Economies of Scale in the Greenhouse Floriculture Industry

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Introduction

Floriculture is a thriving and important part of production agriculture in the US. However, it is an industry with limited information about cost and input demand relationships. For example, from 1996 to 2001 the number of small and medium size growers declined by 16.0% and 2.0% respectively and the number of large growers increased by 1.0% (USDA, 2002). The trend in the number of small, medium, and large growers suggests that insight obtained from estimating economies of scale for the greenhouse floriculture industry could help to determine if there is a cost advantage, due to firm size. Knowledge of scale economies, as well as price responsiveness for factor inputs, can be used to assist growers in planning better for the future and policymakers in formulating regulations for the floriculture industry.

Prior literature relating to cost relationships for greenhouse ornamentals is vastly inadequate. Industries that have been subject to empirical research of estimating a cost function and the related economies of scale include the meat packing industry, the milling and baking industry, the financial services industry, agricultural banking, agricultural supply and marketing cooperatives, and multiple product agribusiness firms (Antle; Buccola, Fugii, and Xia; Featherstone and Moss; MacDonald and Ollinger; Morrison Paul; and Schroeder). Most research for the floricultural industry has been devoted to calculating a cost per square foot or a cost per pot using partial budget or historical information (Brumfield et al.; Christensen; Hodges, Satterhwaite, and Haydu). Other studies have reported a cost per square foot that varies by firm size and or market channel (Brumfield et al.; Hodges, Satterhwaite, and Haydu). No research was uncovered that explicitly estimated a cost function and/or resulting scale economies for the floriculture industry.

The objective of the current study is to estimate cost relationships for floriculture producers, including the cost function, input demands, price elasticities, and scale economies. The cost analysis is conducted using an original data set obtained from a survey of greenhouse firms conducted in the fall of 2000. In the analysis, we first estimate a standard cost model of the floricultural industry and then re-estimate it with nonprice variables, which are included to capture differences in the cost structure and output product mix among growers. Results are reported and discussed for each model, including firm level economies of scale for selected firm sizes. Finally, performance of the two models is compared using both in and out of sample testing.

Theoretical Cost Model

Using duality theory, cost is modeled as a function of output and input prices under the neoclassical assumption of competitive markets with respect to input prices. A general cost function is specified as

$$C=f(\mathbf{Y},\mathbf{P}) \tag{1}$$

where C is the total cost of a firm, and $\mathbf{Y}$ and $\mathbf{P}$ are vectors of output, and input prices, respectively. The corresponding input demand functions can be derived using Shephard's lemma, where $\mathbf{X}=f(\mathbf{Y},\mathbf{P})$, where $\mathbf{X}$ is a vector of inputs.

In a multi-product firm, there may be several outputs that are separable from each other that can be accounted for accurately. However, since most greenhouse growers produce many types of floriculture but do not maintain or are not willing to provide this type of information, using multiple outputs is not possible. To capture the component of having multiple products, we propose to use a single output and specify the cost model as

$$C=f(\mathbf{Y},\mathbf{P},\mathbf{H}) \tag{2}$$

with the related input demands as **X**=f(**Y**,**P**,**H**), where **H** is a vector of firm characteristics. This specification may be viewed as a cost function that is conditional upon a vector of firm characteristics. The use of nonprice variables in a cost function has been used in prior research where multiple outputs were not measurable and to account for differences in cost structures that are not captured by input prices. MacDonald and Ollinger estimated a translog cost function for hog slaughter plants, one nonprice variable was used to account for product mix, a second nonprice variable was included to account for differences in input mix and a dummy variable was included for single plant firms. Antle estimated the impacts of food safety regulation on productions costs in the meat industry; nonprice variables measuring product mix and management per worker were included in the cost equation.

Empirical Model

A normalized quadratic cost function is chosen as the functional form since it is a second order Taylor series approximation of a monotonic transformation of the true underlying function. Additionally, it is flexible in that the value of it's first and second order derivatives equal those of the underlying (true) function at the point of approximation (Diewert). The normalized quadratic cost function is specified as

(3) $$C = A_0 + \sum_i A_i w_i + \sum_i B_i y_i + (1/2)\left\{\sum_i \sum_j A_{ij} w_i w_j + \sum_i \sum_j B_{ij} y_i y_j\right\} + \sum_i \sum_j d_{ij} w_i y_j ,$$

where C is normalized cost, w_i is normalized input prices, y_i is output and the A's, B's, and d 's are parameters to be estimated. Symmetry conditions are imposed by restricting $A_{ij}=A_{ji}$ and $B_{ij}=B_{ji}$.

