Heterogeneity in production technology across farm sizes:

Analysis of multi-output production function using Korean farm-level panel data

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Abstract

In this paper, we analyze the rice production technology in Korea in the context of multi-output framework. The estimation uses a set of national farm-level panel data within the primal approach. The particular focus of the study is to analyze the existence of heterogeneous technologies for different farm sizes, and the possibility of output substitution. Unlike many previous studies, we employ a farm-specific fixed effects model, that accounts for the effects of individual specific characteristics or constraints on production. Our results suggest that considerable differences in technology exist across various farm sizes. Interestingly, input substitution and output substitution possibilities are more limited for smaller farms. However, in general, output substitution possibilities are very limited across all farm sizes.

Introduction

The farm size distribution and its relationship with productivity growth have been subjects of considerable interest in theoretical and empirical research (Sumner et al., 2002, Hoque, 1991, Kumbhakar, 1993). Using the land area as a measure of farm size (Sumner and Wolf, 2002)), this paper examines the possibility of heterogeneous production technologies for different farm sizes in Korean agriculture.

The issue of farm size is important in Korean agriculture, particularly in the current environment of market opening. In an effort to improve farm productivity, considerable public efforts have been devoted to the expansion of individual land holdings. Furthermore, the anticipation of gradual opening of the rice market may also change the country's farm culture, that is dominated by rice farming. In the near future, it will be inevitable that Korean rice farmers have to find alternative crops to replace some of their rice crop. In this paper, we particularly focus on these two technology issues; production technology that may be specific to farm size, and the possibility and extent of output substitutions. The analysis of the latter, particularly, necessitates a multi-output context, and given the survey information used in this study, we adopt the primal approach within the multi-output framework.

In the formulation of production technology, we follow Mundlak (2000), who points out the importance of state variables such as human capital, physical environments and incentives to determine technology. To account for these unobservable individual effects on technology, we adopt a farm specific fixed effects model within the generalized linear transformation function (Diewert, 1973).

The specification of multi-output primal production technology

For the primal approach[1], various estimation methods have been used: 1) the estimation of an aggregated single production function by aggregating the multi-outputs into a single output index (Mundlak, 1963), 2) the estimation of separate production functions for each output using allocated input data for each output (Just et al., 1983; Shumway et al., 1984), 3) the estimation of a distance function (Lovell et al., 1994; Paul et al., 2000; Orea et al., 2002), and 4) the estimation of a transformation production function (Diewert, 1973). Each approach has pros and cons, and the choice of the appropriate approach depends on availability of data, model assumptions and study objectives. In this study, we employ a transformation production function for our empirical analysis.

Suppose a farm produces a vector of outputs $Y = (y_1, ..., y_M)$, using a vector of inputs,

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[1] Our choice of the primal approach is dictated by our data. Our panel data do not include prices. Especially, in the short panel, it is difficult to obtain appropriate price variations across firms for significant econometric parameter estimates.

$X = (x_1,...,x_K)$. W also assume a set of shift variables, $Z = (z_1,...,z_S)$. The set of feasible combinations of output, input, and shift variables may be described by the transformation function, $\tilde{T}(Y, X; Z) = 0$. For an alternative representation of the technology, Diewert (1973) suggests that the maximum production of any arbitrary y , say y_1 , given X and the rest of outputs, $Y^* = (y_2,..., y_m)$, can be expressed as $y_1 = T(Y^*, X; Z)$. For $T(Y^*, X; Z)$ to be well behaved, the transformation function must satisfy a standard set of regularity conditions: (a) Non-negative condition, i.e., $T(Y^*, X; Z) \geq 0$ over the range of the data, (b) non-decreasing in inputs, $\frac{\partial T(Y^*, X; Z)}{\partial x_k} = MP_{y_1, x_k} \geq 0$, (c) non-increasing in outputs, $\frac{\partial T(Y^*, X; Z)}{\partial y_m} = MRPT_{y_1, y_m} \leq 0$, and (d) concavity. The last concavity condition requires that the matrix of second order partial derivatives of $T(Y^*, X; Z)$ is negative semi-definite.

