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Effects of land fragmentation and returns to scale in the Chinese farming sector

GUANG H. WAN* and ENJIANG CHENG‡

Department of Agricultural Economics, The University of Sydney, NSW 2006, Australia and ‡Chinese Economy Research Unit, The University of Adelaide, SA 5001, Australia

Using household survey data from rural China, economies of scale as measured by returns to scale and the effects of land fragmentation on crop outputs are examined. While these effects are found to be detrimental, statistically significant and substantial, existing economies of scale appear to be too small to suggest radical land policy changes in China.

I. INTRODUCTION

Economies of scale or returns to scale[1] in farming have been an important issue in China ever since the well-praised rural economic reforms began in the late 1970s (Lu 1985, p. 191; Zhu *et al.*, 1986; Chen, 1992). This is not at all surprising as the pre-reform commune system was founded on the premises of a large scale of operation and collective ownership (recall the famous slogan: *yida ergong*), which were expected to reap economies of scale. Rural reforms in China, however, have resulted in virtual collapse of the collective ownership and tiny scales of farming. On the other hand, land fragmentation has received little attention until recently (Fleisher and Liu, 1992). While decollectivization is shown to contribute to agricultural growth (Lin, 1992), empirical evidence is lacking with regard to the current status of economies of scale and the impacts on outputs of land fragmentation that was brought about by the rural economic reforms.

Analysing the effects of land fragmentation and returns to scale is important for the future course of rural economic reforms in China. If the effects of land fragmentation on Chinese farming are negative and significant, design and implementation of land consolidation policies would be urgently needed. Land consolidation, by its definition, does not necessarily lead to alterations in the total land holdings allocated to individual households. On the other hand, if increasing returns to scale prevail and are substantial, more radical policies such as land reform aiming at enlargement of household land holdings may be more relevant. The choice and perhaps sequence of policy options clearly appeal for empirical assessment of the impacts on outputs of land fragmentation relative to that of economies of scale.

In this paper, the standard translog production function is extended to incorporate land fragmentation effects. The extended model is then fitted to a set of household survey data from China. Statistical testing and model selection procedures are followed to ensure the quality of empirical results. Based on the estimated models for rice, wheat, maize and tuber crops, economies of scale in the Chinese farming sector are quantified and output losses corresponding to various degrees of land fragmentation are evaluated via simple simulations.

The plan of the paper is as follows. In the following section, relevant issues regarding land fragmentation in China are discussed. This also serves to provide the foundation for model specification in Section III. Section IV presents estimation results for maize, wheat, rice and tuber crops. Discussions on returns to scale and the

* Corresponding author. E-mail: g.wan@agec.usyd.edu.au

[1] The terms – returns to scale and economies of scale – will be used interchangeably in this paper. This concept refers to changes in output following proportionate changes in inputs. A related concept is economies of size which refers to changes in the average cost of production following output expansion or contraction. See Debertin (1986, pp. 151–4). This paper focuses on economies of scale rather than size economies simply because the former not the later attracts considerable attention in and outside China.

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impacts of land fragmentation on crop outputs are also presented in Section IV. Finally, policy implications and conclusions are drawn in Section V.

II. LAND FRAGMENTATION IN CHINA: SOME THEORETICAL AND EMPIRICAL CONSIDERATIONS

Land fragmentation can be defined as spatial dispersion of fields into separate and distinct parcels (Binns, 1950). Presence of land fragmentation in China is attributable to the way in which land was allocated to each household upon the implementation of the current family farming or production responsibility system in late 1970s. It is known that household entitlement to land was mainly based on family size and in many regions on the number of labourers in the household (Wan, 1995). The per capita allotment (*kouliang tian*) is necessary in order to meet basic food requirement of every family member and the remainder (*zeren tian*) is allocated according to the principle of 'ability to cultivate'. Needless to say, labourers usually consume more food than nonlabourers. Due to differences in qualities and locations of land, each household often obtained disjointed pieces of land with different characteristics. This was done in order to ensure equity among households in a village. While elsewhere land fragmentation occurs mainly as a result of inheritance customs (a farm holding is more or less equally divided among heirs), in China land re-allocation is often required when the registered population of a village changes, e.g., when a child is born or a local student enters university. It is well-known that the population in China is on the increase and, due to industrialization and urbanization, arable land is in the decline. Thus, land fragmentation, if unattended, will become worse over time.

Given China's territorial size and varying population density, it is not surprising to find that the degree of land fragmentation varies substantially from region to region. For example, in most parts of Hubei province, each household operated on eight plots of land. But in some areas of the same province, individual families cultivate, on average, 19 disjoint pieces of land with a mean size of 0.227 *mu* or 0.015 hectare (1 ha = 15 mu). See Chen (1992). Based on their data, Fleisher and Liu (1992) found that the number of plots per family ranges from one to ten. According to the survey data to be used in this study, land fragmentation varies in degrees from crop to crop with rice being the worst and maize the least affected (see Table 1).

