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The Impact of Land Fragmentation on Rice Production Cost and Input Use

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This article estimated the impacts of land fragmentation on production costs and input demands using panel data of Japanese rice farms. Empirical results reveal that fragmentation increases production costs and offsets economies of size, and that these impacts are strong especially for large size farms. This result implies that as the farm gets larger, emphasis should be switched from increasing size to the settlement of fragmentation, in order to enhance efficiency. Moreover, it was demonstrated that fragmentation increases not only fuel inputs and labor hours for weeding and harvesting as generally accepted, but also managerial labor such as bookkeeping and meeting, and materials such as fertilizers and pesticides probably due to the substitution effects from labor. The range of fragmentation's impacts is spread beyond our scope. This result implies that the settlement of fragmentation will bring not only the reduction of production cost but also an environmental benefit by reducing fertilizers and pesticides.

Key words: economies of size, farmland fragmentation, panel data, factor demands, stochastic frontier cost function.

1. Introduction

In Japan, where farms are quite small in size, cost reduction by increasing farm size has been an important policy issue for a long time. However, over the last two decades, the average size of rice farms has increased meagerly from 0.74 to 0.90 ha.[1] According to a survey conducted by the Ministry of Agriculture, Forestry and Fisheries (MAFF), 38% of farmers stated that the dispersion of plots is why an increase in farm size does not occur (MAFF [23]), and 65% of large farmers (approximately 4 ha or more) stated that they give priority to land consolidation over an increase in size (MAFF [24]). Land fragmentation is regarded as an obstacle to farm size growth and efficient rice production.

Yet rigorous empirical studies are rare. Despite the attention land fragmentation receives, we know little about the impact of land fragmentation quantitatively. Fragmentation likely requires more time and fuel for traveling between plots, more water and weed management, and eventually, it results in higher production cost. But it remains unclear how much land fragmentation increases the inputs, and how much fragmentation increases the production cost. To help fill this gap, this article clarifies these impacts using the panel data of Japanese rice farms.

The structure of the article is as follows. In the next section, the literature on land fragmentation is overviewed and its limitations are discussed. The impact on cost is analyzed in the third section using a stochastic frontier cost function, while the fourth sec-

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tion analyzes the impact on inputs use. The final section summarizes our findings and concludes.

2. Previous Studies

Table 1 summarizes previous studies which analyzed land fragmentation econometrically. The degree of fragmentation is measured either by the number of plots, the number of parcels (a "parcel" refers to a gathering or complex consisting of several neighboring plots), travel distance, travel time, plot size, or the Simpson Index (SI). SI of ith farm is defined as $1-\sum_{k=1}^{K_i}(A_{ik}^2)\Big/(\sum_{k=1}^{K_i}A_{ik})^2$ where A_{ik} is the acreage of the kth plot of the ith farm ($i\in\{1,\ldots,N\}$, $k\in\{1,\ldots,K_i\}$). A value of zero indicates complete land consolidation (one plot only), while a value of one is approached by the holdings of numerous plots.

Intuitively, the number of plots/parcels, time, distance and SI are expected to be correlated positively with input quantity and cost, and negatively with output. However, such results are not always obtained. Suginaka and Hashimoto [28], for example, find negative correlation between the number of parcels and the production cost. Similarly, some of other studies also arrive at contradictory or insignificant results.

Possible explanations for such an unsatisfactorily results are, first, they use aggregated data across several crops, rather than a single crop. Since the impact of fragmentation can vary across different crops, aggregation must cause biases. Secondly, unobserved heterogeneity in farm efficiency is not always controlled for. Although a few studies controlled for it with a stochastic frontier model, most of them uses cross section data which requires more restrictive assumptions on the efficiency distribution than that of panel data studies (Kumbhakar and Lovell [18]). In addition, although numerous attempts have been made to estimate the impact of fragmentation on output by using the production function approach, their results do not fully reflect fragmentation costs. The cost-function approach is suitable to measure fragmentation costs appropriately.

Apart from econometric studies, Matsuoka [21] shows a good example of how land fragmentation increases the production cost among Japanese rice farms. He calculates the travel cost, loading time and operation time based on the survey, and concludes that the sum of labor cost and material cost increases by up to 10%. [2] However, the result depends on just eight farms in Ehime Prefecture whose farm size is about one hectare. It is important to clarify the impact of fragmentation more comprehensively using a larger dataset.

3. The Impact on Production Cost

1) Model

Our econometric model addresses all of these issues: it measures the impacts on the cost side rather than the production side, and our stochastic frontier analysis controls for unobserved heterogeneity. Our detailed panel data on rice farms allow us to avoid aggregation bias as well as ad-hoc assumption on the efficiency distribution. The analysis consists of two stages, and the cost function is estimated in the first stage. We use the well-known translog form, defined as follows.

$$\begin{aligned}\ln C_{it}=&\alpha_0+\alpha_Y\ln Y_{it}+\alpha_{YY}\ln Y_{it}\ln Y_{it}\\&+\sum_{m=1}^{4}\alpha_m\ln w_{mit}+\sum_{m=1}^{4}\alpha_{Ym}\ln Y_{it}\ln w_{mit}\\&+\frac{1}{2}\sum_{m=1}^{4}\sum_{n=1}^{4}\alpha_{mn}\ln w_{mit}\ln w_{nit}\\&+\sum_{t=1996}^{2006}\alpha_tT_t+u_i+v_{it}\end{aligned}\quad(1)$$

Here, C is the cost, Y is the output, w is the input price, T is the year dummy, u is a farm-specific inefficiency, v is a random error, subscript i and t denote farm and year respectively ($t\in\{1995,\ldots,2006\}$), and subscript m and n denote inputs ($m,n\in\{1,2,3,4\}$). There are four types of inputs: land, capital, labor, and materials. Farm-specific effect u is assumed to be constant over time since the length of the data per farm is just 4.9 years on average. [3] Although this assumption ignores farm-specific technological change, average technological change that is common to all farms is captured by year dummies.