This approach permits the possibility of substitution between every pair of outputs with no further assumptions on outputs, and accommodates zero-valued observations with the appropriate choice of the functional form.[2] However, there are two major shortcomings of this approach. The estimation results depend on the output choice of the dependent variable, and the empirical equation does not have any theoretical justification for regularity conditions on the output relationships (Orea et al., 2002). However, our choice of this approach is due to one major benefit of this approach: this method allows us to examine overall production patterns: input-output relationships, output-output relationships, and input-input relationships.

In terms of input-output relationships, the shape of a production function in y_1 and x_k

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2 This is an important aspect for our study because about 15 percent of our observations contain zero-values. Some previous studies have dealt with zero-valued data by either discarding zero value observations or allowing potential bias by replacing zeroes with very small numbers (Paul et al, 2000).

space is represented through the marginal product (MP) of input, holding all other arguments of the function constant. The marginal product normalized by the observed output and input can be defined to express a proportionate change in the output return corresponding to a proportionate change in input x_k:

$$(1)\quad \varepsilon_{y_1,x_k} = \frac{\partial y_1}{\partial x_k}\frac{x_k}{y_1} = \frac{\partial \ln y_1}{\partial \ln x_k}.$$

Furthermore, the sum of output elasticities with respect to all inputs[3] represents the returns to y_1, associated with a proportionate change in inputs:

$$(2)\quad \varepsilon_{y_1} = \sum_{k=1}^{K}\frac{\partial \ln y_1}{\partial \ln x_k} = \sum_{k=1}^{K}\varepsilon_{y_1,x_k}\ .$$

Even though the notion of ε_{y_1} is similar to the returns to scale in the single output case, note that in (2) only y_1 changes, holding all other outputs constant. In this context, in what follows, we will term ε_{y_1} as "the restricted returns to scale." As usual, the extent of scale in output y_1 is represented by the degree of excess of ε_{y_1} from 1.

In the view of output-output relationships, the slope of the production possibilities frontier in y_m and y_n space, i.e., the marginal rate of product transformation (MRPT) indicates the rate at which one output displaces another at a given level of input and output (excluding y_m and y_n from the output vector) bundles. Due to the implicit function theorem, we define the marginal rate of product transformation (MRPT): $MRPT_{y_m,y_n} = \frac{\partial y_m}{\partial y_n} = -\frac{\partial T(.)/\partial y_n}{\partial T(.)/\partial y_m} = -\frac{\partial y_1/\partial y_n}{\partial y_1/\partial y_m}$. Note that each of outputs, y_m, y_n, could be y_1, and the MRPT involving y_1 can be computed. The production

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[3] Since the output elasticity with respect to input is measured holding other outputs fixed, we'll call the sum of output elasticities with respect to each input as the restricted output returns to scale in this paper.

possibilities frontier is concave to the origin, which implies an increasing rate of MRPT as the ratio of outputs $\frac{y_m}{y_n}$ falls. To represent this output transformation, we adopt the relative marginal rate of production transformation normalized by the observed output mix, following Grosskopf et al. (1995) and Paul (2000):

(3) $$\varepsilon_{y_m,y_n} = \frac{\partial y_m/\partial y_n}{y_m/y_n} = -\frac{\partial y_1/\partial y_n}{\partial y_1/\partial y_m}\frac{y_n}{y_m} = -\frac{\varepsilon_{y_1,y_n}}{\varepsilon_{y_1,y_m}}.$$

The absolute value of ε_{y_m,y_n} diverging from 1 reflects relative difficulty in substitution between these two outputs.

