed in Flacco and Larson (1992). These are non-parametric measures that do not require specific knowledge of the production or the utility function.

The firm is assumed to be competitive in both output and resource markets and facing a fluctuating output price. The firm decides its optimal output given its production function before the output price is known. The variability of output price is perceived by the producer to be a subjective probability distribution represented by the relationship,

$$p = \overline{p} + e$$

where p = output price, $\overline{p}$ = expected price of output, and e = random variable with a zero mean, $E(e)=0$, and finite variance.

The model assumes producers maximize expected utility of wealth in the presence of price uncertainty. The behavior under uncertainty can be expressed by a Von Neumann-Morgenstern utility function which is assumed to be well-behaved, continuous, twice differentiable, and concave. The utility function is strictly increasing, $U'(W_t) > 0$, and marginal utility strictly decreasing in wealth, $U''(W_t) < 0$, where W_t represents wealth as a sum of profits accumulated in period t, π_t, and initial wealth, W_0.

The firm's objective is to choose output to maximize expected utility of wealth

$$(1) \qquad Max_y E[U(W_t)] = Max_y E[U(p \cdot y - C(w,y,t) - FC + W_0)]$$

where E denotes the expectation operator, p represents output price (a random variable), y denotes output, $C(w, y, t)$ denotes the dual variable cost function (Chambers, 1988) reflecting the presence of exogenous technical change reflected by t, and FC denotes fixed cost.[1] The necessary and sufficient conditions for a maximum are

$$(2) \qquad \frac{\partial E[U(W)]}{\partial y} = E[U'(\cdot)(p - C_y(w,y,t))] = 0$$

(3) $$\frac{\partial^2 E[U(W)]}{\partial y^2} = E\left[U''(\cdot)(p - C_y(w,y,t))^2 - U'(\cdot)C_{yy}(w,y,t)\right] < 0.$$

Under certainty, increasing marginal cost, $C_{yy} > 0$, is necessary for the existence of a competitive equilibrium. However, under uncertainty even a constant marginal cost or the case of decreasing marginal cost followed by constant marginal cost allows an optimal output level to exist (Sandmo 1971).

2.1. *Elasticity of Scale Under Uncertainty*

Using Pratt's definition of the risk aversion premium and following Flacco and Larson, the certainty equivalent problem associated with the firm's objective function is

(4) $$Max_y U(\bar{p} \cdot y - C(w,y,t) - FC + W_0 - \rho(y)),$$

where $\rho(y)$ represents a risk premium as a function of output and is defined as the monetary equivalent a risk averse person is willing to pay to avoid a fair gamble (Pratt, 1964, p. 124). The first order condition for a maximum is

$$U'(W)(\bar{p} - C_y - \rho_y) = 0$$

implying

(5) $$\bar{p} - \rho_y = C_y$$

where ρ_y is the marginal risk premium.

Using $w'x$ for variable cost in the uncertainty model leads the producer to choose the input vector x to maximize expected utility of wealth. Explicitly incorporating the price distribution into the model in (1) and differentiating with respect to x_i yields the first order condition for a maximum

(6) $$E[U'(W)((\bar{p} + e) \cdot F_{x_i} - w_i)] = 0$$

where $F(x, t)$ represents a well-behaved production function; i.e., $F(\bullet)$ is increasing and quasi-concave. Rewriting (6) yields

(7) $$F_{x_i} = \frac{w_i}{\bar{p} + \theta} \qquad where \quad \theta = \frac{E\,[U'(W) \cdot e]}{E\,[U'(W)]}.$$

Given the definition of elasticity of scale under certainty, ε_C, as a percentage change in output given a percentage change in inputs

$$\varepsilon_c = \sum_i F_{x_i} \frac{x_i}{y}$$

and using (7), the measure of elasticity of scale under uncertainty is

(8) $$\varepsilon_U = \sum_i \frac{w_i x_i}{(\bar{p} + \theta) y}.$$

Chambers (1983) notes the empirical estimation of the scale elasticity measure requires specification of the utility or production function. Some knowledge about risk attitudes of farmers is necessary to obtain the marginal risk premiums required to calculate elasticity and technical change under price uncertainty. Only under the assumption of expected profit maximization can the measures be determined solely on the basis of observed output and input quantities and prices.

Flacco and Larson (1992) present the elasticity of scale under uncertainty as the same as its certainty equivalent, *AC/MC*, evaluated at the output consistent with expected utility of profit maximization. Risk averse behavior causes the producer to stop short of the certainty long-run equilibrium, where marginal cost, *MC*, equals average variable cost, *AVC* (Sandmo, 1971). *MC* differs from *AVC* by the magnitude of the marginal risk premium, *MRP*, an additional risk premium the producer requires when output increases.