In estimating this equation using micro data, two problems arise. The first is the treatment of the farm-specific effect u. If this is ignored and OLS is performed, heterogeneity bias arises when the farm-specific effect and independent variables are correlated. There-

Table 1. Summary of previous studies on land fragmentation

	Crop	Country	Frontier analysis	Panel data	Dependent variable	Impact of land fragmentation				
						No. of plots	No. of parcels	SI	Travel distance	Travel time
Ali, Parikh and Shah (1994)	Aggregated	Pakistan	Yes	No	Revenue	n. s.	—	—	—	—
Ali, Parikh and Shah (1996)	Aggregated	Pakistan	Yes	No	Cost	n. s.	—	—	—	—
Blarel et al (1992)	Aggregated	Rwanda and Ghana	No	No	Output	n. s.	—	n. s.	n. s. or P or N	—
Byiringiro and Reardon (1996)	Aggregated	Rwanda	No	No	Output	n. s.	—	—	—	n. s.
Fleisher and Liu (1992)	Aggregated	China	No	No	Output	N	—	—	—	—
Hung et al (2007)	Aggregated	Vietnam	Yes	Yes (2 years)	Output	N	—	—	—	—
Jabarin and Epplin (1994)	Wheat	Jordan	No	No	Variable cost	—	—	—	—	—
Jha, Nagarajan and Prasanna (2005)	Aggregated	India	Yes	Yes (5 years)	Output	N	—	—	—	—
Nguyen, Cheng and Findlay (1996)	Rice, wheat and maize	China	No	No	Output	—	—	—	—	—
Parikh and Shah (1994)	Aggregated	Pakistan	Yes	No	Output	N	—	—	—	—
Rahman and Rahman (2009)	Rice	Bangladesh	Yes	No	Output	N	—	—	—	—
Suginaka and Hashimoto (2007)	Rice	Japan	No	No	Total cost and labor cost	—	n. s. or N	—	—	—
Tan et al (2008)	Rice	China	No	No	Cost Labor Materials	— — —	— — —	n. s. P n. s. or N	— — —	P P n. s. or P
Wadud and White (2000)	Aggregated (95% is rice)	Bangladesh	Yes	No	Output	—	—	—	—	—
Wan and Cheng (2001)	Rice, wheat, maize and tuber crops	China	No	No	Output	N	—	—	—	—

Note: "P" indicates significantly positive, "N" significantly negative, while "n. s." means not significant. "—" indicates result is not available.

fore, the panel data approach is required. The second problem is that output variable is stochastic, and therefore, it may be correlated with the error term, giving rise to measurement error bias. This problem, known as "regression fallacy" (Walters [31]), can be solved using an instrument for output which is uncorrelated with the error term. Following Martin [20] and Alvarez and Arias [3], we estimate the production function and use the predicted output as a proxy in the cost function.

The second stage investigates the determinants of inefficiency by regressing the predicted inefficiencies, obtained from the estimated cost functions, upon a vector of farm-specific factors, such as the index of land fragmentation (F) and vectors of other determinants ($\mathbf{D}$). Since u is time-invariant, explanatory variables are averages over years. [4)]

$$u_i = \beta_0 + \beta_F F_i + \mathbf{D}_i \boldsymbol{\beta} + v^*_i \qquad (2)$$

2) Data

The micro data is obtained from the 1995-2006 *Kome Seisanhi Chosa Tokei* (*Production Cost Statistics of Rice*). Cost is total production costs. [5)] An output is defined as kilograms of rice excluding by-products (rice straw or poorly ripened rice).

The amount of land is defined by total planting acreage, and land rent is obtained by dividing land cost (the land rent actually paid plus the opportunity cost of own land evaluated at regional average of the land rental rates) by the amount of land.

For labor input, wage is derived from dividing the expenditure on labor (wage actually paid for hired labor plus the opportunity cost of unpaid family labor evaluated at regional wage rate) by the sum of hired labor hours and family labor hours. [6)] The challenging task is to decompose the expenditure on the "rental services." This is the sum of the expenditure on the outsourcing and machinery leasing, and so the labor cost and capital cost are mixed. To separate these two, we first estimate labor hours in rental services by multiplying outsourcing acreage (by farm, year and operation type. Operation type is categorized into six: seed raising; tillage and soil preparation; planting; pest control; harvesting; drying and processing) by average operation hours among contracted farms (by year and types). Here, "contracted farm" refers to the farms offering services for outsourcing activities (while "outsourcing farm" refers to the farms which outsource any tasks to others). Next, we calculate imputed labor cost by multiplying wage by estimated labor hours in rental services. Imputed capital cost is obtained by subtracting imputed labor cost from the rental services. Then we define the amount of labor by summing hired labor hours, family labor hours and estimated labor hours in rental services.

