Godfrey EJIMAKOR*, Obed QUAICOE* and Fafanyo ASISEH*

Agricultural factor use and substitution in the south-eastern United States

A study of the agricultural factor markets that support the farm economy of the southeastern United States aids the understanding of how farmers change the mix of factors as product and factor prices change. Factor demand elasticities were estimated for capital, land, labour, chemicals, energy and other intermediate inputs. On average, labour accounted for USD 0.410 of every USD 1 spent on agricultural inputs followed by other intermediate inputs, which accounted for USD 0.255. The demands for farm labour and other intermediate inputs were inelastic. The demand for farm chemicals was elastic, which indicates a lack of pricing power by companies that sell them. A substantial reduction in the use of farm chemicals could be achievable by increasing their price. Most of the factors are substitutes with the exceptions of capital and energy, and land and chemicals, which were found to be complements.

Keywords: agricultural factor/input, factor share, elasticity, substitution

* North Carolina A&T State University. Greensboro, NC 27411, USA. Corresponding author: ejimakor@ncat.edu

Introduction

The volatility in agricultural product markets has been accompanied by volatility in the factor markets. Changes in the prices of crops and livestock products have resulted in changes in the demand for agricultural inputs. These changes have been confounded by those in the market for fossil fuels. Higher prices for fossil fuels result in increased demand for maize and other agricultural products used for biofuels, thereby affecting agricultural factor markets. In addition, fossil fuels are farm inputs so changes in their prices also affect agricultural input markets. As demand and prices for farm inputs change, sellers of agricultural inputs such as equipment and chemicals must find ways to adjust due to the substitution of some inputs for others and complementarity between some inputs. In addition, changing prices affect the revenues of such companies. Farm-level responses to changes in factor prices have implications for public policy.

The application of inputs such as chemicals and fertilisers has been associated with the impairment of streams and aquifers (Parris, 2011). Despite the concerns over runoff and leaching that have encouraged the promotion of best agricultural management practices, anecdotal evidence indicates that the use of conventional practices, especially in crop production, has changed little since the early 1990s. An opportunity to substitute for some of these harmful inputs could improve environmental quality by reducing water pollution and the carbon footprint associated with their use. Information on input use and substitution could be used to determine the appropriate levels of taxes or subsidies on given inputs that will achieve reductions in the use of potentially harmful agricultural chemicals that can compromise environmental quality, and the health of consumers and farm workers. This study explored the types and magnitudes of the relations between agricultural inputs in the agricultural sector of south-eastern U.S. Specifically, the study estimated the input demand elasticities for south-eastern U.S. agriculture.

The work of Allen (1938), supplemented by Varian (1994) and Takayama (1993), established the fundamental concepts on the economics of input substitution. Ferguson and Pfouts (1962) and Berndt and Christensen (1973) developed the theoretical background of applied substitution in production while Sato and Koizumi (1973) developed the link between Allen relative elasticities and cross price elasticities. Several studies (Hudson and Jorgenson, 1974; Berndt and Wood, 1975; Fuss, 1977; Magnus, 1979) on factor substitution have examined the substitution between energy and non-energy inputs, with emphasis on the role of energy in production.

Most of the preceding studies on factor demand and substitution may be dated and, as a result, findings from such studies may no longer be relevant. In addition, the changes in demand for agricultural commodities and corresponding changes in the demand for agricultural inputs in recent years are unprecedented relative to the period during which most of these studies were done. Also, most of these studies focused on U.S. agriculture as a whole, but there could be regional differences in factor demand, possibly due to differences in regional agricultural production practices and weather. Therefore, conclusions drawn for U.S. agriculture may not necessarily be applicable to south-eastern U.S. agriculture. This study revisits factor demand and input substitution in agriculture from a south-eastern U.S. perspective, and investigates the relationships between agricultural factors. We hypothesise that capital are complements to land, energy and chemicals, and a substitute to labour.

Methodology

Theoretical model

Translog cost functions developed by Christensen *et al.* (1973) are very useful in studies of factor demand. In general, the translog cost function may be represented as:

$$\ln C = \beta_0 + \beta_q \ln Q + \frac{1}{2}\beta_{qq}(\ln Q)^2 + \sum_i \beta_{qi} \ln Q \ln w_i + \sum_i \beta_i \ln w_i + \frac{1}{2}\sum_i \sum_j \beta_{ij} \ln w_i \ln w_j \quad (1)$$

where C is cost, Q is output, w_i is the price of input i, w_j is the price of input j; and $i, j = 1,2,...,n$.

