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The costs and benefits of land fragmentation of rice farms in Japan*

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Land fragmentation, in which a farm operates multiple, separate plots of land, is a common phenomenon in Japan and many other countries. Usually, land fragmentation is regarded as a harmful phenomenon as it increases production costs and reduces the advantages of scale economies. However, it is also known that fragmentation may have beneficial effects in reducing risk through spatial dispersion of plots. Thus, land fragmentation has both costs and benefits, and whether it is beneficial or harmful is determined by the magnitude of these costs and benefits. This article investigates the costs and benefits of land fragmentation empirically using panel data from Japanese rice farms. The empirical results reveal that fragmentation increases production costs and offsets economies of size, and these impacts strengthen as farm size increases. Moreover, although fragmentation does reduce production risk, its monetary value is far below the cost of land fragmentation. From these findings, we conclude that land fragmentation is an impediment to efficient rice production in Japan.

Key words: economies of size, farmland fragmentation, Just–Pope production function, panel data, stochastic frontier cost function.

1. Introduction

Many countries face land fragmentation, in which a farm operates multiple, separate plots of land. The existence of fragmentation increases the time and fuel required to travel between plots, increases the need for water management or weeding, and decreases the output because of harvest loss around the corners of a plot, or by the area loss in boundaries and access routes. Most empirical studies have concluded that fragmentation is an impediment to efficient crop production as a result of these harmful or costly effects.

On the other hand, fragmentation has a beneficial effect in that it reduces risk through the spatial dispersion of plots. Blarel *et al.* (1992) investigated this effect empirically and concluded that fragmentation is so efficient that alleviating fragmentation may actually make farmers worse off.

Thus, fragmentation has both costs and benefits, and whether it is beneficial or harmful is determined by the size relationships between the costs and benefits. Have previous studies compared these two conflicting effects

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appropriately? First, although numerous attempts have been made to estimate the impact of fragmentation on output by using the production function approach (Blarel *et al.* 1992; Fleisher and Liu 1992; Parikh and Shah 1994; Byiringiro and Reardon 1996; Nguyen *et al.* 1996; Wadud and White 2000; Wan and Cheng 2001; Hung *et al.* 2007; Rahman and Rahman 2009), their results do not fully reflect fragmentation costs. The cost-function approach is desirable to measure fragmentation costs appropriately; however, studies using the cost-function approach (Jabarin and Epplin 1994; Ali *et al.* 1996; Tan 2005; Tan *et al.* 2008) have not analyzed the beneficial effects. Only Blarel *et al.* (1992) focused on the beneficial effects empirically, but a full analysis of the cost side was not made because they only estimated the production function. Therefore, it is difficult to make a judgment using the existing literature to determine whether fragmentation is beneficial or harmful.

The purpose of this article is to clarify the costs and benefits of fragmentation using the panel data of Japanese rice farms. In the following section, the present status, causes, and land consolidation policies in Japan are discussed. The impact on cost is analyzed in the third section using a stochastic frontier cost function, whereas the fourth section analyzes the impact on risk using the Just–Pope production function, after which the benefits and costs are compared.

2. Land fragmentation in Japan

In Japan, where farms are quite small in size, cost reduction by increasing farm size has been important policy concerns 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 per cent of farmers stated that the dispersion of plots is why an increase in farm size does not occur (MAFF 2004), and 65 per cent of large farmers (approximately 4 ha or more) stated that they give priority to land consolidation over an increase in size (MAFF 2006). Fragmentation is regarded as an obstacle to farm size growth and efficient rice production.

Table 1 reports the mean values of fragmentation indices by farm size (rice planting area) category. The data source is the 1995–2006 Rice Production Cost Statistics (*Kome Seisanhi Chosa Tokei*) maintained at MAFF, which is a national sample survey, conducted annually using a partially overlapping panel design.

As shown in the table, the number of parcels (a 'parcel' refers to a gathering or complex consisting of several neighboring plots) increases monotonically over the size range, and farms in the largest category hold no less than nine parcels. The Simpson Index (SI), defined as $1 - \sum(A_i^2)/(\sum A_i)^2$, where A_i is the area of ith plot, is used widely in empirical studies. A value of zero

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[1] Data from 1985 and 2005 (MAFF 2007).

Table 1 Mean values of land fragmentation indices by farm size

	Obs.	Area planted (ha)	No. of parcels	Simpson Index (SI)
Under 0.5 ha	3,553	0.35	2.20	0.596
0.5–1 ha	4,491	0.73	3.03	0.753
1–2 ha	4,798	1.43	4.00	0.839
2–4 ha	2,872	2.72	5.05	0.900
4–8 ha	1,592	5.60	6.11	0.943
Over 8 ha	1,477	16.20	9.29	0.966
All classes	18,783	2.77	4.18	0.801

indicates complete land consolidation (one plot only), whereas a value of one is approached by the holdings of numerous plots. This index also implies that the degree of fragmentation is in progress as farm size increases.

