Evaluating Agricultural Research and Productivity

Proceedings of a Symposium
Atlanta, Georgia
January 29-30, 1987

Miscellaneous Publication 52-1987
Minnesota Agricultural Experiment Station
University of Minnesota

DISTRIBUTION OF AGRICULTURAL RESEARCH IMPACTS

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INTRODUCTION

When there is a correspondence between two logical systems, duality can be used to derive a correspondence between results in one system and results in another system (Russell and Wilkinson, 1978). Under appropriate regularity conditions, dual functions such as normalized profit functions in production economics embody the same information on technology as the more familiar primal production functions. The technology can be examined directly using the primal approach or indirectly using the dual approach. It is often easier to estimate product supply and input demand relationships using a dual approach, because only endogenous variables appear on the left-hand side of equations and only exogenous variables appear on the right-hand side of equations (Shumway, 1983).

Duality concepts allow the estimation of output supply and input demand functions that are consistent with underlying economic theory (Shumway, 1986). Estimation generally requires that the equations be estimated as a system in order to account for relevant cross-equation restrictions. Regularity conditions related to homogeneity, symmetry, and curvature properties required to ensure that a profit-maximizing solution exists can be maintained through appropriate restrictions or tested.

Considering the versatility and power of the duality approach, one would conclude that empirical estimates using this approach might be better in some sense than estimates from other models that were not consistent with economic theory. The purpose of this paper is to review empirical estimates related to technological change in U.S. agriculture that have been obtained using the duality approach. Both static and dynamic duality models will be considered, although there is only limited empirical evidence on technological change using the dynamic duality approach.

DISTRIBUTION EFFECTS CONCEPTUALIZED

Agricultural research has important distributional effects within farming and within rural areas in general. Research affects the relative productivity of land, labor, and capital, which in turn affects the efficient mix of inputs and the share of income attributable to each of these inputs. These changes in productivity can be viewed as shifts in factor demand curves. The interaction of supply and demand will determine levels of factor use and factor returns. Hence factor supply elasticities are important in determining the income effects due to shifts in factor demands, resulting from agricultural research. Land services are quite inelastic in supply, which means that land rental rates and land prices are sensitive to shifts in demand for land services. In contrast, most other farm inputs have more elastic price elasticities of supply, indicating shifts in factor demand might change input usage with little or no impact on factor prices.

Farm Operators

Results from agricultural research may have varying effects on producers by size categories, by geographical region, and by commodities being produced. Some mechanical innovations have favored large-scale farms on the basis of economic efficiency rather than some physical limitation. A technology which is adopted only in a limited geographical area, particularly biological innovations such as the development of improved crop varieties, can alter comparative advantages among regions. Using new technologies in the production of one commodity may impact on the production and/or utilization of other commodities. For example, an improvement in beef production resulting in lower beef prices might affect pork and poultry consumption and the demand for feed grains.

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Whenever economies of size are present there are economic pressures to expand farm size, because larger farms would have lower costs per unit of output than smaller farms. There is considerable controversy over the magnitude of cost savings associated with increasing farm size. Distinguishing between technical economies and pecuniary economies sheds some light on the controversy. There appears to be a significant technical basis for economies of size, i.e. technology has lowered per unit costs by a greater degree on large farms than on small farms (Hall and LeVeen, Jensen). When only technical economies are considered, it appears that relatively modest sized farms can achieve a major portion of the possible cost savings associated with size. Costs in highly mechanized crops generally continue to decrease slowly throughout the entire range of surveyed farm sizes; but in vegetable and fruit crops, costs do not appear to decease substantially after an initial phase of rapid decline (Hall and LeVeen). Miller, Rodewald, and McElroy in a study of economies of size of U.S. field crop farming found that as farm size increases in most field crop regions, per unit costs decline at first, and then are relatively constant. There is some evidence that when pecuniary economies are considered, the unit cost curve does not flatten out but continues to decline with larger farm sizes (Knutson, Penn and Boehm).