The first derivative of the translog function with respect to input prices (w_i) is:

$$\delta \ln C / \delta \ln w_i = (\delta C / \delta w_i) * (w_i / C) \quad (2)$$

By use of Shephard's lemma, equation 2 could be expressed as a system of factor share equations (S_i) that are functions of factor prices (w_i) and output (Q) where S_i is the proportional share of the i^{th} input relative to total cost.

$$\frac{\partial \ln C}{\partial \ln w_i} = S_i = \beta_i + \beta_{qi} \ln Q + \sum_j \beta_{ij} \ln w_j \quad (3)$$

Homogeneity restrictions require that the sum of the price effects as well as the product effects be each equal to zero. Symmetry also requires the respective cross price effects to be equal.

The translog cost function can be applied to multiproduct, multifactor production processes. However, estimating the cost function as a single-equation model even with restrictions imposed for linear homogeneity in the input prices may be either impossible or inappropriate. Therefore, estimating the system of equations leads to much higher efficiency (Subhash, 1982).

The Allen elasticity of substitution between any two inputs in a multiple input production system is defined as the effect of a change in relative factor prices on the relative factor quantities, holding output and other input prices constant (Sato and Koizumi, 1973). The parameters from a system of factor share equations could be used to compute the own price and Allen elasticities of substitution. The own price elasticity (ε_{ii}) is given by:

$$\varepsilon_{ii} = (\beta_{ii} - S_i + S_i^2) / S_i^2 \quad (4)$$

where β_{ii} is the own price coefficient of input *i*; and S_i is the share of input *i*. The Allen elasticity of substitution (ε_{ij}) between input *i* and input *j* is given by:

$$\varepsilon_{ij} = (\beta_{ij} + S_i * S_j) / S_i * S_j \quad (5)$$

where β_{ij} is the cross price coefficient of input *i* with respect to the price of input *j* and S_j is the share of input *j*.

Empirical model

Data on input prices and output levels used in this study were obtained from USDA (2009) and USDA (2010). Data on the prices of capital, labour, land, energy, chemicals and other intermediate inputs for each year from 1960 to 2004 were collected for each of the eleven states (Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee and Virginia) in the south-east U.S. In addition, data on the output of crops and livestock were collected for the region for each of the years. This yielded a total of 495 observations. The price variables used in this study were measured as indices from 1960 to 2004 with 1996 as the base year. The output variables (crop and livestock) were also measured as indices for the 45-year period (1960-2004) with 1996 as the base year. All the relevant data for more recent years are not available.

Factor shares used in south-eastern US agriculture were computed for capital, labour, land, energy, chemicals and other intermediate inputs. The factor share for each input is the ratio of the expenditure on the input to the expenditure on all inputs for a given year:

$$S_{it} = e_{it} / E_t \quad (6)$$

where S_{it} represents factor share of agricultural input *i* in year *t*; e_{it} represents expenditure on agricultural input *i* in year *t* and E_t is the overall or total input expenditure in year *t*.

The effects of output and input price changes were obtained from the estimation of a system of factor share equations (equation 3). To estimate the system of factor share equations as related to agriculture in south-eastern U.S., agricultural output (Q) is specified to be a function of six inputs such that:

$$Q = f(Capital, Labour, Land, Energy, Chemicals, Other\ intermediate\ inputs) \quad (7)$$

It was assumed that the individual inputs in the production function (equation 7) are weakly separable from other input materials. Profit maximisation by farms and competitive agricultural product and input markets were assumed.

The impact of changes in input prices and output quantities on the factor share of each input (equation 3) were estimated as a system of the following six equations:

$$S_{capital} = f(w_{capital}, w_{land}, w_{labour}, w_{energy}, w_{chemicals}, w_{other\ intermediate\ inputs}, crop, livestock, trend) \quad (8)$$

$$S_{land} = f(w_{land}, w_{capital}, w_{labour}, w_{energy}, w_{chemicals}, w_{other\ intermediate\ inputs}, crop, livestock, trend) \quad (9)$$

$$S_{labour} = f(w_{labour}, w_{capital}, w_{land}, w_{energy}, w_{chemicals}, w_{other\ intermediate\ inputs}, crop, livestock, trend) \quad (10)$$

$$S_{energy} = f(w_{energy}, w_{capital}, w_{land}, w_{labour}, w_{chemicals}, w_{other\ intermediate\ inputs}, crop, livestock, trend) \quad (11)$$

$$S_{chemical} = f(w_{chemicals}, w_{capital}, w_{land}, w_{labour}, w_{energy}, w_{other\ intermediate\ inputs}, crop, livestock, trend) \quad (12)$$