With the firm being a cost minimizer, the dual version of the expected utility of profits maximization model can be used to show the expressions for elasticity and technical change do not change under uncertainty. Assuming the firm to be a cost minimizer, optimal input vector $x^* = x^*(w,y,t)$. Thus, the indirect production function is $y = F(x^*(w,y,t),\ t)$.[2] Differentiating $F(\bullet)$ with respect to y yields

$$1 = \sum_i F_{x_i} \frac{\partial x_i}{\partial y}.$$

The analysis proceeds under the assumption that economic agents generating the data are cost minimizers and choose inputs optimally, $x^*(w,y,t) = x(w,y,t)$, where $x(\bullet)$ is the observed input vector. Substituting from (7) and rearranging implies

$$\bar{p} + \theta = \sum_i w_i \frac{\partial x_i}{\partial y}$$

leading to

$$\bar{p} + \theta = C_y(w,y,t). \tag{9}$$

Comparing (9) and (5) indicates $\rho_y = -\theta$.

Elasticity of scale is defined as percentage change in output given percentage change in cost. Under certainty, the measure translates into the ratio of average to marginal cost

$$\varepsilon_C = \sum_i F_{x_i} \frac{x_i}{y} = \sum_i \frac{w_i x_i}{MC \cdot y} = \frac{AC}{MC}. \tag{10}$$

Using (9) in (8) demonstrates the conceptual definition does not change under uncertainty

$$\varepsilon_U = \frac{\sum_i w_i x_i}{y C_y} = \frac{C(w,y,t)/y}{C_y} = \frac{AC}{MC}, \tag{11}$$

but the practical distinction is that the AC and MC are generated under the presence of uncertainty. Hence, the output level that AC and MC are conditioned upon is different for the risk averse and risk neutral decision makers. Neither the knowledge of producer's utility function nor explicit specification of the firm's production function is necessary to determine the elasticity of scale under uncertainty if a measure of marginal cost can be obtained. By using the nonparametric approach to estimating marginal cost, explicit specification of the firm's cost function is also avoided.

2.2. *Nonparametric Estimation*

Marginal cost can be obtained directly from observable panel data without having to estimate the firm's cost function. The indirect cost function for firm *j* at time *t*, $C(j,t)$, is a function of input prices, output, and time, where input prices and output are functions of *j* and *t*; namely,

$C(w(j,t), y(j,t), t)$. This assumes that each firm implicitly embodies the same underlying production technology.

Following Flacco and Larson, the cost function is differentiated with respect to *j*, which is tantamount to looking at differences in the costs across firms, holding output and input prices constant. This leads to

$$\text{(12)} \qquad \frac{dC}{dj} = \sum_{i=1}^{n} C_{w_i} \frac{dw_i}{dj} + C_y \frac{dy}{dj}.$$

Since the cost function is the sum of input prices and optimal input use, the change in costs across firms can also be expressed as

$$\text{(13)} \qquad \frac{dC}{dj} = \frac{d\left[\sum_i w_i x_i\right]}{dj} = \sum_i \left(x_i \frac{dw_i}{dj} + w_i \frac{dx_i}{dj} \right).$$

Setting (12) equal to (13) and using Shephard's lemma $C_{w_i} = x_i$, the marginal cost is

$$\text{(14)} \qquad C_y = \frac{\sum_i w_i \frac{dx_i}{dj}}{\frac{dy}{dj}}.$$

This yields

$$\text{(15)} \qquad \varepsilon_U = \frac{AC}{MC} = \frac{C(\cdot)}{y} \cdot \frac{\frac{dy}{dj}}{\sum_i w_i \frac{dx_i}{dj}} = \frac{dy/dj}{y} \cdot \frac{C(\cdot)}{\sum_i w_i \frac{dx_i}{dj} \frac{x_i}{x_i}} = \frac{dy/dj}{y} \cdot \frac{1}{\sum_i \frac{w_i x_i}{C} \frac{dx_i}{dj} \frac{1}{x_i}},$$

which involves measuring percentage changes across firms. This is not unexpected since the strategy for generating the nonparametrically measured marginal cost is by looking at differences in costs across firms.

The elasticity of scale formula is alternatively expressed as

$$\text{(16)} \qquad \varepsilon_U = \frac{\dot{y}}{\sum_{i=1}^{n} s_i \dot{x}_i},$$

where $\dot{y}$ represents the percentage change in output from one firm to another, s_i represents the cost share of input *i*, and $\dot{x}_i$ represents the percentage change in the use of input *i* from one firm to another.