To impose curvature (concavity in input prices and convexity in output) the matrix of coefficients of the quadratic terms of input prices and output quantities are reparameterized into semi-definite matrices (Lau). For example, consider three inputs where only 2 input demands are used during estimation. Matrix V is defined in terms of model parameters as defined in equation (3):

(4) $$\mathrm{V} = \begin{bmatrix} A_{11} & A_{12} \\ A_{12} & A_{22} \end{bmatrix}.$$

Then, V is reparameteized using Cholesky decomposition into a negative semi-definite matrix:

(5) $$\mathrm{V} = -\begin{bmatrix} a_{11} & 0 \\ a_{12} & a_{22} \end{bmatrix}\begin{bmatrix} a_{11} & a_{12} \\ 0 & a_{22} \end{bmatrix} \quad .$$

which implies

(6) $$\begin{bmatrix} A_{11} & A_{12} \\ A_{12} & A_{22} \end{bmatrix} = -\begin{bmatrix} a_{11}a_{11} & a_{11}a_{12} \\ a_{11}a_{12} & a_{12}a_{12} + a_{22}a_{22} \end{bmatrix}$$

In the optimization process, the a_{ij}'s are estimated and then substituted back into (6) to recover the A_{ij}'s. Imposing convexity in outputs is identical except the coefficients are reparameterized into a positive semi-definite matrix. Input demands are specified as:

(7) $$x_i = A_i + \sum_j A_{ij} w_{ij} + \sum_j d_{ij} y_j \, .$$

To incorporate nonprice variables into the cost function, equation (3) can be modified in the following manner:

(8) $$C = A_0 + \sum_i A_i w_i + \sum_i B_i y_i + (1/2)\left\{ \sum_i \sum_j A_{ij} w_i w_j + \sum_i \sum_j B_{ij} y_i y_j \right\} + \sum_i \sum_j d_{ij} w_i y_j$$
$$+ \sum_k s_k h_k + \sum_k \sum_l f_{kl} h_k h_l + \sum_i \sum_l g_{il} w_i h_l + \sum_i \sum_l y_{il} y_i h_l$$

where h's are firm characteristics, the s's, f's, g's, and y's are parameters to be estimated, and all remaining variables are defined identical to equation (3). The input demands that result from equation (8) are specified by

(9) $$x_i = A_i + \sum_j A_{ij} w_{ij} + \sum_j d_{ij} y_j + \sum_l g_{il} h_l \, .$$

Equations (3) and (7) constitute a complete system of cost and demand equations, while equations (8) and (9) make up a complete system augmented with nonprice variables.

Elasticities

Cost elasticities can be calculated from parameters estimated in the models specified above. The elasticity of cost with respect to output, y (assuming only one output) results in the measure of scale economies:

$$(9) \qquad e_{Cy} = \left[B_1 + B_{11} y + \sum_i d_i w_i + \sum_i y_i h_i \right] [y/C].$$

The term $B_1(y/C)$ is the direct effect of output on the cost elasticity for growers at the mean of the data. The second term $B_{11} y (y/C)$ measures how the elasticity varies as sales (output) increases or decreases from the sales sample mean. The term $d_i w_i (y/C)$ measures the change in elasticity as input prices change. The last term $y_i h_i (y/C)$ measures the change in elasticity due to changes in grower characteristics.

Similarly, the elasticity of cost with respect to grower characteristics can be calculated as:

$$(10) \qquad e_{Ch_k} = \left[s_k + \sum_l f_{kl} h_l + \sum_i g_{ik} w_i + y_k y \right] (h_k/C).$$

The term $s_k (h_k/C)$ is a direct effect of the grower characteristic, h_k on costs at the sample means for all variables. The term $f_{kl} h_l (h_k/C)$ measures the combined effects of the grower characteristics, h_l and h_k on costs. The term $g_{ik} w_i (h_k/C)$ measures the combined effect of input prices and grower characteristic, h_k on costs. The last term $y_k y (h_k/C)$ measures impact of the interaction of output and the grower characteristic, h_k on costs.

Input elasticities can be calculated from parameter estimates of the model. The elasticity of inputs with respect to price can be calculated using the following equation:

(11) $$e_{x_i w_j} = A_{ij} \left[{w_j}/{x_i} \right].$$

Similarly, the elasticity of inputs with respect to nonprice variables are given by

(12) $$e_{x_i h_l} = g_{il} \left[{h_l}/{x_i} \right].$$

Elasticity estimates are calculated at mean values of the independent and dependent variables.

Price and Nonprice Inputs

Three input prices that are considered for the current study include labor (x_1); materials (x_2), which includes variable production costs such as plants, seeds, fertilizer, and chemicals; and energy (x_3). The prices for labor, materials, and energy are denoted by w_1, w_2, and w_3, respectively.

Similar to prior studies (Antle; MacDonald and Ollinger), to account for differences in cost structure not captured by input prices, we add nonprice variables to the cost function defined by (3) and (7). Augmenting the cost function as in (8) and (9), we add a vector of characteristics, **H,** that serves as a proxy to account for differences in product mix and cost structure. Further explanation of the variables included in the **H** vector follows. See table 1 for a summary of the nonprice variables along with their definition.

