Land Fragmentation and Rice Production:

A Case Study of Small Farms in Jiangxi Province, P. R. China

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Land Fragmentation and Rice Production:

A Case Study of Small Farms in Jiangxi Province, P. R. China

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ABSTRACT

Agricultural landholdings in China have an average size of only 0.53 hectares and are divided over six different plots on average. This very high degree of land fragmentation is likely to impose important constraints to current government policies aimed at supporting the incomes of rural households, raising domestic grain production, and promoting the overall production capacity of agricultural sector in order to meet the challenges posed by foreign competition. The purpose of this study is to examine the causes of this extremely high degree of land fragmentation and its consequences for food production in China. The analysis focuses in particular on rice smallholders in Jiangxi Province, a major rice production base of China.

The results of the analysis of factors driving land fragmentation indicate that the egalitarian principle used in distributing land to households and in reallocating land to adjust for demographic changes within villages is the main driving factor. Land renting activities and off-farm employment opportunities reduce land fragmentation, but their impact is modest. With respect to the consequences of land fragmentation, this study finds that consolidation of small, fragmented plots into a smaller number of larger plots located at smaller distances to the homestead (1) reduces production costs, (2) causes a shift from labor-intensive methods towards the use of modern technologies, (3) reduces technical efficiency and increases input use efficiency, (4) contributes to soil quality improvement, and (5) increases the availability of the two major yield-limiting factors in rice production in the research area.

Four conclusions are drawn from the findings and three policy options are suggested for reducing the high degree of land fragmentation in China, namely to replace land distribution based on physical units by a system based on land values, to provide tradable land use rights to all farmers, and to promote the establishment of a local, small, non-state-owned enterprise sector in rural areas with limited off-farm employment opportunities. A combination of these three policies is likely to lead to a significant reduction in land fragmentation, and thereby provide important incentives to farm households to strengthen the long-term production capacity, and make the agricultural sector more capable of meeting the challenges of increased foreign competition in China.

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CHAPTER 1

INTRODUCTION

1.1 Problem statement

Since the book “Who will feed China?” was published (Brown, 1995), China’s long-term food prospect has received much global attention. In subsequent years, Chinese governments made great efforts to strengthen food production. As a result, grain production reached a peak (512.3 billion kg) in 1998. Yet, since then, the country’s grain production has been in decline for five consecutive years, and reached its lowest point (430.6 billion kg) in 2003, leading to a negative balance of the food supply and demand in China (Zhao, 2004a). Ensuring an adequate supply of affordable food in China remains a top priority of China’s policy makers (OECD, 2005).

China is a country with relatively scarce land resources and a large population. In mainland China, the population reached 1.3 billion by 2005, living on 960 million hectares of total land[1]. Arable land in China accounts for only 13.5% of the total land area, *i.e.* 0.10 hectare per capita (NACO and FASC, 1998). With only 7% of the world’s total cultivated land, China faces the challenge of feeding 22% of the world’s population.

Although the food deficit of 216 million tons for 2030 predicted by Brown (1995) is probably overestimated (due to an underestimation of the potential food production capacity), agricultural production in China will have to meet a huge challenge in satisfying the requirements of food and raw materials by industries due to the increasing population and expected welfare growth (Zhong *et al.*, 1999; Rural Economic Research Center, 2004). According to available predictions, China’s population will increase to around 1.6 billion by 2030 (Zhong *et al.*, 1999). This will put a severe burden on the country’s agricultural sector. The issue of how to maintain and ensure an adequate supply of food and promote sustainable agricultural development in the future has become a major challenge confronting the government as well as scientists.

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[1] Mainland China excludes Hong Kong and Macao Special Administrative Regions and Taiwan.

In order to address this challenge, both the government and researchers are working on ways to further raise agricultural productivity. Given the high population pressure and the scarcity of farmland, sustaining the agricultural production base and improving productivity is generally seen as the most effective way to guarantee an adequate food production in the long-term in China. One important obstacle in this respect may be the high degree of land fragmentation. At the end of the 1990s, landholdings in China had an average size of only 0.53 ha, divided over more than six non-adjacent plots (Rural Fixed Observation Office, 2001).

According to a number of empirical studies, Chinese agricultural growth in the past several decades can be attributed to three major sources: (1) increases in input use; (2) technological changes; and (3) institutional changes (Fan, 1991; Chen *et al.*, 1997; Fan and Pardey, 1997; Lin, 1992; Zhong *et al.*, 1999; Zhang *et al.*, 1996). Fan (1991) estimated that input use accounts for 58% of the increase in total production from 1965 to 1985. Given the scarcity of arable land, the importance of traditional inputs (particularly land) to the increase of agricultural production is decreasing. Modern inputs like chemical fertilizers and pesticides are becoming more and more important. However, the application of chemicals can also be a cause of reduced food quality and may degrade the agricultural environment, which serves as the base for grain production (Zhao, 2004b). Consolidation of fragmented plots may play an important role in contributing to increases in food production. According to Huang (1997), an additional 3-10% of the cultivated land area could be used for agricultural production by eliminating land fragmentation; moreover, consolidating fragmented plots may improve farmers' input use efficiency due to more convenient farm management.

The second source of agricultural production growth from 1965 to 1985 was technology change, accounting for an estimated 16% of the increase in agricultural production (Fan, 1991). This is much lower than in many other countries. For instance, technology change contributed 47% to agricultural growth in Japan and 84% in America from 1960 to 1980 (Hayami and Ruttan, 1985). From 1985 to 1990, the contribution of agricultural technology change to the growth of agricultural production amounted 28% in China, compared to 81% in the United States (Li *et al.*, 1998). This suggests that there exists a great potential for agricultural growth in China by encouraging farmers to use modern technologies in production. However, the small sizes of land holdings and the high degree of land fragmentation may be important obstacles to the adoption of new technologies by smallholders.

The third main source of agricultural growth from 1965 to 1985 was institutional change which according to Fan (1991) contributed 27%. In the first years of The Economic Reform, the institutional transition from the community system to the household responsibility system (HRS) played a major role in stimulating agricultural production. The HRS provides farmers with incentives for increasing production by giving them land use rights and freedom of decision-making, linking income closely with their own performance (McMillan *et al.*, 1989; Lin, 1992; Hu, 1997; Carter and Yao, 1999). It has proven to be a great success. However, its role in stimulating further production increases is probably limited.

Since the beginning of 2004, the Chinese government has implemented a series of income support policies for rural households. These measures include direct income subsidies to grain farmers, cuts in agricultural taxes, subsidization of improved seeds and machinery, and increased spending on rural infrastructure (State Council, 2004; Gale *et al.* 2005). Grain production in 2004 increased to 469 million tons, and the per capita net real income of rural households grew by 6.8% (NBS, 2005), making 2004 the year of the largest income increase for farmers since 1997 and a key year for reversing the decline in grain production. The Chinese government realizes, however, that the main factors driving the increase in agricultural production and farmers' income in 2004 were price increases and favorable weather conditions. Maintaining such growth in the future will be much more difficult. The area of arable land has decreased in recent years, and irrigation and water conservation facilities are ageing and not adequately maintained. Agricultural science does not produce sufficient applicable research results, and the system for technology promotion is considered inadequate. Strengthening agricultural production capacity therefore becomes a top policy priority in 2005 (State Council, 2005). Proposed measures include intensifying the conservation of arable land and improving the ecological environment, accelerating the construction of irrigation and water conservation facilities, and promoting agricultural science and technology. All these measures may, to some extent, be strengthened by a consolidation of fragmented pattern of land holdings in China.

1.2 Objectives and research questions

The objective of this study is to examine how and to what extent the high degree of land fragmentation affects food production in China. The insights gained from the study may contribute to improved policies for increasing agricultural production capacity and ensuring an adequate supply of food for China's growing population.

The focus of the study is on rice smallholders in Jiangxi Province, a major rice production base of China. Rice is the most important crop in China, not only because it is the largest cereal crop cultivated (27-29% in terms of the sown area, and 41-45% in terms of grain production), but also because it supplies 40% of calorie intake and about 60% of the Chinese population consumes rice as the main staple food (Zhang, 2002; Zhao, 2004a). The importance of rice production for food security and for the economy in China can thus hardly be overemphasized.

Jiangxi Province was selected for this study as it is both a major rice growing area in China and an area with a high degree of land fragmentation. In 2002, the area sown with rice constituted 87.4% of the area sown with grain (including soybeans). Agriculture accounts for 21.9% of regional GDP in 2002, 6.5% higher than the national level (15.4%) (NBS, 2003). Yet, the average agricultural household managed only 0.33 ha in 1999, compared to 0.53 ha in China as a whole. The average number of plots per farm household was 8.4 in the same year, compared to a national average of 6.1[2].

Thus Jiangxi Province presents an ideal case study for meeting the objective of this research. This objective is met through addressing the following specific research questions:

1. What are the characteristics of land fragmentation in China? What drives differences in fragmentation?
2. What is the impact of land fragmentation on smallholder rice production costs?
3. What is the impact of land fragmentation on the technical efficiency of rice producers?
4. What is the relative importance of land fragmentation in smallholder farm

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[2] The source for the national data is Rural Fixed Observation Office, 2001. Land fragmentation data for Jiangxi Province are collected by the author for the province-level Rural Fixed Observation Office in Nanchang.

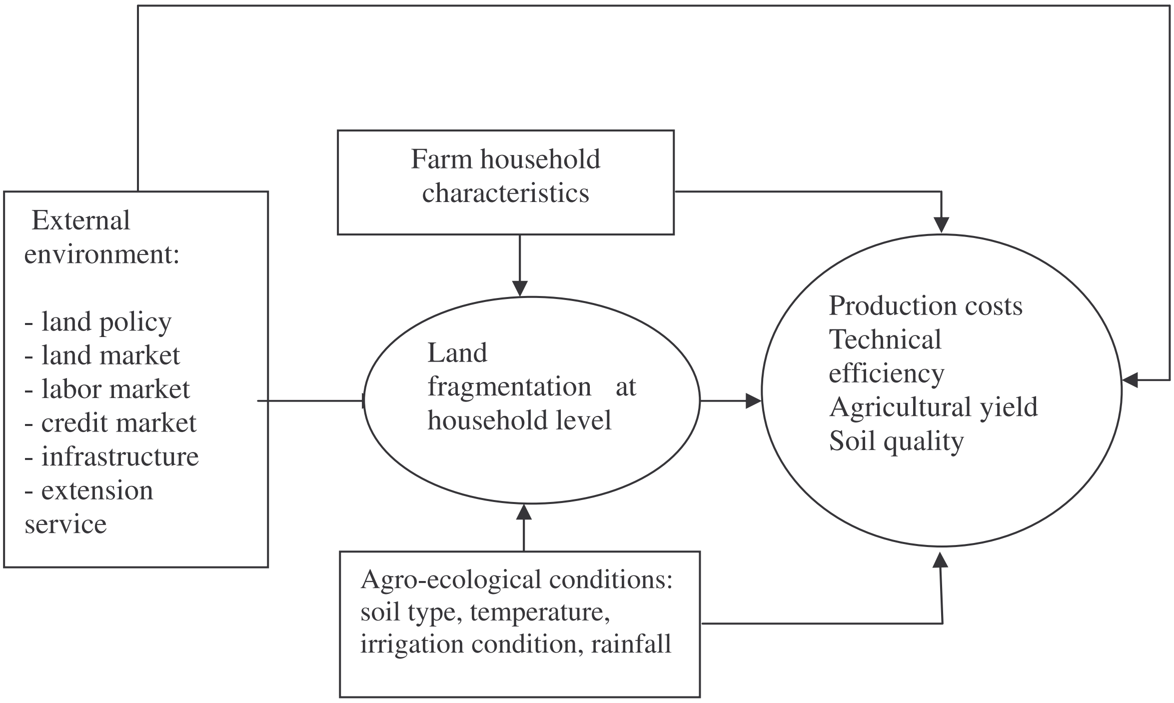
management decisions compared to other factors?

5. How do the resulting farm management decisions affect rice yield and soil quality?

1.3 Analytical framework

These five research questions will be analyzed within the framework shown in Figure 1.1. Here the factors shown within the circles are considered as endogenous variables and the factors in the rectangles are considered as exogenous variables that influence the endogenous ones.

Figure 1.1 Analytical framework



Land fragmentation at the household level depends on external policy and market factors, agro-ecological conditions, and farm household characteristics. The resulting level of fragmentation, together with external factors, agro-ecological conditions and farm characteristics, affects agricultural production. To examine the impact of land fragmentation on agricultural production in more detail, a distinction is made between production costs, technical efficiency, soil quality, and yield. Each of these aspects will be analyzed in turn.

1.4 Outline of the thesis

This study is divided into two main parts. The first part addresses research question 1, namely the characteristics and driving causes of land fragmentation in China. This question is addressed in chapters 2 and 3.

Chapter 2 first briefly reviews literature on land fragmentation issues and discusses the definitions, measurement, causes and effects of land fragmentation. This provides a framework for quantifying causes and effects of land fragmentation in later chapters. Then, it explores the recent trends in land fragmentation in China and its different regions, using time-series data from the National Rural Social-Economic Survey[3]. Finally, it compares land fragmentation in China to that in other countries. This allows the reader to get an impression of the trends and severity of land fragmentation in China.

Chapter 3 more specifically explores the driving forces of land fragmentation in Jiangxi Province, using Rural Fixed Observation data for 860 households in 11 villages (located in 11 different prefectures) in 2000.

The second part of this study focuses on the effects of land fragmentation on small farmers' agricultural production. This part consists of three chapters: the first two chapters focus on research questions 2 and 3 and examine the direct impact of land fragmentation on smallholders' rice production in terms of costs and technical efficiency.

Chapter 4 analyzes the impact of land fragmentation on rice production costs. This chapter draws on fieldwork data from 334 households from three villages in Jiangxi Province[4]. The household characteristics (including the composition of the household, its members' ages, education and position), farm characteristics (including farm size, the number of plots, ownership of oxen and tractors, access to extension, savings, and availability of credit), and plot level data (including plot size, distance of plot to the homestead, and soil fertility, *etc*.) were collected for the agricultural year 2000. Production costs are the outcome of household decision-making under given socio-economic and agro-ecological conditions facing households. A reduced-form farm household model is used for this purpose.

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[3] These data will be called Rural Fixed Observation data throughout the remainder of this study. For detailed information about this survey, see Appendix 1.1.

[4] This survey was conducted under the framework of the SERENA project. For details of this survey, see Chapter 4.

Chapter 5 examines the impact of land fragmentation on rice producers' technical efficiency, applying a parametric approach. Rice production in this chapter is distinguished into three types: early, one-season and late rice, representing the main different production structures. The same data set of 334 households in the three villages is used in this chapter.

Chapters 4 and 5 are partial analyses of the direct effects of land fragmentation on rice production. However, farmers usually take simultaneous decisions on activities, technologies and investment. Chapter 6 therefore analyzes the impact of fragmentation on smallholders' rice production decisions and the consequences for soil quality, using a household/plot level model. This model is estimated with Two Stages Least Square (2SLS) econometric techniques. Data used in this chapter are from a plot-level data set collected for a sub-set of the households in the same three villages. Combining data from the more detailed plot level survey with household level data for the same households makes it possible to address the last two research questions. This plot-level survey was undertaken in the beginning of 2003 and was held among 57 households. It covers plot level input/output information for the agricultural year 2002. Soil samples were taken from 315 plots and tested for soil total nitrogen, soil total carbon, soil pH value, soil available potassium, soil available phosphorus, and clay contents.

Chapter 7 reviews the main findings of the research, their policy implications, and makes suggestions for further research. New findings with respect to land fragmentation and its impact on smallholder's agricultural production from this study receive special attention in this chapter.

This study contributes to the existing literature in a number of ways. First of all, it provides in-depth analysis of land fragmentation and its impact on smallholder agricultural production in China. Rural Fixed Observation data are used to examine the dynamic aspects of land fragmentation. Such accurate and large scale data sets are rarely available in developing countries where land fragmentation is widespread. These data are used in this study to examine the trends in land fragmentation and to analyze the driving forces behind these trends in order to formulate feasible policy recommendations for reducing land fragmentation. This is the second major contribution of this study.

The third innovation is the use of a broad range of land fragmentation indicators, covering different dimensions of the problem. This study uses not only the number of plots (as used by, for instance, Fleisher and Liu, 1992) and average plot size (used by Su and Wang, 2002, for example), but also the distance of a plot to the homestead to reflect the spatial distribution of the plots. By using indicators of different dimensions of the land fragmentation problem, more detailed insights into its impact on agricultural production can be obtained.

The fourth innovation is the use of a farm household model framework to examine the impact of land fragmentation on production costs and technical efficiency. Under this approach, farm households are assumed to maximize their utility within the boundaries of the given constraints they face. It allows a formal derivation of the control factors to be included in empirical analyses of the impact of land fragmentation.

Finally, this study empirically examines the impact of land fragmentation on soil quality, a major factor in (future) agricultural production capacity. It develops a model of interactions between farm management activities, rice yield, and soil quality, and examines how land fragmentation affects farm management decisions, soil quality and rice yield. The production function used in this analysis differs from traditional functions used in agricultural economics by including soil quality indicators (as proximate determinants of yield) instead of soil management variables. Under this approach, which is based on insights from agronomy and soil science, fertilizer use and manure application affect rice yield in an indirect way by changing soil quality. Moreover, fertilizer use is subdivided into N, P and K according to the nutrient content of the applied fertilizers[5], because different crops or crop varieties generally react differently to different macro-nutrients, and because application of fertilizer types with different compositions has different effects on soil quality. The separation of fertilizer use into its macro-nutrient components makes it possible to estimate which component is the main limiting factor on yield in the research area, and to formulate specific recommendations regarding the required changes in fertilizer applications for farm households in the research area.