As for materials, price index is defined as $\sum_{s=1}^{5} PM_{st} \cdot CM_{sit} \Big/ \sum_{s=1}^{5} CM_{sit}$ where subscript s denotes to five kinds of materials (seeds and seedlings; fertilizers; pesticides; fuels; miscellaneous materials), PM is the price index cited from *Nogyo Bukka Shisuu Tokei* (*Agricultural Price Index Statistics*), and CM is the expenditure on each material. Dividing the total material expenditure (the sum of above five categories and management cost) [7)] by this price index defines the amount of materials.

The amount of capital is defined by the sum of asset value of fixed capital (building, machinery, car and land improvement facility). The capital price is derived from dividing the expenditure on capital (the sum of depreciation and repair cost of machinery; depreciation of management cost ; land improvement and irrigation cost; imputed capital cost of rental services; and interest) by the amount of capital. [8)]

The land fragmentation (F) is measured by the number of plots, the number of parcels, [9)] the Simpson Index (SI) or plot size. Table 2 reports the averages of fragmentation indices by farm size (measured by rice planting acreage). It shows that the number of plots and parcels increases monotonically over the size range, and farms in the largest category hold more than 60 plots over 9 parcels. Plot size increases as farm size grows; however, SI which takes account of both plot size and the number of plots indicates that larger farms face more severe land fragmentation.

In order to stabilize the results, we use data from farms that have more than three observations, whose land is less than 50 ha, and are located neither in Hokkaido nor Okinawa Prefecture. As a result, the data used for estimation is an unbalanced panel consisting of 13,562 observations from 2,754 farms. The length of the data per farm is on average 4.9 years (three years at the minimum, 12 years at the maximum).

3) Results

Table 3 shows estimated results of equation (1). We imposed the usual homogeneity and symmetry restrictions. The former is carried out by dividing cost and input prices by material price. The latter symmetry restrictions impose $\alpha_{mn}=\alpha_{nm}$ for $m \neq n$ in equation (1). Following standard practice, all variables are normalized (dividing by their own average). Therefore, the coefficients of the first-order parameters can be interpreted as the input

Table 2. Mean values of land fragmentation indices by farm size

	Obs.	Acreage (ha)	No. of plots	No. of parcels	SI	Plot size (ha)
Under 0.5 ha	3,553	0.35	3.9	2.2	0.60	0.12
0.5-1 ha	4,491	0.73	6.3	3.0	0.75	0.15
1-2 ha	4,798	1.43	10.1	4.0	0.84	0.18
2-4 ha	2,872	2.72	15.8	5.1	0.90	0.22
4-8 ha	1,592	5.60	26.2	6.1	0.94	0.26
Over 8 ha	1,477	16.20	62.9	9.3	0.97	0.40

Source: 1995-2006 *Kome Seisanhi Chosa Tokei* (*Production Cost Statistics of Rice*).

Table 3. First-stage regression results

	(1)	(2)	(3)		(1)	(2)	(3)
Predicted output	Yes	Yes	No		(contd)	(contd)	(contd)
Model	FE	OLS	FE				
Output	0.736	0.846	0.628	Year dummies (1995=0)			
	[53.7]***	[88.4]***	[44.5]***	1996	−0.0226	−0.0247	−0.0258
Output×Output	0.0055	0.0158	0.0004		[4.6]***	[2.9]***	[4.9]***
	[1.3]	[9.1]***	[0.1]	1997	−0.0144	−0.0193	−0.0214
Wage	0.175	0.201	0.245		[3.0]***	[2.3]**	[4.1]***
	[3.6]***	[3.9]***	[4.7]***	1998	−0.0021	−0.0030	−0.0186
Wage×Wage	−0.083	0.224	−0.065		[0.4]	[0.4]	[3.1]***
	[1.3]	[3.5]***	[1.0]	1999	−0.0282	−0.0354	−0.0414
Land rent	0.194	0.113	0.206		[4.9]***	[4.0]***	[6.8]***
	[9.3]***	[5.5]***	[9.2]***	2000	−0.0690	−0.0764	−0.0776
Land rent×Land rent	0.0541	0.0589	0.0525		[11.6]***	[8.7]***	[12.2]***
	[6.8]***	[7.6]***	[6.2]***	2001	−0.0796	−0.0844	−0.0919
Capital price	0.00957	−0.03840	0.01160		[12.9]***	[9.5]***	[14.0]***
	[1.8]*	[6.6]***	[2.0]**	2002	−0.0830	−0.0937	−0.0947
Capital price×Capital price	−0.00716	0.00315	−0.00740		[12.3]***	[9.7]***	[13.1]***
	[10.2]***	[3.4]***	[9.9]***	2003	−0.0318	−0.0420	−0.0522
Wage×Land rent	0.0568	−0.0359	0.0411		[4.5]***	[4.2]***	[6.8]***
	[1.6]	[1.0]	[1.1]	2004	−0.0806	−0.0791	−0.0905
Wage×Capital price	−0.0342	0.0055	−0.0151		[9.2]***	[7.0]***	[9.7]***
	[2.3]**	[0.3]	[1.0]	2005	−0.0961	−0.1120	−0.1040
Land rent×Capital price	−0.00398	−0.00282	0.00284		[10.4]***	[9.5]***	[10.5]***
	[0.6]	[0.4]	[0.4]	2006	−0.101	−0.128	−0.113
Output×Wage	−0.0404	0.0397	−0.0207		[10.2]***	[10.4]***	[10.7]***
	[2.1]**	[2.6]**	[1.0]	Constant	0.168	−0.070	0.139
Output×Land rent	0.0179	0.0221	0.0199		[11.8]***	[5.0]***	[9.3]***
	[2.4]**	[3.9]***	[2.5]**				
Output×Capital price	0.0005	0.0182	0.0004	Observation	13,562	13,562	13,562
	[0.1]	[6.0]***	[0.1]	R-squared	0.897	0.916	0.888

Note: Absolute values of *t*-statistic are in brackets. Asterisk (*), double asterisk (**) and triple asterisk (***) denote variables significant at 10%, 5% and 1% respectively.

elasticities at the point of approximation (sample mean). All of them are positive and significantly different from zero in the expected manner except for the capital price in column (2).