Blarel *et al.* (1995) and Heston and Kumar (1983) argue that land fragmentation may be beneficial to farmers as it may lead to reduction in production risks associated with land dispersion. In rural China, however, a production team or village typically has some 100–200 population with 15 ha of land, all distributed around the village. It is unlikely for natural disasters to strike one block while not others within such a small vicinity/locality. Therefore, the only potential benefit possibly associated with land fragmentation, namely risk reduction, is not really applicable to China. On the contrary, land fragmentation causes resource disutilization and underutilization because (a) land is lost in forming plot boundaries and access routes; (b) extra labour and fuel inputs are used for multiple travel among land plots; (c) more inputs are wasted due to increased leakage and evaporation of fertilizer, water, pesticide and so on; and finally (d) as argued by Fleisher and Liu (1992), land fragmentation reduces efficiencies in pollination control and use of sunlight and other environmental resources. In addition, as the number of plots increases, disputes between neighbours are likely to rise. Clearly all these factors contribute to the detrimental effects of land fragmentation and the effects will accumulate as the number of plots increases. Thus, the impacts of land fragmentation are related to the number of plots. Further, when land holding is fixed (that is, for a given total sown area), the number of plots inversely relates to the average plot size. In this sense, both the average plot size and plot number are good indicators of land fragmentation. It is not difficult to establish that these arguments hold at the farm level as well as for individual crop-specific operations.

As is widely known, in rural China land title is unclear and trading of land in general is forbidden. These are the root causes of absence of a land market in China, which, in turn, rules out any possibility of market-related solutions to the problem of land fragmentation. By China's constitution, rural land is owned by collectives and thus individual farmers only have the user rights and their operation on the land is bound by lease. However, the collectives which were accounting and production units do not really exist under the current production responsibility system. In essence, it is the central and provincial governments that make decisions on land usage including clauses on and terms of land lease. With few exceptions where farming is taken as a sideline of rural industrial enterprises, local governments and community leaders generally do not possess the political power or economic means for rectifying the fragmentation problem (Cheng, 1993). Thus, it is not the lack of initiatives of farmers which impedes land consolidation. Rather, it is the incompleteness of property rights in rural China that prevents a land market from being formed or functioning properly (see also Perkins, 1994; Wan, 1995). Clearly, improvement in land fragmentation awaits for changes in land policy to be made by the central government. Although experiments are being conducted in China which aim at stabilizing land entitlements to individual households and avoiding frequent adjustments, they, however, do not lead to land consolidation unless land exchanges occur.

Currently, there exists an erroneous perception in China. Both economists and politicians attribute stagnation or

Table 1. *Summary description of the survey data*

Independent variables	Units of measurement	Mean	Standard deviation	Range Minimum	Range Maximum
Maize (sample size = 512)					
Output	*jin*	5762.4	7982.7	18	5 200
Land	*mu*	6.669	7.965	0.10	36.0
Labour	person-days	54.085	39.994	3.50	210.0
Capital	*yuan*	702.15	990.95	3.20	5 039.6
Plot no.	pieces	2.394	1.516	1	13
Late Indica Rice (sample size = 470)					
Output	*jin*	4860.6	7817.7	150	95 000
Land	*mu*	6.356	9.517	0.20	118.0
Labour	person-days	91.349	73.092	3.0	478.80
Capital	*yuan*	954.87	2227.6	48.0	27 922.0
Plot no.	pieces	4.042	3.159	1	32
Winter Wheat (sample size = 389)					
Output	*jin*	1962.6	1619	70	8250
Land	*mu*	2.979	1.918	0.20	10.0
Labour	person-days	50.209	29.475	7.0	186.0
Capital	*yuan*	420.840	381.240	10.20	2010.0
Plot no.	pieces	2.746	1.541	1	15
Early Indica Rice (sample size = 375)					
Output	*jin*	5285.0	8216.9	80	97 760
Land	*mu*	6.847	9.890	0.10	118.0
Labour	person-days	98.184	76.863	3.0	586.25
Capital	*yuan*	1110.5	2328.7	8.0	27 522.0
Plot no.	pieces	3.904	3.127	1	18
Tuber Crops (sample size = 284)					
Output	*jin*	2022.5	1888.4	100	12 000
Land	*mu*	1.089	0.908	0.10	6.0
Labour	person-days	24.234	16.028	3.80	104.0
Capital	*yuan*	89.41	103.42	5.60	816.0
Plot no.	pieces	2.394	1.962	1	13

Notes: 1 *jin* = 0.5 Kg,
1 *mu* = 1/15 ha,
1 *yuan* = 0.125 US dollar

negligible growth in the Chinese farming sector to small scale of household farming. As a consequence, they focus their attention almost exclusively on enlarging land holdings of individual families in order to reap economies of scale. This is evident from the speeches and writings of ministers and top officials of the central government (e.g. Wen, 1995; Wan B. R., 1995; Ministry of Agriculture, 1995). As observed by Wan and Cheng (1996), few in China realize that economies of scale can be absent or negative. It is without doubt that policies designed to enlarge family holdings would only bring about social and economic costs with no benefits unless positive economies of scale exist. Further, enlarging family holding is not a sufficient nor necessary condition for the resolution of the land fragmentation problem. In the next stage of rural reform, the Chinese government may adopt two options: tackling land fragmentation without changing farming scales; or increasing scales which may not necessarily solve the land fragmentation problem. Obviously, the most crucial argument in favour of the second option is the presumed existence of positive economies of scale in the Chinese farming sector. Due to various reasons, including manual operations being the dominant farming technique, negligible overheads, huge amount of surplus labour and extremely low land/population ratio, such a presumption may well be unrealistic. Nevertheless, empirical studies on the effects of returns to scale and land fragmentation on crop outputs in rural China are lacking, despite an appeal by the then Director-General of the Department of Policy, Law and Regulations of the Ministry of Agriculture (Guo, 1995). These may have contributed to the absence of land policy initiatives from the Chinese government in recent years.