2.3. ***Technical Change Under Uncertainty***

Differentiating the production function with respect to time and dividing through by output yields

$$\text{(17)} \qquad \dot{y} = \frac{\sum_i F_{x_i} x_i}{y} \cdot \dot{x}_i + \frac{F_t}{y},.$$

Defining the rate of technical change, $\dot{T}$, as the percentage shift in the production function for small continuous changes in time and using the first order conditions in (9) leads to technical change being measured as

$$\dot{T} = \frac{F_t}{F(x,t)} = \dot{y} - \sum_i \frac{w_i x_i}{C_y y} \cdot \dot{x}_i \tag{18}$$

This expression for $\dot{T}$ can be alternatively presented as

$$\dot{T} = \dot{y} - \sum_i \frac{w_i x_i}{C} \frac{C}{y} \frac{1}{C_y} \dot{x}_i = \dot{y} - \frac{AC}{MC} \sum_i s_i \dot{x}_i . \tag{19}$$

Since elasticity of scale under both certainty and uncertainty can be expressed as the ratio of average to marginal cost, the rate of technical change under uncertainty differs from the certainty case only in the measure of the elasticity of scale and evaluation of *AC* and *MC* at expected utility maximizing output. Thus, the technical change under certainty [for *y* being a solution to $max_y \; py - C(w, y, t)$] is denoted

$$\dot{T} = \dot{y} - \varepsilon_C \sum_i s_i \dot{x}_i \tag{20}$$

and under uncertainty [for *y* being a solution to (4)]

$$\dot{T} = \dot{y} - \varepsilon_U \sum_i s_i \dot{x}_i . \tag{21}$$

The technical change estimates can be used to calculate total factor productivity growth. Total factor productivity growth, $\dot{T}FP$, is the residual growth in output not accounted for by the growth in input use

$$\dot{T}FP = \dot{y} - \sum_i s_i \dot{x}_i \tag{22}$$

Using (21), (22) can be expressed as a sum of technical change and scale effects

$$\dot{T}FP = \dot{T} - (\varepsilon_U - 1) \sum_i s_i \dot{x}_i . \tag{23}$$

3. Empirical estimation

The definition of ε_U in (16) can be rewritten as

$$\varepsilon_U = \frac{dy/dj}{y} \cdot \frac{1}{\sum_i \frac{w_i x_i}{C} \cdot \frac{dx_i}{dj} \cdot \frac{1}{x_i}} = \frac{\dot{y}}{\sum_i s_i \dot{x}_i} . \tag{24}$$

The empirical approximation of elasticity of scale under uncertainty follows from the Tornqvist approximation

$$\varepsilon_{U,t} = \frac{\ln(y_{t,j})}{\sum_{i=1}^{n} \frac{1}{2} (s_{t,i,j} + s_{t,i,0}) \ln(x_{t,i,j} / x_{t,i,0})} , \tag{25}$$

where $y_{t,0}$, $x_{t,i,0}$, $s_{t,i,0}$ represent output, units of input *i*, and the cost share of input *i* for the reference farm at time period *t*; $y_{t,j}$, $x_{t,i,j}$, $s_{t,i,j}$ represent output, input *i*, and cost share of input *i* for farm *j* at time period *t*. Output *y* is denoted in the pounds of milk sold. Data on physical units of inputs used are not available and expenses on inputs *i, i=1,...,n* are substituted instead, assuming the same price for individual inputs across firms. The assumption is not unreasonable considering all farms under study are located in one state with efficient input markets. The cost share is calculated as the ratio of expense on input *i* and total cost *C.*

The equation (21) for calculating technical change under uncertainty is empirically estimated as

$$\dot{T}_{U,t+1} = \ln(\frac{y_{t+1}}{y_t}) - \varepsilon_U \sum_{i=1}^{n} C_{i,t+1} \ln(\frac{x_{i,t+1}}{x_{i,t}}) \tag{26}$$

where *t + 1* denotes the period following period *t.*

3.1. *Data*

The data used in the study are from a panel of dairy farmers over the period 1986 to 1992 in Pennsylvania, the fourth largest producing state in the U.S. with about 6.8 percent of the nation's milk supply in the last year of the panel (USDA, NASS, 1994). The data set contains dairy farms using the record-keeping system provided by the farm management services division of the Pennsylvania Farm Bureau. The sample for this study involves 25 farms meeting the criteria of focusing on the single output enterprise of milk production with at least 80 percent of farm income from milk production with consistently positive profits.

Table 1 reports descriptive statistics for the dairy farms in the sample. The average herd size is 70 dairy cows in with an average crop acreage of 186 acres and 63 percent of the feed fed grown on the farm. Milk sales generate 87 percent of revenues on the farms. Average yield per cow is 18,737 lbs. Farmers rely less on debt capital with a net worth of 81 percent of total assets. They receive $3,030 per year on average in non-farm capital contribution, which includes off-farm income as well as random lump sum income.