According to Matsuoka (1995) and Kajii (1990), one of the causes of fragmentation is the relatively closed land market, where land sales and rentals are typically handled among relatives or acquaintances, and the information is not open to the public. Therefore, farmers who are willing to increase their farm size must compromise by purchasing remote plots because it is difficult to find neighboring plots. The other reason is that the amount of sales or rentals per deal is very small. Because of the motives for holding assets, suppliers sell their land piece by piece, not all at one time. Even if farmers are older or have an off-farm job, they are reluctant to release their land. On the demand side, it is financially difficult to buy or borrow a large amount of land at one time. Both of these factors result in the fact that the average amounts of sales and rentals per deal are just 0.20 and 0.30 ha, respectively (MAFF 2008). Generally speaking, suppliers dominate deals in Japan, and it is difficult for buyers to control or choose the location of the plot they purchase.

In order to ease fragmentation, several land consolidation programs have been implemented in Japan. One is called *kanchi* and is linked to the land-improvement schemes of plot reshaping, plot size expansion, drainage and irrigation development, and road building. Land-improvement schemes have been implemented as public works and lead to consolidation by allocating property or tenancy rights of the newly created plots. On the other hand, there is a program which is not linked to land improvement. Under this program, called *kokan bungo*, farmers exchange plots without changing the plot size or shape, and the government provides subsidies and tax exemptions for doing so.

Although these policies have a long history, fragmentation still widely prevails in Japan. For that reason, new consolidation programs have been recently launched. The first is payments for farmers who acquire a new plot that is contiguous to his existing farmland. The per-unit subsidy increases with the area acquired. Second, when farmers, having achieved consolidation, invest in agricultural machinery or equipment, they receive subsidies of up to 30 per cent of the total investment cost. The third is the program for coordinators who manage the consolidation schemes. Consolidation schemes require deep knowledge and involve significant transaction costs for things such as surveying, negotiations, and the complicated registration procedures of reallocated rights. This program pays wages for coordinators and subsidizes local governments to encourage the education and training of coordinators. The fourth program aims to promote small-scale land improvement to realize spatially continuous farm operations, such as removing the paddy ridges, or covers or caps on an irrigation channel, that lie between plots.

3. Costs of land fragmentation

3.1 Model

In this section, attention is focussed on the cost side of fragmentation. The Battese and Coelli (1995) stochastic frontier model is employed, which allows for identifying factors that may explain differences in efficiency levels between farms. Consider the following function,

$$\ln C_{it} = \alpha_0 + \alpha_Y \ln Y_{it} + \frac{1}{2}\alpha_{YY} \ln Y_{it} \ln Y_{it} + \sum_m \alpha_m \ln P_{mit} + \sum_m \alpha_{Ym} \ln Y_{it} \ln P_{mit} + \frac{1}{2}\sum_m \sum_n \alpha_{mn} \ln P_{mit} \ln P_{nit} + \sum_t \alpha_t T_t + U_{it} + V_{it}. \quad (1)$$

Here, we employed well-known translog form (Christensen *et al.* 1973) where C represents the production cost, Y is the output, P is the input price, T is the year dummy capturing technological change, U is a non-negative random variable associated with cost inefficiency, V corresponds to statistical noise distributed with N(0, σ_V^2), and αs are parameters to be estimated. It is further assumed that U and V are independently distributed from each other. Subscript i and t denote farm and time (year), respectively, and subscript m or n denote inputs. There are four types of inputs: land, capital, labor, and materials.

The cost inefficiency effect is defined by the truncation (at zero) of the N($\mathbf{Z_{it}}\boldsymbol{\beta}$, σ_U^2) distribution where farm-specific mean is specified as follows:

$$U_{it} = \mathbf{Z_{it}}\boldsymbol{\beta} + W_{it} \quad (2)$$

where $\mathbf{Z}$ is a vector of inefficiency explanatory variables including fragmentation indices, $\boldsymbol{\beta}$s are unknown parameters to be estimated, and W is a random variable truncated at $-\mathbf{Z_{it}}\boldsymbol{\beta}$ from below.

The parameters of Equations (1) and (2) can be estimated simultaneously using maximum likelihood, together with the variance parameters that are expressed in terms of σ^2 where $\sigma^2 = (\sigma_\mathrm{U}^2 + \sigma_\mathrm{V}^2)$ and γ where $\gamma = \sigma_U^2/\sigma^2$ and has a value between zero and one. The likelihood function can be obtained by making a simple sign changes to the likelihood function presented in Battese and Coelli (1993).

In estimating this model using micro data, problem is that agricultural production fluctuates due to weather, pests and plant diseases, and hence output variable is stochastic which gives rise to measurement error bias. This problem, known as 'regression fallacy' (Walters 1960), can be solved using an instrument for output which is uncorrelated with the error term. Following Martin (1983) and Alvarez and Arias (2003), we estimate the production functions and use the predicted outputs as a proxy in the cost functions.