When crop-specific data are available, it is best to examine various economic issues at the disaggregated crop-specific level. Generally speaking, as land allocation to a family increases, production scales for individual crops are likely to expand. But, the contrary may not be true. In a hypothetical case, a farmer may opt to plant only one instead of several crops on many plots. Consequently, the production scale of that crop increases several folds, while the household land holding remains the same. This kind of specialization is a classical source of economies of scale. In reality, it is not uncommon for a farmer to expand outputs by altering scales of operation of some crops without changing the overall farm scale. Unless studies are conducted at the crop-specific level, these economies or diseconomies of scale may not be adequately analysed. Further, it is a rule rather than exception that data aggregation always leads to information loss and thus inefficiency and possible biases of quantitative results. With availability of disaggregated data, it is generally preferable to obtain disaggregated or crop-specific results and then compute the aggregated or farm-level counterparts. The contrary, however, cannot be done. It is trivial to construct an example where economies of scale at the farm-level are absent or negative while some cropping activities display positive and others display negative economies of scale (cf. Nelson and Wohar, 1983). In any case, disaggregated studies are more enlightening and useful for government policy makers and the farmers.

3. MODEL SPECIFICATION AND ESTIMATION

Previous studies on Chinese agriculture typically adopt a Cobb–Douglas (CD) production model. See Wan and Anderson (1990), Fan (1991), Lin (1992) and Wan *et al.* (1992). This may be acceptable when highly aggregated data, typically with small sample sizes, are used. In that case, the parsimony principle takes precedence over flexibility in model specifications. Since data to be used here consist of at least 284 household observations, the flexible translog functional form is to be employed. Let Y_h denote the output of a crop from household h, $X_{h1}, \ldots, X_{hK}$ denote the corresponding inputs, a translog production function can be written as

$$\ln Y_h = \gamma_0 + \sum_{j=1}^{K} \alpha_{j=1} \ln X_{hj} + 0.5 \sum_{i=1}^{K} \sum_{j=1}^{K} \gamma_{ij} \ln X_{hi} \ln X_{hj} \tag{1}$$

The translog model allows elasticities of substitution to vary between different pairs of inputs while the CD function restricts all of them to be unitary. Given the severe scarcity of land, shortage of rural credit and a huge amount of surplus labour in rural China, elasticities of substitution are expected to be different from unity and vary from one pair of inputs to another. In other words, use of CD may well yield specification error thus produce distorted results. Note that by constraining all γ_{ij}s to zero in Equation 1, the translog reduces to CD. Thus, conventional F-tests can be performed to select between the CD and translog specifications.

As argued in the preceding section, land fragmentation affects the entire production process rather than a particular input or particular phase(s) of production. Note also that land fragmentation is not an input itself. Rather, this variable enters the production system through its possible impacts on productive efficiency. Following directly from the CD and the well-known CES model, γ_0 in the translog model is the efficiency parameter. It is thus natural to augment the translog function by relating land fragmentation to γ_0. Recall that land fragmentation can be denoted either by the number of plots operated by each household for a particular crop or by the average plot size when sown area is controlled in a model.[2] However, the average plot size is likely to be highly correlated with the sown area variable as a larger family usually possesses more land with bigger pieces, but usually not more plots. Moreover, using plot number to indicate land fragmentation also facilitates interpretation of estimation results and drawing policy implications. For example, elimination of land fragmentation can be simply interpreted as when $P_h = 1$; the corresponding output gains can be easily calculated. As another example, it is easier for policy makers to set and implement targets on average plot numbers rather than the average plot size for each household. In fact, it is impossible to set a target on the average plot size since per capita possession of arable land changes significantly from locality to locality. Thus, land fragmentation will be represented by the number of plots in this paper.

Based on the foregoing discussions, a function relating land fragmentation to productive efficiencies can be specified as follows:

$$\gamma_0 = \alpha_0 + \beta_0 \ln P_h \tag{2}$$

For easy reference, the above Equation will be termed efficiency function. Substituting Equation 2 into Equation 1 gives

$$\ln Y_h = \alpha_0 + \beta_0 \ln P_h + 0.5 \sum_{j}^{K} \alpha_j \ln X_{hj} + \sum_{i}^{K} \sum_{j}^{K} \gamma_{ij} \ln X_{hi} \ln X_{hj} \tag{3}$$

[2] To elaborate, let A denote sown area, then the plot number, say P, is an exact function of the average plot size, say, S such that $S = A/P$.

In the above model, land fragmentation is assumed to exert neutral impacts only – it does not affect marginal products, marginal rate of substitution or output elasticities. To allow for nonneutral effects, as suggested by a referee of this journal, interactive terms involving $\ln P_h$ and $\ln X_{hj}$ are to be included:

$$\ln Y_h = \alpha_0 + \beta_0 \ln P_h + \sum_{j}^{K} (\alpha_j + \beta_j \ln P_h) \ln X_{hj} + 0.5 \sum_{i}^{K} \sum_{j}^{K} \gamma_{ij} \ln X_{hi} \ln X_{hj} \tag{4}$$

It is not difficult to show that if the average plot size 5_h rather than the plot number P_h is used, the resultant production function would be equivalent to Equations 3 or 4.[3]

Equations 3 and 4 are extended versions of the standard translog function, which can be used to analyse the economies of scale and effects of land fragmentation on crop outputs.[4] The effects can be measured by elasticity of land fragmentation which is given by $\partial \ln Y_h / \partial \ln P_h$ or by a quasielasticity of land fragmentation defined as $\partial \ln Y_h / \partial P_h$. The latter is a better measure as it has the intuitive interpretation of a percentage change in output when land fragmentation is further increased by one more plot.