Column (1) in Table 3 shows fixed effect (FE) estimates using predicted output from the Cobb-Douglas production function.[10] Since the Hausman test could not accept the orthogonality of the farm-specific effects and the regressors at any reasonable size of the test, the FE model, rather than the random effect model, is applied to estimate both production functions and cost functions.

For comparison, OLS estimates (using the predicted output) are shown in column (2), and FE estimates without the predicted output are shown in column (3). That is, column (2) can suffer from heterogeneity bias and column (3) from measurement error bias. Generally speaking, especially when the length of the panel is short, FE is strongly influenced by the measurement error and results in downward bias. We find the existence of this bias from the fact that the coefficient of output in column (3) is lower than that of column (1). Moreover, when farm-specific effects and other independent variables are correlated, OLS gives rise to heterogeneity bias. As suggested by the Hausman test, such a correlation does exist. Therefore, we can see that most coefficients in column (2) are different from those of column (1).

In column (1), the F-test rejects the Cobb-Douglas and homotheticity, and accepts the translog form (F-statistics are omitted in the table). R-squared is approximately 0.9, meaning the explanation power of the model is strong. Fitted cost share for each input calculated by Shephard's Lemma (the logarithmic partial derivative of the cost function with respect to input prices) is positive in most cases,[11] meaning that monotonicity is satisfied for the relevant range.

Results of the second stage regressions are shown in Table 4. Here, dependent variables (farm-specific inefficiency u) are obtained from the estimated cost functions shown in column (1) in Table 3. Most notably, the number of plots, the number of parcels, and SI are all significantly positive, implying that land fragmentation induces cost inefficiency. Unlike SI, the number of plots and the number of parcels do not reflect the plot size. Thus, we added plot size as a explanatory variable to columns (1) and (2), but columns (4) and (5) shows that plot size is insignificant and makes little difference. Therefore, we rely on the columns (1) through (3) for further analysis.

Among other variables, the outsourcing dummy is negative implying that outsourcing reduces costs. On the other hand, the contracted farm dummy is insignificant or positive. However, these results do not necessarily mean that contracted farms are less profitable because their farm income is not only from the rice they produce, but also from the contracted services they offer. The direct seeding dummy is not significant. It is known that direct seeding reduces production cost by 10% through saving labor hours and seed raising costs. But it also has a negative side effect in reducing rice yield by 10%; therefore production cost per output changes little (MAFF [25]). Our result reflects such a stylized fact. As expected, geographical dummies imply that the inefficiency is the largest in hilly and mountainous areas, followed by urban areas and then flat farming areas. Farms with more than 80% readjusted land are also cost-effective.

Table 5 reports elasticities of average cost (total cost C divided by the output Y) calculated with estimated parameter values (column 1 in Table 3 and columns 1 through 3 in Table 4) and sample means in each size category. Elasticities of average cost with respect to the number of plots, the number of parcels, and SI are consistently negative and their absolute values increase over size range. To see how large the impacts of fragmentation are, assume that farms consolidate several separate parcels into a single parcel. For example, if farms in the largest category consolidate nine parcels (see Table 2) into a single parcel, the production cost can be reduced by 11.6% ($0.130 \times -8/9$). Similarly, if farms in the category of "4-8 ha" consolidate six parcels into a single parcel, the cost reduction amounts to 6.5% ($0.078 \times -5/6$). The impact of fragmentation on the cost is by no means trivial.

From the output elasticity in column (4), it turns out that cost can be reduced by 0.275%