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[5] P and K represent P_2O_5 and K_2O, respectively.

Appendix 1.1 An introduction of National Rural Social-Economic Survey (1986-2000)

To help evaluate the effectiveness of rural reform in China, the Fixed Observation Villages were established on the basis of the national social and economic survey conducted in 1984 by the former Rural Policy Research Department of the Central Committee of the Chinese Communist Party and Research Center for Rural Development of State Council with the authorization by the Secretariat of Central Committee of Chinese Communist Party. The survey uses a nationwide panel system of village and rural households, selected through a combination of categorizing and sampling. Its function is to supply important information for agricultural and rural policy making to the central government and administrative departments at various levels.

The major data collection is based on primary data collected from more than 300 Rural Fixed Observation Villages since 1986. The data are aggregated annually according to the economic region (East, Center and West) and to rural household income levels (see Figure 1.2-1.4 for the distribution of the surveyed villages). This survey reflects the social and economic development of more than 300 villages and more than 20 thousand rural households. The survey includes data on rural households, comprehensive data on villages, as well as data on ranchers and pasturing villages. Data collection is based on daily record keeping that is used for calculating annual totals.

The survey indicators of the Rural Fixed Observation Villages were revised in 1993 and 1995. In 1992 and 1994 there was no survey. The sample size was set in 1991 at about 26 thousand rural households, 900 rancher households, 300 farming villages and 14 pasturing villages. It was reduced in 1993. Since 1995, the sampled size has been maintained basically at 21 thousand villages, 650 rancher households, 300 farming villages and 15 pasturing villages. To generate a panel data survey, the selected villages and households in each province (municipality, autonomous regions) has been kept constant since 1995. Household that emigrate from the villages are replaced by other households from the same village with similar characteristics. These replacement households can be identified within the data set.

Figure 1.2 Distribution of the villages across economic regions

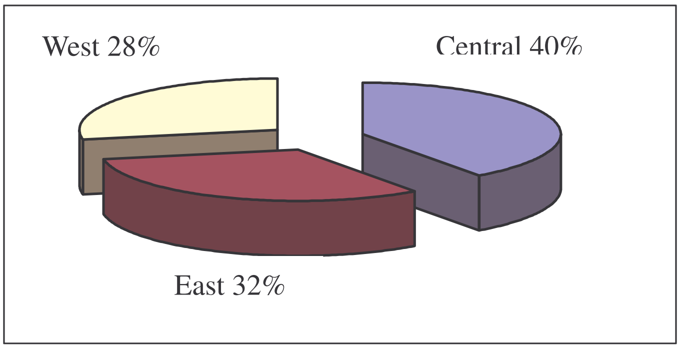


Figure 1.3 Distribution of the villages in terms of topography

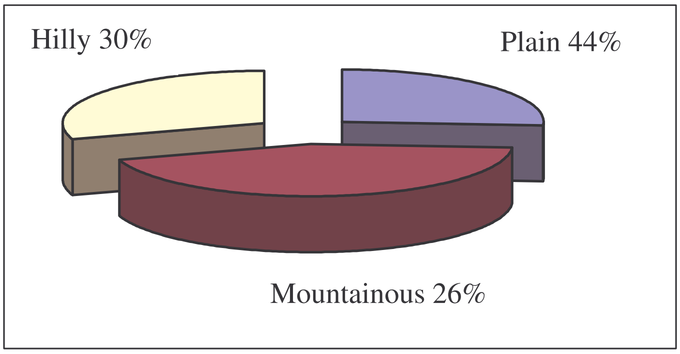
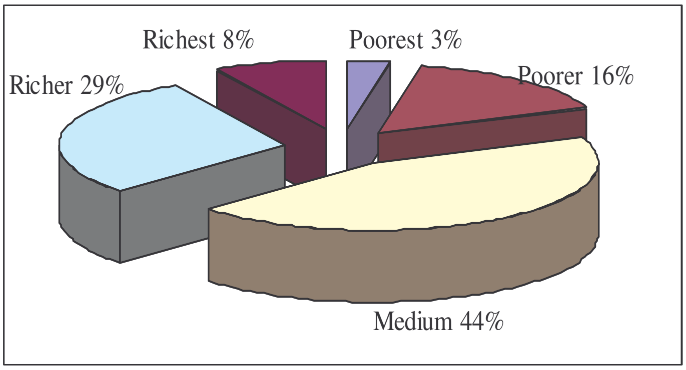


Figure 1.4 Distribution of the villages in terms of income



Source: Rural Fixed Observation Office (2001).

CHAPTER 2

REVIEW OF LITERATURE AND RECENT TRENDS IN CHINA

2.1 Introduction

Land fragmentation has been a prominent feature in many countries since at least the 17th century. Global concern about it, especially researchers' interest in quantifying its impact on agricultural production, started much later. It can be dated back to 1911, when a conference on the "consolidation of scattered holdings" was held to deal with the "evils of fragmentation" (Lusho and Papa, 1998). A voluminous literature on land fragmentation has been generated since then. The major issues associated with land fragmentation, however, are far from settled. The main reason for this, according to McPherson (1983), is that analysis of the phenomenon from the farmer's perspective is rare. This chapter reviews the available literature on land fragmentation issues. This provides a framework for examining fragmentation issues in the Chinese context in later chapters. Before proceeding with the analysis of land fragmentation in China, however, it is useful to review recent trends in land fragmentation in China and compare the current degree of fragmentation with other countries. This is done in the second part of the chapter.

2.2 Land fragmentation theories

This section first reviews the most commonly used definitions of land fragmentation; based on this, it explores how the existing literature measures land fragmentation. Next, the literature on the main causes of land fragmentation is reviewed. Finally, the gains and losses associated with land fragmentation from the perspective of individual farmers and from the viewpoint of society as a whole are discussed in the last section.

2.2.1 Definitions

In the literature, land fragmentation is defined in different ways. McPherson (1982) argues that "when a number of non-contiguous owned or leased plots (or 'parcels') of land are farmed as a single production unit, land fragmentation exists". This means that the plots in a farm are spatially separate. Schultz (1953) defines fragmentation as a "misallocation of the existing stock of agricultural land." He points out that a fragmented farm is "…a farm consisting of two or more parcels of land so located one to another that it is not possible to operate the particular farm and other such farms as efficiently as would be the case if the parcels were reorganized and recombined". It is obvious that Schultz sees land fragmentation as a source of inefficiency.

Dovring (1960) regards land fragmentation as "the division of land into a great number of distinct parcels…" when he analyzes land reform in Europe. He points out that the French used two concepts for land fragmentation in their consolidation operation: "*îlot de propriété*" and "*parcelle*" (see McPherson, 1982). The former referred to a piece of land owned by a single person and surrounded by the property of others. The latter was a plot located apart from the *îlot de propriété*. Land fragmentation meant that farmers owned *parcelles* which did not form part of their *îlots de propriété*. Dovring also introduces the notion of "excessive fragmentation", which he identifies as existing if the number of plots in a farm exceeds its size in hectares (for further explanation, see subsection 2.2.3). He argues that the distance between the parcels is the main source of inefficiency created by fragmentation.

Like Dovring, Papageorgiou (1963) emphasizes the role of distance in fragmentation. He notes that fragmentation means a holding consisting of several scattered plots over a wide area. Agarwal (1972), based on a detailed review of work on land consolidation, defines land fragmentation as a decrease in the average size of farm holdings; an increase in the scatteration of each farmer's land; and a decrease in the size of the individual plots in a farm holding.

Differing from the above definitions, Binns (1950) sees fragmentation as "…a stage in the evolution of the agricultural holding in which a single farm consists of numerous discrete parcels, often scattered over a wide area". According to Binns' definition, land fragmentation represents a stage in agricultural holding's evolution. This suggests that if the holding is evolving towards consolidation, land fragmentation may be a temporary phenomenon.

To sum up, even though land fragmentation is defined in different ways, three distinct interpretations can be identified: (1) it implies the subdivision of farm property into undersized units that are too small for rational cultivation; (2) it suggests that the plots are noncontiguous and are intermixed with plots operated by other farmers; and (3) the last type sees distance as an important aspect of land fragmentation.

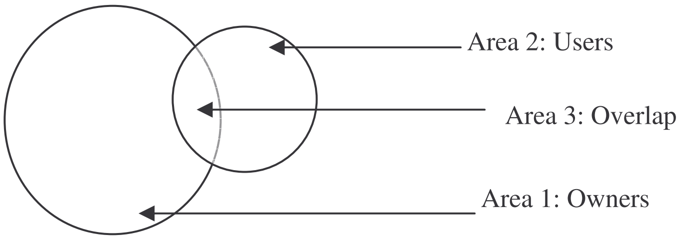
In the current study, we consider land fragmentation as a phenomenon existing in farm management. It exists when a household operates a number of owned or rented non-contiguous plots at the same time. Land fragmentation is very common in the case study area of this study as well as in other parts of China, as we will see in section 2.3.

2.2.2 Measurement

Despite being a common phenomenon, measures of land fragmentation are diverse. In the past, many ways were used to measure land fragmentation. According to the measures, the extent of land fragmentation varies greatly across countries. Fragmentation thus becomes a vague term: it means different things to different people (Walker, 1990). Generally, a distinction can be made between single dimension indicators and integrated indicators.

Single dimension land fragmentation indicators are used in many studies. For example, Rembold (2004) uses three single indicators: (1) the number of land owners per country (or region); (2) the number of users per country (or region); and (3) the overlap of these two.

Figure 2.1 Rembold’s approach to measuring land fragmentation



The area within the circles represents the number of owners and users. Shrinking of the circles and/or increase in overlap mean reduction of fragmentation.

Figure 2.1 explains this approach. Area 1 represents the number of owners. Given the total land area and population pressure, a larger circle corresponds to a larger number of land owners and thus to a smaller area per landowner. This is commonly used as indicator for fragmentation in Central-European and Eastern European analyses (Rembold, 2004). However, ownership distribution alone does not give a complete image of fragmentation. The fragmentation of managed land is often much lower in the areas where land leasing is common. The number of users indicated by area 2 is therefore used as the second indicator of fragmentation. The third indicator of fragmentation is the overlap of the two areas. This overlapping area represents owners that are also users. Area 1 minus area 3 thus represents the number of land owners who do not cultivate the land themselves; and area 2 minus area 3 denotes the number of users who do not own their land. It is obvious that any shrinking of the circles and/or increase in overlap means a reduction of fragmentation. Although these measures are popular for analyzing land fragmentation in Central and Eastern European countries, they are not much used in other countries. A possible explanation is that of land markets. Another possible reason is that these measures only focus on the average sizes of owned or managed holdings, not on the number of plots within holdings or the spatial dispersion of plots within holdings.

Dovring (1960), in his analysis of land reform in early twentieth century in Europe, uses the ratio of the number of plots to the total farm size in hectares to measure “excessive” fragmentation. He claims that excessive fragmentation exists if the number of plots in a farm exceeds its size in hectares. For example, a 10-hectare farm suffers from excessive fragmentation if it is divided into more than 10 plots. Dovring also quantifies the distance factor by measuring the total distance that the farmer would make by visiting all of his plots and returning to his farmstead after each visit. A major shortcoming of this measure is that it assumes uniform field sizes and farmers’ routines (McPherson, 1983). In practice, the indicators suggested by Dovring are not generally used to quantify land fragmentation due to the arbitrary threshold level used for defining excessive fragmentation and the shortcomings of the distance indicator.

Some studies (King, 1977; Bentley, 1987; Simmons, 1988) identify six parameters to measure the extent of fragmentation: farm size, total number of plots in the farm, average plot size, distribution of plot sizes, spatial distribution of plots, and the shape of plots. Farm size is used to measure the total holding of a farm. Among the remaining parameters, size and spatial distribution (i.e. distance) are often considered to be most significant. The shape of the plots is an important parameter when mechanization is introduced into an agricultural system. For example, farm machinery is regarded to be most efficient on rectangular plots.

Differing from the single dimension indicators, the integrated indicators try to capture the information from several single indicators into one index. The two most popular integrated indicators are the Januszewki index and the Simpson index (Blarel *et al.*, 1992). The Januszewki index (*JI*) is defined as:

$$JI=\sqrt{\sum_{i=1}^{n} a_i} \Big/ \sum_{i=1}^{n} \sqrt{a_i}$$

where n is the number of plots, and a_i is the area of each plot. This index is located within the range of 0 to 1. The smaller the *JI* value, the higher degree of land fragmentation.

The *JI* value combines information on the number of plots, average plot size and the size distribution of the plots. It has three properties: fragmentation increases (the value of the index decreases) when the number of plots increases, fragmentation increases when the average plot size declines, and fragmentation decreases when the inequality in plot sizes increases. The index, however, fails to account for farm size, plot distance, and shape of plots.

The Simpson index (*SI*) resembles, to some extent, Januszewski's index. It measures the degree of land fragmentation in the following way:

$$SI = 1-\sum_{i=1}^{n} a_i^{\,2} \Big/ \left(\sum_{i=1}^{n} a_i\right)^2$$

The Simpson index is also located between 0 and 1. Contrary to the *JI*, a higher *SI* value corresponds with a higher degree of land fragmentation. The value of the Simpson index is also determined by the number of plots, average plot size and the plot size distribution. It also does not take farm size, distance and plot shape into account.

The choice of appropriate measures deserves much attention due to its importance in quantitative analyses of land fragmentation. Theoretically, an indicator system including farm size, the number of non-contiguous plots, the area of each plot, the distance of each plot to the homestead, and the plot shape can provide a full picture of land fragmentation at the farm level. Data limitations, however, usually limit the choice of indicators. This study uses both single dimension indicators (farm size, number of plots, average size, and distance to the plots) and the Simpson Index. The choice of the fragmentation index differs across chapters due to different purposes and will be motivated in each chapter. Plot shape is not taken into account in this study, because such information is not available due to measurement problems. Moreover, compared with farm size and plot size, the shape of plots is probably less important in the Chinese context.

2.2.3 Causes

Two broad viewpoints are normally distinguished with regard to the emergence and persistence of land fragmentation, namely “supply-side” and “demand-side” explanations (McPherson, 1982; Bentley, 1987). The former treats fragmentation as an exogenous imposition on farmers, resulting e.g. from inheritance, population pressure, and land scarcity. Many authors with this viewpoint claim that partible inheritance in a growing population logically leads to fragmentation when farmers desire to provide each of several heirs with land of similar quality (Downing, 1977; World Bank, 1978; Anthony *et al.*, 1979).

Another supply-side factor is the breakdown of common property systems under the pressure of population growth. This breakdown has led to increased fragmentation in developing countries such as Kenya (King, 1977) and Nigeria (Udo, 1965). Likewise, land scarcity may lead to fragmented holding as farmers in quest of additional land will tend to accept any available parcel of land within reasonable distance of their house.

Supply-side explanations cannot always fully explain land fragmentation. When plots differ with respect to soil type, water retention capability, slope, altitude and agro-climatic conditions, demand-side factors may play a role as well. Demand-side explanations view fragmentation primarily as a positive choice made by farmers. This viewpoint presumes that the benefits of fragmentation to a farmer exceed its cost. Some researchers argue that, when alternative risk-spreading mechanisms such as insurance, storage or credit are not available or are more costly, land fragmentation will persist as a means for risk reduction (Charlesworth, 1983; Ilbery, 1984). In less-developed areas, farmers need land as a safeguard. When land quality is not homogenous, the scattering of parcels can reduce the risk of loss from flood, drought, fire, or other perils, and farmers can diversify their cropping mixtures across different growing conditions. When food commodity markets fail, land fragmentation may be beneficial for crop diversification, allowing farmers to grow (non-marketed) subsistence crops.

Another demand-side explanation was given by Fenoaltea (1976). He argued that the scattered parcels enable farmers to better allocate their labor over the seasons. If an agricultural labor market is missing, supply of farm labor is determined by household size, and the need for spreading labor requirements over time is greater.

Several studies have examined land fragmentation in China in the past and the present (*e.g.* Buck, 1937; Chao, 1986; Nguyen *et al.*, 1996). Two "supply-side" theories have been used to explain the existence of fragmented landholdings before the foundation of the People's Republic of China in 1949 (Chao, 1986). One is the Chinese *fenjia*, a system of dividing the family property equally among the sons whenever one of them married. The married son could get his own share of family property (among which, land was the most important) that was separated from his parents' family property. The other explanation is the shortage of farmland that emerged with the increase of population after the eleventh century. Given the serious shortage of land, demand for it greatly exceeded supply. A so-called seller's market emerged, leading to land fragmentation. As an agricultural country, what we call off-farm activities today was very limited in China at that time. Most people had to make a living by cultivating land. Therefore, once a household had acquired land, it would be very reluctant to give it up. A typical landowner normally ended up holding small plots scattered throughout the same village or even in neighboring villages. Since most buyers could afford only small plots, large plots were often cut into small pieces when they were sold.

Some researchers have examined the factors causing land fragmentation in contemporary China. Kung (1994), Chen *et al*. (1997) and Lin (2000) argue that the system of land distribution is to a great extent responsible for the current level of fragmentation in China. However, detailed empirical analyses that test the relevance of this hypothesis and other prevailing theories for explaining the causes of land fragmentation in present-day China are lacking. Chapter 3 will present results of such an empirical analysis.

2.2.4 Benefits and costs

The debate on why land fragmentation is persistent and widespread in rural societies focuses on the trade-off of its benefits and costs for the individual farmer or the society as a whole. The presence of social costs and benefits suggests that the optimal level of fragmentation for private farmers may not be the same as the social optimum.