3.2 Data

Farm-level data is obtained from the 1995–2006 Rice Production Cost Statistics.[2] Cost is total production costs. An output is defined as kilograms of rice excluding by-products (rice straw or poorly ripened rice). Quantity of land, labor, and capital are total planting area, total labor hours, and total value of fixed capital (building, machinery, car, and land improvement equipment), respectively. And their prices are derived from dividing land cost (the land rent actually paid plus the opportunity cost of own land evaluated at regional average of the land rental rates), labor cost (the wage actually paid for hired labor plus the opportunity cost of unpaid labor evaluated at regional average of the hired wage rate) and capital cost (depreciation and repairing cost of building, machinery and car, irrigation cost, rental cost, and interest on capital) by quantity of land, labor, and capital, respectively. For materials, its price index is defined as $\sum_s P^M_{st} \times C^M_{sit} / \sum_s C^M_{sit}$, where P^M is the yearly price index of materials cited from Agricultural Price Index Statistics (*Nogyo Bukka Shisu Tokei*), C^M is the cost of materials with subscript s denoting to five kinds of materials (seeds and seedlings, fertilizers, pesticides, fuel, and miscellaneous materials). The quantity of materials is calculated from dividing the total material cost by this price index.

The variables (**Z**) explaining differences in farm efficiencies include fragmentation indices, farm characteristics, and plot conditions. Fragmentation is measured by the number of parcels and SI.[3] As it is difficult for farmers to choose their plot location or control the degree of fragmentation as mentioned earlier, the fragmentation indices are assumed to be exogenous. Farm characteristics are measured by the family labor ratio and an outsourcing dummy. As a number of studies have suggested that hired labor is inefficient relative to family labor (Binswanger and Rosenzweig 1986), the family labor ratio, defined as the ratio of total family labor hours to total labor hours, is

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[2] Because of the confidentiality of data, the micro data used in the article is not available for replication purposes. To access the data used here, permission by MAFF and Ministry of Internal Affairs and Communications is required. However, program code and its outputs are available upon request.

[3] Unfortunately, our database does not provide a variable to identify the traveling time or distance between plots. However, on average, the number of parcels and SI must have a positive relationship with traveling time or distance, and hence, can be used as proxies for them.

included. The outsourcing dummy is equal to one if the farm transfers any task to an external farmer, and zero otherwise. For farmers who do not own agricultural machines, outsourcing tasks like planting or harvesting are effective in reducing production costs. Plot conditions are measured by geographic dummies and land improvement ratio dummies. Geographic dummies represent whether the farm is located in a flat farming area, an urban area, or in a hilly/mountainous area. Land improvement ratio is defined by $A_{\mathrm{I}}/A_{\mathrm{T}}$, where A_{T} is total planting area and A_{I} is total improved area. Here, land improvement refers to construction projects aimed at reshaping or enlarging plots, creating irrigation/drainage canals, and creating or improving farm roads. Regional dummies are also included to account for unobserved differences across regions.

In order to stabilize the results, we use data from farms that have more than three observations, with land less than 50 ha, and that are located in prefectures other than Hokkaido and Okinawa.[4] As a result, the data used for estimation is an unbalanced panel consisting of 13 268 observations from 2705 farms. The length of the data per farm is 4.9 years on average (3 years in minimum, 12 years in maximum). Summary statistics for the variables used in the empirical model, including those used for the model in the next section, are shown in Table 2.

3.3 Results

Estimated stochastic frontier cost functions using predicted output from three patterns of production functions, translog (TL), generalized Leontief (GL), and quadratic (QD)[5,6] are shown in Table 3. They are estimated using the FRONTIER 4.1 program (Coelli 1996). Also given in the table are the estimates for the preferred frontier models, obtained after testing various null hypotheses, discussed below. In addition, usual homogeneity and symmetry restrictions are imposed. The former is carried out by dividing cost and input prices by material price. The latter symmetry restrictions impose $\alpha_{mn} = \alpha_{nm}$. Following standard practice, all variables are normalized (dividing by their own average).

A number of tests were conducted on the structural form of the translog model by incorporating restrictions on the parameters. The restrictions were tested using the likelihood ratio test, where the test statistic is given by

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[4] These are the most northern and the most southern prefectures in Japan. When analyzing Japanese rice farms, it is the usual manner to exclude the data from these regions because their ecological conditions are so different than those of the rest of Japan.

[5] They are defined as follows. TL: $\ln y = b_0 + \sum b_m \ln x_m + \sum\sum b_{mn} \ln x_m \ln x_n$, QD: $y = b_0 + \sum b_m x_m + \sum\sum b_{mn} x_m x_n$, GL: $y = b_0 + \sum b_m \sqrt{x_m} + \sum\sum b_{mn} \sqrt{x_m x_n}$, where y is yield, x is inputs per hectare (labor, capital, materials), and b_i are parameters. Year dummies are also included and estimated by the fixed effects model.