Table 4. Second-stage regression results

	(1)	(2)	(3)	(4)	(5)
No. of plots	0.00320			0.00322	
	[2.6]***			[2.6]***	
No. of parcels		0.0104			0.0104
		[8.9]***			[8.8]***
SI			0.384		
			[11.8]***		
Average plot size				0.00013	−0.00006
				[0.3]	[0.1]
Family labor ratio	−0.0696	−0.0680	−0.1060	−0.0681	−0.0686
	[1.0]	[1.0]	[1.6]	[1.0]	[1.0]
Contracted farm dummy	0.0201	0.0303	0.0095	0.0199	0.0303
	[1.2]	[2.5]**	[0.8]	[1.1]	[2.5]**
Outsourcing dummy	−0.0881	−0.0927	−0.0709	−0.0879	−0.0928
	[7.6]***	[8.6]***	[6.4]***	[7.5]***	[8.6]***
Direct seeding dummy	−0.0243	−0.0156	−0.0033	−0.0254	−0.0151
	[0.6]	[0.4]	[0.1]	[0.6]	[0.4]
Geographical dummies (flat farming area=0)					
City areas	0.0454	0.0449	0.0437	0.0460	0.0446
	[3.5]***	[3.5]***	[3.4]***	[3.6]***	[3.4]***
Hilly areas	0.0672	0.0712	0.0667	0.0679	0.0709
	[6.3]***	[6.6]***	[6.3]***	[6.2]***	[6.4]***
Mountainous areas	0.0900	0.0928	0.0915	0.0907	0.0925
	[4.9]***	[5.0]***	[5.0]***	[4.9]***	[5.0]***
Land readjustment ratio dummies (under 50%=0)					
50-80%	−0.0197	−0.0240	−0.0084	−0.0201	−0.0238
	[1.1]	[1.3]	[0.5]	[1.1]	[1.3]
over 80%	−0.0356	−0.0386	−0.0141	−0.0366	−0.0382
	[2.8]***	[3.0]***	[1.1]	[2.8]***	[2.9]***
Regional dummies (Tohoku=0)					
Hokuriku	0.0759	0.0762	0.0750	0.0749	0.0843
	[6.4]***	[6.4]***	[6.2]***	[6.2]***	[7.3]***
Kanto/Tosan	0.0075	0.0076	−0.0048	−0.0048	0.0233
	[0.6]	[0.6]	[0.4]	[0.4]	[1.9]*
Tokai	0.0272	0.0277	0.0123	0.0121	0.0524
	[1.3]	[1.3]	[0.6]	[0.6]	[2.7]***
Kinki	0.0784	0.0788	0.0579	0.0577	0.1100
	[4.3]***	[4.3]***	[3.2]***	[3.2]***	[6.2]***
Chugoku/Shikoku	0.0328	0.0332	0.0181	0.0179	0.0528
	[1.8]*	[1.8]*	[1.1]	[1.1]	[3.2]***
Kyushu	0.0014	0.0015	−0.0130	−0.0131	0.0193
	[0.1]	[0.1]	[0.8]	[0.8]	[1.2]
Constant	0.0551	0.0514	0.0575	0.0591	−0.2170
	[0.8]	[0.7]	[0.8]	[0.8]	[3.0]***
Observations	2,754	2,754	2,754	2,754	2,754
R-squared	0.127	0.118	0.154	0.127	0.118

Note: Absolute values of *t*-statistic are in brackets. Asterisk (*), double asterisk (**) and triple asterisk (***) denote variables significant at 10%, 5% and 1% respectively.

from 1% size expansion for farms in the smallest category, and 0.168% for farms in the largest category. That is, although the slope gradually becomes less steep, the average cost curve is downsloping in all categories, suggesting the existence of economies of size—costs increase less than proportionately to changes in output.

Among agricultural economists (e.g., Alavarez and Arias [3] and Castle [6]), it is

Table 5. Average cost elasticities

	(1) No. of plots	(2) No. of parcels	(3) SI		(4)	(5)	(6)	(7)
					Output			
				Offset effect:	None	No. of plots	No. of parcels	SI
Under 0.5 ha	0.013	0.023	0.240		−0.275	−0.231	−0.255	−0.220
0.5-1 ha	0.020	0.032	0.300		−0.254	−0.210	−0.234	−0.199
1-2 ha	0.033	0.042	0.333		−0.232	−0.188	−0.212	−0.177
2-4 ha	0.052	0.055	0.357		−0.210	−0.166	−0.190	−0.155
4-8 ha	0.089	0.078	0.375		−0.189	−0.145	−0.170	−0.135
Over 8 ha	0.160	0.130	0.380		−0.168	−0.124	−0.149	−0.114
All classes	0.035	0.042	0.313		−0.239	−0.195	−0.219	−0.184

controversial whether economies of size are found in large size farms, or disappear (the average cost curve is L-shaped), or diseconomies of size are found (U-shaped). For Japanese rice farms, several authors (e.g., Kako [14], [16] and Chino [7]) tackled this issue using aggregated data and found that economies of size disappeared on farms of sizes over 5 ha. However, this article's results imply that economies of size do not disappear, even at sizes of 16 ha (average farm size of the category of over 8 ha. See Table 2). One of the reasons for such a difference is that aggregated data studies did not control for the impact of land fragmentation. Since positive correlation exists between the degree of fragmentation and farm size as shown in Table 2, if output (size) increases, fragmentation will be exacerbated and partially offsets economies of size. Since aggregated data studies did not use fragmentation variables explicitly, the impact of such an offset effect is not excluded in their estimates. By contrast, an offset effect is excluded in this article. That is, economies of size are derived when output is assumed to increase without exacerbation of fragmentation.

To see how much these offset effects are, columns (5) through (7) report re-calculated output elasticities that include such an offset effect. Algebraically, when the cost C and fragmentation index F are expressed as $C=C(Y, F, \mathbf{D_1})$ and $F=F(Y, \mathbf{D_2})$ respectively, the following equation (3) holds. Here, Y is an output, and $\mathbf{D_1}$ and $\mathbf{D_2}$ are vectors of other determinants.

$$\frac{dC}{dY}=\frac{\partial C}{\partial Y}+\frac{\partial C}{\partial F}\cdot\frac{\partial F}{\partial Y} \qquad (3)$$

The second term of the right-hand side is an offset effect. Column (4) in Table 5 shows the elasticities derived under the assumption that the offset effect is zero, meaning that F stays constant when Y increases. On the other hand, F is assumed to vary when deriving the elasticities shown in columns (5) through (7).[12] Here, $C(\cdot)$ is derived by substituting equation (2) into equation (1), while $F(\cdot)$ is derived by regressing the fragmentation indices on output, land readjustment ratio dummies, geographical feature dummies, regional dummies, year dummies, and the constant using the random effect model.