The first nonprice variable, sales per square feet (h_1) captures differences in product mix, which varies by firm. The second nonprice variable, h_2, is a dummy variable representing the region the firm is located. The dummy variable is a proxy to account for different product mix due to the location of the firm. In the floriculture industry, certain crops may be produced in specific regions due to more favorable environmental conditions, in particular weather. For example, the majority of ivy geranium production is located in the Midwest and northeast, since too warm of a climate is not conducive to growing ivy geraniums. Similarly, orchid production is predominantly located in Florida and California since climatic conditions in these states are more favorable for growing orchids than northern states.

To capture cost differences due to technology, the variable selected is the percentage of production area that is hand watered (h_3). The percentage of production area that is hand watered is an inverse measure of the whether a grower uses the latest technology in production. A producer who hand waters a large percentage of its crops has not adopted some of the latest technology available in automated watering systems. Furthermore, a grower who hand waters a large percentage of production area has a different cost configuration than a grower who predominantly uses an automated watering system.

An additional variable (h_4) measures the percentage of sales that are wholesale (vs. retail) and is included to capture differences in costs due to selling in two different markets. The cost structure of a firm selling primarily wholesale may be substantially different than the cost structure of a grower selling primarily retail. Ornamentals that are sold directly to the retail market are typically under production longer; therefore we would expect firms that sell primarily to retail to have a higher cost structure than firms that sell primarily to wholesale outlets.

Four additional nonprice variables are added to the cost model to depict differences in cost composition due to management and cultural and pest management production practices. These variables include the age of management (h_5), a binary variable (h_6) equal to one if the grower fertilizes with each watering, a binary variable (h_7) equal to one if the grower uses scouting, and a binary variable (h_8) equal to one if the growers uses preventive application of chemical pesticides.

Data, Estimation, and Testing

Total sales, total cost, quantity of labor, and square footage data used in this research are obtained from a greenhouse grower survey conducted in the fall of 2000 for the year 1999, which consist of 98 observations. Prices for labor by geographic region are obtained from the National Agricultural Statistics Service (NASS), Agricultural Statistics Board, U.S. Department of Agriculture. Prices for materials (in dollars per sq. ft.) by region and size are obtained from a survey conducted by Greenhouse Product News, a publication dedicated to greenhouse production (Cosgrove). Energy prices (in dollars per sq. ft) by state are obtained from the 1998 USDA Census of Horticultural Specialties. All prices and costs are stated in 1999 dollars. During estimation, cost and prices are normalized on the price of energy. Summary statistics of the variables used in the estimation are presented in table 2.

Imposing symmetry, homogeneity, and curvature two cost models are estimated. Model I does not include any nonprice variables, while model II includes nonprice variables previously described and defined in table 1. Both models are estimated using Iterative Seemingly Unrelated Regression (ITSUR) procedure in SHAZAM. For both models the elasticities for labor and materials are calculated using parameter estimates from the model at mean values for continuous variables, and binary variables h_2, h_6, h_7, and h_8 are set equal to one. The elasticity of energy is recovered by imposing the homogeneity condition. This restriction requires that the own-price elasticity and cross-price elasticities for an input sum to zero. The Hessian terms for energy are recovered from the corresponding elasticity estimates.

Confidence intervals for cost and input elasticities are calculated using a jackknife approach. It has been shown that the jackknife resampling method of calculating confidence intervals is a viable alternative for inference (Judge et al.). A jackknife confidence interval is calculated by eliminating one observation, and estimating the cost model and then using the estimates to calculate the input and output elasticities as specified in equations (9), (10), (11), and (12). This estimation process is completed for all n=98 observations. Confidence intervals (90%) are estimated using the jackknife elasticity estimates using endpoints associated with ordered jackknife estimates numbered 6 and 93.

To compare performance of the models, the out of sample root mean squared error is calculated for each model and formally compared using the Ashley, Granger, Schmalensee (AGS) approach. The AGS test provides a method to test for the statistical significance of the difference between RMSEs of two competing forecasts. This out of sample comparison is chosen since determining effects of changes in cost by changes in dependent variables can be made directly by calculating a predicted cost given a change in output quantity and/or input prices. The predicted cost can be compared to the actual cost to see how changes in one or more dependent variables affect cost. This method of analyzing the effects of changes in quantities or input prices is dependent on the ability of the model to accurately predict out of sample.

In order to calculate RMSEs out of sample, a jackknife approach is used to predict cost out of sample. A jackknife prediction is made by eliminating one observation, estimating the cost model, and then using the eliminated observation and the parameter estimates to obtain an out of sample prediction of cost. This estimation and prediction process is completed for all 98 observations. The out of sample RMSE is calculated as

$$(13) \qquad RMSE = \left\{ \left[\sum_{i=1}^{n-1} \left(c_i^T - c_i^P \right)^2 \right] / \left(n-1 \right) \right\}^{1/2},$$

where c_i^T is the true cost, c_i^P is the predicted cost for out of sample observation i, where i=1 to n.