Technology affects farmers according to the speed with which new innovations are adopted. Progressive farmers can benefit from a new technology through early adoption. Adoption lags, which systematically favor the larger farmers, occur because it is more profitable for large farms than small to invest in acquiring information. There is a concern that in the case of integrated agriculture, certain types of information may be only available to those that are a part of the system. In a study of adoption of new crop varieties, Perrin and Winkelman noted that new seed varieties and fertilizer which should help both large and small farms, favored larger farms because the small farms lagged behind in the early stage of adoption.

Farmland Owners

Technological change affects the productivity of land and hence impacts on the demand for farmland and its price. Farmers would therefore be affected according to the amount of farmland owned. An increase in the value marginal product of land will favor owners relative to renters. The distinction between farmland owners and renters is becoming more important because an increasing proportion of farmland is rented and a larger proportion of farmers rent part of the land they operate (U.S. Department of Agriculture, Agricultural Statistics). Herdt and Cochrane (1966) reported that technological advance with stable or rising prices has benefited farmland owners, not necessarily farm operators. They said that farmers view technological change as reducing the cost of production and hence are able to bid up the price of farmland accordingly. Heady (1971) argued that rapid increases in agricultural productivity would lower the value productivity of farmland in the case of low price elasticities of demand for farm products, reducing farm revenue. While the net effect of technological change would be to lower the share of total income attributable to farmland, farmland prices increased during periods in which the government supported prices because of compensatory government programs. With price supports, increased productivity resulted in sizable capital gains to farmland owners (Cochrane, 1965). However, these capital gains must be evaluated in terms of the government programs in effect to support farm prices and not be considered as the sole responsibility of technological change.

Farm Workers

Changes in the proportion of farm income attributable to labor depends on the type of technology. Labor-saving technology reduces the demand for labor. Mechanical technology, which has been developed almost entirely by private sector research, generally can be characterized as labor-saving (Evenson, 1980). Estimated income effects indicate that technological changes have increased the marginal physical productivity of labor used in farming (Wallace and Hoover, 1966). The result is an increase in the demand for labor if farm product prices are unaffected. However, as farm prices adjust downward to expanded output resulting from technological change, the demand for labor declines because the demand for agricultural products is inelastic (Bauer, 1969).

The differential impact of technological change on certain groups of labor is evident. Workers whose skills complement agricultural innovations have experienced an increase in their marginal productivity and in their real income. However, unskilled workers who do the same work that can be done by mechanical innovations have experienced a decline in the demand for their efforts. Those workers remaining in agriculture have faced prospects of declining real incomes.

The substitution of capital for farm labor can have adverse effects on workers not suited for nonfarm employment because of age, lack of skills or inadequate employment opportunities. This problem has associated with it social costs that include unemployed resources and increased social services for displaced farm workers.

STATIC DUALITY

Theory

The roots of duality traced primarily to two pioneering works by Hotelling and Shephard. Hotelling first introduced the application of duality to economics in 1932. Then Shephard presented a comprehensive treatment of duality in production economics, including derivation of fundamental theories and lemmas in 1953. Theoretical developments by Berndt and Christensen, Diewert, Lau, and McFadden in the 1970's formed the basis for numerous empirical applications.

The static dual profit function is

(1) $\pi^* = F(P, W, Z)$

where π^* is the maximum level of profit associated with the exogenous competitive prices, G is a convex function of prices, P is a vector of normalized output prices, W is a vector of normalized input prices, and Z is a vector of exogenous variables. Technical change can be considered in this model by including either a time variable or a research expenditure variable among the exogenous variables.

Maximum profit in the model can be determined by specifying the functional form and deriving the first-order conditions. The Cobb-Douglas functional form was initially used in duality but more recently more flexible functional forms such as the generalized Leontief, translog, or quadratic forms have been used. These latter functional forms can be interpreted as a second-order Taylor series approximation of the unknown underlying technology. Simultaneous solution of the first-order conditions for a maximum obtained using Hotelling's lemma yields factor demand and output supply equations.