For example, column (7) presents the elasticities which consider the offset effects by SI. That is, while an increase in output reduces production cost (economies of size), it also leads to higher SI which partially offset economies of size. Comparing column (7) with (4), while SI offsets economies of size by 20% (from 0.275 to 0.220) in the smallest category, the offset effect amounts to 32% (from 0.168 to 0.114) in the largest category. The same trend is found in the number of plots or parcels. Land fragmentation offsets economies of size, and its magnitude is greater among larger farms.

4. The Impact on Input Use

In this section, further investigation explores how fragmentation affects the amount of each input such as labor and fuel. To achieve this purpose, the straightforward method will be to derive factor demand functions by applying Shephard's Lemma to the estimated cost function. Although it meets theoretical properties (e. g., cross restrictions on parameters), it immediately means that inputs are classified into only four. Rather, our approach here is to use more disaggregated inputs as dependent variables and repeat two-stage regressions as in the previous section. That is, substituting cost with various kinds of inputs in the equation (1), we re-estimate modified equation (1) and (2).

The data source is same as before. Labor is measured by operation hours, which includes travel time and machinery installation time, making it possible to see the impact of land fragmentation. For "machinery and cars," "buildings and construction," and "land improvement facilities," their asset values are used. The amount of "seeds and seedlings," "fertilizers," "pesticides," "fuels," "miscellaneous materials" and "rental services," are obtained by dividing expenditure by price indices cited from *Agricultural Price Index Statistics*. For "seeds" and "seedlings" (not aggregated "seeds and seedlings"), our database has their quantity information directly. Derivation of the *total* amount of labor, material, and capital are as discussed in section 3. 2.

After taking logarithms of more than twenty kinds of inputs, they are used as dependent variables in the equation (1). Sets of explanatory variables are basically same as in Table 3 and column (3) in Table 4. Exceptions are that the outsourcing dummy is dropped in the second stage, and that six kinds of outsourcing acreages (seed raising; tillage and soil preparation; planting; pest control; harvesting; drying and processing) are added in the first stage if the dependent variable is other than "rental services." This modification enables us to control for the impact of outsourcing on factor demands more precisely.

Table 6 shows estimated coefficients of SI in the second stage regression (it corresponds to the coefficient of SI in column 3 of Table 4) along with elasticities which exhibit percent change in input use when SI increases by 1 percent. For labor, the table also shows the change in operation hours per hectare when SI increases by 1 percent. Elasticities and change in hours are evaluated at sample average. Even if we use the number of plots or the number of parcels instead of SI, qualitative results were almost the same and so not shown here.

Starting from the labor,[13] the largest impacts are found (see "change in hours"), in order, "3. Tillage and soil preparation," "10. Harvesting," "8. Maintenance," "5. Planting," "2. Seed raising," "13. Indirect work," "11. Drying" and "12. Management." These results reflect the fact that land fragmentation substantially increases soil puddling (row 3), harvesting and transporting harvests (row 10), weed management of paddy field ridge (row 8), transporting seedlings and planting (row 5) and ridge-plastering (row 2). A possible explanation for the increase in "13. Indirect work" (maintenancing irrigation facilities and repairing machinery) is that fragmented lands face more diversified water supply sources, and fragmentation induces more frequent machinery breakdown because of longer travel distance. Besides, farms with higher SI tend to have more machinery as shown later. This also explains why machinery repair increases. Generally, land fragmentation facilitates the planting of multiple rice varieties such as fast-growing, mid-season and late-growing rice so as to overcome seasonal labor bottlenecks (Hung, MacAulay and Marsh [11]). This will increase the drying task (row 11) because the harvest season is diversified. The largest elasticity and t-statistics are found in "12. Management." Even if it is disaggregated into meeting, training and bookkeeping, SI is consistently positive. The increase in meeting can be explained in two ways. Firstly, land fragmentation scatters farmland over multiple villages, forcing farmers to attend different meetings in different villages. Second, fragmented land implies the coexistence of lots of farms within the region (otherwise, fragmentation would not occur), meaning that coordination of opinions takes a longer time, thereby requiring more meetings. The increase in training may be due to the greater rice varieties and more machines. The same reason will be applied to the bookkeeping, but it also reflects the fact that land fragmentation requires more paperwork for contracts with lots of landlords.

Next, we focus on labor tasks which are af-

Table 6. The impact of land fragmentation on the input use

Dependent variable	Coefficient of SI	*t*-statistic	Elasticity	Change in hours
Labor total	0.373	[6.4]***	0.295	0.880
1. Seed pretreatment	0.070	[0.7]	0.055	0.002
2. Seed raising	0.326	[4.3]***	0.257	0.092
3. Tillage and soil preparation	0.470	[6.2]***	0.371	0.134
4. Ground fertilizer	−0.220	[2.8]***	−0.174	−0.016
5. Planting	0.312	[4.5]***	0.247	0.102
6. Additional fertilizer	0.092	[1.2]	0.073	0.005
7. Weeding	0.166	[1.8]*	0.131	0.020
8. Maintenance	0.245	[3.5]***	0.193	0.113
9. Pest control	0.156	[1.6]	0.123	0.009
10. Harvesting	0.352	[2.9]***	0.278	0.123
11. Drying	0.445	[3.4]***	0.352	0.058
12. Management	0.911	[7.9]***	0.719	0.048
Meeting	0.213	[2.2]**	0.169	0.004
Training	1.700	[7.2]***	1.343	0.015
Book keeping	0.355	[2.4]**	0.281	0.008
13. Indirect work	0.887	[7.4]***	0.700	0.073
Materials total	0.165	[5.0]***	0.131	
14. Seeds and seedlings	−0.584	[4.8]***	−0.461	
Seeds	0.154	[4.2]***	0.121	
Seedlings	−1.730	[8.7]***	−1.363	
15. Fertilizers	0.201	[4.1]***	0.159	
16. Pesticides	0.285	[5.2]***	0.225	
17. Miscellaneous materials	0.215	[2.1]**	0.169	
18. Fuels	1.130	[14.0]***	0.896	
Capital total	0.843	[11.7]***	0.666	
19. Machinery and cars	1.510	[11.5]***	1.193	
20. Buildings and construction	0.720	[4.7]***	0.569	
21. Land improvement facilities	1.270	[1.8]*	1.000	
22. Rental services	−1.960	[14.1]***	−1.550	