The AGS test statistic is obtained by regressing the difference between forecast errors on the sum of the forecast errors less the mean of the sum of the forecast errors as specified in the following equation:

(15) $D_t=B_0+B_1(S_t\text{-}Smean)\text{-}e_t$,

where D_t is the difference between forecast errors (the forecast errors associated with the lower-RMSE forecast are subtracted from those of the higher-RMSE forecast), S_t is the sum of the forecast errors; *Smean* is the sample mean of *S* and e_t is a white noise residual. An F-test of the joint hypothesis that B_0=0 and B_1=0 is appropriate when both parameter estimates are positive. However, the significance levels are one-fourth of what is reported in an F-distribution table because the F-test test does not consider the sign of the coefficient estimates.

Results and Model Selection

Results for Models I and II are presented, followed by testing of the models in sample and out of sample. Parameter estimates for model I are presented in table 3. Five out of 10 of the parameter estimates are found to be significantly different from zero at the 10% percent level or lower. The coefficients on the output variable *y*, and the interaction terms of price of labor and price of materials, price of labor and sales, and price of materials and sales are significant at the 1% level. The squared materials term is found to be significant at the 10% level. The R-square for the cost equation is calculated to be 0.8691.

The parameter estimates for model II are presented in table 4. Twenty-two out of 74 parameters are found to be significantly different from zero at the 10% level or lower in model II. As in model I, both the coefficients on the output variable, *y* and the interaction terms of input prices and output are found to be significant at the 1% level. The price of materials and the squared price of materials coefficients are found to be significant at the 1% level. The coefficient on the interaction term of the price of labor and the price of materials is found to be significant at the 5% level.

Sixteen nonprice coefficients are found to be significant at the 10% level or lower. Nonprice variables found to be significant at the 1% level include sales per sq. ft. squared, percentage handwatered squared, the interaction terms of sales per sq. ft. and scouting; fertilizes with each watering and scouting; price of materials and sales per sq. ft.; price of materials and scouting; sales and sales per sq. ft.; sales and fertilizers with each watering; and sales and scouting. In addition, the parameter estimates for the variable percentage handwatered, and the interaction terms of percentage handwatered and preventive application of pesticides; price of labor and sales per sq. ft.; and price of labor and location are found to be significant at the 5% level. The interaction terms of sales per sq. ft. and age; location and percentage handwatered; and location and age are found to be significant at the 10% level. The R-square for the cost equation for model II is calculated to be 0.9208.

Input Elasticities

Input elasticity estimates are computed at mean values for continuous variables, and binary variables h_2, h_6, h_7, and h_8 equal to one and are presented in table 5. Additionally, lower and upper critical values for 90% confidence intervals for all input price elasticities are computed using the jackknife approach. Labor and energy own-price elasticities are negative and inelastic in both models, which demonstrates that the cost function is concave in input prices. The materials own-price elasticity estimate is negative and inelastic in model I and negative and elastic in model II. The cross-price elasticity estimate of labor with respect to the price of materials is positive and inelastic in both models, suggesting that materials are a substitute for labor. The cross-price elasticity estimate of labor with respect to the price of energy is negative and inelastic in both models, implying that energy is a complement of labor. The cross-price elasticity estimates of materials with respect to the price of labor are positive and inelastic in both models, suggesting that labor is a substitute for materials. The cross-price elasticity estimate of materials with respect to the price of energy is positive and inelastic in Model I and positive and elastic in model II, suggesting that materials are a substitute for energy. The cross-price elasticity of energy with respect to the price of labor is negative and inelastic in both models, implying that labor is a complement of energy. In contrast, the cross-price elasticity of energy with respect to the price of materials is positive and inelastic, implying that materials are a substitute for energy. Both models suggest that materials are more elastic than labor or energy with respect to changes in own price or cross-price. Additionally, results from the two models are consistent in that both suggest that labor and materials are substitutes, labor and energy are complements, and materials and energy are substitutes.

The elasticity of inputs with respect to grower characteristics, the h variables, are also estimated for continuous variables and are shown in table 5, with lower and upper critical values. The elasticity estimates for energy with respect to the h variables are not recoverable in model II. All input elasticity estimates indicate that labor and materials are inelastic with respect to grower characteristics.

The elasticity of labor with respect to h_1, h_3, h_4 and h_5, are –0.0882, -0.0195, 0.0649, and 0.1106, respectively for model II. These results suggest that the demand for labor would decrease, given an increase in sales per square feet or an increase in percentage of sales that is wholesale. In contrast, if hand watering increases, the model predicts that the demand for labor would increase. The model also predicts that older growers demand more labor holding all else constant.

The elasticity of materials with respect to h_1, h_3, h_4 and h_5, are –0.7614, 0.2811, -0.0593, and 0.2243, respectively in model II. The model predicts that given an increase in sales per sq. ft., or percentage handwatered the demand for materials would decrease. In contrast, given an increase in the percentage wholesale or age of management, the demand for materials would increase.