In terms of input-input relationships, the slope of isoquant in x_k and x_l space, i.e., the marginal rate of technical substitution (MRTS) represents the rate of trade-offs between x_l and x_k to produce a constant level of output y_1. The implicit function rule can be applied to derive the MRTS: $MRTS_{x_k,x_l} = \frac{\partial x_k}{\partial x_l} = -\frac{\partial T(.)/\partial x_l}{\partial T(.)/\partial x_k} = -\frac{\partial y_1/\partial x_l}{\partial y_1/\partial x_k} = -\frac{MP_{y_1,x_l}}{MP_{y_1,x_k}}$. If farms allocate inputs efficiently for a level of output, the slope of isoquant, $MRTS_{x_k,x_l}$ is equivalent to the ratio of two input prices under cost minimizing conditions. A typical isoquant is convex to the origin, which implies a decreasing rate of $MRTS_{x_k,x_l}$ as the ratio of input $\frac{x_k}{x_l}$ increases. Again, expressing this rate in elasticity form (normalizing MRTS by the observed ratio of two inputs), we obtain:

(4) $$\varepsilon_{x_k,x_l} = \frac{\partial x_k/\partial x_l}{x_k/x_l} = -\frac{\partial y_1/\partial x_l}{\partial y_1/\partial x_k}\frac{x_l}{x_k} = -\frac{MP_{y_1,x_l}}{MP_{y_1,x_k}}\frac{x_l}{x_k} = -\frac{\varepsilon_{y_1,x_l}}{\varepsilon_{y_1,x_k}}.$$

The absolute value of ε_{x_k,x_l} diverging from 1 suggests that there is a low degree of substitutability between these two inputs.

Turning to the discussion on shift variables, in addition to the usual term, the output elasticity of a shift factor (say z_s), $\varepsilon_{y_1,z_s} = \frac{\partial y_1}{\partial z_s}\frac{z_s}{y_1}$, the effect of a change in z_s on the MP_{y_1,x_k} also provides useful information:

(5) $$\varepsilon_{MP_{y_1,x_k},z_s} = \frac{\partial MP_{y_1,x_k}}{\partial z_s}\frac{z_s}{MP_{y_1,x_k}}.$$

Technical change can be specified by directly incorporating a time index in the function. Following Paul (1999), productivity change is defined in terms of technical change. More specifically, in the context of our transformation production function, the change in productivity is defined as the rate of growth of output y_1, holding all output and input constant, that is:

(6) $$TC_{y_1,t} = \frac{\partial T(.)}{\partial t} = \frac{\partial y_1}{\partial t} = \frac{d\ln y_1}{dt} - \sum_{m=1}^{M}\varepsilon_{y_1,y_m}\frac{d\ln y_m}{dt} - \sum_{k=1}^{K}\varepsilon_{y_1,x_k}\frac{d\ln x_k}{dt}.$$

Data

This study uses the panel data set collected from a national farm survey conducted by the Korean Ministry of Agriculture and Forestry (MAF). The data set includes detailed output and input information and farm characteristics. We have a balance panel data set of 2,636 farms for the period of 1998-2001. Most of our data were collected in value terms, and the data in value terms are deflated in real terms.

Input and output variables are aggregated into four inputs (k =4) and four outputs (m =4) for our empirical analysis. Four input categories are land (=x_A), labor (=x_L), capital (=x_C), and the purchased inputs (=x_P). The value for land input is imputed as the annualized flow of services from the price of land, calculated as an annuity based on a 20 year life and 10 percent annual rate of interest. Capital input includes machinery depreciation, repairs and leased farm equipment. Labor input consists of hired labor and family labor. The value for family labor is imputed at the regional average wage[4]. Purchased inputs include fertilizer, pesticide, livestock specific inputs, fuel, electricity, seed, and miscellaneous operating expenses. Four output categories are rice (= y_R), horticultural crops (= y_H), livestock products (= y_S), and other outputs (= y_O).

The average land holding in Korea is about 3 hectares. We grouped the sample farms into four by the size of land holding: SizeI (small farms) for the land holing less than 1ha, SizeII (medium farms) for the land holding between 1ha and 2ha, SizeIII (large farms) for the land holding between 2ha and 5ha, and SizeIV (very large farms) for the land holding greater than 5ha. Table 1 provides mean values of input and output related variables and farm size. Output shares and input shares are evaluated at total farm revenue and total farm expenditures, respectively. To investigate pattern of output diversification across farm sizes, we measure an index for diversification, the Herfindahl index. In table 2, the Herfindahl index $\mathrm{H_o}$ represents a degree of diversification of outputs. It is defined as $\mathrm{H_o} = 1 - \sum_{m=1}^{4} \gamma_m^2$, where γ_m is the revenue share of output m in the total farm income. The index value closer to zero indicates less diversification.