Note: Asterisk (*), double asterisk (**) and triple asterisk (***) denote SI significant at 10 %, 5% and 1% respectively. "Elasticities" stands for percent change in input use when SI increases by 1 percent, while change in operation hours per hectare when SI increases by 1 percent is shown under "Change in hours."

fected little by fragmentation. "7. Weeding" is positively correlated with SI, but the change in hours is negligible because base operation hours are not so long. Note that this category captures weed management *within* the plots, while weed management *around* the plots (paddy field ridge) is captured by "8. Maintenance" and is affected substantially by fragmentation. SI is insignificant for the "1. Seed pretreatment," "6. Additional fertilizer" and "9. Pest control"; even less negative impact is found in "4. Ground fertilizer." The result found in "1. Seed pretreatment" is acceptable since seeds are usually prepared in one place, and hence are not affected by fragmentation. Somewhat surprisingly, labor spent on fertilizer (row 4 and 6) and pesticide (row 9) does not increase despite these activities usually involving traveling between plots. Given that farms with higher SI own more machinery as explained later, these results may arise because farms spend less time on *spreading* fertilizer and pesticides using more efficient sprinklers, which in turn offset an increase in *travel* time.

Apart from labor inputs, we now focus on materials. At first glance, "15. Fertilizers," "16. Pesticides," "17. Miscellaneous materials" (seed bed materials, ropes, etc.) and "18. Fuels" are all increasing functions of SI. Elasticity is especially large in fuels (0.896), reflecting that fragmentation forces farms to travel more. Perhaps, the increase in fertilizers and pesticides could stem from substitution effects associated with labor. The more land fragmented, the more travel time is required; therefore less time can be spent on farming activities. This leads to higher *net* wage (total labor cost divided by total working hours excluding travel time), causing substitution from labor to fertilizers and to pesticides. This result implies that the settlement of fragmentation will bring not only the reduction of production cost but also an environmental benefit by reducing fertilizers and pesticides. Elasticities of fertilizers and pesticides with respect to SI are 0.159 and 0.225 respectively, which are by no means trivial compared to the elasticity of cost (0.313. See Table 5).

"14. Seeds and seedlings," by contrast, is a decreasing function of SI. Seen separately, "Seeds" are an increasing function, while "Seedlings" are a decreasing function. In general, farmers face the choice between purchasing seeds or seedlings. In the former case, farms must grow the seeds into seedlings, but generally spend less expenditure since seeds are cheaper than seedlings. In the later case, meanwhile, farms do not have to grow the seeds, but spend more expenditure. Land fragmentation seems to lead farms to reduce expenditure through choosing seeds rather than seedlings. Reflecting the increase in seeds, "17. Miscellaneous materials" (seed bed materials, ropes, etc.) also increases.

Turning to the capital inputs, "19. Machinery and cars," "20. Buildings and construction" and "21. Land improvement facilities" increase when SI gets higher. There is no need to explain why land improvement facilities (irrigation tunnel, drainage facility, etc.) and construction (underdrainage, pipes, etc.) increase. Similar to fertilizers and pesticides, the increase in machinery could be due to the substitution effect. Needless to say, the more machinery a farm owns, the larger the warehouse required (row 20).

Finally, "22. Rental services" is negatively correlated with SI strongly, implying that fragmentation leads to less outsourcing and machinery borrowing. According to Yamaura [33], when farms newly rent out their farmland, they tend to negotiate with neighboring farm first. Therefore, farms with more fragmented land have more chances to obtain new farmland. The same will hold true for contracted farming. Our two-stage regressions (results omitted) using seven categorized acreages of contracted services (all tasks; seed raising; tillage and soil preparation; planting; pest control; harvesting; drying and processing) as dependent variables[14] reveal that all kinds of contracted services except for pest control are positively correlated with SI. In short, farms with fragmented land own more machinery rather than they borrow, and engage in more contracted farming rather than outsourcing tasks to others.

5. Conclusions

Land fragmentation has long been recognized as one of the distinguishing features of Japanese agriculture that prevent efficient rice production. However, empirical analysis of land fragmentation is limited and we know little about the impact of land fragmentation quantitatively. In this article, the impacts of land fragmentation on production cost and input use were examined using large panel data from Japanese rice farms. Our results have confirmed that the number of plots, the number of parcels and Simpson Index (SI) increase production cost significantly, and their impact is far from trivial.

Although previous studies concluded that economies of size are hardly found when farm size exceeds 5 ha, this article has shown that if the size increment accompanies no exacerbation of land fragmentation, then economies of size work rather well, even for much larger farms. These results indicate that land fragmentation increases costs both statically (at the present) and dynamically (when increasing size). Therefore, alleviating fragmentation not only reduces production costs immediately, but also gives farms greater incentive for increasing in size, which eventually decreases costs further.