$$S_{other} = f(w_{other\ intermediate\ inputs}, w_{capital}, w_{land}, w_{labour}, w_{energy}, w_{chemicals}, crop, livestock, trend) \quad (13)$$

where $S_{capital}$ = factor share of capital: capital is defined to include depreciable assets and beginning inventories of livestock and crops; S_{labour} = factor share of labour: labour includes self-employed and unpaid family labour as well as hired workers; S_{land} = factor share of land: land constitutes land area and values; S_{energy} = factor share of energy: energy includes petroleum fuels, natural gas, renewable energy and electricity; $S_{chemical}$ = factor share of all chemicals; S_{other} = factor share of other intermediate inputs: other intermediate inputs include feed, seed, fertiliser, livestock purchases, maintenance and repairs as well as irrigation water. $w_{capital}$ = log of the index of annual capital price; w_{land} = log of the index of annual land price; w_{labour} = log of the index of annual wage rate for farm labour; w_{energy} = log of the index of annual energy price; $w_{chemicals}$ = log of the index of annual agricultural chemical price; $w_{other\ intermediate\ inputs}$ = log of the index of annual other intermediate inputs price. *crop* = log of the index of annual crop production: crops include an aggregate measure of all

Table 1: Estimated coefficients of factor share equations for agricultural inputs in the south-eastern United States.

Equation no.	Dependent variable		Independent variables								
	Variable	Mean	*Constant*	$w_{capital}$	w_{land}	w_{labour}	w_{energy}	$w_{chemicals}$	*crop*	*livestock*	*trend*
8	$S_{Capital}$	0.123	-2.561***	-0.036***	0.035***	-0.017***	0.007***	0.025***	-0.029***	-0.013***	0.001***
			(-8.630)	(-5.640)	(16.31)	(-4.160)	(-4.550)	(6.460)	(-9.910)	(-4.680)	(9.120)
9	S_{Land}	0.106	-0.288	0.035***	-0.015***	-0.014***	0.003***	-0.009***	0.009***	-0.010***	0.0002*
			(-1.360)	(16.31)	(-9.540)	(-5.460)	(6.630)	(-5.550)	(4.300)	(-5.270)	(1.770)
10	S_{Labour}	0.411	4.763***	-0.017***	-0.014***	0.025***	-0.000008	0.005	0.020***	-0.099***	-0.002***
			(11.970)	(-4.160)	(-5.460)	(4.040)	(-0.010)	(1.540)	(2.630)	(-13.650)	(-11.120)
11	S_{Energy}	0.032	-0.242***	-0.007***	0.003***	-0.000008	-0.012***	0.016***	0.001**	0.003***	0.0001***
			(-3.140)	(-4.550)	(6.630)	(-0.010)	(-10.820)	(16.770)	(2.280)	(5.650)	(3.600)
12	$S_{Chemicals}$	0.073	-0.671***	-0.025***	-0.009***	0.005	0.016**	-0.037***	0.028**	-0.016***	0.0004***
			(-2.450)	(6.460)	(-5.55)	(1.540)	(16.77)	(-10.150)	(11.570)	(-6.870)	(2.670)
13	S_{other}	0.255	-0.00001	-0.000002	-0.000003	-0.000003	0.000003	-0.000001	-0.029	0.135	0.0003

***, **, * statistically significant at the 1%, 5% and 10% levels, respectively; T-values are in parenthesis; N=4
Source: own calculations

crop production; *livestock*=log of the index of annual livestock production: livestock includes an aggregate measure of all livestock production; *trend*=trend (technology) and is measured as the years of data collection (1960 to 2004).

Trend (in years) was included to measure changes in knowledge during the period of study (1960 to 2004). Since factor shares must add up to one, five ($n-1$) of the six factor share equations containing five input prices (excluding the price of other intermediate inputs) in each equation were estimated. This helps to avoid the problem of singularity. The equation for other intermediate inputs (equation 13) and the coefficients of the price of other intermediate inputs in each of the five factor share equations were estimated based on the parameters of the first five equations. The five factor share equations were estimated with Statistical Analysis System software using a nonlinear Seemingly Unrelated Regression technique, which ensures efficiency in estimation by combining information on different equations (Moon and Perron, 2004). Estimates of parameters in the system of factor share equations were used to derive the own price and Allen elasticities of substitution matrix using equations (4) and (5).

Results and discussion

Our results and discussion are presented in three subsections. In the first subsection, we discuss the estimated regression coefficients for each of equations 8 to 13. The second subsection contains the discussion of the estimated Allen own-price elasticities. Finally, we discuss the estimated Allen elasticities of substitution in the third subsection.