Input elasticity estimates are not estimated for the *h* binary variables, however, the coefficient g_{il}, measures the shift of the variable h_{il} on the input demand. The effect of the *h* binary variables on the demand for inputs are calculated and reported in table 6. Model II predicts that if a grower is located in the MW, NE or SO, they demand 2.13 less employees than growers in other regions. If a grower fertilizes with each watering model II predicts that the grower demands 0.32 more employees than a grower who does not fertilize with each watering. If a growers uses scouting, the grower demands 1.21 fewer employees than a grower who does not use scouting. If the grower uses preventive application of chemical pesticides, the grower demands 0.86 more employees than a grower who does not use preventive application of chemical pesticides.

A grower's demand for materials is estimated to be 11,269 square feet less if the grower is located in the MW, NE or SO. Similarly, a growers demand for materials is estimated to be 9,5494 square feet less if the growers fertilizes with each watering. The use of scouting and preventive application of chemical pesticides results in lower demand for materials of 102,925 and 10,500 square feet, respectively.

Cost Elasticities

Cost elasticities are calculated at mean values for continuous variables and binary variables h_2, h_6, h_7, and h_8 equal to one and are presented in table 7. Again, lower and upper critical values for cost elasticities are reported in table 7 beneath the elasticity estimates. Output elasticity is the percentage change in cost, given a one percent increase in output. If output elasticity is less than one, than increasing returns to scale exist. Output elasticity is estimated to be 0.94 and 0.80 for model I and II, respectively. Both models indicate that at the mean values of output, $654.88 thousand sales, increasing returns to scale exist.

The elasticity of cost with respect to grower characteristics is estimated for model II and are presented in table 7 along with jackknife confidence intervals. Cost is estimated to increase by 0.0468 percent, given a one percent increase in sales per square feet. Similarly, cost is estimated to increase by 0.1238 percent, given a one percent change in h_3, percentage of sales from wholesale. In contrast, given a one percent change in h_4, percentage of production area that is hand watered, cost is estimated to decrease by 0.0340 percent. Given a one percentage change in the age of the principal manager, cost is predicted to decrease by 0.3765 percent.

Cost elasticities for the *h* binary variables are not estimated, but their impacts on cost are calculated along with jackknife confidence intervals and are reported in table 8. A grower located in the MW, NE or SO is predicted to have lower total cost by $124,073. Models II predicts that a grower who fertilizes with each watering has a higher cost by $111,989. A grower who uses scouting is predicted to have lower costs by $254,836. Model II predicts that a grower who uses preventive application of chemical pesticides has a higher cost by $37,462.

In addition to calculating output elasticities at mean values, output elasticities were calculated for each observation for each model using parameters in tables 3 and 4 and then averaged by size. Output elasticities by model for 3 sizes are reported in table 9. The average sales by size for small, medium, and large growers are $220.41, $687.15, and $1,625.62 thousands of dollars, respectively. The output elasticities for model I are 0.78, 0.94, and 0.97 for small, medium, and large growers, respectively, suggesting that economies of scale exist at all grower size categories. The output elasticities for model II are 0.81, 1.80, and 0.95 for small, medium and large growers, respectively. The output elasticity estimates by category are consistent across models for small and large growers, but not for medium growers.

Model Testing

To formally test the performance of models in sample, the likelihood ratio test is used. The likelihood ratio test statistic is used to test the null hypothesis that all of the coefficients on the nonprice variables are jointly equal to zero. The likelihood test statistic is calculated to be 145.26 with a chi-square critical value of 83.66 at the 5% significance level. Since the likelihood test statistic is larger than the critical value, the null hypothesis is rejected. In sample, using the likelihood ratio test, Model I is determined to be the preferred model.

To formally compare the models out of sample, RMSEs are calculated using equation (13) and reported in table 10. To test the statistical difference between the out of sample RMSEs across models, an AGS test is performed comparing competing models using a 5% significance level. The result of the AGS test is reported in table 11. Model I has the lowest out of sample RMSE, and based on the results of the AGS tests, the RMSE in model I is significantly different than the RMSE in model II. Overall model I performs the best out of sample when using the AGS test to compare the competing models. The results from model testing demonstrate a trade-off between in sample and out of sample fit. Nonprice variables add information to the cost model and increase the accuracy of in sample predictions, but when moving to an out of sample environment, model performance decreases with the inclusion of nonprice variables.

Discussion

Based on the results from out of sample testing, model I is the superior model; we limit our discussion of results to Model I only. The results from model I suggest that all inputs are inelastic with respect to own price and cross-price. Additionally, the demand for materials is more elastic than labor or energy with respect to its own price or cross-price. Cross-price elasticities between both labor and materials are inelastic and positive, which suggests that labor and materials are substitutes for one another. Similarly, the cross-price elasticities with respect to materials and energy are positive, suggesting that materials and energy are substitutes. In contrast, the results of model I suggest that labor and energy are complements rather than substitutes.

The output elasticity for model I is 0.94 at mean values and 0.78, 0.94, and 0.97 for small, medium and large growers, respectively. Theses results suggest that scale economies exist for growers with sales at or below $654.88 thousands and they could lower their average cost of production by increasing their size. These findings also suggest that the average cost curve declines over the sample used in this study and optimal firm size is larger than the maximum firm size used in this study.