[6] Although the likelihood dominance criterion (LDC) indicates that GL production technology dominates the other two functional forms, all three functional forms are reported here to check the robustness of the analysis.

Table 2 Summary statistics

Variable	Unit	Mean	Standard deviation	Minimum value	Maximum value
Production cost	1000 yen	2658	2872	70	34900
Output	1000 kg	9.60	13.08	0.66	166.95
Yield	1000 kg/ha	5.22	0.67	2.56	7.89
Factor price					
Wage	1000 yen/hour	1.53	0.22	0.79	2.42
Material price	–	1.00	0.02	0.96	1.16
Land rent	1000 yen/ha	239	95	24	1370
Capital price	–	0.54	0.58	0.004	4.96
Factor input					
Labor	hour	541	502	10	6742
Material	–	422941	552134	15095	7890924
Land	ha	1.81	2.47	0.13	37.18
Capital	1000 yen	2737	3681	31	66500
Land fragmentation indices					
No. of parcels	–	4.08	3.91	1.00	90.00
Simpson Index (SI)	–	0.79	0.17	0.00	0.99
Family labor ratio	–	0.95	0.09	0.00	1.00
Geographic dummies					
Flat farming area	0 or 1	0.48	0.50	0	1
Urban area	0 or 1	0.18	0.38	0	1
Hilly or mountainous area	0 or 1	0.35	0.48	0	1
Land improvement ratio dummies					
Under 50%	0 or 1	0.18	0.38	0	1
50–80%	0 or 1	0.10	0.30	0	1
Over 80%	0 or 1	0.72	0.45	0	1
Outsourcing dummy	0 or 1	0.64	0.48	0	1

Total observations = 13268.

$LR = 2(\ln[L(H_1)] - \ln[L(H_0)])$. Here, $\ln[L(H_0)]$ and $\ln[L(H_1)]$ are the values of the likelihood function under the null and alternative hypothesis, respectively. This has a chi-square distribution, with the degrees of freedom given by the number of restrictions imposed. The test statistics associated with the models using the prediction from the GL production function are given in Table 4. The first test explores the null hypothesis that each farm is fully cost efficient and hence that systematic cost inefficiency effects are zero. As this is clearly rejected, the traditional cost function is not an adequate representation of rice production in Japan. The second null hypothesis that the variables included in the inefficiency model have no effect on the inefficiency is strongly rejected. The third and fourth null hypothesis, that the cost function is homothetic or Cobb-Douglas, are also rejected. Therefore, the translog stochastic frontier and inefficiency model was used as the preferred model. The test statistics associated with the QD and TL production functions implied the same conclusion and hence are not presented.

Estimated parameters of the inefficiency model are shown at the bottom of Table 3. As expected, we find that the number of parcels and SI are both

Table 3 Regression estimates for the stochastic frontier and inefficiency model

Production function specifications		(1) Generalized Leontief (GL)		(2) Quadratic (QD)		(3) Translog (TL)	
	Parameter	Estimates	*t*-ratio	Estimates	*t*-ratio	Estimates	*t*-ratio
Stochastic frontier							
Constant	α_0	−0.042	−5.26***	−0.040	−5.41***	−0.043	−5.28***
Output	α_Y	0.768	240.07***	0.769	244.95***	0.769	242.52***
Output × Output	α_{YY}	0.018	9.82***	0.018	14.63***	0.018	10.25***
Wage	α_1	0.080	3.97***	0.077	4.13***	0.076	3.67***
Land rent	α_2	0.151	21.36***	0.152	21.27***	0.151	21.25***
Capital price	α_3	−0.051	−12.99***	−0.051	−13.14***	−0.051	−12.95***
Output × Wage	α_{Y1}	−0.009	−0.60	−0.010	−0.69	−0.011	−0.71
Output × Land rent	α_{Y2}	0.028	4.80***	0.027	4.80***	0.027	4.73***
Output × Capital price	α_{Y3}	0.021	6.10***	0.021	6.26***	0.021	6.09***
Wage × Wage	α_{11}	0.192	2.96***	0.191	3.95***	0.185	2.82***
Wage × Land rent	α_{12}	−0.007	−0.19	−0.006	−0.18	−0.005	−0.15
Wage × Capital price	α_{13}	−0.032	−1.68*	−0.033	−1.97**	−0.033	−1.72*
Land rent × Land rent	α_{22}	0.046	5.95***	0.046	6.13***	0.046	6.01***
Land rent × Capital price	α_{23}	0.004	0.57	0.005	0.61	0.005	0.60
Capital price × Capital price	α_{33}	−0.031	−12.01***	−0.031	−12.38***	−0.031	−11.91***
Year dummies							
1996	α_{1996}	−0.018	−2.18**	−0.018	−2.22**	−0.017	−2.00**
1997	α_{1997}	−0.010	−1.26	−0.010	−1.28	−0.009	−1.07
1998	α_{1998}	0.012	1.44	0.012	1.57	0.014	1.67*
1999	α_{1999}	−0.019	−2.22**	−0.019	−2.32**	−0.017	−1.98**
2000	α_{2000}	−0.057	−6.63***	−0.057	−7.04***	−0.056	−6.48***
2001	α_{2001}	−0.066	−7.63***	−0.066	−8.06***	−0.065	−7.46***
2002	α_{2002}	−0.079	−8.42***	−0.079	−9.12***	−0.078	−8.27***
2003	α_{2003}	−0.032	−3.28***	−0.032	−3.61***	−0.031	−3.17***
2004	α_{2004}	−0.064	−5.80***	−0.064	−6.41***	−0.062	−5.64***
2005	α_{2005}	−0.097	−8.40***	−0.097	−9.25***	−0.095	−8.25***
2006	α_{2006}	−0.113	−9.43***	−0.113	−10.22***	−0.112	−9.33***