McPherson (1983) reviews the adverse and beneficial effects of land fragmentation in a renowned paper “Land fragmentation in agriculture: adverse? beneficial? and for whom?”. He distinguishes two reasons why farmers prefer to fragment their plots: to reduce the risk through the spatial diversification of activities and to have access to land with different quality.

Bentley (1987) supports this viewpoint. He claims that fragmentation allows farms with scattered plots to benefit from risk management through the use of multiple ecozones and the practice of crop scheduling. Farmers cannot only plant more diverse crops, but also grow the same crop on several different plots. Thus, fragmentation enables farmers to disperse and reduce risk by using a variety of soils and other micro-climatic and micro-environmental variations. Fragmentation also makes it possible for farmers to grow a variety of crops that mature and ripen at different times, so that they can concentrate their labor on different plots at different times, thereby avoiding household labor bottlenecks. It may be noted that the argumentation provided by McPherson (1983) and Bentley (1987) is very similar to the demand-side explanation of land fragmentation discussed in the previous sub-section. Private benefits are the basis for the demand-side explanation.

In addition to private gains, fragmentation may offer social benefits. Fragmentation induced by land distribution during land reform in many countries (Bulgaria, Vietnam and China, for example) realized a high degree of equity among smallholders and contributed to a high degree of national food self-sufficiency.

The costs associated with high levels of fragmentation are seen principally in terms of inefficient resource allocation (labor and capital) and the resulting cost increase in agricultural production. According to the existing literature (McPherson, 1983; Simmons, 1987), land fragmentation may impose detrimental effects on agriculture in three ways: (1) creating inefficiency; (2) hindering agricultural modernization; and (3) making it costly to modify its adverse effects by consolidation schemes.

From an individual farmer’s point of view, land fragmentation may be detrimental to agricultural production by causing physical problems, operational difficulties and foregone investment. Physical problems may include the labor time lost in traveling, the land lost in marking the borders or constructing access roads, and higher costs in fencing or border construction. Operational difficulties include the moving of heavy equipment, use of tractors and other machinery, pest control, and so on. Moreover, it is more difficult to manage the farm and to supervise laborers. Plots at relatively large distances from the homestead are therefore more likely to be abandoned. Finally, due to the existence of scale effects and externalities, investments in improved agricultural facilities, soil and water conservation, and so on are less profitable on farms with severe land fragmentation.

From the viewpoint of society, land fragmentation may also have some costs. For example, it is more difficult to invest in infrastructure like roads and irrigation systems, and to implement regional agricultural policies such as the assignment of specific zones for commercial agricultural production. As a result, regional or national output is affected negatively. The resulting lower levels of productivity and relatively higher food prices imply costs to the consumers, which are not considered in farmers' decision-making on production.

2.3 Land fragmentation trends in China

Although land fragmentation may have different meanings in different countries or regions, it covers two main aspects: (1) it refers to the spatial dispersion of farmers' plots over a wide area; and (2) it implies the subdivision of farm property into undersized units that are too small for rational (efficient) cultivation. As we have seen, such subdivision into small units, may however be beneficial to farmers in certain circumstances (if markets for insurance, agricultural labor and so on are missing) and at certain points in time (depending on the technology level and institutional arrangements).

Land fragmentation is not a new phenomenon in China. According to Buck (1937), land fragmentation was an important characteristic in the 1930s, when a farm household had an average of 0.34 hectare of land dispersed over 5.6 plots, or 0.06 hectare per plot. However, the new land tenure system introduced at the end of the 1970s, known as the household responsibility system, makes this phenomenon more pronounced in current China compared with that in the 1930s and before the land tenure reform (Hu, 1997).

In this section, we review recent trends in land fragmentation in China. We first present land fragmentation trends in China since the 1980s, based on the Rural Fixed Observation data, in subsection 2.3.1. These trends are compared for the three major regions in China: East, Center, and West[6]. In subsection 2.3.2, land fragmentation in China is compared with that in other countries. Farm size, the number of plots and average plot size are used to measure land fragmentation in this chapter. Information on plot size distribution, distance between plots and plot shapes is not available from the Rural Fixed Observation data.

2.3.1 Land fragmentation in China since the 1980s

Current patterns of land fragmentation in China originate from the end of the 1970s and beginning of the 1980s with the introduction of the household responsibility system. Before the HRS, rural land was owned and managed collectively; land was divided to match the soil type, irrigation and drainage conditions, and for convenience of management. Under the HRS, arable land use rights were generally assigned to individual households for a period of 15 years. What is crucial for land fragmentation under this system is that households have equal user rights to the land, taking into account differences in land quality. Therefore, land fragmentation became more pronounced compared with that in the 1930s. Chapter 3 will discuss this in more details.

Land fragmentation across regions

Figures 2.2 to 2.4 show the degree of land fragmentation in China and its major regions since 1986, when systematic data collection on this issue has started[7]. In this survey, farm is defined as the land area contracted by a household. Figure 2.2 shows that the average

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[6] Three economic regions are generally distinguished in China. The Eastern part includes Liaoning, Hebei, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, and Hainan Provinces, Guangxi Autonomous Region, and Beijing and Tianjin Municipalities; the Central part covers Heilongjiang, Jilin, Shanxi, Henan, Hubei, Hunan, Jiangxi and Anhui Provinces and Neimeng Autonomous Region, and the Western part includes Shaanxi, Gansu, Qinghai, Sichuan, Yunnan and Guizhou Provinces and Xizang, Ningxia, Xinjiang Autonomous Regions.

[7] Data for Figures 2.2 to 2.7 are from the Rural Fixed Observation Office (2001). Unfortunately, no data on 1992 and 1994 are provided (see Chapter 2). Data for 2000 and later have not yet been published.

area per farm household has decreased from 0.61 ha in 1986 to 0.53 ha in 1999. The average farm size is largest in the Central region and smallest in Eastern China. Average farm size decreased most before 1996, and remained roughly constant afterwards. There has been a very small increase in the Eastern part since about 1996.

Figure 2.2 Average area per household per region (in ha)

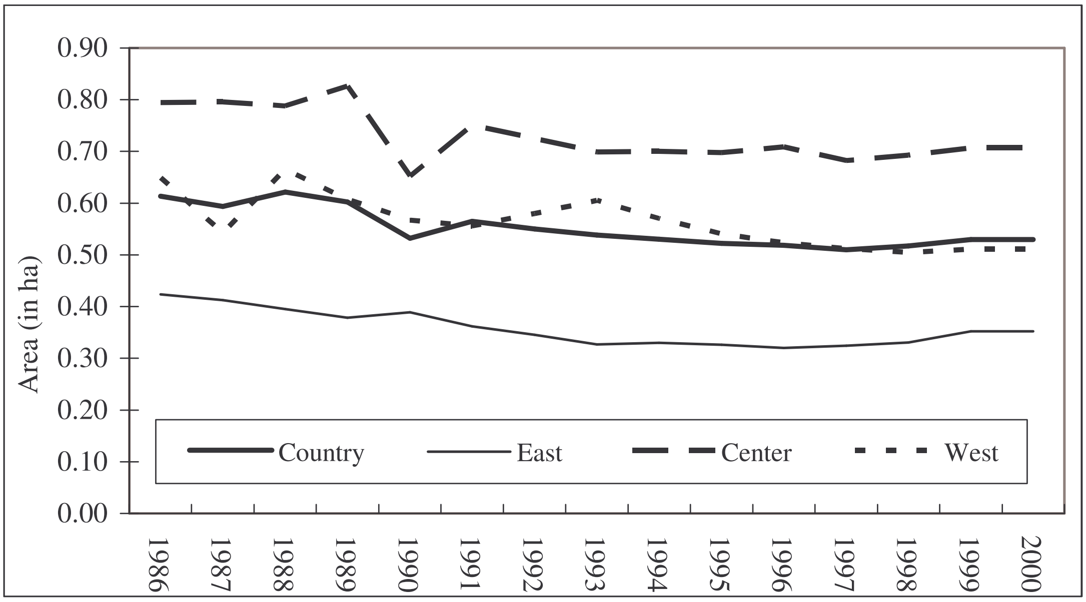


Figure 2.3 Average number of plots per household per region (in ha)

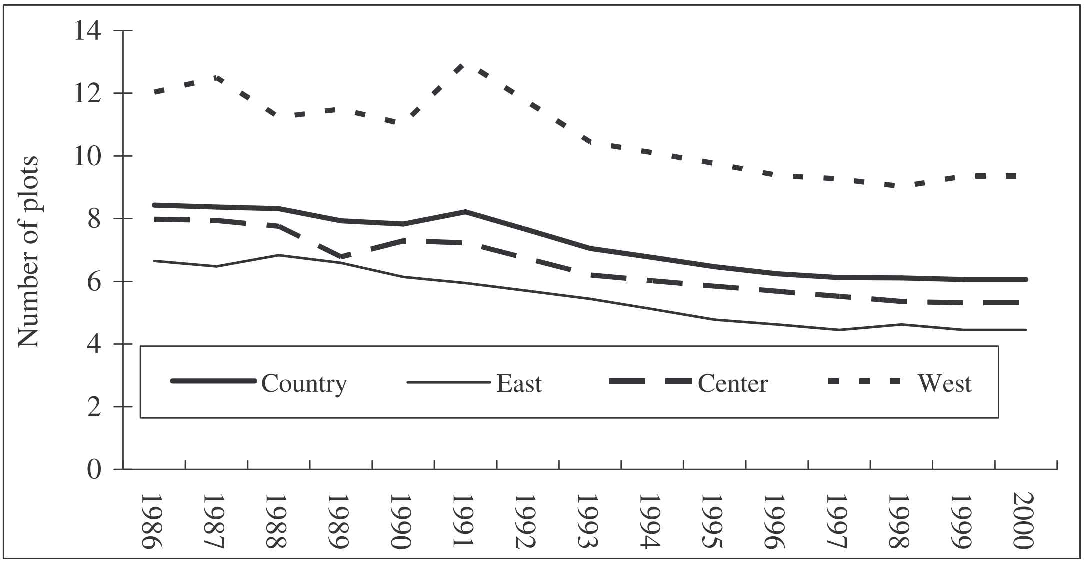
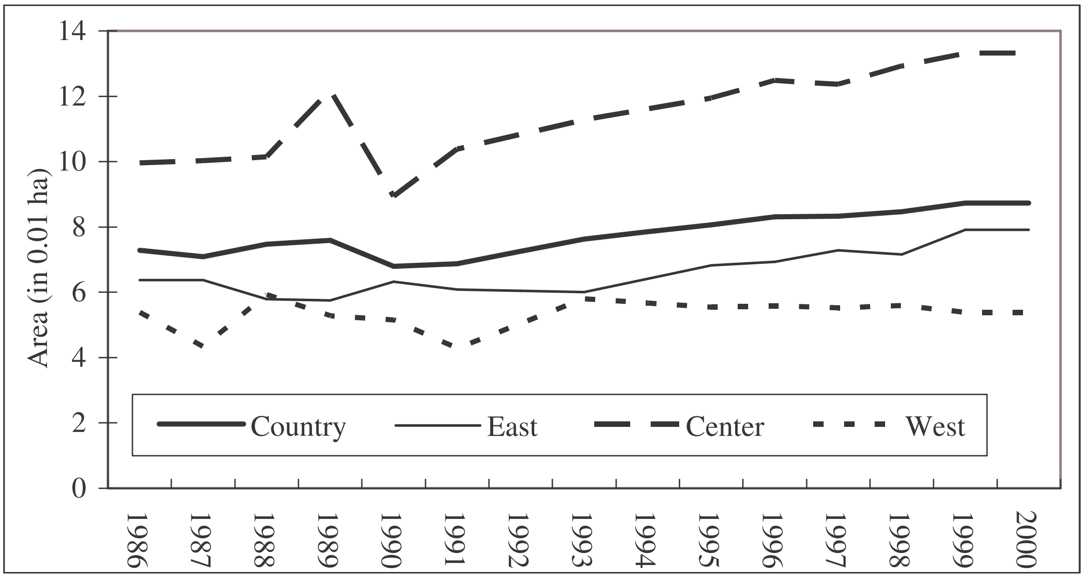


Figure 2.3 shows the average number of plots per farm household. It confirms that a few years after the start of the HRS, the degree of land fragmentation was high in China.

In 1986, farm households had on average 8.43 plots. Throughout the entire 1986-99 period, the number of plots per household was highest in the West and lowest in the East. It has been decreasing over time in all three regions, although some small fluctuations can be observed. In 1999, farm households had on average 6.06 plots.

Figure 2.4 Average area per plot per region (in 0.01 ha)



The average area per plot, shown in Figure 2.4, slightly decreased until the beginning of the 1990s, but increased afterwards. The average area per plot was highest in the Central region throughout the entire period. Since 1993, it increased in the Eastern and Central regions, but not in the West. The overall conclusion that can be drawn from these trends is that land fragmentation is most severe in Western China (large number of plots and small plot area) and Eastern China (small farm size and plot sizes). During the 1990s, land fragmentation has decreased slightly (larger plot sizes and fewer plots) in all three regions.

Plot size distribution within the regions

Figures 2.5 to 2.7 provide more details of land fragmentation within each region. Unfortunately, these data are only available for 1993 and from 1995 to 1999. Figure 2.5 indicates the plot size distribution amongst farm households in Eastern China. Three groups are distinguished: (1) small plots: smaller than 1.0 *mu*[8]; (2) medium plots: between 1.0 and 3.0 *mu*; and (3) large plots: larger than 3.0 *mu*. The average number of small plots

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[8] One *mu* is 1/15 hectare.

Figure 2.5 Plot size distribution in Eastern China

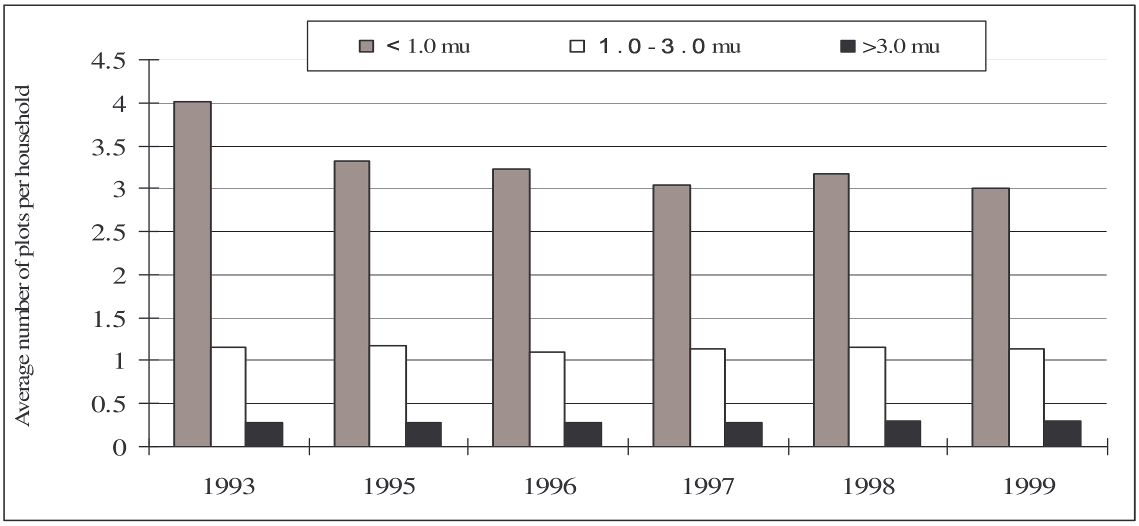
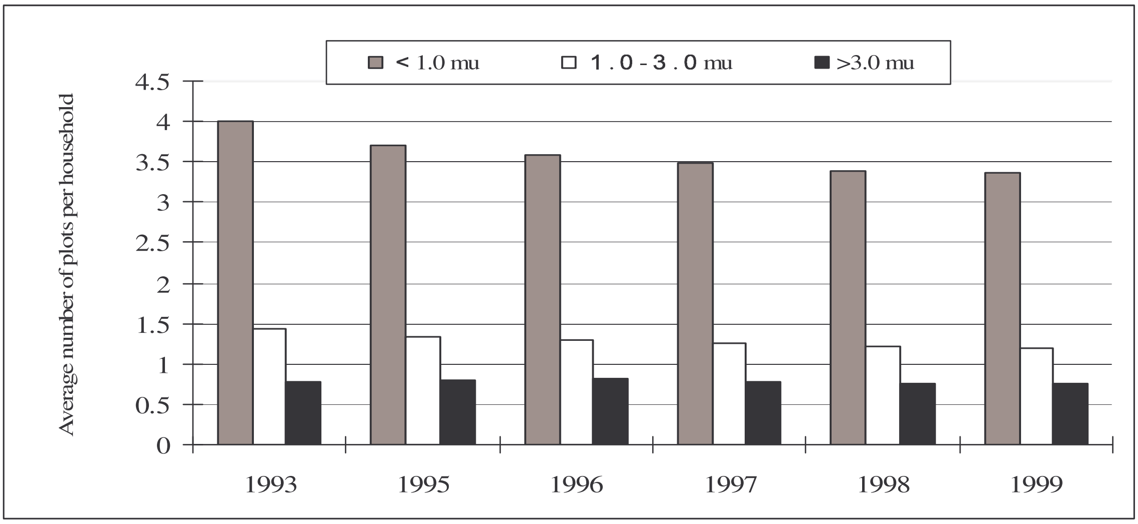


Figure 2.6 Plot size distribution in Central China



per households is much larger than the average number of medium and large plots. In 1993, the number of small plots in this group was more than 3 times the average number of medium plots with and more than 14 times the average number of large plots. Subsequently, the number of small plots decreased gradually, from 4.01 in 1993 to 3.01 plots per household in 1999. The number of plots with a medium size remained relatively stable. It fluctuated between 1.11 and 1.16 plots over this period. The average number of large plots per household was also rather constant, at a level of 0.28-0.30 plots. We thus conclude that in Eastern China, the number of the smallest plots per household has decreased gradually, while the number of medium and large size plots has remained constant.