Conclusion

In this paper, we provide several new contributions. Most importantly, we find economies of sales in the floriculture industry, which is consistent with findings from economy of scale studies of other agricultural products (Buccola, Fujii, and Xia; Morrison Paul). Large greenhouse growers can produce ornamental crops at a cost per square ft. that is 18% lower than growers that are half their size. As horticultural producers become larger and more automated, they have a cost advantage, due to size, than smaller producers who are producing the same output mix. Moreover, we provide measures of price responsiveness of input demands. When analyzing the effects of input prices on cost, changes in energy prices and wages have the largest impact on costs with cost elasticities of 0.6276, and 0.3712, respectively, implying that materials inputs are not highly substitutable for energy or labor. A change in materials price has the smallest impact on cost with a cost elasticity of 0.0012.

While this study is conducted using only one year of cross-sectional data, it does provide cost information that is important to greenhouse producers. Output elasticity is estimated to be 0.80, and 0.94, for small and medium size growers, respectively, which suggests that growers with sales at or below $654.88 thousands would benefit by increasing their size. These results suggest that average grower size may increase in the future thru expansion and or consolidation as growers reap benefits associated with cost efficiencies of larger producers. While this is the first article to provide empirical research in the area of cost relationships in the greenhouse ornamental business, the authors hope the work presented here will encourage additional applied research in this industry.

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Table 1. Definitions of Nonprice Variables

Variable	Definition
h_1	sales per square feet
h_2	a binary variable equal to one if the grower is located in the midwest, northeast, or the south, zero otherwise (other regions include the midatlantic and the west)
h_3	percentage of sales that is wholesale (vs. retail)
h_4	percentage of production area that is hand watered
h_5	age of the principal manager
h_6	a binary variable equal to one if the grower fertilizes with each watering, zero otherwise
h_7	a binary variable equal to one if the grower uses scouting as a method of pest management, zero otherwise
h_8	a binary variable equal to one if the grower uses preventive application of chemical pesticides, zero otherwise

Table 2. Summary Statistics

Variable	Mean	Standard Deviation	Minimum	Maximum
Sales ($000's)	654.88	600.82	25.00	2725.30
Labor (#of employees)	11.06	11.69	1.20	50.50
Materials (000's sq. ft.)	92.53	136.76	3.00	715.00
Labor price ($/employee/yr)	18763	3608	14087	25348
Materials Price ($/sq. ft.)	7.14	1.38	5.10	11.42
Energy Price ($/sq. ft.)	0.93	0.55	0.42	2.12
Cost ($000's)	559.54	466.39	35.00	1500.00
Sales per sq. ft ($)	12.68	11.04	1.08	91.67
Region (MW,NE, SO)	0.82	0.39	0.00	1.00
Percentage wholesale	0.57	0.40	0.00	1.00
Percentage hand-water	0.59	0.34	0.00	1.00
Age of principle manager	48.62	12.15	24.00	75.00
Fertilize with each watering	0.69	0.46	0.00	1.00
Scouting	0.85	0.36	0.00	1.00
Preventive application of pesticides	0.58	0.50	0.00	1.00

Observations=98

Table 3. Parameter Estimates for Model I

Parameter	Estimate		Std. Error	T-Ratio
Constant	67391.00		42829.00	1.5735
Price of labor	-0.8559		0.6053	-1.4139
Price of materials	4.6871		26.9740	0.1738
Sales	652.49	***	48.68	13.4042
Price of labor^2	0.0000		0.0000	-0.9200
Price of labor*price of materials	0.0022	***	0.0006	3.7421
Price on materials^2	-7.4666	*	4.1248	-1.8101
Sales^2	0.0000		0.0000	0.0000
Price of labor*sales	0.0186	***	0.0007	26.83
Price of materials*sales	0.1666	***	0.0172	9.6751

***Indicates significance at 1% level, ** indicates significance at 5% level and * indicates significance at 10% level. Cost Equation r-square=0.8691,Labor Equation r-square=0.8871, SF Equation r-square=0.4506