Estimated factor share coefficients

Table 1 contains the results of the six estimated factor share equations. Labour (S_{labour}) and other intermediate inputs (S_{other}) accounted for the largest factor shares at 41.1 and 25.5 per cent respectively. The regression results indicate that an increase in the price of capital ($w_{capital}$) will result in decreases in the factor shares of capital ($S_{capital}$), labour (S_{labour}), energy (S_{energy}), chemicals ($S_{chemicals}$) and other intermediate inputs (S_{other}), and result in a 0.035 point increase in the factor share of land (S_{land}). Increases

Table 2: Estimated own and cross price elasticities of substitution for factors of production in south-eastern United States agriculture.

Factor	$w_{capital}$	w_{labour}	w_{land}	w_{energy}	$w_{chemicals}$	$w_{other\ inputs}$
Capital	-1.17	0.27	0.39	-0.02	0.28	0.25
Labour	0.08	-0.53	0.07	0.03	0.09	0.25
Land	0.45	0.28	-1.04	0.06	-0.01	0.25
Energy	-0.10	0.41	0.20	-1.34	0.57	0.26
Chemicals	0.47	0.48	-0.02	0.25	-1.43	0.25
Other inputs	0.12	0.41	0.11	0.03	0.07	-0.74

Note: row 1 indicates source of price change
Source: own calculations

in the price of land (w_{land}) will result in reductions in the factor shares of land, labour, chemicals and other intermediate inputs and increases in those of capital and energy. Increases in the farm wage rate (w_{labour}) will increase the factor shares of labour and chemicals and reduce the factor shares of each of the other four inputs. Increases in the factor shares of land, chemicals and other intermediate inputs will result from increases in the price of energy (w_{energy}) while reducing those of capital, labour and energy. An increase in the price of chemicals ($w_{chemicals}$) will result in reductions in the factor shares of land, chemicals and other intermediate inputs and increases in each of the shares of capital, labour and energy. Increases in crop production (*crop*) will result in decreases in the shares of capital and other intermediate inputs while reducing the factor shares of each of the other inputs. Increased livestock production will result in reductions in the factor shares of all inputs except those of energy and other intermediate inputs. The factor shares of all inputs except for those of labour increase with the passage of time.

Estimated Allen own-price elasticities

Table 2 contains the estimated Allen own-price elasticities (diagonal elements) and substitution elasticities (off-diagonal elements) for the various inputs. The estimates indicate that the demand for capital, land and energy in south-eastern U.S. agriculture are elastic. The own-price elasticity coefficients range from -1.43 for chemicals to -1.01 for land. The own-price elasticity coefficient of -1.43 for chemicals suggests that agricultural chemical companies have limited pricing power, as a 10 per cent increase in price will result in a 4.3 per cent reduction in revenue. Likewise, the estimated own-price elasticity of -1.17 for capital implies that a 10 per cent increase in the price of capital equipment will result in a 1.7 per cent reduction in the revenue of companies that sell them to the farm sector. The own-price elasticity coefficient for energy is -1.34, suggesting that a 10 per cent increase in the price of energy will reduce energy use on farms by 13.4 per cent. This finding differs from that of Miranowski (2005), which indicates that energy demand in U.S. agriculture is inelastic. The demand for agricultural labour and other inputs were found to be inelastic with coefficients of -0.53 and -0.74 respectively.

Estimated Allen elasticities of substitution

The estimated Allen elasticities of substitution suggest that most of the inputs are weak substitutes. The Allen elasticity of substitution of chemicals with respect to energy prices is 0.25 per cent, suggesting that a 10 per cent increase in the price of energy will result in a 2.5 per cent increase in the use of agricultural chemicals in south-eastern U.S. agriculture. Likewise, a 10 per cent increase in the price of chemicals will increase energy use by 5.7 per cent. The results also suggest that energy and labour are substitutes which is consistent with the findings of Hudson and Jorgenson (1974), Berndt and Wood (1975), Fuss (1977), Magnus (1979) and Gopalakrishnan *et al*. (1989). However, they contradict the findings of Carlson *et al*. (1993). Capital and energy were found to be complements, suggesting that their substitution for each other is technically infeasible in south-eastern U.S. agriculture. The estimated elasticity of substitution of -0.02 implies that a 10 per cent increase in the price of energy will result in a 0.2 per cent decrease in the use of capital, which is consistent with our hypothesis. An elasticity of -0.10 implies that a 10 per cent increase in the price of capital will be accompanied by a 1.0 per cent decrease in the use of energy. In addition to being consistent with our hypothesis, this finding is also in agreement with those of Hudson and Jorgenson (1974), Berndt and Wood (1975), Fuss (1977) and Magnus (1979), who also found energy as a complement for capital in U.S. agriculture. However, the finding is inconsistent with those of Griffin and Gregory (1976) who found energy and capital to be substitutes in U.S. agriculture.