Figure 2.6 shows the plot size distribution for households in Central China. The average number of small plots is 3.4 - 4.0. This is almost the same as in Eastern China. The number of small plots is also declining, but less rapidly than in Eastern China. The average number of medium-size plots is also comparable to the Eastern region, but the average number of large plots (around 0.80) is almost three times more than in the Eastern region.

Figure 2.7 Plot size distribution in Western China

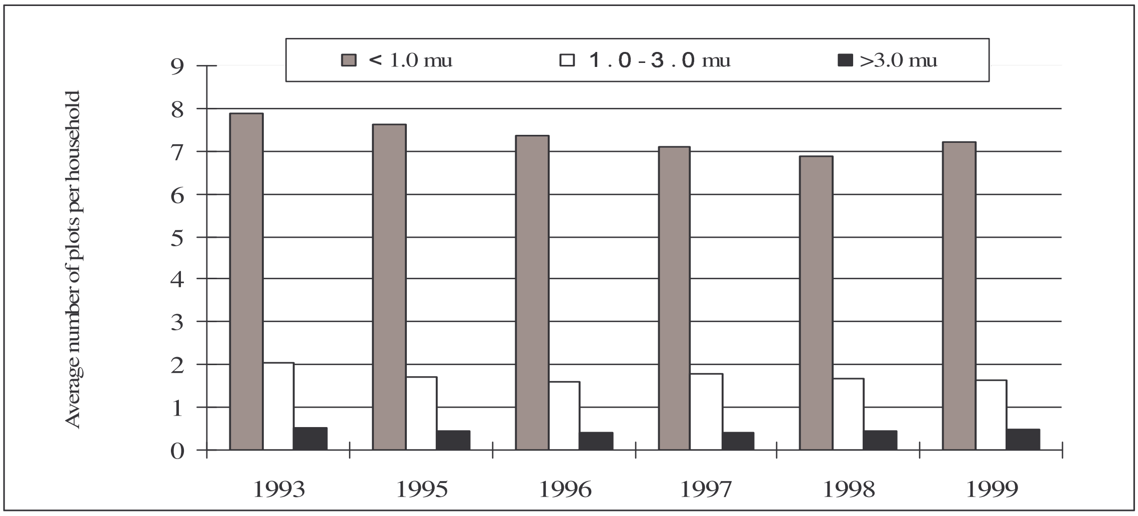


Figure 2.7 shows the plots distribution for households in Western China, where the number of small plots is much larger than in Eastern and Central China (7 - 8 *vs*. 3 - 4). The figure shows that the number of small plots is also decreasing. Likewise, the average number of medium-size plots is larger (1.8 - 2.0 *vs*. 1.1 - 1.4) and declining. The average number of large plots per household is around 0.5, more than in Eastern China, but less than in Central China.

2.3.2 Comparison with other countries

Information on the number of plots per farm household, average plot size and average farm size in three different periods in China and in some other countries is presented in Table 2.1. It shows that farm households in China nowadays face much more severe land fragmentation than their counterparts in these countries. Average plot size and farm size is almost one-tenth of the average level in these countries, while the average number of plots is more or less the same.

Table 2.1 Land fragmentation in some countries

Country (year)	Average plot size (ha)	Number of plots per household	Farm size (ha)
India (1960-61)[1]	0.46	5.7	2.62
Netherlands (1950)[2]	2.30	3.2	7.36
Belgium (1950)[2]	1.10	6.8	7.48
Western Germany (1949)[2]	0.70	10.0	7.00
Romania (1948)[2]	0.90	6.6	5.94
Romania (2000)[3]	0.85	4.4	3.74
Greece (1950)[2]	0.50	5.6	2.80
Spain (1945)[2]	1.60	7.0	11.2
China (1929-33)[4]	0.38	5.6	2.13
China (1986)[5]	0.07	9.0	0.61
China (1999)[5]	0.09	6.1	0.53

Sources: [1]Minhas (1970); [2]Dovring (1960); [3]Rusu *et al.* (2001); [4]Buck (1937); [5]The Rural Fixed Observation Office (2001).

Land fragmentation in China shows major differences between the three periods. In 1986, the average number of plots per farm household equaled 9.0. But since then, it has declined to 6.1 plots on average in 1999, slightly more than in 1929-33. Average plot size equaled 0.087 hectare in 1999, giving an average farm size of just 0.53 hectare. Farms in China are much more fragmented nowadays than in 1930s, when the average farm size was 2.1 ha, and the average size was 0.38 ha.

2.3.3 Discussion and concluding remarks

Although numerous studies have been devoted to land fragmentation, little attention has been given to the dynamic aspects of the fragmentation process itself. In particular, analyses of changes in the degree of fragmentation over time in a given locality are rare (see McPherson, 1983). This section contributes to this aspect by comparing land fragmentation over time in different regions within China and between China and other countries. The main finding is that land fragmentation is more severe in Western China (large number of plots and small plot area) and Eastern China (small farm size and plot sizes) than in Central China. In all three regions, the number of plots and the average farm size decreased, although the average plot size increased between 1986 and 1999. Compared to other countries, the average farm and plot size are extremely small.

Large differences exist across the regions in the distribution of plots. In Western China, the average number of small plots (less than 1.0 *mu*) per household is about twice the number in Eastern and Central China. In Central China, on the other hand, the average number of large plots (larger than 3.0 *mu*) per household is more than twice the number in Eastern China and more than 50% greater than in Western China.

The focus of the remaining chapters in this study is on Jiangxi Province. Although located in Central China, the degree of land fragmentation there is relatively high, partly as a result of the large share of hilly and mountainous land in this province. Data provided to the author by the Rural Fixed Observation Office in Nanchang shows that in 1993 the average land area managed per household equaled about 0.41 ha. It was scattered over 10.2 plots, with an average plot size of 0.04 ha. In 1999, the average land holding area less than 0.33 ha, divided over 8.4 plots with an average size of less than 0.04 ha. So, the number of plots and the farm size decreased, with average plot size remaining relatively constant.

CHAPTER 3

WHAT DRIVES LAND FRAGMENTATION IN CHINA?[9]

3.1 Introduction

The existence of fragmented landholdings is regarded an important feature of less-developed agricultural systems. It can be a major obstacle to agricultural development, because it hinders agricultural mechanization, causes inefficiencies in production, and involves large cost to alleviate its effects (see e.g. McPherson, 1982; Soltow, 1983; Heston and Kumar, 1983; Simmons, 1988; Najafi and Bakhshoodeh, 1992; Blarel *et al.*, 1992; Birgegard, 1993; Jabarin and Epplin, 1994; Parikh and Shah, 1994; Nguyen *et al.*, 1996; Gorton, 2001; Najafi, 2003). In view of these considerations, numerous land consolidation and land reform policies have been implemented to reduce fragmentation in European countries like the Netherlands and France, in African countries like Kenya, Tanzania, Rwanda and elsewhere (Elder, 1962; Hyodo, 1963; Udo, 1965; King, 1977; Zhou, 1998; Sabates-Wheeler, 2002).

Land fragmentation is very severe in China compared with other countries (see Chapter 2). In order to reduce fragmentation, village-level land consolidation and land redistribution programs have been implemented in China since the mid–1980s. In some areas, particularly plain areas in coastal provinces like Jiangsu and Shandong, it is comparatively easy to implement such programs. In other areas the process of consolidating land plots contracted to individual households may involve significant transaction costs. This holds in particular for areas in Central and Western China where the degree of land fragmentation is high due to topographical factors and where rural households depend largely on agricultural production for their incomes. In order to consolidate land, farmers have to gather frequently to discuss how to implement the

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[9] A paper based on this chapter and parts of Chapter 2, co-authored by Nico Heerink and Futian Qu, has been accepted for publication in Land Use Policy. I would like to thanks Richard Louis Edmonds and Keijiro Otsuka for their precious comments on a previous version of this chapter.

policy in a satisfactory way for each household. This may cause a loss of labor time both on-farm and off-farm. In addition, government funds are needed to assist in the engineering part of the programs. More information is given in section 3.2 and Appendix 3.1.

A good understanding of the causes of land fragmentation may help policy makers to gain insights into policies that (often unintentionally) contribute to the problem and decide which measures are appropriate for reducing it. Although land fragmentation is a recognized problem in China (Qu *et al.*, 1995; Hu, 1997), little empirical research has been done on its driving factors and their relative importance. A better understanding of the causes of land fragmentation in China is needed, especially now that the country is confronted with the challenge of agricultural modernization resulting from its entry into the World Trade Organization (WTO). New technologies are required urgently to reduce production cost and to improve farm households' well-being.

This chapter intends to examine the causes of land fragmentation at the village and household level in present-day China. It is organized as follows. Section 3.2 discusses the background of land fragmentation in China since the HRS, focusing on the introduction of the HRS and the land distribution and reallocation processes under this system. In section 3.3, an analytical framework is derived that forms the basis for the empirical analyses. The model specification is discussed in section 3.4, while the results of the regression analyses are presented and discussed in section 3.5. Section 3.6 discusses this study and summaries the major conclusions.

3.2 Background of land fragmentation

Introduction of the HRS had a large impact on land fragmentation. Liu (2000) and Kung (2000) distinguish three main types of land distribution under the HRS. The first is that all land was simply assigned to households in relation to family size. A nation-wide survey of 300 villages conducted by China's State Council in 1988 found that nearly 70% of the villages used this land assignment rule (State Council, 1992). The second is that *kouliangtian* (food ration land) was equally distributed per person, and *zerentian* (responsibility land) was allocated according to the number of laborers in a household[10]. The third is that all land was allocated according to the number of laborers. Richer areas tended to use a combination of the second and third rule, while poor areas had a preference for the first rule of allocation (Liu, 2000).

Plots that were homogenous in soil and irrigation and drainage conditions, and where the same type of land use was possible, were grouped into one land class within a hamlet. Where necessary, as required by farmer consensus on the degree of homogeneity, a land class could be further divided into several subclasses, depending on variations in the conditions of the land within the class itself. Each class and subclass was used as an area unit where at least one plot was allocated to each household. In principle, each person should get an equal share of each class of land. If, for example, four classes of land are distinguished in a village, then a family of five persons could get five shares of all four land classes. To reduce the number of plots, the land within the same class for the five members was kept in one place as much as possible. In this way, the household obtained at least four plots. The location of a plot allocated to each household was done by lottery. Differences in family size made the plot size and/or the number of plots within each class different. The more varied the water and soil conditions, the higher the number of land classes and the higher the number of plots would be in this process.

Traditionally egalitarian concepts have had a major influence on land allocation and thus on fragmentation. The land reform of 1951 realized land privatization based on the principle of equality. Because land was considered both a production factor and a form of social welfare security, land became the common property of the collective after 1958, with each villager having equal rights of access. In other words, land was shared equally in the farmers' understanding (Zhang, 2001). This notion was strengthened in the period of the people's communes when land was owned and managed by the collectives. Since the introduction of the HRS, this attitude has resulted in frequent land reallocations to correct for demographic changes within villages[11]. To the extent that such reallocations

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[10] *Zerentian* means the farmland assigned by the village to a household to pay agricultural tax and state quota. The remaining land assigned to a household is called *kouliangtian*.

[11] Results of a nationwide survey show that by the beginning of the 1990s around 95% of the villages had adjusted the land distribution at least once since the adoption of the HRS; on average, land reallocations had occurred 3.1 times (Yang, 1995). The research of Yao (2000a) and Kung (2000) among 83 villages in eight

led to subdivision of existing plots, they may have contributed to land fragmentation.

In order to prevent further fragmentation, which was increasingly regarded as an obstacle to agricultural development, land consolidation programs started to be implemented by local governments since the mid-1980's in some coastal regions (Eastern provinces) and a few years later also in some Central provinces in China. Land consolidation means the exchange of spatially dispersed fragments of farmland to form new holdings at one place, or at as few places as possible (Oldenburg, 1990). It has become an important element of so-called Comprehensive Agricultural Development Program, the purpose of which is to improve the agricultural infrastructure (irrigation and drainage conditions, etc.) so as to strengthen the agricultural development capacity in the future, and to enhance farmers' incomes[12]. For consolidation, plots have to first be taken back by collectives. Then a program is conducted to make each plot between 0.13 - 0.20 ha in plain areas and around 0.07 ha in hilly areas. After that, land is reallocated to individual farm households[13].

Although the government has called for land consolidation for some years, the response was often slow. An important reason for this may be that consolidation involves substantial transaction costs. As we have noted already, in current China, the consolidation process involves many households in each village. Moreover, in order to implement it successfully and to keep it balanced, farmers have to participate at all stages of the process (including decision-making) to find appropriate solutions for all the farm households concerned. In the Western provinces, farm households and their farmland are spread over a much larger area compared with the Eastern and Central parts due mainly to the topographical factors. Land consolidation therefore involves relatively higher transaction costs in Western China. This may be one of the reasons why the number of plots is the largest while average plot size is the smallest in Western China (see section 2.3).

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counties within four typical provinces (Jiangxi, Zhejiang, Henan and Jilin) offers some interesting conclusions on village characteristics that affect land reallocations and thus land fragmentation.

[12] For detailed information about this, see Appendix 3.1.

[13] According to discussions held in 1999 by the author with people responsible for land consolidation in Jiangxi Province, the government invests around 250 *yuan* per *mu* (i.e. about $450 per ha) in such programs while farm households have to supply labor.

A new nationwide land consolidation program was launched at the end of the 1990s. It aims at consolidating fragmented and underused land, reclaiming wasteland and damaged land and developing unused land resources while protecting China's natural resources. By June 2004, the program involved 731 projects, with an average size of 648 ha each. Central government investment in this program amounts to $1,300 per ha[14].

The new Land Management Laws issued in 1998 in China also have some impact on land fragmentation. According to these laws, farm households can use their contracted land for an additional 30 years[15]. Land was again redistributed within a few years after the laws' implementation. Once the land has been allocated, it may be used for 30 years. The purpose of extending the contract period is to increase land use security so that land becomes a safeguard in farmers' minds. This requires that any land allocation must be more considerate and equitable than ever. It must be well balanced in the process of the distribution. In consequence, land is divided into several plot classes in terms of soil type, water access, drainage condition, road access, and any other conditions that the farmers consider to affect agricultural yield and land management. According to Zhu (2001), land has become more fragmented as a result of the gradual implementation of the 30-year contracts[16].

Another factor affecting land fragmentation is the re-emergence of land rental markets. As described in section 2.4, the combination of land scarcity with land markets (and the system of partible inheritance) in a largely agricultural society led to a high degree of land fragmentation in China before the foundation of the People's Republic. In present-day China, farm households cannot buy or sell agricultural land, but in many villages it is possible nowadays to rent land from other households or from the village collective. Particularly farm households involved in off-farm employment outside the village are often inclined to rent their land to other households in the same village. In case of unemployment, the households that rented their land out can fall back on it for making

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[14] Source: China Daily, 5 June 2004, p. 5.

[15] The extension of land use rights for an additional 30 years intends to increase land tenure security and thus stimulate land conservation investments (Ye *et al.*, 2000; Zhu, 2001). Land reallocations are forbidden. But recent evidence from areas that implemented this arrangement show that land is still readjusted every 3 to 5 years in many villages (Zhu, 2001; Vermeer, 2004)

[16] Note that Figures 2.2-2.4 cannot be used to examine whether this assertion is correct or not, since the data in these figures go until 1999 only.

a living.

The emergence of a rental market for land does not necessarily lead to an increase in land fragmentation. When there are no major bottlenecks in markets for risk insurance, food commodities or agricultural labor, farmers are likely to prefer an increase in the scale of their plots by renting land neighboring their own plots. Whether or not the emergence of rental markets for land has decreased the degree of land fragmentation in present-day China is therefore an empirical question. Section 3.5 seeks to address this question.

3.3 Analytical framework

From the discussions above, it follows that land fragmentation in China is mainly determined by:

(1) the land distribution instigated by central policies (with the introduction of the HRS and land contracts for 30 years in recent years),
(2) the frequency and magnitude of land reallocations by villages or hamlets,
(3) the implementation of land consolidation programs, and
(4) the presence of a land rental market.