(2) $X_i^* = -X_i^*(P, W, Z) \quad i = 1, \ldots, m$

$Y_j^* = Y_j^*(P, W, Z) \quad i = 1, \ldots, n$

The actual form of these equations is dependent on the functional form.

Empirical Applications

The first application of duality in agriculture was reported by Lau and Yotopoulos (1972). They derived supply and factor demand functions from a Cobb-Douglas profit function. The profit function and the labor demand function were estimated jointly. The estimated model did not account for technological change. Subsequent studies used more flexible functional forms and accounted for technological change.

Binswanger estimated an aggregate dual translog cost function for U.S. agriculture, explicitly considering technical change. The Cobb-Douglas form of cost and production functions was rejected. The coefficient of the time variable was significant in the labor and machinery equations. These findings imply non-neutral technical change during the period 1949-1964. Technical change was labor saving and machinery using.

A surge of empirical applications using dual approaches appeared in the agricultural economics literature in the 1980's. Babin, Willis, and Allen (1982) examined industrial demand for production inputs. Chambers (1982) examined the meat products industry. Heien (1982) examined food demand. Lopez (1980) analyzed the structure of Canadian agricultural production. Using a generalized Leontief model, he estimated derived demand equations for four inputs for the 1946-1977 period. The hypothesis of no factor augmenting technical progress could not be rejected for Canadian agriculture. Hence the observed decrease in farm labor demand and increased capitalization in Canadian agriculture reflected changes in relative prices rather than technological change. In addition to these studies on duality there have been a number of studies in U.S. agricultural production which will be reviewed below.

Ray (1982) estimated a translog cost function for U.S. agriculture for 1939-1977. The rate of technical change in U.S. agriculture as measured by the Hicks-neutral technical change coefficient on the time variable indicated a 1.8% growth rate in productivity. The measure of technological change estimated from the regression approach is the net of factor substitution, which should make it a more precise measure of productivity growth than a simple trend in aggregate productivity data.

Weaver estimated the translog form of the profit function to characterize agricultural production in North and South Dakota from 1950-1970. Three output categories and five input categories were modeled. Technical change was found to be labor saving relative to all other input categories. Furthermore, technical change was capital saving relative to fertilizer, petroleum, and materials.

Antle utilized a single product translog profit function to measure the structure of U.S. agricultural technology over the 1910-1978 period. During the 1910-1946 period the hypothesis of neutral technical change was rejected with the bias primarily towards machinery and against land. However, the biases were not large. The 1947-1978 estimates showed a dramatic change in the magnitude and direction of biased technical change. For the postwar period the technology was labor saving and capital and chemical using. Technical change was biased most toward chemical inputs and against labor.

Shumway (1983) examined the structure of agricultural production for Texas field crops. He estimated interrelated supply functions for six commodities and input demand functions for fertilizer and hired labor for the 1957-1979 period. The statistically significant coefficients related to technological change indicated a positive shift in the supply curve for cotton, negative shifts in the supply of wheat and corn, and a positive shift in the demand for fertilizer. No statistically significant technological change was evidenced in the supply for rice and hay and the demand for hired labor.

Shumway and Alexander (1986) estimated supply for five output groups and demand for four inputs groups for ten U.S. production regions, 1951-1982. Homogeneity, symmetry, and convexity were maintained in each of the models. Coefficients for the trend variable in the demand and supply equations are reported by regions in table 1. In 74 out of 90 cases the trend coefficient was positive in the demand and supply equations. The largest technical shifts by region were as follows: materials - Southern Plains, hired labor - Northeast, machinery - Corn Belt, energy - Corn Belt, feed grains - Corn Belt, food grains - Northern Plains, oil crops - Corn Belt, other crops - Pacific, and livestock - Southern Plains. Since the endogenous quantities were obtained by dividing input expenditures or value of production by a Divisia price index equal to one in the base period, the magnitude of these coefficients is directly comparable. The aggregate technical shifts were greater for machinery and energy than for hired labor and materials. The greatest technical shift in the supply functions was in oil crops, followed by livestock and feed grains. The technical shifts in the supply functions were generally greater than the technical shifts in the input demand functions.