Table 4. Parameter Estimates for Model II

Parameter	Estimate	Std. Error	T-Ratio
Constant	-1,232,900	1,080,300	-1.1412
Price of labor	0.3340	2.6774	0.1248
Price of materials	204.92***	68.87	2.9754
Sales	1,177.30***	427.57	2.7536
Price of labor^2	0.0000	0.0000	-0.8605
Price on materials ^{2}	-14.0138***	2.9851	-4.6945
Sales^2	0.0000	0.0000	0.0000
Price of labor*price of materials	0.0020**	0.00	2.1072
Price of labor*sales	0.0187***	0.0007	26.2832
Price of materials*sales	0.1685***	0.0161	10.4842
Sales per sq. ft.	25,324.00	27,121.00	0.9337
Location	184,430.00	545,040.00	0.3384
Percentage sales wholesale	9,020.60	7,863.50	1.1471
Percentage handwatered	16,226.00**	6,885.70	2.3564
Age	-1,332.10	23,833.00	-0.0559
Fertilizes with each watering	-46,224.00	425,500.00	-0.1086
Scouting	650,740.00	526,190.00	1.2367
Preventive application of pesticides	422,810.00	468,740.00	0.9020
Sales per sq. ft.^{2}	-1,059.00***	269.24	-3.9335
Sales per sq. ft.*Location	-5,874.60	8,074.40	-0.7276
Sales per sq. ft.* Percentage sales wholesale	-94.30	156.20	-0.6037
Sales per sq. ft.* Percentage handwatered	194.82	205.48	0.9481
Sales per sq. ft.* Age	523.68*	315.27	1.6611
Sales per sq. ft.* Fertilizes with each watering	-10,023.00	9,210.70	-1.0882
Sales per sq. ft.* Scouting	-37,458.00***	10,268.00	-3.6481
Sales per sq. ft.* Preventive application of pesticides	11,092.00	7,688.00	1.4428
Location*Percentage sales wholesale	1,659.60	1,716.90	0.9667
Location*Percentage handwatered	4,581.70*	2,522.30	1.8165
Location*Age	-11,551.00*	6,300.90	-1.8333
Location*Fertilizes with each watering	-113,390.00	160,460.00	-0.7067
Location*Scouting	30,349.00	272,260.00	0.1115
Location*Preventive application of pesticides	162,850.00	138,990.00	1.1716
Percentage sales wholesale^2	-41.2870	30.5140	-1.3531
Percentage sales wholesale*Percentage handwatered	-16.9300	36.6690	-0.4617
Percentage sales wholesale*Age	-4.7733	60.4150	-0.0790
Percentage sales wholesale*Fertilizes with each watering	-341.72	1,906.00	-0.1793
Percentage sales wholesale*Scouting	-2,334.20	2,372.00	-0.9841
Percentage sales wholesale*Preventive application of pesticides	106.40	1,378.10	0.0772
Percentage handwatered^2	-98.05***	34.96	-2.8049
Percentage handwatered*Age	-59.88	74.84	-0.8001
Percentage handwatered*Fertilizes with each watering	-1,116.70	1,944.10	-0.5744
Percentage handwatered*Scouting	-3,868.00	2,857.60	-1.3536
Percentage handwatered*Preventive application of pesticides	-3,448.70**	1,719.60	-2.0055

Table 4. Parameter Estimates for Model II (cont.)

Parameter	Estimate	Std. Error	T-Ratio
Age^2	96.5060	154.7700	0.6236
Age*Fertilizes with each watering	-4,662.50	4,676.30	-0.9971
Age*Scouting	5,128.80	6,002.50	0.8544
Age*Preventive application of pesticides	-4,716.00	4,348.30	-1.0846
Fertilizes with each watering*Scouting	456,180.00***	145,630.00	3.1326
Fertilizes with each watering*Preventive application of pesticides	-45,242.00	104,200.00	-0.4342
Scouting* Preventive application of pesticides	-150,000.00	186,260.00	-0.8053
Price of labor*Sales per sq. ft.	-0.0781**	0.0382	-2.0460
Price of labor*Location	-2.1347**	0.9767	-2.1858
Price of labor*Percentage sales wholesale	-0.0038	0.0121	-0.3145
Price of labor*Percentage handwatered	0.0123	0.0141	0.8741
Price of labor*Age	0.0255	0.0324	0.7882
Price of labor*Fertilizes with each watering	0.3248	0.8995	0.3610
Price of labor*Scouting	-1.2075	1.0996	-1.0981
Price of labor*Preventive application of pesticides	0.8625	0.7911	1.0902
Price of materials* Sales per sq. ft.	-4.1735***	0.8798	-4.7436
Price of materials*Location	-11.2690	21.4620	-0.5251
Price of materials*Percentage sales wholesale	0.3407	0.2741	1.2429
Price of materials*Percentage handwatered	-0.0699	0.3254	-0.2147
Price of materials*Age	0.3206	0.7341	0.4367
Price of materials*Fertilizes with each watering	-9.5947	19.7640	-0.4855
Price of materials*Scouting	-102.93***	25.75	-3.9964
Price of materials*Preventive application of pesticides	-10.5000	17.6460	-0.5950
Sales*Sales per sq. ft.	26.9430***	8.9206	3.0203
Sales*Location	-110.61	137.75	-0.8030
Sales*Percentage sales wholesale	1.6838	2.4665	0.6827
Sales*Percentage handwatered	-0.3490	1.7476	-0.1997
Sales*Age	-4.2194	5.4561	-0.7733
Sales*Fertilizes with each watering	459.09***	125.30	3.6640
Sales*Scouting	-981.30***	227.10	-4.3210
Sales*Preventive application of pesticides	-131.35	151.97	-0.8643

***Indicates significance at 1% level, ** indicates significance at 5% level, and *indicates significance at 10% level. Cost Equation r-square=0.9208, Labor Equation r-square=0.8984, SF Equation r-square=0.5773