3.2. *Results and Interpretation*

Table 2 presents statistics for elasticities of scale by year and herd size groups. The number of observations, median, minimum, and maximum values for each group are listed. The median is preferred to an outlier sensitive mean since the first two herd size groups contain results for scale elasticity out of the plausible range. The first herd size group does not contain an adequate number of observations and is excluded from the analysis. The results are presented in the table for completeness.

Comparison within herd size groups demonstrates the differences in risk aversion between individual years. It is assumed farms in one herd size group use the same technology. Thus, differences in elasticity of scale are largely an implication of differing risk preferences. A general trend toward capturing scale economies and thus decreasing risk aversion can be traced out between years 1986 and 1989. The trend is reversed for size categories II and V in 1990 and for all categories in 1991. The increase in risk aversion as indicated by elasticity of scale measures may be a lagged result of the 1989 drought. The experience of the drought year increases uncertainty for farmers and increases their risk aversion. The drought has a more immediate effect on farmers in size categories II and V because of the more pronounced effect of the increased production costs and lower revenues of 1989 on these farms. Small size farms, being single output enterprises, have small incomes relative to larger scale operations. A poor weather year is likely to threaten the basic income necessary to cover the family living expenses and directly threatens the family's financial security.

Large scale farms of category V are more likely to be dependent on outside markets and rely more heavily on debt capital. Similarly, a higher market price for inputs combined with a low output price is likely to bring about a larger percentage increase in production costs for these farms. However, the increase in the measures of elasticities of scale may partially be a response to a drop in milk prices in 1991 relative to 1990 and consequently a contraction in revenues.

With the effects of the drought fading, farmers are willing to take more risks and increase output in 1992. The measures for 1992 indicate a movement toward capturing economies of scale, relative to 1991, for all herd size groups. The largest percentage improvement occurs in group II, the group exhibiting the highest variability in elasticity of scale measures within each year. Large scale farms with 100 dairy cows and over exhibit the smallest fluctuations in output over the years. The variability in each year between farms in the large scale category is also the lowest.

Estimates of technical change under uncertainty for different size groups in individual years are presented in table 3. The median technical change is the lowest in year 1988 for groups II, IV, and V and second lowest in group III. The median change in this year moves in the range of -6 percent to -2 percent. The largest negative change of 23 percent occurs on a farm of the group IV in 1989. A rebound from negative and small positive technical changes is realized in 1991. All size categories exhibit positive changes of 7, 11, and 12 percent. The largest changes occur in group IV with 20 percent and group V with 31 percent.

Table 4 presents the total productivity growth and the components of the measure. Means reported in the table indicate a positive total factor productivity growth for all herd size groups in spite of the negative scale effect in the first three groups. The negative effect of scale is the greatest for the farms with 40-60 milk cows, making the average annual productivity growth of this herd size category the smallest of all size categories. The positive technical change clearly dominates in larger scale groups. The productivity growth increases with increasing size as the negative scale effect becomes smaller. The total factor productivity grows at the fastest rate in the size group with 100 cows and over. Technical change accounts for 97 percent of productivity the growth in this group.[3]

4. Relating risk preferences to socio-economic attributes of farmers

Risk preferences of farmers can be characterized by their marginal risk premiums. The magnitude of *MRP* shows how risk averse (risk preferring) individual farmers are since it represents the additional risk premium required by the farmer to increase output by one unit. Average price and marginal cost for each farmer are needed to calculate the marginal risk premium. Rewriting the marginal cost in (14) as

$$C_y = \frac{\sum_i w_i \frac{dx_i}{dj}}{\frac{dy}{dj}} \cdot \frac{x_i}{x_i} \cdot \frac{y}{y} = \frac{\sum_i w_i x_i}{y} \cdot \dot{x}_i \cdot \frac{1}{\dot{y}},$$

leads to the nonparametric formula for *MRP* using (9) to be expressed as

$$MRP = -\theta = \overline{p} - \frac{\sum_i w_i x_i}{y} \dot{x}_i \cdot \frac{1}{\dot{y}_i}. \tag{27}$$

The empirical approximation of (27) is

$$MRP = \overline{p} - \frac{\sum_i C_i}{Y} \cdot \frac{\ln(x_{i,j} / x_{i,0})}{\ln(Y_j / Y_0)}. \tag{28}$$

The marginal risk premium is positive for risk averse, negative for risk preferring, and zero for risk neutral decision makers. However, it is implicitly a function of mean output price and output, which is endogenously determined. The marginal risk premium generated is regressed against socio-economic attributes of farmers as well as the mean output price and lagged output, which serves as an instrument for current output.