Regarding economies of scale, it is not difficult to show that constant returns to scale (nil economies of scale) can be tested via the following joint hypotheses:

$$\sum_{j}^{K} \alpha_j = 1 \qquad \sum_{j}^{K} \beta_j = 0 \qquad \sum_{i}^{K} \gamma_{ij} = 0 \qquad \sum_{j}^{K} \gamma_{ij} = 0$$

When symmetry conditions ($\gamma_{ij} = \gamma_{ji}$) are imposed as in this paper, one of the last two expressions becomes redundant. If Equation 3 instead of Equation 4 is considered, the second hypothesis is also redundant.

It is important to note that the variable P_h must take positive integer values. When land fragmentation is absent (i.e., $P = 1$), the augmented models (3) and (4) reduce to the conventional form of Equation 1. Of course, a linear efficiency function, say $\gamma_0 = \alpha_0 + \beta_0 P_h$, may be adopted, which leads to the replacement of $\ln P_h$ by P_h in Equations 3 and 4. As little is known, theoretically or empirically, about the algebraic form of the efficiency function, both the loglinear and linear specifications will be attempted in the empirical sections of the paper.

The above models are readily subject to econometric estimations once stochastic disturbance terms are added. Since cross-sectional household data are to be used, all estimations will be accomplished by using White's (1980) procedure in order to account for unknown forms of heteroscedasticity. Meanwhile, dummy variables will be included to incorporate into the production functions differences in land quality and other environmental conditions among regions.

Although F-tests can be utilized to make selections between the CD and translog specifications and to test for economies of scale and various forms of fragmentation effects, the choice between the efficiency functions proves to be not so straightforward. This is because the two efficiency specifications result in nonnested production functions thus conventional tests can not be easily applied.

4. DATA, ESTIMATION RESULTS AND DISCUSSIONS

A large-scale household survey was conducted in China jointly by the Chinese Economy Research Unit of the University of Adelaide and the Ministry of Agriculture of China. Input–output data for the years 1993 and 1994 were collected from the following representative provinces: Jilin, Shandong, Jiangxi, Sichuan and Guangdong. Four counties were selected from each of these provinces as sampling points and five villages were chosen from each of the selected counties. Some ten households in each village were asked to keep records on relevant production activities and these records were then collected by the survey team towards the end of the year. The 1994 data have been chosen for their better quality and larger sample sizes. Five major crops (early indica rice, late indica rice, winter wheat, maize and tuber crops) are considered in this study. All variables are crop-specific. Outputs Y are measured in *jin* ($= 0.5$ Kg), sown areas X_1 are measured in *mu* ($= 1/15 ha$), labour inputs X_2 are measured in person–days, and capital inputs X_3 are measured in *yuan* ($\approx$US\$0.125). The capital variable comprises fertilizer cost (85% or more) and other expenditures (15% or less) such as hired labour, service charges on drought animals, machinery and the like. Because most households did not use inputs other than land, labour and fertilizer, it is necessary to combine fertilizer with other residual inputs to form a capital variable. Note that capital stock is not

[3] Without loss of generality, assume a translog function with land input A and other inputs O. The model can then be written as $\ln Y = f(A, O, S) = \delta_0 + \delta_1 \ln A + \delta_2 \ln O + \delta_3 \ln S + \delta_4 (\ln A)^2 + \delta_5 (\ln O)^2 + \delta_6 (\ln A \ln O) + \delta_7 (\ln S \ln A) + \delta_8 (\ln S \ln O) = \delta_0 + \delta_1 \ln A + \delta_2 \ln O + \delta_3 \ln A - \delta_3 \ln P + \delta_4 (\ln A)^2 + \delta_5 (\ln O)^2 + \delta_6 (\ln A \ln O) + \delta_7 (\ln A \ln A) - \delta_7 (\ln A \ln P) + \delta_8 (\ln A \ln O) - \delta_8 (\ln O \ln P) = \delta_0 + \delta_1^* \ln A + \delta_2 \ln O + \delta_3^* \ln P + \delta_4^* (\ln A)^2 + \delta_5 (\ln O)^2 + \delta_6^* (\ln A \ln O) + \delta_7^* (\ln P \ln A) + \delta_8^* (\ln P \ln O) = f(A, O, P)$, where $\delta_1^* = \delta_1 + \delta_3$, $\delta_3^* = -\delta_3$, $\delta_4^* = \delta_4 + \delta_7$, $\delta_6^* = \delta_6 + \delta_8$, $\delta_7^* = -\delta_7$ and $\delta_8^* = -\delta_8$.

[4] A referee suggested use of the Just–Pope model. Unfortunately, the Just–Pope model cannot be fitted to a pure cross-sectional data set. See Griffiths and Anderson (1982).

considered as very few families possess equipment or machinery for cropping. Since not all households covered in the survey produced all the five crops, sample sizes vary from crop to crop (cf. Table 1). For details on the survey design and data compilation, see Wu (1995).