Table 5. Input Elasticities

	Price of Labor	Price of Materials	Energy	h_1	h_3	h_4	h_5
Model I							
Labor	-0.0014*	0.0019*	-0.0005*	-	-	-	-
Lower	-0.0016	0.0017	-0.0005	-	-	-	-
Upper	-0.0013	0.0021	-0.0004				
Materials	0.5884*	-0.7890*	0.2006*	-	-	-	-
Lower	0.5209	-0.8559	0.1710				
Upper	0.6420	-0.7315	0.2295	-	-	-	-
Energy	-0.0003*	0.0004*	-0.0001*	-	-	-	-
Lower	-0.0003	0.0003	-0.0001				
Upper	-0.0002	0.0004	-0.0001	-	-	-	-
Model II							
Labor	-0.0006*	0.0018*	-0.0011	-0.0882*	-0.0195*	0.0649*	0.1106*
Lower	-0.0075	0.0015	-0.0012	-0.0095	-0.0308	0.0520	0.0907
Upper	-0.0005	0.0021	0.0058	-0.0834	-0.0083	0.0756	0.1369
Materials	0.7315*	-2.0198*	1.2883*	-0.7614*	0.2811*	-0.0593*	0.2243*
Lower	0.6394	-2.1507	1.1712	-0.7957	0.2459	-0.1159	0.1490
Upper	0.8560	-1.8898	1.3925	-0.7298	0.3177	-0.0149	0.3223
Energy	-0.0005	0.0015*	-0.0009*	-	-	-	-
Lower	-0.0006	0.0014	-0.0038	-	-	-	-
Upper	0.0025	0.0016	-0.0008	-	-	-	-

Note: Elasticities are calculated at mean values for continuous variables, and binary variables h_2, h_6, h_7, and h_8 equal to one. Lower and upper numbers are 90% confidence intervals of the elasticities calculated using the jackknife approach.
*Indicates significance at the 10% level.

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Table 6. Effects of Binary Variables on Input

	h_2	h_6	h_7	h_8
Model II				
Labor(#of employees)	-2.13	0.32	-1.21	0.86
Lower	-2.25	0.18	-1.58	0.73
Upper	-1.99	0.45	-1.09	0.99
Materials(000's sq.ft.)	-11.27	-9.59	-102.93	-10.50
Lower	-15.65	-12.36	-108.55	-13.39
Upper	-8.84	-5.07	-99.63	-8.47

Note: The effects of binary variables are calculated at the mean values for continuous variables and binary variables h_2, h_6, h_7, and h_8 equal to one. Lower and upper numbers are 90% confidence intervals of the effects calculated using the jackknife approach.

Table 7. Cost Elasticities

	Output	W_1	W_2	W_3	h_1	h_3	h_4	h_5
Model I	0.9425*	0.3712*	0.0012*	0.6276*	-	-	-	-
Lower	0.9383	0.3685	0.0012	0.6250	-	-	-	-
Upper	0.9479	0.3737	0.0012	0.6303				
Model II	0.8032*	0.3200*	0.0008*	0.6792*	0.0468	0.1238*	-0.0340	-0.3765*
Lower	0.7692	0.3110	0.0007	0.6706	-0.0125	0.0925	-0.0609	-0.4359
Upper	0.8410	0.3286	0.0008	0.6883	0.0918	0.1474	0.0060	-0.2675

Note: Elasticities are calculated at mean values for continuous variables and binary variables h_2, h_6, h_7, and h_8 equal to one. Lower and upper numbers are 90% confidence intervals of the elasticities calculated using the jackknife approach.
*Indicates significance at the 10% level.

Table 8. Effects of Binary Variables on Cost ($000's)

	h2	h6	h7	h8
Model II	-124.07	111.99	-254.84	37.46
Lower	-162.43	76.93	-402.45	15.69
Upper	-81.29	134.52	-163.63	62.94

Note: The effects of binary variables are calculated at the mean values for continuous variables and binary variables h_2, h_6, h_7, and h_8 equal to one. Lower and upper numbers are 90% confidence intervals of the effects calculated using the jackknife approach.

Table 9. Mean Output Elasticities for Small, Medium and Large Growers

	Mean Sales ($000's)	Mean Sq. Footage (000's)	Model I	Model II
Small	220.41	23.45	0.78	0.81
Medium	687.15	101.51	0.94	1.80
Large	1625.62	241.75	0.97	0.95

Note: Elasticities for each observation were calculated from parameters in tables 3 and 4 and averaged by size.

Table 10. Comparison of Models

		RMSEs ($000's)	
Model	Cost function R-square	In Sample	Out of Sample
I	0.8691	369.79	387.89
II	0.9208	278.82	614.83

Note: The RMSEs out of sample are calculated by estimating the model without one observation and predicting cost using the observation not used in the estimation. This is completed with all 98 observations.

Table 11. Results of Comparison of Models

Models Compared	Model with the lowest RMSE	Significantly Different
I vs. II	I	Yes

Note: RMSEs are compared out of sample using the Ashley, Granger, Schmalensee approach. Significance level is 5%.