Figure 3.1 shows the four main determinants of land fragmentation at the village level in China, and some major underlying factors that affect these determinants. The number and size of land plots assigned per household during the land distribution process depends on the number of land classes that are distinguished, the land available per household, and the share of agricultural households in a village. The number of land classes mainly depends on supply side factors like topography, soil types, water and drainage conditions, access to roads and so on (Zhu and Jiang, 1993), but demand factors may also have some impact[17]. When there are imperfections in the labor market, the food market or the market for insurance, households in a village may push to increase the number of soil quality classes in order to spread labor requirements and increase the number of crops that are grown. For example, a survey conducted by China's State Council found that egalitarian

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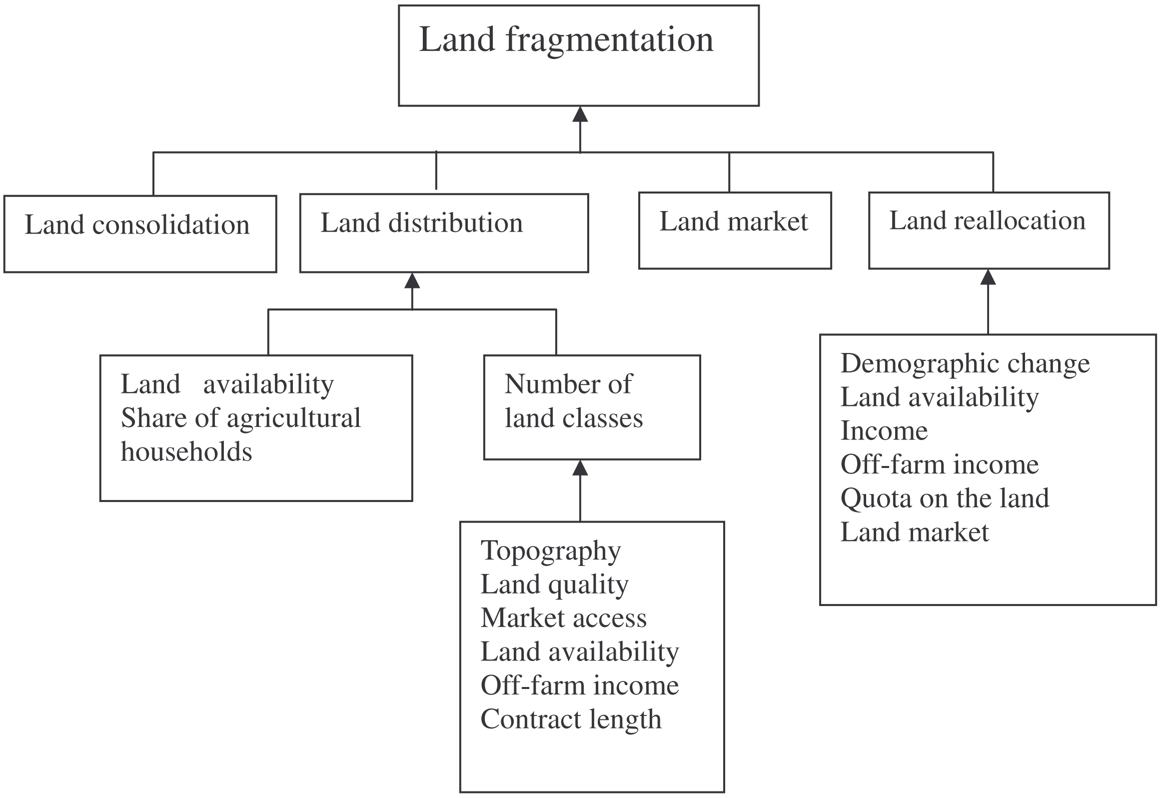
[17] See section 2.2.3 for a discussion of demand and supply factors as causes of land fragmentation.

tendencies in land distribution were stronger in villages poorly endowed with land and lacking off-farm employment opportunities (Liu *et al.*, 1998). And Zhu (2001) argues that the duration of the contract matters influences the number of land classes. This also suggests that land fragmentation is partly a demand-driven process.

Figure 3.1 Factors affecting land fragmentation in China



Land reallocation, according to Kung (2000) and Yao (2000a), depends on demographic change, land availability, income level, off-farm employment, quota on the land, and availability of a land market. As discussed above, both supply and demand factors seem to play a role. Finally, land consolidation programs and (possibly) the presence of land rental markets can have important effects on land fragmentation as well.

3.4 Empirical analysis

The analytical framework derived in the previous section suggests several factors that potentially affect the degree of land fragmentation in China. It is used in this section to derive a structural model analyzing factors affecting fragmentation. Due to problems with data availability for some of the driving factors, it is not possible to empirically estimate the whole set of structural equations. Through substitution, however, reduced-form equations that can be estimated are obtained. The structural equations are helpful in deriving expected signs for the variables in the reduced-form equations and for interpreting results. Implementation issues, such as the quantification of variables listed in the model, are discussed in section 3.4.2.

3.4.1 The structural model

The analysis in section 3.3 indicates four factors that are directly responsible for land fragmentation in China. With respect to the last factor, the land rental market, it may be useful to distinguish between renting in and renting out of land, since their impact on land fragmentation is expected to differ. The analysis in section 3.3 further indicates that the number of land classes plays a crucial role in land distribution decisions. Therefore, a separate equation is added to the model describing (supply and demand) factors that are expected to influence the number of land classes distinguished in a village. This gives a model consisting of four equations to describe the factors that drive land fragmentation at the **village level**.

The first equation gives the factors directly affecting land fragmentation (Fv):

$$Fv = f_1(Dv^+, Rv^+, Mv^?, Cv^-) \qquad (3.1)$$

where

Fv = Land fragmentation indicator (e.g. average number of plots per household or average plot size) at village level

Dv = Fragmentation resulting from land distribution process

Rv = Frequency and/or magnitude of (partial) land reallocation since land distribution
Mv = Presence of land rental market
Cv = Presence of land consolidation program
$f_1(.)$ = Functional relationship that needs to be specified.

The signs of the expected effects are shown immediately behind each variable.

By definition, the fragmentation resulting from land distribution (Dv) has a positive impact. The frequency and size of land reallocations (Rv) can in principle lead to both higher and lower fragmentation. In practice it tends to increase fragmentation, since land is taken away from households that have become smaller and added to the land of, generally non-neighboring, households that have expanded. In order to meet with the equality principle, land plots may need to be sub-divided. The impact of the land rental market (Mv) can be positive as well as negative, depending on whether or not farm households split (merge) their plots if they rent out (in) part of their land and the relative size of rented out (in) plots. Land consolidation (Cv) by definition has a negative impact on fragmentation.

The second and third equations describe the process of land distribution[18]:

$$Dv = f_2(NCv^{+}, LAv^{+/-}, SNv^{+/-}) \qquad (3.2)$$

$$NCv = f_3(TPv^{+}, LQv^{+}, CLv^{+}, MAv^{-}, LAv^{-}, OFv^{-}) \qquad (3.3)$$

where
NCv = Number of land classes distinguished during the land distribution process
LAv = Indicator of land availability (e.g. arable land per capita)
SNv = Share of non-agricultural households in the village
TPv = Indicator of topography (e.g. share of hilly or mountainous area)
LQv = Indicator of variation in land quality (soil types, water access, drainage conditions, road access, and so on)

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[18] A '+/-'-sign indicates that the variable in question has a positive impact on land fragmentation measured by the number of plots and a negative impact on land fragmentation measured by average plot size (i.e. average plot size increases when the variable in question increases). Likewise, a '+/?'-sign indicates that the variable in question has a positive impact on land fragmentation measured by the number of plots whereas the impact on land fragmentation measured by average plot size may be either positive or negative.

CLv = Length of land use contract (in years)
MAv = Indicator of market access
OFv=Share of off- farm income in total village income.

The fragmentation caused by the land distribution process is positively linked to the number of land classes (NCv) that is distinguished during this process. Within each land class, the number of plots assigned per household and/or the average plot size is positively related to the availability of land, i.e. availability of arable land per capita (LAv). In some cases, no land is distributed to households with residence in the village but involved more or less permanently in off-farm employment. Hence, the land assigned (i.e. no. of plots and/or average plot size) to households within each land class is also positively related to the share of non-agricultural households in a village (SNv).

The number of land classes distinguished during land distribution depends partly on topography (TPv) and on the variation in land quality (LQv) within a village. The duration of the contract (CLv) affects the number of land classes positively, as Zhu (2001) indicates. The need to distinguish more classes is expected to be lower when a village has better access to markets for labor, food, and insurance (MAv), has more land available (LAv), and when more income is obtained from off-farm employment (OFv).

The fourth equation explains the process of (partial) land reallocations due to demographic factors:

$$Rv = f_4(DCv^{+}, LAv^{?}, ILv^{-}, OFv^{-}, QUv^{-}, Mv^{-}) \tag{3.4}$$

where
DCv = Indicator of demographic change (e.g. birth rate, death rate, or indicator of migration) in the village
ILv = Average income level of the village
QUv = Quota on the land.

The frequency and magnitude of land reallocations is positively related to demographic changes in a village (DCv). But, as the studies of Kung (2000) and Yao (2000a) indicate, the income level (ILv), involvement in off-farm employment (OFv), the presence of grain quota on the land (QUv), and the possibility to rent land (Mv) all negatively affect the demand for such reallocations. The availability of land in a village

(*LAv*) may affect the demand for reallocations as well; according to Yao (2000b), its impact can be positive as well as negative.

Decisions on land distribution, land reallocation, land consolidation, and permitting land markets are made in China at the village or higher levels. Hence, they are exogenous for individual households in a village. In this study, we will use household-level data on land fragmentation to examine its driving forces. At the **household level,** fragmentation (*Fh*) depends on village-level fragmentation (*Fv*), individual household characteristics that determine the extent to which the number and size of plots assigned to a household deviate from the village-level average, and the land rented in and rented out by the household:

$$Fh = f_5(Fv^{+}, HSh^{+/-}, LFh^{+/-}, OFh^{-/+}, HOh^{-/?}, HIh^{+/?}) \qquad (3.5)$$

where

Fh = Fragmentation indicator (e.g. number of plots or average plot size) at household level

HSh = Household size

LFh = Share of laborers in household

HOh = Size of household land that is rented out

HIh = Size of household land that is rented in

OFh = Share of off-farm income in total household income.

Clearly, village-level fragmentation (*Fv*) is positively related to fragmentation at the household level. Households with a relatively large size (*HSh*) and a large share of laborers (*LFh*) are expected to obtain more and larger plots during the distribution process. Hence, the impact on fragmentation at the household level may be positive or negative, depending on which indicator is used. Households with a high share of income obtained from off-farm employment (*OFh*) may obtain less and/or smaller plots from the village during land re-allocation. After household members return from migration or other types of off-farm employment, the land will generally be returned to the household. The renting out of land (*HOh*) will reduce either the number of plots or their average size (if a share of a plot is rented out) or both. The average plot size may also increase, namely when relatively small plots are rented out. Conversely, the renting in of land (*HIh*) may increase the number of plots and either increase or decrease the average plot size.

The equations specified above describe the land fragmentation processes at village and household levels in China. In order to obtain empirical estimates of the relative importance of each factor, choices have to be made with respect to the selection of the appropriate indicators and the functional forms of the relationships. Moreover, data may not be available on some of the variables listed in the models, implying that proxy variables may have to be used or adjustments need to be made in the model. The next sub-section discusses the choices that we made for estimating the model from a data set for 860 households in 11 villages.

3.4.2 Data set and model specification

Household- and village-level data on land fragmentation and a large number of variables listed in equations *(3.1) – (3.5)* are available for 11 villages in Jiangxi Province for the year 2000.

Table 3.1 Main characteristics of villages used for analysis

Village number	Topography 1=plain 2=hilly 3=mountainous	Village type 1=agricultural area 2=forestry area 3=grazing area 4=fishery area, 5=others	Location 1=suburban 2=other rural	Annual net income per capita (*yuan*)
01	3	1	2	1351
02	2	1	2	2220
03	2	1	1	2027
04	1	1	2	1303
05	1	1	1	2067
06	1	1	2	2812
07	1	1	2	2160
08	3	2	2	1922
09	2	5	1	2966
10	2	2	2	1840
11	2	1	1	3289

Source: Rural Fixed Observation Office (2001).

Criteria used by the provincial office for the selection of villages were that they should reflect differences in topography (plain, hilly or mountainous areas), distance from the (provincial or county) capital, and level of economic development. The 11 villages are spread across the 11 prefectures in the province. Table 3.1 shows their main characteristics.

The average income level of the poorest village is about 40% of that of the richest village. Using the official exchange rate (RMB 8.27 = US$ 1), the average annual per capita income level varies from $158 to $398 between the villages. Four villages are located in plain areas, the others in hilly (five villages) or mountainous areas (two villages). Four of the villages are located in suburban areas.

Although the data set provides information on land fragmentation and some of its major explanatory variables, no information is available on the left-hand variables Dv, Rv and NCv. Moreover, the degree of freedom for estimating the village-level equations is very small. Substituting equations (*3.1*) - (*3.4*) into equation (*3.5*) gives the following reduced-form equation:

$$Fh = f_6(TPv^{+}, LQv^{+}, CLv^{+}, MAv^{-}, LAv^{?}, OFv^{-}, SNv^{+/-}, DCv^{+}, ILv^{-}, QUv^{-}, Mv^{?}, Cv^{-}, HSh^{+/-}, LFh^{+/-}, OFh^{-/+}, HOh^{-/?}, HIh^{+/?}) \qquad (3.6)$$

An important question is how land fragmentation should be measured. Potential indicators are the number of plots, average plot size, average distance from plots to dwellings, and the Simpson index. The available data set only contains information on the first two indicators: both will be used for our analysis.

For four explanatory variables in equation *(3.6)*, length of contract (CLv), land quality (LQv), demographic change (DCv), and presence of land consolidation program (Cv), no information is available in the data set. Hence, they had to be left out of the model. In addition, all 11 villages have an active land rental market. So, Mv is also left out of the model. For the topography variable, we use dummy variables indicating whether a village is located in a hilly area (DHv) or in a mountainous area (DMv). For market access, a dummy variable indicating whether the village is located in a suburban area (DSv) is used as a proxy variable. Assuming linear relationships and adding a random disturbance term to the equations, gives the following two regression equations:

$$NPh = c_0 + c_1HSh + c_2LFh + c_3OFh + c_4HOh + c_5HIh + c_6DHv + c_7DMv + c_8DSv + c_9LAv + c_{10}OFv + c_{11}SNv + c_{12}ILv + c_{13}QUv + u_1 \qquad (3.7)$$

$$PSh = d_0 + d_1HSh + d_2LFh + d_3OFh + d_4HOh + d_5HIh + d_6DHv + d_7DMv + d_8DSv \\ + d_9LAv + d_{10}OFv + d_{11}SNv + d_{12}ILv + d_{13}QUv + u_2 \qquad (3.8)$$

where NPh represents the number of plots, and PSh is the average plot size per household. The c_i and d_i denote unknown coefficients, while the u_i denote random error terms with (assumed) standard properties. The definitions of the variables and the expected signs of the coefficients in each of the two equations can be found in Table 3.2.

Table 3.2 Variables used in the regression analyses and their expected effects

Variable names	Unit	Symbol		
Dependent variables				
Number of plots managed by household	plots	NPh		
Average plot size	*mu*	PSh		
			Predicted sign	
Explanatory variables			NPh	PSh
Household size (number of rural persons in household)	persons	HSh	+	+
Share of labor force members in household	%	LFh	+	+
Share of off-farm income	%	OFh	-	-
Size of land rented out	*mu*	HOh	-	?
Size of land rented in	*mu*	HIh	+	?
Hilly area dummy (= 1 if village is located in hilly area, = 0 otherwise)		DHv	+	-
Mountainous area dummy (= 1 if village is located in mountainous area, = 0 otherwise)		DMv	+	-
Suburban area dummy (= 1 if village is located in suburban area, = 0 otherwise)		DSv	-	+
Arable land area per capita	*mu*	LAv	?	?
Off-farm income share	%	OFv	-	+
Share of non-agricultural households in village	%	SNv	?	?
Average annual net income per household	10^4 *yuan*	ILv	-	+
Grain (rice) quota on land per *mu*	*jin*	QUv	-	+

As discussed in section 3.1, the impact of village-level variables on the average plot size is expected to be opposite to that on the number of plots. Of the 950 households that are in the data set, 860 provide information on all the variables listed in equations *(3.7)* and *(3.8)*[19]. Descriptive statistics for these 860 households are presented in Table 3.3. The number of plots cultivated by a household ranges from 1 to 48. The average is almost 9, about three plots more than the national average at the end of the 1990s (see Figure 2.3). The average plot size varies from 0.03 *mu* to 2.90 *mu*, with an average of 0.73 *mu* (or 0.049 ha), which is 44% lower than the national average (see Figure 2.4).

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[19] In addition, one household that reported cultivating as much as 80 plots was excluded from the sample.

The average household size equals 4.39 persons, with about two-third of the household members on average belonging to the labor force. The average size of land rented in (0.32 *mu*) is substantially larger than the average size of land rented out (0.19 *mu*). This may either reflect that a substantial share of the land is rented from the village collective, or that a large share of the households renting out are not included in the survey because they are involved in employment outside the village. Comparing the share of off-farm income of the households in the sample (mean value: 19.6%) with the share of off-farm income for the villages as a whole (mean value: 31.8%) confirms that households heavily involved in off-farm employment are not included in the sample.

Table 3.3 Descriptive statistics of variables used in the regression analyses

Variable names	Min	Max	Mean	Stdev
Number of plots managed by household	1	48	8.95	6.60
Average plot size	0.03	2.90	0.73	0.41
Household size (number of rural persons in household)	1	17	4.39	1.82
Share of labor force members in household	0	100	67.0	21.9
Share of off-farm income	0	100	19.6	28.6
Size of land rented out	0	10.4	0.19	0.98
Size of land rented in	0	11	0.32	1.22
Hilly area dummy (= 1 if village is located in hilly area, = 0 otherwise)	0	1	0.48	0.50
Mountainous area dummy (= 1 if village is located in mountainous area, = 0 otherwise)	0	1	0.16	0.37
Suburban area dummy (= 1 if village is located in suburban area, = 0 otherwise)	0	1	0.37	0.48
Arable land area per capita	0.46	2.02	1.19	0.54
Off-farm income share	10.9	74.7	31.8	21.1
Share of non-agricultural households in village	0.00	2.56	0.91	1.01
Average annual net income per household	0.57	1.38	0.91	0.25
Grain (rice) quota on land per *mu*	0	844	104	236

Source: Rural Fixed Observation Office in Jiangxi Province (2000).