Table 1 reports summary statistics of the output and input variables. From Table 1, the worst land fragmentation occurs in rice production, with an average of four plots (rounded to the next integer) per household for both early and late indica rice. In the most extreme case, a family cultivated late indica rice on 32 noncontiguous plots. Maize is least fragmented in terms of both the mean and standard deviation of the plot number variable. The average plot size (i.e., ratio of average land area to average plot number) ranges from 0.45 *mu* (tubers) to 2.79 *mu* (maize) with late rice (1.57 *mu*), early rice (1.75 *mu*) and wheat (1.08 *mu*) as intermediate cases. Since resource disutilization, in particular land wasted for formation of plot boundaries and access routes, is much more severe for smaller average plot sizes, the gains in outputs following improvement in land fragmentation are expected to be more significant in wheat, late rice and tuber crops than in maize and early rice.

Clearly, the choice between the efficiency functions is important. The choice can be made using nonnested hypothesis tests such as the J test of Davidson and MacKinnon (1981) and/or using the popular test of Ramsey (1969), namely RESET. It is also possible to construct and estimate a composite model, which contains both the linear and log–linear specifications for the efficiency function. F-tests can then be applied to assess which specification is to be accepted. A common deficiency of these tests lies in that they may result in an 'all accept' or 'all reject' outcome. An alternative, preferred by Granger *et al.* (1995) and suggested by a referee of this journal, is to adopt a model selection procedure, which is developed in the econometric literature to avoid the 'all accept' or 'all reject' problem. Another advantage of the procedure is that it will give rise to the same final model as long as the same data are used. Consequently, the likelihood dominance criterion (LDC) of Pollak and Wales (1991) will be employed here for selecting efficiency functions.

The LDC relies on comparison of the so-called 'adjusted likelihood values', which equal the conventional likelihood values of individual models plus an adjustment. The adjustment is a function of the difference in the number of parameters between the individual and the relevant composite models. It is useful to note that estimation of the composite model is not needed in implementing this procedure. When two models under consideration contain the same number of parameters, LDC always prefers the one with the higher (unadjusted) likelihood.

Since all of the competing models in this paper have the same dependent variable and the same number of parameters, applying LDC is equivalent to simple comparisons of the loglikelihood values and R^2s or adjusted R^2s. Implicitly, this is the practice adopted by Kakwani (1977), Bewley (1982) and Wan (1996). Table 2 tabulates adjusted R^2s and log–likelihood values under different specifications of the efficiency function. The results indicate that a log–linear efficiency function should be used for modelling maize and wheat while a linear efficiency function ought to be used for modelling rice and tuber crops in China.

Table 2. R^2 *and Log–likelihood values of alternative models*

Crops	Efficiency function	Adjusted R_2	Log–likelihood
Maize	Log–linear	0.943	−219.16
	Linear	0.943	−220.30
Late rice	Log–linear	0.880	−70.56
	Linear	0.881	−67.39
Wheat	Log–linear	0.945	51.68
	Linear	0.944	48.11
Early rice	Log–linear	0.951	104.27
	Linear	0.952	107.65
Tubers	Log–linear	0.636	−210.84
	Linear	0.644	−207.40

As discussed earlier, the choice between a CD and a translog model can be made using F-tests with a null of $\gamma_{ij} = 0$ for all i, j. The relevant F-values can be found in Table 3 together with corresponding degrees of freedom. Since the null hypothesis is rejected in all cases at the 5% (for maize) or 1% (for other crops) level of significance, it can be concluded that the CD form is not appropriate for studying crop production in China. Given this finding, results in Fleisher and Liu (1992), Wan and Cheng (1996) and Nguyen *et al.* (1996) are questionable as they all adopted CD specifications.

Conditional on the above choices, constant returns to scale will now be tested. The relevant F-values are tabulated in Table 3 as well. At the 1% or 5% level of significance, economies of scale are found to be absent in maize and late rice production while nonconstant returns to scale exist in other cropping activities. Since the scale elasticity under the extended translog model is given by $\sum_i(\alpha_i + \beta_i \ln P_h) + \sum_i \sum_j \gamma_{ij} \ln X_j$ (with $\ln P_h$ replaced by P_h for tuber and rice crops), its value can be easily obtained by replacing $\ln X_j$ and the fragmentation variables by their geometric sample means. The calculation produces values of 1.08, 0.982 and 1.113, respectively for wheat, early rice and tuber crops. These values indicate that positive economies of scale are present in wheat and tuber production while early rice production exhibits negative economies of scale.

Turning to effects of land fragmentation, attempts are made to test for neutral and then nonneutral effects. The

Table 3. F-*Values for testing CD versus translog and constant returns to scale*

	H_0: CD		H_0: Constant returns to scale	
Crops	F-value	Degrees of freedom	F-value	Degrees of freedom
Maize	2.23*	6, 495	1.47	5, 495
Late rice	24.06**	6, 454	2.06	5, 454
Wheat	11.98**	6, 374	3.83**	5, 374
Early rice	3.11**	6, 359	5.57**	5, 359
Tubers	6.93**	6, 267	3.43**	5, 269

Notes: ** Reject H_0 at the 1% significance level.
* Reject H_0 at the 5% significance level.