Table 3 (*Continued*)

	Production function specifications	(1) Generalized Leontief (GL)		(2) Quadratic (QD)		(3) Translog (TL)	
	Parameter	Estimates	*t*-ratio	Estimates	*t*-ratio	Estimates	*t*-ratio
Inefficiency model							
Constant	β_0	−0.516	−14.22***	−0.549	−3.68***	−0.541	−8.43***
Land fragmentation indices							
No. of parcels	β_1	0.00296	3.45***	0.00299	3.71***	0.00298	3.31***
Simpson Index (SI)	β_2	0.572	14.40***	0.590	16.25***	0.585	14.91***
Family labor ratio	β_3	0.018	1.18	0.020	0.29	0.023	0.48
Geographic dummies (flat farming area is standard)							
Urban area	β_4	0.047	3.48***	0.048	4.59***	0.047	3.36***
Hilly or mountainous area	β_5	0.076	6.59***	0.077	11.21***	0.076	5.96***
Land improvement ratio dummies (under 50% is standard)							
50–80%	β_6	0.004	0.27	0.003	0.21	0.004	0.25
Over 80%	β_7	−0.004	−0.37	−0.005	−0.42	−0.004	−0.32
Outsourcing dummy	β_8	−0.001	−0.15	−0.001	−0.13	−0.002	−0.23
Variance parameter							
Sigma-squared	σ^2	0.048	63.17***	0.048	59.20***	0.047	48.72***
Gamma	γ	0.078	6.54***	0.087	6.74***	0.085	7.11***
Observations		13268		13268		13268	
Number of groups		2705		2705		2705	
Log likelihood		1350		1346		1340	

Note: Asterisk (*), double asterisk (**) and triple asterisk (***) denote variables significant at 10%, 5% and 1%, respectively. Regional dummies are also included in the inefficiency model.

Table 4 Generalized likelihood ratio tests

	H_0: Null hypothesis	$\ln[L(H_0)]$	$\ln[L(H_1)]$	LR	Critical value (1% significance)	Decision
1	No inefficiency ($\gamma = \beta_0 = \beta_1 = \beta_2 = \ldots = \beta_8 = 0$)	956	1350	788	31[a]	Reject H_0
2	Insignificance of the inefficiency model ($\beta_1 = \beta_2 = \ldots = \beta_8 = 0$)	1019	1350	662	29	Reject H_0
3	Homothetic cost function ($\alpha_{Y1} = \alpha_{Y2} = \alpha_{Y3} = 0$)	1331	1350	39	11	Reject H_0
4	Cobb-Douglas cost function ($\alpha_{YY} = \alpha_{Ym} = \alpha_{mn} = 0, \forall m, n$)	1140	1350	420	23	Reject H_0

[a] The critical value for the test involving $\gamma = 0$ is obtained from Kodde and Palm (1986).

significantly positive, implying that fragmentation increases cost inefficiency. Moreover, no matter which production functions are used, sizes of the coefficients are almost the same. Turning to other variables, geographic dummies are significant implying that the size of inefficiency is the largest in hilly and mountainous areas, followed by urban areas and then flat farming areas.

Table 5 reports several elasticities of average cost (total cost C divided by the output Y) calculated with estimated parameter values and sample means in each size category. Although it reports the results associated with the GL production function, results were almost same whichever form had been chosen. Elasticities of average cost with respect to the number of parcels and SI are all positive, and their absolute values increase over size range.