The number of the observations is 860.

3.5 Regression results

Estimation of equations (*3.7*) and (*3.8*) was confronted with a number of econometric problems. Results for the Jarque-Bera test indicated that the assumption of normally distributed disturbances should be rejected for both models. Taking the natural logarithm of the dependent variables substantially reduced this problem[20]. Ramsey's RESET test results showed that the null hypothesis of no misspecification should also be rejected. Taking the natural logarithm of household size (*HSh*) led to substantially lower values of the test statistic for both equations. Transformations of other explanatory variables had no significant impact. Remaining misspecifications are at least partly caused by omitting contract length, land quality, demographic change, and land consolidation from the models (see above). Finally, White's test of heteroskedasticity showed that the null-hypothesis of homoskedastic disturbances should be rejected. White's method for obtaining heteroskedasticity-consistent estimators was applied so that the confidence intervals and hypothesis tests are valid for our relatively large sample (see e.g. Thomas, 1997).

The resulting outcomes of the regression analyses are shown in Table 3.4. Coefficient estimates for variables with either a plus or a minus-sign in Table 3.2 are tested one-sided, while coefficients with both signs are tested two-sided. F-statistics are high enough to reject the null hypotheses that the variables cannot explain the variations in land fragmentation between the households in the sample. The R-squared values show that 55% of the variation in (the logarithm of) the number of plots and 42% of the variation in (the logarithm of) plot size is explained by our models.

Household size is an important determinant of both the number of plots and average plot size. The estimated elasticity is higher for the number of plots (0.63) than for average plot size (0.36), with the sum of the two elasticities being almost equal to one (0.994). So, an x-percent increase in household size causes a similar x-percent increase in land area, with almost two-thirds of the increase coming from an increase in the number of plots

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[20] Deleting outliers from the sample can further reduce the value of the Jarque-Bera statistic for both equations. The outliers, however, differ between the two equations. Moreover, none of the conclusions that we draw from the regression results will change if the outliers are removed.

assigned to a household, and around one-third coming from an increase in average plot size.

Table 3.4 Regression results

Independent variables	Dependent variables	
	Log(Number of plots)	Log(Average plot size)
Constant	-0.577**	-0.422*
	(-3.10)	(-2.38)
Log(Household size)	0.632**	0.362**
	(11.9)	(6.92)
Share of labor force members in household	0.002**	0.001
	(2.62)	(1.42)
Share of off-farm income	-0.003**	-0.001
	(-3.93)	(-1.29)
Size of land rented out	-0.111**	-0.026
	(-3.77)	(-1.51)
Size of land rented in	0.091**	0.062**
	(7.40)	(6.96)
Hilly area dummy (= 1 if village is located in	0.325**	-0.212**
hilly area, = 0 otherwise)	(4.40)	(-3.36)
Mountainous area dummy (= 1 if village is	1.230**	-1.417**
located in mountainous area, = 0 otherwise)	(12.1)	(-14.4)
Suburban area dummy (= 1 if village is	0.594**	-0.881**
located in suburban area, = 0 otherwise)	(3.76)	(-6.09)
Arable land area per capita	0.928**	-0.320**
	(8.82)	(-3.40)
Off-farm income share	-0.005**	0.004*
	(-2.50)	(2.13)
Share of non-agricultural households in	0.043	-0.042
village	(1.58)	(-1.68)
Average annual net income per household	0.043	0.198
	(0.21)	(1.05)
Grain (rice) quota on land per *mu*	-0.0008**	0.0011**
	(-5.34)	(8.87)
R^2	0.565	
Adj. R^2	0.558	
F-statistic	84.5	
Jarque-Bera	87	
Ramsey F-statistic	0.14	

Note: Estimated with White's heteroskedasticity-consistent standard errors and covariance.
t-statistics are between brackets; * significant at the 5% level; ** significant at the 1% level.

The share of labor force members in a household also plays a role in land distribution, as expected from section 3.3. The results indicate that when the labor force share increases by 1 percentage point, the number of plots goes up by 0.25% while the average plot size does not change significantly. So, its impact is only marginal. The hypothesis that off-farm employment of household members plays a role in land reallocation is supported by the regression outcomes. An increase in the share of income obtained from off-farm employment by 1 percentage point is associated with a decrease in the number of plots assigned to a household by 0.35%.

The findings further indicate that land rental markets reduce land fragmentation. Application of the Wald coefficient restriction test indicates that the (absolute value of the) coefficient of *HOh* is significantly different from the coefficient of *HIh*[21]. So, one *mu* of land rented out by one household to another household reduces the number of plots on average by 11.1% - 9.1% = 2.0%. Moreover, land rented in increases average plot size, while land rented out does not have a significant impact on plot size. One *mu* of land transferred increases average plot size of the receiving household by 6.2%, because these households either rent in relatively large plots or plots that are next to their contracted plots.

The renting in and out of land may not be exogenous, but depends to some extent on land fragmentation. Households with many dispersed plots may use the land rental market to reduce the fragmentation of their land and increase production efficiency. In that case, land renting in and out depends positively on land fragmentation. Unfortunately, our data set does not contain any variables that can serve as suitable instruments for testing endogeneity and applying instrumental variables techniques to correct for it, if necessary.

At the village level, topography plays an important role. The average number of plots assigned to households is larger in hilly and mountainous areas as compared to plain areas, while the average plot size is significantly smaller. Villages located in suburban areas also assign significantly more and smaller plots to their households. This finding contradicts the hypothesis that farmers in areas with poor market access prefer more fragmented plots so as to spread risks, crops, or household labor. One possible explanation is that the suburban dummy variable is a very poor proxy for market access. But, it may also be that farmers in areas with better market access tend to diversify their crops and thus to fragment their plots[22].

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[21] The Wald test statistic equals 15.1, with a probability of 0.000.

[22] Results from survey work in three villages in Northeast Jiangxi Province in the year 2000 by researchers from Nanjing Agricultural University and Wageningen University support this explanation. Farmers in Banqiao and Gangyan, the villages with better access to market, are found to plant more cash crops like

Per capita land availability in a village is likely to be correlated with variation in land quality (soil types, water access, drainage conditions, road access, and so on), one of the omitted variables in our model. The regression results for land availability therefore partly reflect the impact of variation in land quality on land fragmentation. The results show that an increase in land availability (and hence variation in land quality) causes a significant increase in the number of plots per household and a significant, but smaller, decline in the average plot size.

Income from off-farm employment is expected to diminish land fragmentation by reducing the need to distinguish more land classes and by lowering the need for land re-allocation. The regression results support this. An increase in the share of income from off-farm employment by 1 percentage point is associated with a decrease in the number of plots by 0.5% and an increase in average plot size by 0.4%.

It should be noted that, like the land rental market, involvement of off-farm employment may not be exogenous but depend on the number of plots and their average size. Our data set, however, does not contain variables that can serve as instruments for testing endogeneity (and correcting for it, if necessary).

The share of non-agricultural households in a village and the average household income level do not have a significant impact on the two land fragmentation indicators. Less than one percent of the households in the sample villages are classified as non-agricultural (see Table 3.3). This indicator may therefore be too small to influence land redistribution or other land fragmentation-related activities in a significant way. The findings for average household income do not support the results of Kung (2000) and Yao (2000a) on the role in income in land reallocation for the villages in our sample. On the other hand, our regression results strongly support the role played by the grain quota in limiting land reallocations, and therefore land fragmentation, that was found in these two

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peanut, watermelon, sugarcane and vegetables, besides rice. In the remote village, Shangzhu, farmers have a very limited choice in crop production because their products have more difficulties in reaching markets. Moreover, vegetables for own consumption are usually grown on the 'reserved land' (land close to the household's home with long-tem user rights for the household), which is considered just one plot. Seasonal labor requirements are spread in some hamlets in Shangzhu by planting one-season rice instead of two-season rice on some plots. Hence, these households manage to spread their crops and labor without increasing the number of plots.

studies. The estimated coefficients in our study suggests that additional land reallocation following quota abolishment in the sample villages (average quota size is 104 *jin/mu*; see Table 3.3) increases the number of plots by 8.3% and reduces average plot size by 12.1%.

3.6 Discussion and concluding remarks

This study advances beyond previous analyses of land fragmentation in China by providing a more detailed analysis of the processes underlying land fragmentation and using available Rural Fixed Socio-Economic Observation data from 11 villages in Jiangxi province to obtain empirical estimates of the major factors that drive land fragmentation. The results obtained for these 11 villages are assumed to be representative for Jiangxi Province. Moreover, because some important policies related to land fragmentation, such as the HRS and the 30-year contract policy, have similar characteristics throughout the country, some of the insights gained will be relevant for the rest of China as well.

Our analysis shows that land fragmentation in China is caused to a large extent by the egalitarian principles used in distributing land to households and in reallocating land to adjust for demographic changes within villages. One reason is that the land within each village is classified into different classes, with each person receiving land from each land class. Another reason is that the size of land assigned to households is largely based upon family size. Our regression results indicate that large households receive substantially more plots than small households; the difference in average plot size between large and small households is relatively small.

Presence of a land rental market can help to reduce land fragmentation. Our empirical estimates indicate that one *mu* of land rented out by one household to another reduces the number of plots on average by 2.0%. With average landholding sizes in China being around 8 *mu*, this means that land rental markets can only have a modest impact on reducing land fragmentation.

We do not find evidence that limited market access induces land fragmentation in order to enable farmers to spread their risks, crops, or household labor. Instead, we find that landholdings in suburban areas are more fragmented. A possible explanation is that farmers in suburban areas tend to diversify their crops due to better access to markets, and therefore fragment their land.

Our results support the hypothesis that income from off-farm employment diminishes land fragmentation in a village by reducing the need to distinguish more land classes and by lowering the need for land reallocation. In addition, households involved in off-farm employment tend to cultivate fewer plots than households within the same village with no income from off-farm employment.

Finally, our regression results strongly support the role played by grain quota in limiting land reallocations, and therefore land fragmentation. Abolishment of the grain quota therefore tends to stimulate land fragmentation. Since 2002, grain quota have been abolished throughout China (OECD, 2005). Unfortunately, no suitable data are available at the moment to test whether this has induced an increase in land fragmentation or not.

Chapter 2 shows that during the 1990s, land fragmentation in China decreased slightly. But it is still at a high level, with farm households cultivating about 6 plots with an average area of less than 0.1 ha per plot. The findings of this chapter indicate that land fragmentation is likely to remain pervasive and persistent if the current principles underlying land distribution within villages are maintained. The land rental market may make a modest contribution to reduce fragmentation. Further increases in off-farm employment are also expected to contribute to land consolidation, but again the impact is likely to be modest. Our empirical estimates indicate that a doubling of the income share earned from off-farm employment in our sample villages (31.8% on average) will reduce the number of plots by 15% and increase average plot size by 13%. Government-initiated land consolidation programs may also provide an important contribution, but the cost of such programs in terms of government finance and transaction costs to farmers are high (see section 3.3).

On the other hand, a number of other factors may stimulate land fragmentation in the coming years if current policies continue. These factors include the cultivation of a wider range of (high value-added) crops in areas with good market access, and the persistence of land reallocations. Small and highly scattered land plots will therefore remain an important obstacle to cost reduction and productivity improvements in the near future and continue to be a source of rural poverty.

Appendix 3.1 Land Consolidation in China's Comprehensive Agricultural Development Program (CAD)

Launched in 1988, the CAD program is a land development program which aims at inducing investments by farm households, collectives and the state to improve the infrastructure of farming, particularly focusing on transforming low quality land to a higher standard. It covers land consolidation and investments for diversification.

The program is managed by the CAD offices set up at all government levels. In practice, the CAD office at the county level is responsible for the formulation of CAD plans and initial selection, application, implementation and appraisal of the CAD projects, based on information from land and natural resource surveys conducted in earlier years. The CAD offices at higher levels are responsible for final selection and monitoring of project implementation.

Land consolidation in the CAD includes: (a) expanding the irrigated area and improving irrigation and drainage conditions; (b) improving farm plot configuration, including plot size, shape and layout, through a suitable merging of smaller and irregular shaped plots into larger ones of a regular size and shape; (c) improving farm road systems to provide better access to plots for both workers and machinery; (d) consolidating farmer's small, non-contiguous plots scattered in many locations into relatively large ones.

Due to the fact that the rural population in China will continue to grow while the total farmland area will diminish, land fragmentation will, of course, remain an important feature of Chinese agriculture in the longer term. The land consolidation program is unlikely to change this significantly. It is likely, however, to reduce land fragmentation and improve the total factor productivity to some extent.

Adapted from Wu *et al.* (2005).

CHAPTER 4

LAND FRAGMENTATION AND PRODUCTION COSTS[23]

4.1 Introduction

Production costs are not only one of the most important factors of a product's competitive advantage, but also one of the most important factors influencing producers' decision-making (Norton and Alwang, 1993; Fujimoto, 1994). In this chapter, we examine whether, and to what extent, land fragmentation affects the costs of rice production on small farm in China.

Despite the fact that land fragmentation is a widespread and important problem in many countries, quantitative research on the impact of land fragmentation on production costs is scarce[24]. One exception is the study by Jabarin *et al*. (1994) for northern Jordan. The main finding of this study is that average plot size has a significant negative impact on production costs. A one dunum[25] increase in average plot size will induce a decrease of only 0.51 JD[26] in production costs per ton of wheat grain. Because the study only uses average plot size to indicate land fragmentation at farm level, much information about land fragmentation that may also be relevant for production costs, particularly the distance of plots to the homestead, is not taken into account. Moreover, this research does not see production costs as an outcome of household decision-making. Instead of estimating the equation in the framework of a household model, the study simply analyzes the relation between plot size and production costs.

To our knowledge, no research has been carried out thus far to examine the impact of fragmentation on production costs in China. This chapter intends to make an empirical

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[23] A paper based on this chapter will be published in Heerink *et al.* (forthcoming). I would like to thank Xiaobo Zhang for his comments on a draft version of this paper.

[24] Although there are many case studies of land fragmentation in transition countries like Bulgaria, Vietnam, or Armenia, to our knowledge no research on production cost of fragmentation has been carried out in these countries.

[25] Area unit in Middle-East; one dunum = 0.1 ha.

[26] Jordanian dinar, official currency in Jordan. Official exchange rate in the 1990s is $1=0.68-0.71 JD.

examination of this impact for three villages in Northeast Jiangxi Province, where rice farming is the most important source of income. The chapter takes into account different dimensions of land fragmentation and derives the specification of the regression equations from a farm household decision-making model. Results of this research may provide an important input for policy discussions on land fragmentation.

The remainder of this chapter is structured as follows: Section 4.2 presents the analytical framework for the empirical analysis of this chapter. The theoretical farm household model presented in this section also serves as a background for the next two chapters, in which the effects of land fragmentation on the technical efficiency of small rice producer, on farm management, soil quality and rice yield are examined. Section 4.3 is devoted to the empirical analysis. It includes subsections on the research area, the method of sampling and data collection. The same dataset is used for the empirical analysis in Chapter 5. The results of the empirical analysis are presented in section 4.4 and conclusion in section 4.5.

4.2 Analytical framework

Production costs are outcomes of household decision making on agricultural input use. In economic science, these decisions are regarded as being driven by the maximization of utility or profit, given the constraints confronting the household. Farm household theory states that households try to attain their goals and aspirations using their limited resources (including fragmented land) to choose between alternative productive activities both off- and on-farm. The basic agricultural household model[27] consists of a utility function that households try to maximize:

$$Max\ U = u(c,l;\xi) \qquad (4.1)$$

where c is a vector of consumption goods, l is leisure and ξ are household characteristics, like age and education of household head, etc. The utility function is subject to a budget

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[27] Our discussion of the household model builds upon Sadoulet and De Janvry (1995).

constraint:

$$p_c c = p_q q(L, A, K, B;\ \zeta\ )\text{-}\ p_b B - w_L(L^{in}\text{-}\ L^{off})\text{-}w_A(A^{in} - A^{out}) - w_k(K^{in} - K^{out}) \qquad (4.2)$$

where p_c and p_q are vectors of prices of commodities consumed and produced, and p_b is a vector of variable input prices. L is on-farm labor, including own labor and hired labor. A is land, K is capital and B is a vector of material inputs used in production. w_L and w_A are prices related to factor payments (labor and land here), w_k is the price of capital. $q(.)$ is a production function, ζ are farm characteristics, including land fragmentation situation, L^{in} *and* L^{off} is hired and off-farm labor, A^{in} *and* A^{out} is rented-in and rented-out land, and K^{in} *and* K^{out} is rented-in and rented-out capital, respectively. The model is subject to the following resource constraints:

$$L\text{-}\ L^{in} + L^{off} + l = L^{TOTAL}$$
$$A\text{-}\ A^{in} + A^{out} = A^{con} \qquad (4.3)$$
$$K\text{-}\ K^{in} + K^{out} = K^{assets}$$

where L^{TOTAL} is the time endowment of the household. L^{TOTAL} can be allocated to off- and on-farm work as well as to leisure. Land area input in the production balances the household contracted land A^{con} and rented-in land, minus rented-out land. Total capital available for production equals own capital endowment K^{assets} plus rented-in capital, minus rented-out capital.