Table 4. F-*values* (t-*ratios*) *for testing (neutral) fragmentation effects*

	H_1: Fragmentation effects are	
Crops	Neutral	Non-neutral
Maize	−1.933*	3.06*
Late rice	−5.407**	1.42
Wheat	−5.797**	3.62*
Early rice	−5.088**	10.59**
Tubers	−2.187*	6.32**

Notes: ** Accept H_1 at the 1% significance level.
* Accept H_1 at the 5% significance level.

former can be implemented by estimating Equation (3) and examining the t-ratios for the parameter β_0. *A priori* knowledge dictates that $\beta_0 \leq 0$ thus one tailed tests will be used. From Table 4, it can be seen that the neutral effects of land fragmentation are all negative, exist in all the crops under consideration, and are all statistically significant. In fact, this finding is a result of every estimation ever undertaken by the authors using the survey data. In particular, fitting CD or CES functions with or without any restrictions all gives rise to this finding. Consequently, the fragmentation variables $\ln P_h$ or P_h (versus the interactive terms) will be retained in the models when testing for non-neutral effects. According to the F-values in the last column of Table 4, non-neutral fragmentation effects are found to prevail in all crops with late rice as the only exception. Therefore, late rice will be modelled using Equation 3 and the others using Equation 4.

Table 5 summarizes the estimation results of the final models. Coefficients for regional dummy variables are left out as they are largely irrelevant to the following discussions (see also Lin, 1992). Given the use of purely cross-sectional observations, all the models fit the data quite well as they all possess reasonably high coefficients of determination (see Table 2). Further, majority of the model parameters are statistically significant as indicated by the t-ratios. For each individual crop Equation, at least half of the parameters are statistically significant. It should be pointed out that parameter estimates for αs and γs are found to change little when the efficiency specification varies. This may imply negligible or low correlation between the land fragmentation variable or plot number and other independent variables. Should the average plot size be used as the fragmentation variable, such a robustness is likely to disappear.

In Table 5, some estimates of the coefficients for the individual land fragmentation variables $\ln P$ or P are positive and statistically significant. This does not imply that land fragmentation exerts positive effects on crop outputs, just as the coefficients preceding individual input variables in $\ln X_j$s can be positive, negative or 0. The effects of land fragmentation and inputs on crop outputs are to be measured by various elasticities. These elasticities are presented and discussed in the following paragraphs.

It is commonly accepted that estimates of output elasticities from empirical studies represent essential ingredients for various policy-making at different levels. On the other hand, the estimated values, if justifiable, can also provide another check on the specification and estimation of the production models. Following conventional practice, the elasticities are evaluated at the geometric sample means of the relevant variables and are listed in Table 6. As with the famous AIDS demand model and other studies using translog, no statistical significance is attached to the elasticity estimates. Recent developments in econometrics, including bootstrapping and Gibbs sampling techniques, may soon offer a satisfactory solution to this problem common to many flexible models.

From Table 6, the estimated capital elasticities vary from 0.1 to 0.3 and they seem quite reasonable. Recall that the capital variable here comprises fertilizer and other inputs. Therefore, our estimates are broadly in line with those presented in Tian and Wan (2000) who employed region-level aggregated data and obtained separate elasticity estimates for fertilizer and other inputs.

The negative elasticity estimates of labour, however, seem surprising. Previous studies almost exclusively documented positive and significant labour elasticity (Fan, 1991; Fleisher and Liu, 1992; Lin, 1992). It is beyond the scope of this paper to argue against earlier results. Suffice it

Table 5. *Parameter estimates of the preferred models*

Parameter		Maize	Late rice	Wheat	Early rice	Tubers
α_1		2.463**	−2.333**	−1.041	2.471*	−0.937
	t-ratio	4.424	−9.473	−1.610	2.161	−1.275
α_2		−0.599*	1.849**	0.207	0.314	0.124
	t-ratio	−2.086	7.168	0.459	0.770	0.276
α_3		−0.864*	1.483**	1.560**	−1.057	2.109*
	t-ratio	−2.308	6.712	3.785	−1.051	2.234
γ_{11}		0.406**	−0.851**	−0.496**	0.517*	−0.186
	t-ratio	2.800	−11.47	−4.149	1.906	−1.283
γ_{22}		−0.008	−0.227**	−0.233**	−0.126	0.254**
	t-ratio	−0.102	−3.806	−3.096	−1.570	3.785
γ_{33}		0.131*	−0.119*	−0.296**	0.210	−0.115
	t-ratio	2.057	−1.973	−5.075	1.008	−0.455
γ_{12}		−0.134	0.480**	0.138	−0.013	0.107
	t-ratio	−1.642	6.915	1.337	−0.145	1.169
γ_{13}		−0.272**	0.371**	0.304**	−0.315	0.346*
	t-ratio	−2.774	8.845	4.272	−1.362	2.199
γ_{23}		0.141*	−0.252**	0.067	0.019	−0.312
	t-ratio	2.536	−5.745	0.790	0.265	−2.601**
α_0		9.054**	0.466	1.858	8.712**	2.902
	t-ratio	8.419	1.026	1.139	3.495	1.315
β_0	Log–linear	−0.697*	–	0.555	–	–
	t-ratio	−2.414	–	1.348	–	–
	Linear	–	−0.020**	–	−0.337**	0.437**
	t-ratio	–	−5.407	–	−5.135	2.964
β_1		−0.203*	–	0.282*	−0.066**	0.094*
	t-ratio	−2.496	–	2.565	−4.266	2.044
β_2		0.131**	–	−0.048	0.030**	−0.095**
	t-ratio	2.583	–	−0.659	3.983	−3.726
β_3		0.072	–	−0.138*	0.046**	−0.041
	t-ratio	1.254	–	−2.243	3.712	−1.078