On the other hand, from the cost elasticity of output in column (4), it can be seen that costs can be reduced by 0.304 per cent from a 1 per cent

Table 5 Average cost elasticities

	(1)	(2)	(3)		(4)	(5)	(6)
	Average cost (yen/kg)	Average cost elasticities of					
		No. of parcels	Simpson Index (SI)		Output		
				Offset effect	None	No. of parcels	SI
Under 0.5 ha	440	0.007	0.349		−0.304	−0.299	−0.213
0.5–1 ha	373	0.009	0.433		−0.277	−0.271	−0.186
1–2 ha	317	0.012	0.481		−0.248	−0.243	−0.158
2–4 ha	274	0.016	0.515		−0.221	−0.216	−0.131
4–8 ha	232	0.022	0.541		−0.195	−0.189	−0.104
Over 8 ha	221	0.037	0.549		−0.169	−0.163	−0.078
All classes	341	0.012	0.454		−0.257	−0.251	−0.166

size expansion of farms in the smallest category, and 0.169 per cent in the largest category. That is, although slope becomes flat gradually, the average cost curve slopes downward in all categories, suggesting the existence of economies of size – costs increase less than proportionately to changes in output.

Among the agricultural economics literature (see, for example, Castle 1989 and Alvarez and Arias 2003), there is debate as to whether economies of size exist on large size farms or disappear (average cost curve is L-shaped), or whether diseconomies exist (U-shaped). For Japanese rice farms, several authors (e.g., Kako 1983, 1984; Chino 1985) has tackled this issue using aggregated data and found that economies of size disappeared on farms of sizes over 5 ha. However, our results imply that the economies of size do not disappear, even at sizes of 16 ha (average farm size of the largest category. See Table 1). One of the reasons for such a difference is that aggregated data studies did not control for the impact of land fragmentation. As positive correlation exists between the degree of fragmentation and farm size as shown in Table 1, if output (size) increases, fragmentation will be exacerbated and partially offsets economies of size. As aggregated data studies did not use fragmentation variables explicitly, the impact of such an offset effect is not excluded in their estimates. On the other hand, it is excluded in this article, meaning that 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) and (6) report recalculated elasticities that include such an offset effect. Algebraically, when the cost C and fragmentation index F are expressed as $C = C(Y, F, \mathbf{D1})$, $F = F(Y, \mathbf{D2})$, respectively, following Equation (3) holds. Here, Y is an output, and **D1** and **D2** are vectors of other determinants.

$$\frac{dC}{dY} = \frac{\partial C}{\partial Y} + \frac{\partial C}{\partial F} \times \frac{\partial F}{\partial Y} \tag{3}$$

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. To the contrary, F is assumed to vary when deriving the elasticities shown in columns (5) and (6). Here, $C(\cdot)$ is derived from the estimated results shown in Table 3, whereas $F(\cdot)$ is derived by regressing the fragmentation indices on output, land improvement ratio dummies, geographic dummies, regional dummies, year dummies, and the constant using the random effect model.

For example, column (6) presents the elasticities which consider the offset effects by SI. That is, an increase in output leads to an increase in SI, and results in an increase in the production cost. Comparing column (6) with (4), while SI offsets economies of size by 30 per cent (from 0.304 to 0.213) in the smallest category, the offset effect amounts to 54 per cent (from 0.169 to 0.078) in the largest category. On the other hand, the offset effects by the number of parcels are not very strong. It amounts to 1.6 per cent and 3.6 per cent in the smallest and largest category, respectively. These results imply that whether economies of size work well depends heavily on whether fragmentation is exacerbated as a result of an increase in farm size, and the division of farmland into small plots (i.e. increase in SI), rather than an increase in the number of parcels, is the main obstacle to economies of size.

4. Benefits of land fragmentation

4.1 Just–Pope production function

Contrary to its harmful effects, land fragmentation may have a beneficial effect in reducing risk. Blarel *et al.* (1992) found that although fragmentation does not have a significant impact on output, it does reduce the variance of revenue, and concluded that '*consolidation programs are unlikely to lead to significant increases in land productivity and may actually make farmers worse off*'. However, there are two problems with their methodology. First, their dependent variable is the aggregation of several crops, not a single crop, and its unit is value, not quantity. Second, they use only SI and soil fertility index as determinants, but not other factors such as labor input or fertilizer input.

To overcome these problems, we use the Just–Pope production function (Just and Pope 1979), which is defined as $\mathbf{y}_{it} = f(\mathbf{x}_{it}) + e^{*}_{it} = f(\mathbf{x}_{it}) + h^{1/2}(\mathbf{z}_{it})e_{it}$, where y is yield (output per hectare), $\mathbf{x}$ is a vector of factor inputs, $\mathbf{z}$ is a vector of risk determinants, $f(\cdot)$ is the mean function, $h(\cdot)$ is the variance function, and e is an exogenous production shock satisfying $\mathrm{E}(e) = 0$ and $\mathrm{Var}(e) = 1$. As $\mathrm{Var}(y) = \mathrm{Var}(e^{*}) = \mathrm{E}(e^{*2}) = h(\mathbf{z})$, variance of yield is a function of $\mathbf{z}$.