Three categories of socio-economic characteristics are assumed to shape producers' risk attitudes. The first category, representing personal characteristics of the farmer, includes age, education, years of farm experience, and experience as farm manager. The second category of variables characterizes the family of the decision maker and is represented by the number of dependents below age 12 and the number of dependents above age 12. The last category includes variables describing the economic and financial status of the farm. The variables are herd size, net worth as a percentage of total assets, and the ratio of off-farm to total income (total income is calculated as the sum of off-farm income and revenues from milk sales). While herd size, net worth, off-farm/total income ratio and the number of dependents are continuous variables, age, education, farm, and managerial experience is each represented by a binary dummy variable. Table 5 presents descriptive statistics for the dependent and independent variables used in the model. The model is specified[4] as follows

$$MRP = \beta_1 + \beta_2 Dage + \beta_3 Deduc + \beta_4 D\exp + \beta_5 Dmngr + \beta_5 DEPa + \beta_6 DEPb + \beta_7 HERD +$$
$$\beta_8 NETWORTH + \beta_9 OFFTOT + \beta_{10} OUTPUT_{-1} + \beta_{11} PRICE.$$

Dage = 1 if age above 40, 0 otherwise;
Deduc = 1 if high school diploma or higher degree has been obtained by the farmer, 0 otherwise;
Dexp = 1 if more than 30 years of experience, 0 otherwise;
Dmngr = 1 if more than 30 years of managerial experience, 0 otherwise;
DEPa = number of dependents less than 12 years old;
DEPb = number of dependents more than 12 years of age;
HERD = number of dairy cows on the farm;
NETWORTH = net worth as percent of total assets;
OFFTOT = ratio of off-farm to total income which is the sum of off-farm income and revenues from milk sales;
$OUTPUT_{-1}$ = milk output lagged one year; and,
PRICE = average milk price.

Data on age, education, farm experience, experience as farm manager, and number of dependents, however, are available only for the year 1993. The model includes observations for every farm for every individual year 1986-92. Although dairy herd size, networth and the ratio of off-farm to total income vary over this period for each farm, identical values are substituted for every year for age, education, farm and managerial experience, and number of dependents.

4.1. *Results*

The model is estimated using ordinary least squares regression and attempts to identify relationships between risk attitudes of farmers represented by marginal risk premiums and eleven explanatory variables. The *F*-test yields the significance level of one percent with an adjusted R^2 = 0.23. Collinearity analysis of the matrix of the eleven independent variables revealed no multicollinearity problems.

Since the model is assessing a tenuous attitude variable and attempting to capture subtle risk response relationships, the significance level for including explanatory variables in the model is relaxed from the 5 to 10 percent type I error standard. Six explanatory variables are significant at the 10 percent level or better (*Dexp, Dmngr, HERD, NETWORTH, DEPa*) and the remaining variables do not satisfy the 25 percent type I error standard. Further, an *F*-test comparing the unrestricted model with the model restricted to variables *Dexp, Dmngr, HERD, NETWORTH, DEPa* conclusively admits use of the restricted model.

Table 6 presents the parameter estimates for the restricted model. The signs of coefficients on *Dmngr* and *HERD* are negative implying farmers with more managerial experience are more confident in their decision making and more inclined to take risks. The larger the herd size, the higher the income is likely to be, and, *ceteris paribus*, the lower the risk aversion. The number of dependents below age 12 affects risk aversion positively while responsibility for small children makes the farmer more marginally risk averse. The number of dependents older than 12 years has a negative effect on marginal risk aversion. However, this negative effect is only marginally significant at 23 percent. A positive sign on farm experience dummy indicates farmers with more experience tend to be more risk averse at the margin than less experienced farmers. Binswanger (1980) suggests a bad past experience has a significant positive impact on experienced farmer's risk aversion levels. In addition, more risk averse operators are associated with the operators who own a greater part of the farm assets.

Table 7 presents the percentage change in the marginal risk premium given a percentage change in the explanatory variables. The results indicate that net worth has the largest percentage effect on the marginal risk premium in all herd size groups but group V. In group V, a one percent increase in herd size decreases the marginal risk premium of the farmer by more than 2 percent. Percentage differences between experienced and less experienced farmers and between experienced managers and farmers with few years of managerial experience move in opposite directions. Marginal risk premiums are on average 0.4 percent higher for producers with many years of farm experience relative to less experienced farmers. Farmers with many years of managerial experience on average require 2.7 percent lower additional risk premium for increasing output by 10 percent. The number of dependents less than 12 years of age has the smallest percentage effect on risk preferences of farmers.