Institutional constraints govern the ability of households to participate in markets, to have access to services and to use infrastructure:

$$x \le x^{\max}(\psi, \xi, \zeta),\ x \in \{L^{in}, L^{off}, A^{in}, A^{out}, K^{in}, K^{out}, B\} \qquad (4.4)$$

where x is a vector of choice variables and $x^{\max}$ is a function of household characteristics (ξ), farm characteristics (ζ) and institutional characteristics (ψ), like available savings and access to credit, etc. Re-organizing and substituting Eq. (*4.3*) into Eq. (*4.2*) gives

$$p_c c = p_q q(L, A, K, B; \zeta) - p_b B - w_L(L + l - L^{TOTAL}) - w_A(A - A^{con}) - w_k(K - K^{assets}) \quad (4.5)$$

The Lagrangian of this problem can be formulated as

$$\Im = u(c, l; \xi) - \lambda [\, p_c c - p_q q(L, A, K, B; \zeta) + p_b B + w_L(L + l - L^{TOTAL}) + w_A(A - A^{con}) + w_k(K - K^{asset})] - \mu_x (x^{\max} - x) \quad (4.6)$$

where λ is the Lagrange multiplier of the budget constraint, μ_x is the multiplier related to the labor, land, capital, and material inputs. Taking the first order conditions to the choice variables *c, l, L, A, K* and *B* gives

$$\frac{\partial \Im}{\partial c} = \frac{\partial u(c, l; \xi)}{\partial c} - \lambda p_c = 0 \quad (4.7)$$

$$\frac{\partial \Im}{\partial l} = \frac{\partial u(c, l; \xi)}{\partial l} - \lambda w_L = 0 \quad (4.8)$$

$$\frac{\partial \Im}{\partial L} = -\lambda [-p_q \frac{\partial q(A, L, K, B; \zeta)}{\partial L} + w_L] = \mu_L \quad (4.9)$$

$$\frac{\partial \Im}{\partial A} = -\lambda [-p_q \frac{\partial q(A, L, K, B; \zeta)}{\partial A} + w_A] = \mu_A \quad (4.10)$$

$$\frac{\partial \Im}{\partial K} = -\lambda [-p_q \frac{\partial q(A, L, K, B; \zeta)}{\partial K} + w_K] = \mu_K \quad (4.11)$$

$$\frac{\partial \Im}{\partial B} = -\lambda [-p_q \frac{\partial q(A, L, K, B; \zeta)}{\partial B} + \mathrm{p}_b] = \mu_B \quad (4.12)$$

Solving this model gives a set of reduced-form equations:

$$M = f(w_A, w_K, w_L, p_b, p_c, p_q, \xi, \zeta) \quad (4.13)$$

where *M* represents the choice variables *c, l, L, A, K* and *B*.

This assumes that prices are exogenous. However, farm households also confront institutional constraints and market imperfections, which result in the so-called non-separability of household's production and consumption. This compels them to face shadow prices that are not identical to the market prices. We can assume that the prices depend on village location and household specific variables captured by household, farm and village characteristics. This can be displayed as:

$$W = w(\nu, \xi, \zeta) \qquad (4.14)$$
$$P = p(\nu, \xi, \zeta)$$

where W is a vector of the price of land, capital and labor, P is a vector of input, consumption goods and output prices, ν is a vector of village-specific variables.

Production costs C are a function of household choice variables, exogenous prices, and farm characteristics[28]:

$$C = (w_L L + w_A A + w_K K + p_b B)/q(L, A, K, B; \zeta) \qquad (4.15)$$

The reduced-form of the agricultural production cost function can therefore be denoted as:

$$C = g(v, \xi, \zeta) \qquad (4.16)$$

where C represents production costs per ton grain, and $g(.)$ represents the reduced-form equation.

4.3 Data set and model specification

4.3.1 Research area

Data collection for this research was carried out within the framework of the Sino-Dutch SERENA project. The purpose of the research component of this project was to analyze

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[28] Note that total production costs C is closely related to total factor productivity (TFP), a well-known efficiency measure in (agricultural) economics, which is defined as:

$TFP = p_q q/(w_L L + w_A A + w_K K + p_b B)$, Hence $TFP = p_q/C$.

the effects of economic policy reforms on farm household decision-making and soil degradation. Jiangxi was selected as research area for this project. As discussed in Chapter 1, land fragmentation is relatively high in Jiangxi Province.

Figure 4.1 Location of Jiangxi Province and the three case study villages

Jiangxi is an inland province in Southeast China (see Figure 4.1). It is located on the southern bank of the Yangtze River, between 24'29-30'04' North latitude and 113'34-118'28' Eastern longitude. It covers a total area of about 0.17 million square kilometers. The topography of Jiangxi is dominated by mountainous (36%) and hilly land (42%). The annual average temperature is around 18°C, and annual rainfalls range from 1,341 mm to 1,940 mm. The total population was 42.22 million in 2002. Its GDP was 245 billion *yuan* (US$25.59 billion), and the per capita net income of rural households was 2306 *yuan*, 7.3% lower than the national level (NBS, 2003).

Table 4.1 Summary description of the three villages

		Banqiao	Shangzhu	Gangyan
Location	Prefecture/County	Yingtan/Yujiang	Yingtan/Guixi	Shangrao/Yanshan
	Township	Honghu	Tangwan	Wang-er
	Distance	Within 10km to city	Remote	30 km from city
	Road quality	Poor	Bad	Sand & tarmac
Population	Persons/Households	900/220	2028/472	3200/730
	Hamlets/Village groups	4/4	16/8	7/22
Land (*mu*)	Farmland	1700	2759	3880
	Paddyland	1234	2359	3780
	Highland	500	400	100
	Farmland/capita	1.89	1.36	1.21
	Upland/total land	60-70%	97%	'plain'
Agriculture	Main crops	Rice, peanut, fruit trees	Rice, bamboo, fir	Rice, vegetables
	Green manure planting	Yes, with low production	By more than 80% of households	Depends on hamlets
	Manure	Limited use	Limited use	Limited use
	Plowing technology	Animal plow	Animal and human force plow	Animal plows and machines
	Farm irrigation	Good	Rain-fed or irrigated with conserved water	Good
	Irrigated land/ Farmland	73%	86%	97%
	One-season area/ Total rice area	3.4%	71.6%	18.5%
	Rice yield (kg/ha)	5,099	3,950	4,629
Degradation	Soil quality	Worsened	Not clear	Worsened
	Erosion	Highlands	Landslides	None
	Erosion/flood control	No government projects	No government projects	No government projects
	Soil compaction	Yes		
	Other problems	Acidification	Yes, but not important -	Yes Limited flooding
Land tenure	Quality/distance classes	4	3	3/4
	Allocation rule	Family size & labor force	Family size	Family size
	Frequency of adjustment	For some hamlets: never adjusted	Small adjustments	Small: 3-5 years; large: 5-10 years (depends on hamlet)
	Collective management	-	-	Hamlet management of some forest

Source: Fieldwork of SERENA project.

Three villages, Banqiao, Shangzhu and Gangyan were selected as case study villages for the project[29]. The locations of these three villages are shown in Figure 4.1, and their basic characteristics are summarized in Table 4.1.

Banqiao is the smallest village with around 900 people living in 220 households. It is located in a hilly area. The upland area accounts for 60-70% of its total land. Market

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[29] The selected villages are located in a soil degradation prone area. A stratified sample was used that differences in market access, economic development level, geography, land fragmentation degree and in the availability of off-farm opportunities. See Kuiper *et al*. (2001).

access is good. It is within 10 km distance of a major city. But the conditions of roads from its hamlets to the main road are poor. The irrigation condition is adequate. Paddy fields can be easily irrigated with water from the reservoir on payment of irrigation fees. In the upland area, the farming system is rain-fed. Almost all rice planted is two season rice. Paddy yields are high, more than 5,000 kg per ha per harvest. Fertilizer use in rice is also very high, more than 1,000 kg per ha per crop.

Shangzhu is a remote village, about two hours bus ride away from the capital city of the county[30]. Its 16 hamlets are scattered over the mountains, and some are difficult to reach. There are 472 households with 2028 people in this village. The main crops are rice and bamboo. Rice is planted on the terrace of the valley areas, while bamboo and fir (a cash tree) are grown in the hilly areas. The terraces are well-constructed with stone and are several hundred years old. More than 70% of the area planted with rice is planted with one-season rice. Paddy yields are relatively low, less than 4,000 kg per ha per harvest. Fertilizer use in rice is also much lower than in Banqiao, less than 500kg per ha.

Gangyan is the largest village, with 730 households and 3,200 persons. It is located in a plain area, and has medium distance (about 30 km) from the village to the county seat. The main crops in this village are rice and vegetables. Tractors are used in this village. More than 80% of the planted rice is two-season rice. Yields are about 10% lower than in Banqiao, while the fertilizer use in rice is about 30% lower.

4.3.2 Sampling and data collection

About 23% of the households were randomly selected and interviewed in the three villages. The samples were proportionately distributed over the hamlets in each village. The composition of the sample is shown in Table 4.2.

The resulting 339 households were surveyed in the 2000 agricultural season[31], with information collected for 2490 plots. Among the 339 households, 265 planted early rice, 204 planted one-season rice, and 261 planted late rice. In total 323 households planted at least one kind of rice. These households provide the sample that is used in this chapter and the next chapter. Data were collected at different levels. The farm characteristics and

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[30] The distance itself is about 50-60 km, but the roads in the hilly and mountainous areas are very poor. So to measure the real distance does not make sense.

[31] The detailed questionnaire is available upon request from the author.

household characteristics are at the household level, land fragmentation indicators at the plot level and the planting area, yield and the production costs are at the crop level (that is, all plots planted with rice).

Table 4.2 Composition of survey sample

	Number of households	Share in total number of households (%)	Sample size	Share of sample households in village (%)
Banqiao	220	15.5	52	23.6
Shangzhu	472	33.2	112	23.7
Gangyan	730	51.3	174	23.8
Total	1422	100	339	-

Production costs cover the costs of labor, seed, chemical fertilizer, herbicides & pesticides, and oxen & tractors. Labor cost includes all labor used in activities like nursery, land preparation, seeding, weeding, fertilizing, transplanting, harvesting (including the transportation of the harvests from plots to the homestead) and field visit. The agricultural labor market in the research area faces major imperfections (Kuiper, 2005). The shadow wage rate is assumed to be 25 percent lower than the average market price in rice planting activities (20 *yuan*/day), that is 15 *yuan* per day.

Seed cost includes seeds and plastic film (used only in early rice nursery). Two kinds of seeds are commonly used, local and high-yield-varieties (HYV). Local seeds are normally saved by households after harvesting. Their price can be represented by the output price after the harvest. HYVs are bought at the market. Likewise, fertilizers, herbicides and pesticides are bought from the market, so market prices are used in calculating such cost.

Oxen are mainly used on own farms in Banqiao and Shangzhu. In Gangyan, 17% of the households rent in oxen from the hamlet or the village. Tractors are not widely used in rice production; only one household in Banqiao used a tractor for plowing and 20 households in Gangyan. As with the shadow wage rate, the shadow price of own oxen is also assumed to be 25 percent lower than that of rented-in oxen. Tractors were rented in by 20 households. One additional household used its own tractor, and we estimated the shadow price of this on the basis of the average tractor rental price.

Table 4.3 Structure of variable costs in rice production (*yuan*/ton)

	Labor	Fertilizer	Seeds	Herbicides & pesticides	Oxen & tractor	Total
Costs	727	160	33.6	43.6	104	1068
Percentage	68.1	15.0	3.1	4.1	9.7	100

Sources: Calculated from the survey data.

The resulting variable costs in rice production and the percentage of each category are calculated in Table 4.3. It indicates that labor costs account for by far the largest share (68%) of the total costs. Seeds and herbicides & pesticides account for a very small share, 3% and 4%, respectively. Oxen or tractor costs cover about 10% while fertilizer covers about 15% of the total costs.

4.3.3 Choice of variables

Production costs depend on farm size and the technologies adopted in the production process. The factors affecting technology use in rice production (like land fragmentation, farm household characteristics and village characteristics) that we use in this analysis are derived from the farm household model presented in section 4.2. An appropriate land fragmentation indicator system is desired that can provide a relatively full picture of land fragmentation and can be used to derive well-founded policy implications. As reviewed in section 2.2, many indicators can be used to measure land fragmentation. The most commonly used are the Simpson index (Blarel *et al.*, 1992) and the basic three indicators: number of plots, plot size and plot distance.

In this chapter, we use farm size, the Simpson index and the average distance of the homestead to the plots as land fragmentation indicators[32]. Farm size is used to capture economies of scale. The Simpson index is a general measure of land fragmentation. It does not capture farm size and distance to the plots (see Chapter 2). The average distance of plots from the homestead captures the spatial distribution of plots in a farm.

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[32] Alternatively, we used average plot size instead of the Simpson index in the analysis. The results are shown in the appendices to this chapter.

Table 4.4 Descriptive statistics of variables used in the analysis

	Min	Max	Mean	Stdev
Production costs (PC)				
Total costs (*yuan*/ton) (*TC*)	326	5463	1068	516
Labor costs (*yuan*/ton) (*LC*)	166	4716	727	450
Fertilizer costs (*yuan*/ton) (*FC*)	19.6	507	160	75.6
Seed costs (*yuan*/ton) (SC)	3.78	164	33.6	20.7
Herbicide and pesticide costs (*yuan*/ton) (*HC*)	0	180	43.6	23.6
Oxen and tractor costs (*yuan*/ton) (*OC*)	18.2	655	104	66.4
Explanatory variables				
Simpson index (*SI*)	0.00	0.91	0.73	0.17
Farm size (*mu*) (*FS*)	1.00	34.2	10.4	5.68
Average distance of plots to homestead by walking (minutes) (*DT*)	3.00	61.3	16.1	7.70
Age of household head (years) (*AH*)	23.0	75.0	47.1	10.4
Education years of household head (years) (*EH*)	0	13.0	4.79	2.80
Household size (persons) (*HS*)	1	14.0	4.46	1.52
Share of good irrigated land (%) (*GI*)	0	1000	28.7	30.3
Contracted forest land (*mu*) (*CF*)	0	31.0	2.26	3.66
Cattle ownership dummy, 1=owns cattle, 0=not (*DC*)	0	1.00	0.66	0.48
Available savings (*yuan*) (*AS*)	0	40000	2587	5406
Total credit (*yuan*) (*TC*)	0	30000	1722	3810
Dummy variable=1 if Shangzhu village (*DS*)	0	1	0.17	0.38
Dummy variable=1 if Gangyan village (*DG*)	0	1	0.32	0.47

Note: All 323 households planting rice are included in the regression except one household in Shangzhu, which reported fertilizer use as high as 6300 *yuan* per ton grain.

Source: Calculated from the survey data.

Descriptive statistics for the variables used in the empirical models are presented in Table 4.4. Of special interest are the dependent variables and the land fragmentation indicators. There are large spreads in these variables. Total production cost varies from 326 to 5463 *yuan* per ton across households, with a mean value of 1068 *yuan* per ton[33]. Likewise, there is a large spread in the individual cost categories.

Land fragmentation also differs greatly from household to household. The Simpson index varies from 0.00 to 0.91 (0.73 on average)[34]. The average distance of plots to the homestead varies from 3 minutes to more than one hour. It takes 16 minutes from a plot to

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[33] The large variation in production cost is mainly caused by the difference in farmers' perceptions of labor input. Labor costs vary from 166 to 4716 *yuan*.

[34] The number of plots per household varies from 1 to 17, with an average 7.4, while the average plot size varies from 0.36 to 6.84 *mu*, with average value of 1.5 *mu*.

the homestead on average. Farm size is 10.4 *mu* on average, varying from 1 to 34 *mu*. The other indicators also show substantial variations, as required for use in the regression analyses.

4.3.4 Model specification and estimation method

The reduced form equation that we derived in section 4.2 gives us information on the variables that should be included in the model, but not on the functional form that should be used. We therefore tested different functional forms for normality (Jarque-Bera test), misspecification (Ramsey RESTE test) and goodness of fit (R-squared, F-test) in order to select the most appropriate one. The results are shown in Appendix 4.1. The semi-logarithm functional form passed all the tests, while both linear and double logarithm functional forms fail to do so. We therefore select the following model for the empirical analysis:

$$Ln(PC_i)= \alpha_{0i} + \alpha_{1i}SI + \alpha_{2i}FS + \alpha_{3i}DT + \alpha_{4i}AH + \alpha_{5i}EH + \alpha_{6i}HS + \alpha_{7i}GI + \alpha_{8i}CF + \alpha_{9i}DC + \alpha_{10i}AS + \alpha_{11i}TC + \alpha_{12i}DS + \alpha_{13i}DG + \upsilon_{1i} \qquad (4.17a\text{-}17f)$$

with

$PC_i = TC, LC, FC, SC, HC$ and OC, respectively;

$\alpha_{0i},\ldots, \alpha_{11i}$ are unknown coefficients;

υ_{1i} is disturbance term with standard properties.

As mentioned above, the reduced-form of farm household production cost function (*4.16*) derived from section 4.2 can be represented as a function of village-specific variables, household and farm characteristics. In our case, we use two village dummies to denote the differences between the three villages, which cannot be reflected by the included variables in the function. Age and education of household head, and household size represent household characteristics. Farm characteristics in our case include land fragmentation and the other farm characteristics. The definitions and expected impact of each variable on the total production costs are shown in Tables 4.4 and 4.5. The Simpson index is expected to increase production costs, because more fragmented farms need more time to manage. Furthermore, some modern technologies that may reduce production costs (for instance machinery) are more difficult to use on fragmented plots. Farm size is expected to decrease production costs per ton grain due to economies of scale. In contrast, larger average distances to the plots will increase production costs, since greater distance means more travel time lost.