The econometric model

We estimate the generalized linear transformation function suggested by Diewert (1973), which extends a linear functional form by allowing a full set of interactions among arguments in the

4 When regional wage of hired labor is used to deal with unpaid family labor, there may be the possibility of underestimation of the cost of family labor spent on the farm. Schultz (1972) notes that farm operators and members of their households have on average a much larger stock of human capital (education, experience) than their hired farm workers do. Thus, it seems to be plausible that valuing unpaid family labor using an opportunity cost approach based on off farm labor markets. However, availability of data prevents us from using off-farm wage as the opportunity cost of family labor.

function. In the context of panel information, individual i 's production of y_1 given X and Y^* is expressed as:

$$
\begin{aligned}
T(Y^*, X; Z)_{it} = y_{1it} &= \alpha_1 + 2\sum_m \alpha_m y_{mit}^{1/2} + \sum_m \sum_n \beta_{mn} y_{mit}^{1/2} y_{nit}^{1/2} \\
&+ 2\sum_k \alpha_k x_{kit}^{1/2} + \sum_k \sum_l \beta_{kl} x_{kit}^{1/2} x_{lit}^{1/2} + \sum_k \sum_m \beta_{km} x_{kit}^{1/2} y_{mit}^{1/2} \\
&+ 2\sum_s \alpha_s z_{sit}^{1/2} + \sum_s \sum_q \beta_{sq} z_{sit}^{1/2} z_{qit}^{1/2} + \sum_k \sum_s \beta_{ks} x_{kit}^{1/2} z_{sit}^{1/2} + \sum_m \sum_s \beta_{ms} y_{mit}^{1/2} z_{sit}^{1/2} + u_{it}
\end{aligned}
\tag{7}
$$

where t indexes time, and u_{it} is the disturbance term. For notational simplicity, the time variable is included in vector z , and another element in z includes the schooling of farm manager. The outputs included in the right hand side of equation (7) exclude y_1 . If $\alpha_i = 0$ for all i , then the transformation function (7) exhibits linear returns to scale of y_1 (holing the rest of outputs constant).

We assume that the disturbance term is decomposed into three error components. That is, $u_{it} = v_i + \tau_t + \varepsilon_{it}$. The error term v_i accounts for both nested farm fixed effects of the i th farm. Nested farm fixed effects includes all unobserved farm specific components that may vary across farms. The error term τ_t indicates individual invariant and time fixed effect. The last term ε_{it} represents the random error component. Our fixed effects model reduces omitted variables bias by controlling for unobserved farm fixed effects (Baltagi, 2001), which also reduces simultaneous equations bias to the extent that the unobserved components (such as managerial ability and individual specific constraints) affect both production and input use. Mundlak (1978) asserts under certain simplifying assumptions, the fixed effects model (the within estimator or covariance analysis) controls for simultaneity caused by endogenous input use.

Within the specification in (7), the production parameters discussed in the earlier section can be obtained:

(1)' $\varepsilon_{y_1,x_k} = (\alpha_k x_k^{-1/2} + \sum_{l=1}^{L} \beta_{kl} x_l^{1/2} x_k^{-1/2} + \sum_{m=1}^{M} \beta_{km} y_m^{1/2} x_k^{-1/2} + \sum_{s=1}^{S} \beta_{ks} z_s^{1/2} x_k^{-1/2})(\frac{x_k}{y_1})$

(2)' $\varepsilon_{y_1,y_m} = (\alpha_m y_m^{-1/2} + \sum_{n=1}^{N} \beta_{mn} y_n^{1/2} y_m^{-1/2} + \sum_{k=1}^{K} \beta_{km} x_k^{1/2} y_m^{-1/2} + \sum_{s=1}^{S} \beta_{ms} z_s^{1/2} y_m^{-1/2})(\frac{y_m}{y_1})$

(3)' $\varepsilon_{y_1,z_s} = (\alpha_s z_s^{-1/2} + \sum_{q=1}^{Q} \beta_{sq} z_s^{1/2} z_q^{-1/2} + \sum_{k=1}^{K} \beta_{ks} x_k^{1/2} z_s^{-1/2} + \sum_{m=1}^{M} \beta_{ms} y_m^{1/2} z_s^{-1/2})(\frac{z_s}{y_1})$

Finally, mentioned earlier, the choice of y_1 is crucial for the estimation, and depends on the data and research focus. In this study, we chose rice as y_1, given the importance of rice in the Korean agriculture.