Notes: ** Parameter is different from 0 at the 1% significance level.
* Parameter is different from 0 at the 5% significance level.

to state that most labour elasticities in Table 6 are close to zero and all are perhaps insignificant, as found in Nguyen *et al.* (1996).[5] Given the fact that a large amount of surplus labour, in the order of 200 million, exists in rural China (Zhou *et al.*, 1992), true labour elasticities are expected to be quite close to zero. This is in line with the arguments put forward by Fleisher and Liu (1992, p. 119) and Nguyen *et al.* (1996, p. 7). Further, this was the base underlying the practice of Wan and Anderson (1990) and Wan *et al.* (1992) to exclude labour from Chinese agricultural production functions. As is known, econometric estimations of positive but small parameters may well yield negative estimates. Most importantly, in light of the classic works of Lewis (1954, 1955) and Sen (1960), one must question significantly positive estimates of marginal products or elasticities of labour for countries such as China, where acute unemployment and underemployment problems prevail. This is particularly pertinent when yearly data aggregated over crops are utilized. See also Viner (1984) and Leibenstein (1957) for detailed discussions.

Land elasticities are comparable to those obtained by Fleisher and Liu (1992, p. 116), Nguyen *et al.* (1996) and Wan and Cheng (1996). These studies are all based on household data as is this paper and all reported rather higher land elasticities than those which employed aggregated data (e.g., Fan, 1991; Lin, 1992; Wan *et al.*, 1992). Casual examination of earlier studies seems to suggest that the higher is the level of data aggregation, the larger is the downward bias in the estimate of land elasticity and the larger is the upward bias in the estimate of labour elasticity. This may help explain why labour elasticities of Tian and Wan (2000) are mostly nonnegative though very small. One possible explanation of this phenomenon may lie in the increased multicollinearity between labour and sown area variables as aggregation proceeds to higher levels. However, this casual finding and associated explanations are subject to further economic and econometric analyses.

To measure the effects of land fragmentation, both the elasticitity and quasi-elasticity as previously defined, are computed and shown in Table 7. It is found that all elasti-

[5] Several workshop and seminar participants in China and Australia pointed out that they obtained similar results using different household data.

Table 6. *Output and scale elasticities evaluated at the geometric sample means*

	Output elasticities			
Crops	Land	Labour	Capital	Scale elasticities
Maize	0.771	0.102	0.127	1
Late rice	0.805	−0.007	0.202	1
Wheat	0.993	−0.211	0.296	1.08
Early rice	0.903	−0.006	0.085	0.982
Tubers	0.796	−0.002	0.319	1.113

Table 7. *Percentage loss in crop outputs under different fragmentation scenarios*

Plot No.	Maize	Late rice	Wheat	Early rice	Tubers
1	0	0	0	0	0
2	3.09	4.70	11.21	2.33	8.49
3	4.94	9.62	18.34	4.72	17.71
4	6.27	14.77	23.68	7.16	27.71
5	7.31	20.16	27.98	9.66	38.56
6	8.18	25.80	31.61	12.21	50.33
Sample average	3.90	14.99	16.74	6.92	12.04

cities are negative and substantial. Consistent with earlier arguments and *a priori* expectation, the detrimental effects of land fragmentation are most serious in tubers and wheat and moderate in other crops. It is discovered that every increase in land fragmentation by one plot will lead to output losses in the order of 9.8%, 6.5% and no less than 2%, respectively in tubers, wheat, and other crop production. It is worth reiterating that earlier tests show that all neutral as well as non-neutral fragmentation effects are statistically significant except in one case.

It appears quite conclusive that land fragmentation does exert adverse impacts on outputs in every crop production in China. These findings provide strong evidence for refuting the hypothesis advanced by Warriner (1984, p. 469) in support of land division in Asian countries. Together with the findings of a general lack of economies of scale, they also urge economists and policy-makers in China to place land fragmentation rather than household land holdings on the top of the research and government agenda.

The above findings and arguments are inevitably dependent on the estimation results. This is why the flexible translog functions are adopted and considerable efforts are devoted to the choices of alternative efficiency specifications.

To evaluate the magnitude of land fragmentation effects on the output of a crop, a simple simulation can be performed. The simulation involves calculation of predicted outputs based on the finally chosen production functions, where only the plot number is varied with all other variables fixed at their geometric sample means. Setting the plot number to unity, the benchmark output where no fragmentation is present can be computed. Percentage losses corresponding to different fragmentation scenarios can then be obtained by comparing the simulated outputs with the benchmark counterparts. The results are tabulated in Table 8. Consistent with what can be inferred from Table 7, the impacts of land fragmentation on outputs are found to be substantial, particularly for tubers and wheat.

In Table 8, we also report the output levels corresponding to the mean plot numbers (cf. Table 1) in the last row. Comparison between the first and last figures in a column of Table 8 can thus reveal the possible gains in average outputs following elimination of land fragmentation. The outcome of the comparison is staggering but not incomprehensible. For wheat, late rice and tuber crops, outputs would increase respectively by some 17%, 14% and 12%, if complete consolidation of land ($P_h = 1$) can be achieved. The percentages are close to 7% for early rice and 4% for maize.