To estimate this model, the mean function should be estimated in the first step. Here, GL and QD production functions, estimated for output prediction in the previous section, are used.[7] In the second step, the variance function is estimated by OLS, where the dependent variable is the log of the square of the predicted error term calculated from the mean function.

As argued by Bentley (1987), Blarel *et al.* (1992), Fenoaltea (1976) and McPherson (1983), fragmentation can be beneficial to farmers living in imperfect market environments by helping them overcome seasonal labor bottlenecks (crop scheduling) and enabling them to plant a larger variety of food crops for self-consumption (diversification). However, in Japan, labor or commodity markets are not so imperfect that farmers do not have access to hired labor or food. In addition, fragmentation facilitates crop scheduling or

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[7] Because what we have to consider is the level (not log) of yield, a log-log model such as TL should be converted into the level and then estimated by the nonlinear method. However, to capture the farm-specific effect in the nonlinear method, we have to add 2 705 farm dummies, and calculation was not able to be implemented (by STATA). Therefore, the TL form is not used here.

diversification on the condition that fragmentation increases variations in the soil types and other micro-climatic conditions. However, as most paddy fields in Japan have been already irrigated and reshaped and are relatively homogeneous, it is not plausible that fragmentation facilitates crop scheduling or diversification. Therefore, the benefits of crop scheduling or diversification are considered to be few, if any, and hence are not taken into account here.

Estimates of the variance function parameters are shown in Table 6. The data set is the same as that of previous section. According to these results, both GL and QD yield very similar results, and both the number of parcels and the SI are significantly negative. That is, risk is reduced as the number of parcels or SI increases. Among other variables, reflecting wildlife crop damages, risk is lower in the urban area, and higher in the hilly and mountainous area than the flat farming area (dummy standard). According to regional dummies, risk is the highest in the Kyushu region where there are frequent typhoon damages.

4.2 Costs and benefits of land fragmentation

Now, we are ready to compare costs and benefits of land fragmentation. First, the monetary value of benefits (i.e. risk reduction effect) can be measured using the risk premium. Because the relationship between the risk premium and the yield variance is approximately linear (Chavas 2004), the increase in benefit (*dB*) when the number of parcels or SI increases by 1 per cent is calculated by $RP \times E_V$, where RP is the risk premium per hectare, and E_V is elasticity of yield variance with respect to the number of parcels or SI. Following estimates by Koito (2003),[8] RP is set as 60 000 yen/ha. E_V, shown in columns (1) and (5) in Table 7, is calculated from the estimated parameters in Table 6. As results of QD are very similar to that of GL, estimates by GL production function is used here. On the other hand, the increase in cost (*dC*) when the number of parcels or SI increases by 1 per cent is calculated by $AC \times E_C$, where AC is the average cost per hectare and E_C is the average cost elasticities of the number of parcels or SI as listed in column (2) and (3) in Table 5.

Estimated costs and benefits are shown in Table 7. On average, when the number of parcels increases by 1 per cent, while the benefit increases by 26.1 yen, the increment of cost is overwhelmingly large (212 yen). As a result, dB/dC is only 12.35 per cent on average, and 18.49 per cent at maximum (in the largest category). In the same way, dB/dC of SI is 3.15 per cent on average, and 4.72 per cent at maximum. The dB/dC of the number of parcels exceeding that of SI may be partially because the increase in SI does not always involve spatial dispersion of plots, whereas the increase in the number

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[8] Koito used aggregated data of Japanese rice farms in the 1990s. Nakajima (2002) also obtained a similar value for the risk premium.