Besides, the impacts of land fragmentation on the cost side increase in strength as farm size increases, which implies that the solution to cost reduction differs from size to size. For a long time, the Japanese government has aimed to increase farm size for the purpose of reducing rice production cost, but as farms grow, emphasis should be relatively switched from increasing size to alleviating fragmentation, since the harmful effects of fragmentation increase sharply with the increase in farm size.

Interestingly, it was also demonstrated that fragmentation increases not only fuel inputs and labor hours for planting, weeding and harvesting as generally accepted, but also managerial labor such as bookkeeping and meeting, and materials such as fertilizers and pesticides probably due to the substitution effects from labor. The range of fragmentation's impacts is spread beyond our scope. The latter results especially have an important implication. The settlement of fragmentation will bring not only the reduction of production cost but also an environmental benefit by reducing fertilizers and pesticides.

1) Average rice planting acreage of commercial farms (*commercial farms* is defined as farms with total farmland 0.3 ha or more, and with agricultural sales 500,000 yen or more). Data source is 1985 and 2005 Census of Agriculture and Forestry.

2) Variations in each cost category are as follows. Labor cost for traveling: 133 to 1,267 yen, Fuel cost for traveling: 66 to 558 yen, Labor cost for loading and installing machineries: 1096 to 4,177 yen, Labor cost for operating within plots: 19,488 to 22,859 yen, Other material cost (seeds and seedlings, fertilizers, pesticides, fuels, miscellaneous materials, and water utilization): 40,851 yen (Assumed to be constant for all farms). Consequently, total cost varies from 61,634 to 68,445 yen, meaning 11% difference.

3) To model varying farm-specific effects is an important topic that future research should explore.

4) Averaging over farms makes F time-invariant. To treat F as a time-variant variable, one can use it as a regressor in the first stage regression. However, since time variation in F is not very large and is highly correlated with Y (multicollinearity), this strategy is not adopted here.

5) Land can be treated as a fixed input rather than a variable input. In that case, the amount of land should be included as a regressor in the first stage regression. However the amount of land is highly correlated with output (the correlation coefficient is 0.995), raising a multicollinearity problem; hence land is treated as a variable input here.

6) This is a unit value. The views on the appropriateness of unit value diverge among authors (Egaitsu [8], Kako [15], Kuroda [19]). To check the robustness, we alternatively used the yearly wage index of temporary workers in agriculture (cited from *Agricultural Price Index Statistics*). We found that although wage became insignificant, coefficients and elasticities in Table 4 through Table 6 changed little (less than 10 to 20%).

7) Management cost is the sum of purchase and depreciation. Purchase includes transportation fees for meetings, tuition for seminars, license fees, phone bills, expenditures for office equipment which costs less than 100,000 yen, etc. Depreciation, on the other hand, includes depreciation cost of office equipment which costs more than 100,000 yen (e.g., computers). Therefore, we classified the purchase as materials and the depreciation as capital.

8) Another way to define capital is to use the machinery price index as a capital price, and then obtain the amount of capital by dividing depreciation cost by capital price (e.g., Godo [10]). To check the robustness, we tried two similar methodologies. First, capital price was obtained by averaging the machinery price index and building materials price index. Weight for the former was the sum of depreciation cost of machinery, cars and management, while that for the later was depreciation cost of buildings. Then the quantity of capital was obtained by dividing the sum of these depreciation costs by capital price. Secondly, capital price was defined as the machinery price index, and capital input was obtained by dividing the sum of the depreciation cost of machinery, cars and management by capital price. These methods resulted in a violation of concavity in most samples; however, coefficients and elasticities in Table 4 through Table 6 changed little (less than 10 to 20%).

9) A "parcel" refers to a gathering or complex consisting of several neighboring plots which enables the farm continuous operation. Unfortunately, our database does not provide information to identify the travel time and distance. However, on average, the number of parcels and SI must have a positive relationship with travel time and distance, and so they can be used as proxies.

10) The result of fixed effect estimation is as follows.

$$\ln y = 3.60 + 0.0208 \ln x_1$$
$$[4.8]^{***}$$
$$+ 0.0357 \ln x_2 + 0.0036 \ln x_3$$
$$[7.6]^{***} \quad [2.4]^{**} \quad (R^2 = 0.135)$$

where y is output, $x_1 x_2$, and x_3 are labor, material and capital respectively. All variables are divided by amount of land, and absolute t-statistics are shown in brackets. Although not shown here, year dummies are also used as the explanatory variable.

11) The percentage of positive fitted cost share is 100%, 100%, 99.6% and 89.4% for labor, capital, land and capital respectively.

12) Elasticity of average cost with respect to output which account for the offset effect is calculated as $E_{CX}^* = E_{CX} + E_{CF} \times E_{FX}$ where E_{CX} is the elasticity of average cost with respect to output, E_{CF} is the elasticity of average cost with respect to land fragmentation, and E_{FX} is the elasticity of fragmentation with respect to output. The value of E_{CX} and E_{CF} are from columns (1) through (4) in Table 5, while E_{FX} is obtained by regressing fragmentation indices upon output, land readjusted ratio dummies, geographical dummies, year dummies and region dummies with the random effect model.

13) See *Kome Seisanhi Chosa Tokei* (*Production Cost Statistics of Rice*) for the detailed definition of each labor inputs.

14) Explanatory variables in the first stage are the same as in column (1) in Table 3. In the second-stage, variables in column (3) of Table 4 excluding the contracted farm dummy are used.

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