5. Concluding comments

The results of this study demonstrate that output price uncertainty leads the farms in this sample to stay in the range of increasing economies of scale. Scale efficiency of production increases with the increasing size of operations. The elasticity of scale under uncertainty measures indicate large farms come closest to capturing scale economies. However, the differences in scale efficiency levels cannot be conclusively contributed solely to differences in risk aversion. Large scale farms may be facing different sets of constraints (such as credit constraints) or have access to better information. Given the changes in elasticities are partially a response to the drought year, the results of this study suggest that production levels are sensitive to an increase in uncertainty. Unfavorable weather has a positive impact on risk aversion with farmers reducing output following a year of unfavorable weather. The effect is more immediate with small operations and also with large scale farms. The intermediate size operations react to the change in uncertainty with a greater lag. The scale effect is present in terms of magnitude of the impact, with large farms exhibiting the smallest percentage response in output. The scale efficiency level of large operations is relatively robust to changing levels of uncertainty. The small size farmers being hurt more deeply by fluctuations in incomes exhibit the largest increase in risk aversion and their scale efficiency level is affected most by changes in uncertainty. Productivity grows at an average annual rate of 1.6 percent. Although the scale effect is negative, the dominating positive technical change of 8.2 percent per year makes the total factor productivity growth positive.

At the margin, mean output price, output, age, education, and off-farm income as an independent source of income do not appear to have a significant influence on risk aversion. However, given the sample's low variation in education levels and low proportion of off-farm income accounting for income coming into the household (on average, off-farm income constitutes 1.6 percent of total income), the insignificant influence of the education and off-farm income established by this study may not have general applicability. Age is likely to be correlated with experience. The effects of farm experience and experience as manager go in opposite directions. Managerial experience implies higher degree of risk taking while farm experience increases risk aversion at the margin. The size of farm has the most significant negative effect on marginal risk aversion. Since farm size is likely to be highly correlated with income, this relationship suggests marginal risk aversion is decreasing in income. The magnitude of the impact of additions to the farm's dairy herd increases with scale of operations. Effect of dependents on the farmer's risk aversion depends on the age of the dependents. Small children contribute to higher risk aversion while older dependents do not significantly affect risk preferences of the decision maker. Ownership of assets has the largest positive effect on risk aversion at the margin. The magnitude of the effect increases with the size of the farm.

Future directions of this line of research can include addressing effects of uncertainty on diversification versus specialization, effects within multiproduct firms, as well as dynamic implications of uncertainty. Increased capital intensiveness in farms implies increased size and, consequently, a higher degree of specialization. As farms expand by investing into output-specific equipment, the production level of the particular output is increased within the firm. Although the presence of output price uncertainty induces all firms to diversify, results of this study suggest the impact is larger with small farms. Thus, uncertainty can magnify the difference in the rate of diversification between large scale and small farms. Estimating the effect of uncertainty upon diversification would add an interesting new dimension to the present study.

Multiple output firms capture economies not only due to increases in output levels but also due to simultaneously producing multiple products for which public or quasi-public inputs can be shared (Fernandez-Cornejo et al. 1992). In addition to economies of scale, multiproduct firms can benefit from capturing economies of scope. While the empirical analysis of economies of scale and scope under certainty is well represented in literature, few studies have addressed the effect of uncertainty on the measures.

The results of this study support the hypothesis that uncertainty has an output reducing impact on farms. The response to uncertainty should be taken into account when considering new policies at the farm level. The difference in the magnitude of the impact on small and large scale farms should not be ignored.

References

Binswanger, H.P., "Attitudes Towards Risk: Experimental Measurement in Rural India," *American Journal of Agricultural Economics* 62(1980): 395-407.

Chamber, R. G. “Duality, the Output Effect, and Applied Comparative Statics,” *American Journal of Agricultural Economics* 64(1982): 152-56.

Chambers, R.G., "Scale and Productivity Measurement Under Risk." *American Economic Review 73* (1983): 802-5.

Chambers, R.G. *Applied Production Analysis*. Cambridge University Press, 1988.

Fernandez-Cornejo, J., C. Gempesaw, J. Elterich, and S.E. Stefanou, "Dynamic Measures of Scope and Scale Economies and the Dynamic Theory of Cost," *American Journal of Agricultural Economics* 74 (1992): 283-99.

Flacco, P.R. and D.M. Larson, "Nonparametric Measures of Scale and Technical Change for Competitive Firms Under Uncertainty." *American Journal of Agricultural Economics* (1992): 173-6.

Ford, B.P., W.N. Musser, and R.D. Yonkers, "Measuring Historical Risk in Quarterly Milk Prices." *Agricultural and Resource Economics Review* (1993): 20-26.

Luh, Y.-H. and S. E. Stefanou, "Learning-By-Doing and the Sources of Productivity Growth: A Dynamic Model with Application to U.S. Agriculture," *Journal of Productivity Analysis* 4 (1993): 353-70.

Penn State University, *1992 Pennsylvania Dairy Farm Business Analysis.* College of Agricultural Sciences, Cooperative Extension, Extension Circular 414. *Agricultural Economics*, August 1982: 581-4.

Pratt, J.W., “Risk Aversion in the Small and in the Large,” *Econometrica* 32, (1964): 122-36.