Conclusions

Sellers of most agricultural inputs used in south-eastern U.S agriculture have limited pricing power and could increase their total revenues by charging lower prices. Efforts to reduce environmental damage from the use of agricultural chemicals through the use of a tax will be effective as every 10 per cent increase in the price of chemicals will reduce the use of agricultural chemicals by 14.3 per cent and increase the use of capital, labour, land and energy. However, such a tax will adversely affect the revenues of firms that sell farm chemicals. Additionally, the inelastic nature of farm labour suggests that actions or events that increase farm wage rates in the region will be mostly at the expense of farm sector profits.

References

Allen, R.G.D. (1938): Mathematical Analysis for Economists. New York NY, St. Martin's Press.

Berndt, E.R. and Wood, D. (1975): Technology, Prices, and the Derived Demand for Energy. Review of Economics and Statistics **57**, 259-268. https://doi.org/10.2307/1923910

Berndt, E.R. and Christensen, L.R. (1973): The Internal Structure of Functional Relationships: Separability, Substitution and Aggregation. Review of Economic Studies **55**, 403-410. https://doi.org/10.2307/2296459

Carlson, G.A., Zilberman, D. and Miranwoski, J.A. (1993): Agricultural and Environmental Resource Economics. Oxford: Oxford University Press.

Christensen, L.R., Jorgenson, D.W. and Lau, L.J. (1973): Transcendental Logarithmic Production Frontiers. The Review of Economics and Statistics **LV**, 28-45. https://doi.org/10.2307/1927992

Ferguson, C.E. and Pfouts, R. (1962): Aggregate Production Functions and Relative Factor Shares. International Economic Review **3**, 328-337. https://doi.org/10.2307/2525398

Fuss, M.A. (1977): The Demand for Energy in Canadian Manufacturing. Journal of Econometrics **5** (1), 89-116. https://doi.org/10.1016/0304-4076(77)90036-7

Gopalakrishnan, C., Khalegi, G.H. and Shrestha, R.B. (1989): Energy-nonenergy Input Substitution in U.S. Agriculture: Some Findings. Applied Economics **21**, 673-679. https://doi.org/10.1080/758524898

Griffin, J.M. and Gregory, P.R. (1976): An Intercountry Translog Model of Energy Substitution Responses. American Economic Review **66**, 845-857.

Hudson, E.A. and Jorgenson, D.W. (1974): U.S. Energy Policy and Economic Growth, 1975-2000. The Bell Journal of Economics and Management Science **5** (2), 461-514. https://doi.org/10.2307/3003118

Magnus, J.R. (1979): Substitution between Energy and Non- Energy Inputs in the Netherlands: 1950-1976. International Economic Review **20** (2), 465-484. https://doi.org/10.2307/2526494

Miranowski, J. (2005): Energy Consumption in U.S. Agriculture, in: J.L. Outlaw, K.J. Collins and J.A. Duffield (eds), Agriculture as a Producer and Consumer of Energy. Wallingford, UK: CABI Publishing. https://doi.org/10.1079/9780851990187.0068

Moon, H.R. and Perron, P. (2004): Efficient Estimation of SUR Cointegration Regression Model and Testing for Purchasing Power Parity. Econometric Reviews **23**, 293-323. https://doi.org/10.1081/ETC-200040777

Parris, K. (2011): Impact of agriculture on water pollution in OECD countries: recent trends and future prospects. International Journal of Water Resources Development **27** (1), 33-52. https://doi.org/10.1080/07900627.2010.531898

Sato, R. and Koizumi, T. (1973): On the Elasticities of Substitution and Complementarity. Oxford Economic Papers **25**, 44-56. https://doi.org/10.1093/oxfordjournals.oep.a041244

Subhash, C.R. (1982): A Translog Cost Function Analysis of U.S. Agriculture, 1939-77. American Journal of Agricultural Economics **64**, 490-498. https://doi.org/10.2307/1240641

Takayama, A. (1993): Analytical Methods in Economics. Ann Arbor MI: University of Michigan Press.

USDA (2009): State Agriculture Overview [www document]. Available online at http://www.agcensus.usda.gov/ (accessed 27 October 2010).

USDA (2010): Agricultural Productivity [www document]. Available online at http://www.ers.usda.gov/Data/AgProductivity/ (accessed 27 October 2010).

Varian, H.R. (1994): Microeconomic Analysis. New York NY: W.W. Norton and Company.