Table 6 Estimates of variance function parameters

Production function specifications	Generalized Leontief (GL)	Quadratic (QD)
Land fragmentation indices		
No. of parcels	−0.0107	−0.0125
	[1.8]*	[2.1]**
Simpson Index (SI)	−0.527	−0.542
	[3.3]***	[3.4]***
Labor (log)	0.004	−0.014
	[0.1]	[0.3]
Materials (log)	0.083	0.104
	[1.1]	[1.4]
Capital (log)	−0.0534	−0.0490
	[2.2]**	[2.0]**
Land (log)	−0.026	−0.031
	[0.3]	[0.4]
Family labor ratio	−0.310	−0.355
	[1.4]	[1.6]
Geographical dummies (flat farming area is standard)		
Urban area	−0.084	−0.087
	[1.4]	[1.5]
Hilly or mountainous area	0.102	0.110
	[2.1]**	[2.3]**
Land improvement ratio dummies (under 50% is standard)		
50–80%	0.016	−0.006
	[0.2]	[0.1]
Over 80%	−0.034	−0.035
	[0.6]	[0.6]
Outsourcing dummy	−0.016	−0.020
	[0.3]	[0.4]
Regional dummies (Tohoku region is standard)		
Hokuriku	−0.214	−0.218
	[3.4]***	[3.5]***
Kanto/Tosan	−0.113	−0.116
	[1.8]*	[1.8]*
Tokai	−0.291	−0.300
	[3.2]***	[3.2]***
Kinki	−0.053	−0.091
	[0.6]	[1.1]
Chugoku/Shikoku	0.057	0.061
	[0.8]	[0.8]
Kyushu	0.183	0.172
	[2.4]**	[2.3]**
	GL	QD
	(continued)	
Year dummies		
1996	−0.531	−0.526
	[6.1]***	[6.0]***
1997	−0.365	−0.385
	[4.2]***	[4.5]***
1998	−0.088	−0.109
	[1.0]	[1.2]
1999	−0.358	−0.362
	[4.1]***	[4.1]***
2000	−0.428	−0.438
	[4.8]***	[4.9]***
2001	−0.354	−0.362
	[4.0]***	[4.0]***
2002	−0.363	−0.387
	[3.8]***	[4.0]***
2003	−0.061	−0.079
	[0.6]	[0.8]
2004	0.074	0.076
	[0.7]	[0.7]
2005	−0.648	−0.638
	[5.5]***	[5.4]***
2006	−0.334	−0.373
	[2.8]***	[3.1]***
Constant	2.03	1.91
	[2.9]***	[2.7]***
Observations	13268	13268
R^2	0.015	0.016

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

of parcels does, and the risk reduction effects increase when plots disperse spatially. In any case, these results lead to the clear conclusion that although fragmentation has benefits, its monetary value is small relative to the additional costs, meaning that fragmentation can be regarded as a harmful rather than beneficial phenomenon in Japan.

Table 7 Variance elasticites, the costs and benefits of land fragmentation

	No. of parcels				Simpson Index (SI)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	E_v	dB (yen/ha)	dC (yen/ha)	dB/dC (%)	E_v	dB (yen/ha)	dC (yen/ha)	dB/dC (%)
Under 0.5 ha	−0.024	14.3	147	9.72	−0.028	193	7770	2.48
0.5–1 ha	−0.033	19.7	171	11.52	−0.039	240	8147	2.94
1–2 ha	−0.043	25.8	196	13.18	−0.051	266	7898	3.37
2–4 ha	−0.056	33.6	227	14.80	−0.066	285	7537	3.78
4–8 ha	−0.081	48.4	280	17.30	−0.095	299	6769	4.42
Over 8 ha	−0.134	80.6	436	18.49	−0.158	303	6424	4.72
All classes	−0.044	26.1	212	12.35	−0.051	251	7953	3.15

5. Conclusions

Currently, there are two contrasting views concerning land fragmentation. One regards fragmentation as a harmful phenomenon because it increases production costs or decreases outputs. The other view suggests that fragmentation is not necessarily harmful because it can reduce risk or variation of output through the spatial dispersion of plots. Empirical investigation into which of these two opposing effects dominates is sparse, and so there is no clear consensus yet on how to tackle fragmentation.

In this article, the impacts of land fragmentation on production cost and risk were examined empirically using panel data from Japanese rice farms. On the basis of the results, three main policy implications are drawn. First, and most important, although fragmentation reduces risk, its monetary value is estimated to be about 2.5–18.5 per cent of the cost. That is, the benefit of fragmentation is far below the cost. This result leads to the conclusion that fragmentation is indeed an impediment to efficient rice production in Japan. Land fragmentation is a harmful phenomenon as a whole, rather than a beneficial one.

Second, although it has been said that economies of size disappear when farm size exceeds 5 ha in Japan, this article has shown that if the size increment accompanies no exacerbation of 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 at the present time, but also facilitates farm size growth and decreases costs further, creating a positive feedback loop in the long run.

Third, the impacts of land fragmentation on the cost side increase in strength as farm size increases, which implies that the solution to the cost reduction differs when farm size changes. 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 switched from increasing size to alleviating fragmentation, because the harmful effects of fragmentation increase sharply with the increase in farm size. Without solving the problem of fragmentation, efficiency is not fully gained, and the incentive to increase size is discouraged.

These findings provide a foundation for the ongoing land consolidation policies in Japan. However, further research is required to investigate whether such policies are efficient by comparing the costs involved in the policies with the benefits obtained. Our findings provide a quantitative basis for such evaluations.

Finally, it is important to emphasize that these conclusions are based specifically on rice farms in Japan. The benefits of fragmentation are expected to be much smaller in developed economies like Japan compared to less developed economies where alternative risk-spreading mechanisms such as insurance, storage, or credit are not available. The analysis reported in this paper also abstracts away from other benefits such as crop scheduling or diversification because they are considered to be negligible in Japan, where labor and commodity markets are well-organized. However, these factors play an important role in less developed economies where the markets are highly imperfect. Thus, any generalization on land fragmentation that goes beyond the study must be made with caution.

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