It is useful to obtain an overall indication of output loss for the Chinese cropping sector as a whole that is attributable to land fragmentation. For that purpose, Fleisher and Liu (1992) proposed a set of weights which they utilized to aggregate individual losses over crops. However, these weights are based on 1986 purchasing prices of salt and grains. Beside being outdated, the purchasing prices do not necessarily reflect market values of the products in China. For the purpose of aggregation, it is better to use the shares of individual crop outputs in the national total

Table 8. *Elasticities of land fragmentation*

Crops	$\partial \text{Ln}\, Y / \partial \text{Ln}\, P$	$\partial \text{Ln}\, Y / \partial P$
Maize	−0.044	−0.022
Late rice	−0.064	−0.020
Wheat	−0.153	−0.065
Early rice	−0.030	−0.010
Tubers	−0.186	−0.098

as weights. According to 1995 statistics, the shares are 0.2596, 0.4295, 0.2364 and 0.0745, respectively for maize, rice, wheat and tuber crops. Applying these weights with late and early rice combined, elimination of land fragmentation is found to possibly lead to a 15.3% increase in China's foodgrain output. This represents a possible jump of 71.4 million metric tons of cereal output.

V. POLICY IMPLICATIONS AND CONCLUDING REMARKS

Two important findings emerge from this study which carry significant policy implications. First, positive and substantial economies of scale, which underlie arguments for land enlargement or formation of new production cooperatives, do not exist in Chinese farming. They are absent in maize and late rice production, negative in early rice production and positive but small in wheat and tuber cropping. Using the weights from the preceding paragraph, an overall scale elasticity of 1.026 can be obtained. This value implies a negligible impact of returns to scale on output. In other words, when all inputs including family land holdings are increased by 10%, total grain output can only increase by 10.26%, a mere 0.26% gain due to economies of scale. Apart from equity, food security and ideology considerations, any official measures to increase farming land holdings necessitate large-scale emigration of rural population and costly rural adjustment schemes must be implemented immediately. For example, an increase in average farm scale by 10% would require an emigration of 30 million labour force out of agriculture. This could translate into a movement of some 60 million rural population into nonfarming sectors. The economic and social costs involved in implementing such policies, if feasible at all even in the medium-term, are by no means to be compensated by a mere 0.26% gain in cereal outputs. The costs will incur not only as a result of settling emigrants but also for expensive reorganization of the rural economy. In the long run, the feasibility of land enlargement clearly depends on accumulation of capital and development of manufacturing and tertiary sectors within rural areas. This is because urban China already suffers from acute unemployment problem and extreme overcrowding. At least 10 million urban employees lost their jobs in the past a couple of years (Wan 1999).

Second, it is found that China's grain output could rise by 71.4 million metric tons simply by eliminating land fragmentation. This is achievable while leaving current family holdings intact. The gains in output are most apparent in tuber and wheat production and are no less than 3.9% in any of the crops considered in the paper. The overall gain in absolute terms is more than the output increase target of 50 million metric tons set for China's farming sector under the ninth five-year plan. Moreover, eliminating fragmentation here does not mean each family being allocated one piece of land. Rather, it only requires individual crops be planted on the same block at the family farm level. In many aspects, such a policy proposal would be more appealing and easier to implement than requesting one family to cultivate one plot of land. Nevertheless, it should be pointed out that complete elimination of land fragmentation may not be possible in mountainous and hilly areas.

Our findings strongly suggest that the next step in China's rural reform ought to focus on land consolidation rather than on increasing family holdings. In particular, urgent steps are needed to prevent further fragmentation of farming land which has been occurring in China (Chen, 1992). As existence of economies of scale is conditional on the prevailing cropping techniques and state of infrastructure development in agriculture, it may take a long time for them to set in. In any case, unless farming is further commercialized and a notable portion of operations is mechanized, significant economies of scale are not expected to appear. Until that time, Chinese government policies must emphasize plot exchanges and other strategies for land consolidation.

At present, leasing and subcontracting of land cultivation rights are permitted in rural China. These, however, may not lead to improvement in land fragmentation unless adjacent plots are involved. Land exchange is perhaps a better alternative. In this context, involuntary amalgamation of farms and the actions alike should be discouraged. Clearly, extensive economic analyses are needed to establish the manner and base of such exchanges. In particular, how to compensate farmers for losing cultivation rights and for exchanging good plots for worse plots requires careful analysis in the context of equity, food security and long-run agricultural growth. Complementary policy options such as tax concessions, credit assistance and input subsidies can be exercised to speed up the consolidation process.

From a practical point of view, the Chinese government is unlikely to implement any nonvoluntary land policies. In this sense, land consolidation schemes should be initiated or experimented in the northern and western regions of China where wheat and tuber crops are dominant. This is especially important as the base of grain production in China has been gradually shifting from the south and east towards the north and west. The effects of these schemes will be more apparent and thus more illuminative there. Farmers may refuse to participate in any government schemes unless they produce positive results. Note also that land fragmentation is relatively less severe in the north and west regions thus consolidation policies would be easier to implement there than in other parts of the country.

Needless to say, the findings and policy recommendations of this study are conditional on the data and analytical framework employed. Although the survey was conducted at the national level and the data are arguably representative and of reasonable quality, cautions must always be exercised in generalizing from the numerical estimates of the econometric models. Further, there are some questions left unanswered in the paper. For example, why, apart from average plot size considerations, are fragmentation effects so large in wheat and tuber crop production? As another example, how robust are the results to different assumptions on rural economic environment and local geographical conditions? Nevertheless, these represent interesting topics for further research when appropriate data and material become available.

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