In a study of multiple-input multiple-output technology, I analyzed the supply functions for three output groups and four input groups for U.S. agriculture, 1948-1979. The normalized profit function was conceptualized in a quadratic form. Data for the analysis were from Ball (1985). Results from the model are reported in Table 2. The input were considered negative outputs, so the sign on the trend variable (8) has to be reversed for the input demand equations. The demand for labor exhibited a large technical reduction (-0.69). The demand for materials had the largest technical increase (0.34), followed by land (0.04) and capital

Table 1. Temporal Parameters From Input Demand and Output Supply Equations for U.S. Production Regions, 1951-1982

	Demand Equations				Supply Equations				
	Materials	Hired Labor	Machinery	Energy	Feed Grains	Food Grains	Oil Crops	Other Crops	Livestock
Northeast	0.0016	0.0300*	0.0319*	0.0150*	0.0234*	-0.0002	0.0072	-0.0165	0.0514*
Lake States	0.0331*	0.0186*	0.0413*	0.0237	0.0575*	0.0195*	0.0300	0.0173	0.0669*
Corn Belt	-0.0620	0.0160	0.0985*	0.0858*	0.1737*	0.0228	0.2845*	-0.0045	-0.0309
Northern Plains	0.0337*	0.0160*	0.0261*	0.0412*	0.1079*	0.0426*	0.0499*	0.0168*	0.0312*
Appalachia	-0.0244*	0.0181*	0.0228	0.0182*	0.0368*	0.0112*	0.0625*	0.0740*	0.0398*
Southeast	-0.0031	0.0131*	0.0144*	0.0241*	0.0021	0.0121*	0.0681*	0.0538*	0.0642*
Delta States	-0.0082	-0.0134	-0.0023	0.0314*	-0.0041	0.0225*	0.0679*	-0.0295*	0.0423*
Southern Plains	0.0417*	0.0090*	0.0190*	0.0326*	0.0155*	0.0196*	0.0055	0.0176*	0.0791*
Mountains	0.0182*	-0.0047	0.0208*	0.0331*	0.0222*	0.0182*	-0.0021	0.0400*	0.0432*
Pacific	0.0186*	0.0206*	0.0154*	0.0484*	0.0138*	0.0286*	0.0071	0.1876*	0.0662*
Sum	0.0492	0.1053	0.2879	0.3535	0.4488	0.1969	0.5806	0.3566	0.4534

Source: C. Richard Shumway and William P. Alexander. "Agricultural Product Supplies and Input Demands: Regional Comparisons." Texas Agricultural Experiment Station Technical Article, Texas A&M University, College Station, Texas.

*Statistically significant at 5% level.

(0.03). The supply of field crops has a larger technical shift (0.48) than livestock and dairy (0.24) and fruits, nuts, and vegetables (-0.08).

DYNAMIC DUALITY

Theory

The dynamic duality theory developed by Epstein assumes that the objective of a price-taking firm is to maximize the discounted value of the firm. If the firm's profit function meets certain regularity conditions, including convexity in output prices, input prices, and gross investment and twice differentiable, then optimal input demand and output supply equations can be derived by applying Hotelling's lemma.

The dynamic duality theory of Epstein assumed that technology is stationary, i.e., technology in the next period will be the same as technology in this period. If producers are aware of the technological change, the stationary assumption may not be appropriate. Karp, Fawson, and Shumway modified Epstein's theory by including a technology function R(t) in the

Table 2. Parameter Estimates of Output Supply and Input Demand Relationships With Technological Change