Econometric results

We estimated equation (7) separately for the five sets of data, the pooled data (the entire sample) and each of the four subsets grouped by size. Using the pooled data, we first examined whether significant differences in the estimated parameters exist across four farm size classes. The F-test result indicates that we reject the null hypothesis of no technology difference at 5 percent level of significance. We also examined the validity of the specification of individual farm fixed effects model. Our test of the joint significance of individual farm dummies indicates that we reject the null hypothesis of no distinct individual effects at the 5 percent level of significance.

We do not report the parameter estimates. Production parameters are calculated using the expressions above and reported in Tables 3 through 7. All elasticities are evaluated at the sample means. In general, all models reasonably satisfy the regularity conditions for our transformation production function.

Table 3 reports output elasticities with respect to input change. In general, we do not observe any systematic pattern related to size. Output elasticities tend to be smaller for the mid size farms and larger for the small and large farms. However, there is a substantial difference between small and large farms in output elasticities with respect to capital. All farm sizes exhibit decreasing restricted rice returns to scale. In terms of outputs relationships, Table 4 shows that the values for elasticities of output substitutions are close zero. This indicates low substitutability between rice and non-rice crops. The substitution elasticities between horticultural crops and livestock products are relatively higher than those for any output pairs. Especially, SizeIII shows relatively a higher value of –1.96 between horticultural crops and livestock. Overall, our results are consistent with relatively lower diversification index values obtained for small farms and very large farms (Table 1).

The possibility of Input substitutions is in general higher than that of output. As shown in Table 5, for small farms, there exists a relatively higher substitutability between land and labor, and between land and purchased inputs, while capital is not easy to substitute with other inputs. For larger farm size, capital replaces other inputs effectively.

The output elasticity for schooling does not reflect the effect of schooling on output change in the farm fixed effect model as discussed in the previous subsection, thus direct schooling impact on rice production is not interpretable. Instead, we can infer indirect impacts of schooling on marginal products of inputs. In Table 6, schooling has a positive relationship with marginal product of labor, as we expected. Especially, the schooling in very large farms affect positively marginal products of all inputs, implying human capital plays an important role in improving productivity of inputs.

Table 7 reports the results on technical change. Technical change effects for farms in SizeI and SizeII are negative and for farms in SizeIII and SizeIV, these effects are positive. This implies that productivity for rice is increasing for larger farms. As noted earlier, technical change (or productivity change) in our model is measured as the net change in rice production after eliminating the substitution effects between rice and non-rice crops, and scale effects of inputs. Therefore, we need to investigate each term consisting of productivity measure in order to find the reasons for positive rice productivity in larger farms. The results shown in Table 7 imply the productivity growth for larger farms is due to unexplained technical change, rather than scale effects of inputs. This is consistent with our earlier result the restricted rice returns to scale is decreasing.

Summary

We summarize the implications of production parameters representing heterogeneous production technologies across farm sizes. The production technology in term of output mix and input use differ substantially across farm sizes. Small farms are less productive than medium or larger farms. Restricted rice returns to scale, holding non-rice crops fixed, are less than one for all farms, and restricted rice returns to scale for the small farms are much larger than those for medium farms.