Sandmo, A, "On the Theory of the Competitive Firm Under Price Uncertainty." *American Economic Review 61* (1971): 65-73.

Smith, S.F., W.A. Knoblauch, and L.D. Putnam, *Business Summary. New York State. 1992."* Agricultural Economic Research 93-11, Department of Agricultural Economics, Cornell Univ., August 1993.

United States Department of Agriculture, National Agricultural Statistics Service. “Agricultural Statistics, 1994.” United States Government Printing Office, Washington, DC, 1994.

Table 1

SAMPLE CHARACTERISTICS
Mean Values Over Years 1986-92

Sample	Average
No.of farms	25
No.of Dairy Cows (head)	70
Profits ($)	23,662
Crop acreage (acres)	186
Feed grown as % of feed fed	63
Net worth as % of assets	81
% of income from milk sales	87
Yield per cow (lbs)	18,737
Off-farm as % of total income	2

Table 2
ELASTICITY OF SCALE BY HERD SIZE AND YEAR, 1986-92

HERD SIZE		1-39	40-59	60-79	80-99	100 +
YEAR	STATISTICS	I	II	III	IV	V
1986	N	1	11	5	6	2
	Min	14.39	1.32	1.22	1.02	1.12
	Median	14.39	1.58	1.36	1.28	1.14
	Max	14.39	6.2	1.45	1.52	1.16
1987	N	1	11	4	6	3
	Min	3.13	1.25	1.14	1.10	0.88
	Median	3.13	1.39	1.19	1.23	1.13
	Max	3.13	4.28	1.37	1.48	1.18
1988	N	.	10	6	6	3
	Min	.	1.09	1.08	1.08	1.03
	Median	.	1.29	1.23	1.18	1.07
	Max	.	2.07	1.42	1.38	1.23
1989	N	1	7	7	6	3
	Min	1.31	0.92	1.00	0.95	1.00
	Median	1.31	1.13	1.16	1.08	1.01
	Max	1.31	2.07	1.39	1.24	1.26
1990	N	.	9	7	5	4
	Min	.	1.09	0.96	0.92	0.98
	Median	.	1.23	1.10	1.03	1.03
	Max	.	1.89	1.31	1.05	1.21
1991	N	.	8	7	4	5
	Min	.	1.21	1.07	1.07	1.03
	Median	.	1.51	1.19	1.11	1.09
	Max	.	3.11	1.64	1.18	1.33
1992	N	.	10	6	3	6
	Min	.	0.96	1.03	1.06	1.00
	Median	.	1.26	1.13	1.07	1.05
	Max	.	2.71	1.20	1.08	1.37

Table 3

TECHNICAL CHANGE BY HERD SIZE AND YEAR, 1987-1992

HERD SIZE		1-39	40-59	60-79	80-99	100 +
YEAR	STATISTICS	I	II	III	IV	V
1987	N	1	11	4	6	3
	Min	-0.11	-0.08	-0.1	-0.02	-0.25
	Median	-0.11	-0.01	-0.05	0.01	0.01
	Max	-0.11	0.07	0.06	0.14	0.09
1988	N	.	10	6	6	3
	Min	.	-0.16	-0.05	-0.15	-0.08
	Median	.	-0.05	-0.03	-0.03	-0.06
	Max	.	0.02	0.01	0.10	0.31
1989	N	.	7	7	6	3
	Min	.	-0.08	-0.07	-0.23	-0.04
	Median	.	-0.03	-0.03	-0.03	-0.02
	Max	.	0.10	0.03	0.07	-0.01
1990	N	.	9	7	5	4
	Min	.	-0.05	-0.10	-0.21	-0.04
	Median	.	0.03	-0.06	0.02	-0.01
	Max	.	0.10	0.04	0.07	0.14
1991	N	.	8	7	4	5
	Min	.	0.01	0.01	0.04	-0.04
	Median	.	0.12	0.12	0.07	0.11
	Max	.	0.19	0.17	0.20	0.15
1992	N		10	6	3	6
	Min	.	-0.14	-0.12	-0.04	-0.06
	Median	.	-0.04	-0.02	-0.03	0.03
	Max	.	0.02	0.07	0.03	0.09

Table 4

COMPONENTS OF TOTAL PRODUCTIVITY GROWTH, 1987-1992 BY HERD SIZE

HERD SIZE	40 - 59 head		
	TFP	SCALE	TECH. CHANGE
Min	-0.322	-1.660	-0.157
Mean	0.008	-0.043	0.051
Max	0.318	0.087	0.180
HERD SIZE	60 - 79 head		
	TFP	SCALE	TECH. CHANGE
Min	-0.102	-0.138	-0.115
Mean	0.016	-0.001	0.017
Max	0.263	0.068	0.250
HERD SIZE	80 - 99 head		
	TFP	SCALE	TECH. CHANGE
Min	-0.270	-0.074	-0.266
Mean	0.025	-0.003	0.028
Max	0.618	0.066	0.551
HERD SIZE	100 + head		
	TFP	SCALE	TECH. CHANGE
Min	-0.283	-0.038	-0.251
Mean	0.036	0.001	0.035
Max	0.486	0.060	0.426

Total Productivity Growth (TFP) = Scale + Technical Change holds only for means reported.