Parameter[a]	Estimate	Standard Error	Parameter[a]	Estimate	Standard Error
B0	-2.0019	7.1157	D39	0.6841	0.9057
C2	-83.6009*	3.7979	D44	0.6677*	0.2479
C3	-17.2224*	1.4204	D45	-0.6034	0.4548
C4	-7.8073*	0.5123	D46	1.4131	0.3741
C5	-6.7082*	3.1304	D47	-1.5289*	0.1939
C6	36.1738*	3.5026	D48	-0.0431*	0.0048
C7	13.8332*	1.4738	D49	-0.2603	0.3058
C8	0.4751	0.2746	D55	9.6619*	4.2493
C9	25.2323	13.0602	D56	-3.8515	2.8435
D22	-3.6776	9.2774	D57	-1.8518	1.2035
D23	-5.1727*	1.6854	D58	-0.3424*	0.0342
D24	-0.2469	0.7175	D59	-4.4922	2.3882
D25	-1.2064	4.4098	D66	-10.2710	4.2190
D26	-0.9569	4.5452	D67	-1.4076	0.9206
D27	11.7862*	1.3166	D68	0.2429*	0.0420
D28	0.6915*	0.0615	D69	9.3952*	3.8136
D29	9.3310*	4.1406	D77	-8.2659*	0.6066
D33	-0.7177	1.1465	D78	-0.0820*	0.0123
D34	-0.0759	0.2275	D79	0.1457	0.6877
D35	-2.3675	1.5757	D88	0.0026	0.0049
D36	2.2856	1.2598	D89	-0.3373*	0.1518
D37	3.3208*	0.5502	D99	-42.3281	44.6353
D38	-0.0299	0.0166			

[a]Variable numbers: 1 - field crops, 2 - labor, 3 - capital, 4 - land, 5 - materials, 6 - livestock and dairy, 7 - fruits, nuts and vegetables, 8 - research expenditures, and 9 - diversion payments.

*Statistically significant at 5% level.

production function and derived the set of factor demands and output supply functions as follows:

(3) $I^* - \delta K = J_{Kp}^{-1}(rJ_p + \dot{K} - J_{Rp}\dot{R})$

(4) $L^* = rJ_w + J_{Kw}(J_{Kp})^{-1}(rJ_p + \dot{K} - J_{Rp}\dot{R}) + J_{Rw}\dot{R}$

(5) $y^* = r(J - J_w w - J_p P) - (J_K - w'J_{wK} - p'K)(I^* - \delta K) + J_R\dot{R}$

where J = value function of the firm, K = vector of quasi-fixed inputs, L = vector of variable inputs, I = vector of gross investment on quasi-fixed inputs, w = price vector of L, p = price vector of K, F = production function using L and K, $\dot{R} = \partial R/\partial t$, r = the discount rate, δ = depreciation rate of quasi-fixed inputs, and t = time. If producers expect technology to be stationary ($\dot{R} = 0$), then these equations would reduce to those initially derived by Epstein.

Empirical Application

Lyu and White applied dynamic duality theory for ten production regions in the United States, 1949-1979. The technology variable was based on an index of production-oriented research and extension expenditures, assuming a 13-year lag. Parameter estimates of equations (3), (4), and (5) are presented in Table 3. The hypotheses that farm real estate is variable and machinery is variable are tested. Note that equation (3) can be rewritten to have the form of a multivariate flexible accelerator with a constant adjustment coefficient as

(6) $I^* - \delta K = M(K - \bar{K})$

where $M = rU + D$

$\bar{K} = -(rU + D)^{-1}(D[ra_2 + rBp + rGw + rNR - NR])$, and

U is the identity matrix.

M is the constant adjustment matrix and $\bar{K}$ is the vector of steady state stocks. If a factor of production is perfectly variable then $M_{ii} = -1$ and $M_{ij} = 0$. These hypotheses were both rejected at the 1% significance level for farm real estate and machinery, indicating that farm real estate machinery can be specified as quasi-fixed inputs. The rejection of these hypotheses indicates the relevance of dynamic models.