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Table 1. Descriptive statistics, 1998-2001

	All		SizeI		SizeII		SizeIII		SizeIV	
Number of Obs.	10,544		4,480		3,559		2,261		244	
	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D
					- All year averages -					
Production pattern characteristics										
Share of Rice	0.45	0.33	0.43	0.35	0.46	0.30	0.47	0.31	0.61	0.38
Share of Horticulture crops	0.36	0.32	0.37	0.33	0.38	0.32	0.33	0.30	0.23	0.32
Share of Livestock products	0.08	0.16	0.10	0.20	0.06	0.13	0.06	0.12	0.03	0.08
Share of Other output	0.11	0.17	0.11	0.16	0.10	0.15	0.14	0.20	0.14	0.23
Share of Land	0.37	0.21	0.39	0.24	0.36	0.20	0.35	0.17	0.39	0.17
Share of Labor	0.24	0.13	0.25	0.14	0.24	0.11	0.22	0.10	0.17	0.09
Share of Capital	0.15	0.11	0.14	0.11	0.16	0.10	0.18	0.10	0.20	0.11
Share of Purchased inputs	0.23	0.13	0.22	0.15	0.24	0.12	0.25	0.11	0.25	0.10
Farm manager characteristics										
Schooling	2.77	0.99	2.69	1.02	2.73	0.95	2.93	0.93	3.22	1.05

Table 2. Degree of Output Diversification

	All	SizeI	SizeII	SizeIII	SizeIV
			Herfindahl Index		
H_O	0.38	0.37	0.40	0.41	0.25
	(0.21)	(0.21)	(0.20)	(0.20)	(0.19)

Note: Standard errors are shown in parentheses.

Table 3. Output elasticities for inputs

Variable	Farm average	SizeI	SizeII	SizeIII	SizeIV
	$\varepsilon(y_m, x_k)$				
(Rice, Land)	0.31	0.27	0.11	0.15	0.17
(Rice, Labor)	0.23	0.22	0.05	0.06	0.17
(Rice, Capital)	0.13	0.03	0.01	0.11	0.20
(Rice, Purchased input)	0.12	0.22	0.03	0.03	0.10
Restricted rice return to scale	0.79	0.73	0.19	0.35	0.63

Table 4. Elasticities of output substitution

Variable	Farm average	SizeI	SizeII	SizeIII	SizeIV
	$\varepsilon(y_m, y_n)$				
(Rice, Horticulture crops)	-0.08	-0.15	-0.06	-0.01	-0.15
(Rice, Livestock products)	-0.03	-0.02	0.02	-0.03	-0.09
(Horticulture crops, Livestock products)	-0.41	-0.11	-0.27	-1.96	-0.58

Table 5. Elasticities of input substitution

Variable	Farm average	SizeI	SizeII	SizeIII	SizeIV
	$\varepsilon(x_k, x_l)$				
(Land, Labor)	-0.72	-0.81	-0.46	-0.38	-0.95
(Land, Capital)	-0.42	-0.09	0.05	-0.74	-1.13
(Land, Purchased inputs)	-0.37	-0.81	-0.29	-0.22	-0.55
(Labor, Capital)	-0.58	-0.12	0.11	-1.94	-1.18
(Labor, Purchased inputs)	-0.52	-1.00	-0.64	-0.58	-0.58
(Capital, Purchased inputs)	-0.88	-8.68	-5.65	-0.30	-0.49

Table 6. The effects of schooling on marginal products of inputs

Variable	Farm average	SizeI	SizeII	SizeIII	SizeIV
	$\varepsilon\,(MP_{y_{Rice},x_k}, z_s)$				
(MP(Rice, land), schooling)	-0.12	-0.66	0.22	-0.47	1.10
(MP(Rice, labor), schooling)	0.47	-0.24	2.51	-1.34	3.59
(MP(Rice, Capital), schooling)	-2.25	-2.98	-6.57	-2.22	0.46
(MP(Rice, Purchased input), schooling)	-1.08	-0.95	1.59	-1.96	0.37

Table 7. Technical change

Variable	Farm average	SizeI	SizeII	SizeIII	SizeIV
	Technical change (all year average): $TC_{y_1,t}$				
Technical change	-0.02	-0.12	-0.13	0.17	0.97
Output substitution effect	0.01	0.01	0.01	0.00	-0.33
Scale effect of inputs	0.01	-0.02	-0.05	0.09	1.28