Table 5

DESCRIPTIVE STATISTICS FOR DEPENDENT AND INDEPENDENT VARIABLES
25 Farms Over Years 1986-92

Variable	Units	Mean	Minimum	Maximum
MRP		.0295	-.0619	.0970
NETWORTH	%	81	23	100
OFFTOT	%	1.6	0	3.4
HERD	Head	70	38	131
DEPa	No.of dependents	.64	0	8
DEPb	No.of dependents	1.32	0	4
AGE	Years	40-49	< 30	over 60
EDUC	Years	High School	< 12	Advanced Degree
EXP	Years	31-35	16-20	over 50
MNGR	Years	21-25	0-5	46-50

MRP = marginal risk premium; NETWORTH = networth as percent of total assets; OFFTOT = off-farm income as percent of income from milk; HERD = head of milk cows; DEPa = number of dependents less than 11 years old; DEPb = number of dependents between 11 and 15 years old; AGE = age categories; EDUC = years of education or degree earned; EXP = farm experience (year categories); MNGR = experience as farm manager (year categories).

Table 6

PARAMETER ESTIMATES AND OTHER STATISTICS

VARIABLE	PARAMETER ESTIMATE	t-VALUES	PROB > _t _
INTERCEPT	0.01755	1.479	0.14
Dexp	0.01288	3.146	0.002
Dmngr	-0.00910	-1.997	0.05
HERD	-0.00037	-5.491	0.0001
NETWORTH	0.00039	4.016	0.0001
DEPa	0.00400	3.043	0.003
DEPb	-0.00221	-1.215	0.23
N = 175 $R^2 = 0.26$ Adj $R^2 = 0.24$ F-Value = 10.042 Prob>F = 0.001			

Table 7

PERCENTAGE CHANGE IN MARGINAL RISK PREMIUM GIVEN PERCENTAGE CHANGE IN EXPLANATORY VARIABLES BY HERD SIZE GROUPS

HERD SIZE EXPLANATORY VARIABLE	1-39 I	40-59 II	60-79 III	80-99 IV	100 + V
Dexp	0.24	0.32	0.56	0.56	0.72
Dmngr	-0.17	-0.23	-0.39	-0.40	-0.51
HERD	-0.27	-0.44	-1.04	-1.51	-2.34
NETWORTH	0.59	0.87	1.31	1.45	1.57
DEPa	0.06	0.05	0.07	0.00	0.49
DEPb	-0.08	-0.06	-0.13	-0.11	-0.21

a/ Percentage changes are calculated according to the formula $E_x = \frac{\partial y}{\partial x}.\frac{x}{y} = \beta_x.\frac{x}{y}$, where β_x is the coefficient estimate attached to the explanatory variable *x*, *x* is the herd size group average for the explanatory variable, and *Y* is the herd size group average for the dependent variable.

Endnotes

---

1 $C(w, y, t)$ is defined as the dual cost (or value) function associated with the production (or primal) function defined as choosing $C(w,y,t) = min_x w'x$ subject to $y = F(x, t)$.

2 Chambers (1982) defines the indirect production function as

$$V(w,c^*,t) = \max_x F(x,t) \quad \textit{subject to} \quad w'c = c^*$$

where $V(w,c, t)$ is the maximum output that is producible at a predetermined cost level, c^*. This problem is the inverse of the cost minimization problem with states to choose x to minimize total cost, $w'x$, subject to a predetermined production target, $y^o=F(x, t)$. The cost function and its relation to the indirect production function is presented, and consequently, the output effect. An empirical application illustrating the approach to the U.S. meat products industry in presented.

3 These estimates may overstate the contribution of technical change to total factor productivity growth since it represents all effects correlated with time. Luh and Stefanou (1993) find a substantial contribution of learning-by-doing to total factor productivity growth in U.S. agriculture. Efficient learning responses, learning about input quality variations and other forces such as government policy initiatives can contribute significantly to the growth in productivity but are absorbed in the estimate of the technical change component in this study.

4 Since *MRP* is linked to marginal cost via the first order condition in (9), the specification of *MRP* involves an implicit assumption about the functional form of the production technology. Until now, no specific production technology characteristics beyond those involving a well-behaved production technology have been made. A second-order expansion is not superior in estimation to the linear model estimated.