The main concern of this study is to examine how technological change in U.S. agriculture affects factor demands and output supply. The technology elasticities of farm real estate, machinery, labor, intermediate input, and output were calculated by taking the derivatives of equations (3), (4), and (5) with respect to R and evaluating the variables at the sample means. The technology elasticities are .009, .0088, -.0065, -.0542, and 1.553 for farm real estate, machinery, labor, intermediate input, and output respectively. The positive sign of the technology elasticity for farm real estate indicates that the value marginal product of real estate increased as a result of agricultural research. This result coupled with the inelastic supply of farmland indicates that agricultural research contributed to rising farmland prices over the 1949-1979 period.

It is arguable whether the technology variable should have negative impacts on the demand for intermediate inputs, although the general perception is that advances in technology in U.S. agriculture have resulted in the increased use of intermediate inputs. The relationships between the technology variable and demand for machinery and labor and supply of output are as expected. Advances in technology have increased the demand for machinery and reduced the demand for farm labor. The largest effects of the technology variable are on output--a one percent increase in technology increased the total agricultural output by 1.553 percent. Since the technology index is composed of R & E expenditures, there is also a positive relationship between agricultural R & E and agricultural production.

Table 3. Parameter Estimates of Dynamic Factor Demands with Technological Change

Variables	Estimate	Standard Error
Intercept	-1934.40	4545.16
Real estate	-14.36	7.43
Machinery	-.23	4.46
Machinery price	-414.86	75.44
Wage	-2589.74	157.87
Materials price	8.72	74.83
R&E	47.25	93.38
Real estate squared	.06	.02
Real estate machinery	-.01	.01
Machinery squared	-.01	.01
Real estate price squared	-.01	.01
Real estate price, machinery price	.02	.01
Machinery price squared	-.04	.02
Wage squared	-.03	.01
Wage, materials price	.005	.005
Materials price squared	.005	.003
Real estate price, real estate	-.074	.009
Real estate price, machinery	-.13	.015
Machinery price, real estate	-.07	.011
Machinery price, machinery	-.13	.019
Wage, real estate	-3.27	.86
Wage, machinery	4.53	.71
Materials price real estate	-.65	.38
Materials price, machinery	-1.15	.31
R&E squared	-.36	.96
wage, real estate price	-2.77	1.02
Wage, machinery price	13.70	1.85
Materials price, real estate price	.49	.55
Materials price, machinery price	-7.86	.97
R&E, real estate	.10	.07
R&E, machinery	.03	.05
R&E, real estate price	.12	.13
R&E, machinery price	-.80	.41
R&E, wage	.09	.34
R&E, materials price	.38	.23

CONCLUSIONS

Duality provides a framework to estimate output supply and input demand relationships that are consistent with economic theory. Hence it is not surprising that the application of duality to production economics has received considerable attention in the economic literature over the past 15 years. This paper has reviewed the empirical evidence on technical change that has been forthcoming from these studies. The results across studies have been highly consistent, indicating significant technical change in the post war period. The results indicate that the technology has been labor saving and capital and chemical using. These results in themselves are not unlike results from other studies, but they do lend credibility to the general approach to duality.

In addition, there are some unique results available from these duality studies. In particular, the technical shifts in inputs versus outputs are interesting. There appeared to be greater shifts in the supply of such output categories as feed grains, oil crops, and livestock than the shifts in demand for any of the input categories. Also, the geographical distribution of where technical change has occurred is interesting. The Corn Belt experienced the greatest technical changes of all regions in the areas of demand for energy and machinery and supply of feed grains and oil crops. However, the Southern Plains experienced the greatest increase in the demand for materials and supply of livestock. The Northeast and Pacific regions experienced a significant increase in the demand for hired labor.

While the studies of static duality have generally focused on variable inputs, the concept of dynamic duality offers the opportunity to examine all inputs. However, this area of research has not yet attracted as much attention as the area of static duality. Available results from dynamic duality indicate a positive shift from technology in the demand for farmland, capital and output. The elasticity of output with respect to technology is several times greater than any elasticity of demand for inputs. The area of dynamic duality appears to be particularly fruitful for further research.

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