Table 4.5 Anticipated signs of variables included in the analyses

Independent variables	Production costs (*yuan*/ton)
Land fragmentation indicators	
Simpson index	+
Farm size (*mu*)	-
Average distance of plots to homestead by walking (minute)	+
Household characteristics variables	
Age of household head (year)	-/+
Education years of household head (year)	-
Household size (person)	-
Farm characteristics variables	
Share of good irrigated land	-
Contracted forest land (*mu*)	+
Dummy for own oxen	-
Available savings (*yuan*)	-
Available total credit (*yuan*)	-
Locational dummy variables	
Dummy variable =1 if Shangzhu village	+
Dummy variable =1 if Gangyan village	+

Farm household characteristics may affect decision-making on technology adoption and therefore influence production costs. Farmers' age is expected to increase production costs because older farmers may spend more time to manage the plots compared with their younger counterparts. If they are more experienced in managing their fields, however, age is expected to reduce production costs. Education of the household head and household size are expected to decrease production costs, because more educated farmers and larger households may adopt better management methods and be more able to manage the crop in a timely manner.

Other factors being constant, farms with a higher share of good irrigated land will face lower production costs, since good irrigated land is more productive. Farms with more forestland area may face higher production costs in rice because, given farm size, more forestland means less land for rice production. Cattle (oxen) ownership can reduce production costs, because the shadow price is lower than that of rented-in oxen. Both available savings and credit are expected to reduce production costs because they can release cash constraint and enable farmers to adopt improved management methods and to buy material inputs and manage their fields in a timely fashion.

Village characteristics are represented by two village dummy variables, one for Shangzhu and one for Gangyan. Farmers in Shangzhu and Gangyan villages are expected to confront higher rice production costs than farmers in Banqiao because of the poorer market access and probably fewer contacts with agricultural extension services.

It should be noted that farmers may switch from one input to another (for example from fertilizer or herbicides to labor) in response to changes in land fragmentation or other explanatory variables. The signs shown in Table 4.5 therefore apply to total production costs, but may not apply to individual cost categories. We therefore analyze both the impact on total production costs and on individual cost categories.

4.4 Empirical results

The total production cost equation (*4.17a*) and different categories of production cost equations (*4.17b-f*), which are derived from section 4.2, are estimated with ordinary least squares. The results for these equations are presented in Tables 4.6, 4.7 and Appendix 4.2. As an alternative, results estimated with plot size instead of the Simpson index are shown in Appendices 4.4 and 4.5.

4.4.1 Total production costs

The F-statistic in the regression result for total production costs indicates that the null hypothesis that the variation in each production cost category cannot be explained by the listed variables should be rejected at a 1% testing level. Farm size is found to have a significant negative impact on total production costs. Larger farm size reduces production costs. A one *mu* increase in farm size gives causes a 1.5% decrease in production costs.

As expected, the distance of plots to the homestead has a significant positive impact on production costs. One minute's additional travel time to the plots causes a 0.8% increase in production costs. The Simpson index, however, is not found to have a statistically significant impact on production costs per ton. A possible explanation is that farms with a higher Simpson index can facilitate the spreading of (natural) risk, which counterbalances the negative impact on management and technology adoption.

Table 4.6 Regression results for total production costs

Independent variables	Total production costs
Simpson index	0.16 (1.23)
Farm size (*mu*)	-0.015*** (-3.60)
Average distance (minute)	0.008*** (3.19)
Age (year)	0.003* (1.65)
Education (year)	-0.020** (-2.54)
Household size (person)	-0.007 (-0.54)
Share of good irrigated land	-0.001 (-0.72)
Forest land (*mu*)	0.003 (0.59)
Oxen ownership	-0.076* (-1.84)
Available savings (*yuan*)	-1.86E-6 (-0.52)
Available credit (*yuan*)	-8.27E-6 (-1.52)
Shangzhu village	0.41*** (6.98)
Gangyan village	0.10* (1.82)
Constant	6.65*** (37.84)
R^2	0.34
Adj. R^2	0.31
F-statistic	12.1

Notes: The dependent variables are in logarithm. t-statistics are between brackets; *Significant at 10% level, **significant at 5% level and ***significant at 1% level.

In addition, household characteristics are found to have significant impacts on production costs. The age of the household head has a weak positive impact on total production costs, while education of the household head has a significant negative impact on production cost per ton. The latter result confirms that farmers with a higher education level are more skillful in producing rice. The size of the household, however, does not affect total production costs.

As expected, if farmers own oxen, the cost of rice production decreases, either because the shadow price of own oxen is lower than that of rented oxen, or because owning oxen permits greater flexibility and efficiency in preparing the land compared to hiring them from others. The other farm characteristics, however, do not have a significant impact on production costs. Production costs in Shangzhu are 440 *yuan* (41%) higher than in Banqiao, other factors fixed. The difference is much smaller (108 *yuan* or 10%) between Gangyan and Banqiao. The main reason for this is probably that farmers in Shangzhu village face with higher input prices due to more difficult access to markets than farmers in the other two villages. Moreover, they may have less access to extension services.

4.4.2 Production cost categories

The empirical results for total production costs show that farm size and distance, not the Simpson index, significantly affect the production costs for growing rice. The available data allow us to take a closer look at those cost categories that are most significantly influenced by land fragmentation, and how. The main results are presented in Table 4.7. The full regression results, including household, village and other farm characteristics, are presented in Appendix 4.5. All the F-statistics are high enough to reject the null hypothesis that the variation in each production cost category cannot be explained by the listed variables at a 1% testing level (see Appendix 4.2).

The results for the Simpson index show a very interesting pattern. It has a significant positive impact on labor cost per ton, but it decreases fertilizer and oxen costs. A 1% increase in the Simpson index causes a 0.31% increase in labor use, but a 0.25% decline in fertilizer and a 0.28% decrease in oxen and tractor costs. An increase in the Simpson index therefore induces a shift from fertilizer and oxen use towards higher labor use. Management of more fragmented plots therefore requires more labor because of inconvenience in the management of fragmented plots or because farmers avoid household labor bottlenecks by spreading peak labor requirements. On the other hand, adoption of modern technologies is less on more fragmented plots. As a result, total production costs are not significantly affected (as found in Table 4.6).

Table 4.7 Impact of land fragmentation on each cost in rice production

	Labor	Fertilizer	Seed	Herbicides & pesticides	Oxen and tractor
Simpson index	0.43***	-0.35**	-0.31	-0.123	-0.386**
	(2.68)	(-2.35)	(-1.46)	(-0.62)	(-2.20)
Farm size	-0.02***	0.001	-0.01*	-0.014**	-0.004
	(-4.10)	(0.23)	(-1.85)	(-2.26)	(-0.76)
Average distance	0.01***	0.008***	0.01	0.007*	0.007**
	(2.92)	(2.64)	(1.13)	(1.76)	(2.10)
R^2	0.39	0.31	0.25	0.13	0.33
Adj. R^2	0.37	0.28	0.22	0.09	0.31
F-statistic	15.4	10.4	8.05	3.45	11.9

Notes: All the dependent variables are in logarithm.

t-statistics are between brackets; *Significant at 10% level, **significant at 5% level and ***significant at 1% level.

Farm size is observed to have a significant negative impact on labor, seed, and herbicide and pesticide costs. A 1% increase in farm size will cause a 0.21%, 3.59% and 0.15% decrease in labor, seed, and herbicide and pesticide costs, respectively. Costs of fertilizer and oxen, however, are not affected. The average distance to the plots is found to have significant positive impacts on all categories except for seed costs. A 1% increase in the average distance can give rise to 0.14% increase in labor, 0.13% increase in fertilizer and 0.11% increase in herbicides and pesticides and oxen and tractor costs, respectively. The result for labor confirms that plots at larger distances from the homestead require more time for traveling. Fertilizer cost is observed to be significantly higher in farms with larger average distances, because farmers prefer to use more chemical fertilizer to substitute manure, which is much more difficult to transport. More herbicides and pesticides is used on farms with larger average plot distances. A possible explanation is that farmers can spend less time on detecting weed and pest outbreaks on far-away plots and therefore apply more chemicals for prevention.

4.5 Discussion and concluding remarks

In this chapter, a framework of farm household model is developed to address the impact of land fragmentation on rice production costs. This is motivated by the fact that under the existing HRS, the small size of farms and their fragmented plots are generally assumed to give rise to an increase in economic costs and thus weaken the competitive advantage of agricultural commodities in international markets (Cai, 2003). The model specification is derived from the reduced-form equation. It explicitly accounts for the role of household characteristics, farm characteristics, land fragmentation at farm level and village-specific variables on the total production costs as well as on individual cost categories by influencing farm production decision-making on technology use.

Estimation results from the ordinary least squares indicate that land fragmentation and oxen ownership are found to have a significant impact on production costs (see Table 4.6). Farm size and average distance to plots have significant negative and positive effects on production costs, respectively. The Simpson index, however, does not show a significant impact on the total production costs. This is explained through a more detailed examination of the impact of land fragmentation on individual cost category. A higher Simpson index increases labor costs but reduces fertilizer, seed and oxen costs. Apparently, farmers with highly fragmented plots switch to more labor-intensive methods and use fewer modern technologies, and the net impact on total production costs is not significant. The increase in labor input on fragmented plots may be due to the inconvenience in the management of fragmented plots or to avoidance of household labor bottlenecks through spreading peak labor requirements over the plots. The detailed examination further shows that a larger farm size reduces labor, seed, and herbicide and pesticide costs, but not those of fertilizers, oxen & tractors. A larger average plot distance increases all cost categories except seed.

To sum up, land fragmentation has a significant impact on rice production costs of households. Keeping other factors constant, an increase in farm size and a reduction of the average distance to plots decrease the total production costs per ton. Changes in the average plot size and its distribution, as measured by the Simpson index, cause a shift in input use but do not affect total production costs.

Detailed information from the household survey allows us to calculate the net income from rice farming (see Appendix 4.3). In our research area, the net income is 178 *yuan* per *mu*, or 579 *yuan* per ton, if labor cost (mainly from own family) is excluded[35]. If labor cost is included, however, the net income becomes negative, namely minus 28 *yuan* per

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[35] Due to data limitations, costs of irrigation and manure are also not included.

mu and minus 148 *yuan* per ton[36]. This indicates that, at price levels prevailing at the time of the survey, rice production is a non-profitable activity in our research area[37]. The results of this chapter indicate that the small farm sizes and the time lost in traveling to the (fragmented) plots are important factors in this respect.

Considerable differences exist in production costs between the three villages, even when differences in factors that might explain production costs are taken into account (farm size and distance, for example). Compared with their counterparts, farmers in Shangzhu have to pay much higher input prices due to difficult market access. This implies that in very remote hilly villages like Shangzhu, rice production is much less profitable, or even unprofitable if family labor costs are taken into account. To convert the farming system there may be a good option to improve income and reduce poverty in such villages, provided access to food markets is improved. However, for detailed proposal on which farming system will be converted from rice farming, further survey and research are still needed in this village.

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[36] Net income for early rice, one season rice and late rice is given in the Appendix 4.3.

[37] The analysis in this chapter is based on prices for the year 2000. Since the autumn of 2003, rice prices have grown rapidly and rice production has become more profitable as a result.

Appendix 4.1 Comparison of the functional forms

		Total	Labor	Fertilizer	Seed	Herbicide & pesticide	Oxen
TC, LC, FC, SC, HC and OC are in logarithm	Normality test (prob.)	6.17 (0.05)	1.02 (0.60)	1.65 (0.44)	81.3 (0.00)	5.72 (0.06)	3.31 (0.19)
	Ramsey test (prob.)	0.97 (0.32)	1.80 (0.16)	6.39 (0.01)	0.37 (0.54)	0.22 (0.64)	0.24 (0.62)
	R-square	0.34	0.39	0.30	0.25	0.13	0.33
	Adj. R-square	0.31	0.37	0.28	0.22	0.09	0.31
	F-statistic (prob.)	12.13 (0.00)	15.39 (0.00)	10.39 (0.00)	8.09 (0.00)	3.45 (0.00)	11.92 (0.00)
Linear	Normality test (prob.)	3472 (0.00)	5340 (0.00)	255 (0.00)	912 (0.00)	185 (0.00)	4814 (0.00)
	Ramsey test (prob.)	7.17 (0.01)	9.18 (0.00)	0.25 (0.62)	0.93 (0.34)	2.11 (0.15)	8.40 (0.00)
	R-square	0.30	0.33	0.22	0.27	0.13	0.26
	Adj. R-square	0.27	0.31	0.19	0.24	0.09	0.23
	F-statistic	10.08 (0.00)	11.88 0.00)	6.62 (0.00)	8.69 (0.00)	3.52 (0.00)	8.45 (0.00)
Double log	Normality test (prob.)	3.63 (0.16)	0.92 (0.63)	43.4 (0.00)	69.5 (0.00)	22.07 (0.00)	0.50 (0.78)
	Ramsey test (prob.)	1.08 (0.30)	2.90 (0.09)	0.56 (0.46)	0.02 (0.89)	0.00 (0.97)	0.57 (0.45)
	R-square	0.35	0.40	0.26	0.25	0.17	0.36
	Adj. R-square	0.33	0.37	0.23	0.22	0.13	0.33
	F-statistic (prob.)	12.81 (0.00)	15.6 (0.00)	8.28 (0.00)	7.89 (0.00)	4.75 (0.00)	13.1 (0.00)

Note: In the double log functional form, dummies are used to represent education (1 if household head received formal education; 0 otherwise), the share of good irrigated land area (1 if a farm has good irrigated land, 0 otherwise), forest area (1 if a farm has forest land; 0 otherwise), savings (1 if a household has savings; 0 otherwise) and credit (1 if credit can be available for a household; 0 otherwise).

Appendix 4.2 Results for rice production cost category (*yuan*/ton)

Independent variables	Labor	Fertilizer	Seed	Herbicides & pesticides	Oxen
Constant	5.89***	5.56***	42.13***	3.849***	4.247***
	(27.23)	(27.39)	(12.35)	(14.37)	(17.88)
Shangzhu village	0.623***	-0.607***	22.50***	-0.391***	0.847***
	(8.53)	(-8.79)	(7.27)	(-4.31)	(10.57)
Gangyan village	0.196***	-0.242***	6.916***	-0.283***	0.477***
	(2.86)	(-3.77)	(3.14)	(-3.33)	(6.33)
Simpson index	0.429***	-0.351**	-12.07**	-0.123	-0.386**
	(2.68)	(-2.35)	(-1.46)	(-0.62)	(-2.20)
Farm size (*mu*)	-0.021***	0.0011	-0.345**	-0.014**	-0.004
	(-4.10)	(0.23)	(-1.85)	(-2.26)	(-0.76)
Average distance	0.0089***	0.008***	0.090	0.0067*	0.007**
(minute)	(2.92)	(2.64)	(1.13)	(1.76)	(2.10)
Age (year)	0.005**	0.003	-0.146	0.0023	0.0016
	(2.04)	(1.23)	(-1.62)	(0.72)	(0.57)
Education (year)	-0.021**	-0.03***	-0.794**	-0.0047	-0.005
	(-2.23)	(-3.25)	(-2.23)	(-0.40)	(-0.51)
Household size	-0.010	-0.002	0.035	0.0374*	-0.015
(person)	(-0.61)	(-0.12)	(-0.63)	(1.82)	(-0.84)
Share good irrigated	-0.001	-0.0006	-0.027	0.00058	-0.001
land	(-0.98)	(-0.87)	(-0.55)	(0.57)	(-1.16)
Forest land (*mu*)	0.0068	-0.010	0.330	-0.0122	-0.008
	(0.97)	(-1.60)	(1.66)	(-1.41)	(-1.04)
Own oxen	-0.098**	-0.065	0.828	-0.016	0.0357
	(-1.94)	(-1.37)	(1.67)	(-0.26)	(0.64)
Available savings	-8.64E-07	-7.30E-06*	0.0003*	-7.99E-06	-2.00E-06
(*yuan*)	(-0.20)	(-1.79)	(1.93)	(-1.47)	(-0.42)
Available credit (*yuan*)	-7.42E-06	-1.31E-05**	-0.0002	-6.92E-06	-1.27E-06
	(-1.11)	(-2.10)	(-0.29)	(-0.83)	(-0.17)
R^2	0.39	0.31	0.25	0.13	0.33
Adj. R^2	0.37	0.28	0.22	0.09	0.31
F-statistic	15.4	10.4	8.05	3.45	11.9

Notes: All the dependent variables are in logarithm.

t-statistics are between brackets; *Significant at 10% level, **significant at 5% level and ***significant at 1% level.

Appendix 4.3 Net income of rice production

	Net income per *mu* (*yuan*)		Net income per ton (*yuan*)	
	Including labor	Excluding labor	Including labor	Excluding labor
Early rice	-62.76	148.24	-275	508
One season rice	-51.08	198.92	-258	583
Late rice	17.76	204.76	-23	625
Rice as a whole	-28.16	177.84	-148	579

Source: calculated by authors based on the TVS data.

Price for early rice is 0.88 *yuan*/kg, for one season rice is 0.92 *yuan*/kg and for late rice is 0.96 *yuan*/kg on average. The average rice price is 0.92 *yuan*/kg as a whole.

Appendix 4.4 Results of total production cost equation

Independent variables	Total production costs
Shangzhu village	0.413*** (6.93)
Gangyan village	0.097*** (1.74)
Plot size (*mu*)	-0.019 (-0.64)
Farm size (*mu*)	-0.012*** (-2.54)
Average distance (minute)	0.008*** (3.39)
Age (year)	0.003* (1.67)
Education (year)	-0.020*** (-2.65)
Household size (person)	-0.007 (-0.54)
Share of good irrigated land	-0.001 (-0.81)
Forest land (*mu*)	0.003 (0.52)
Own oxen	-0.073* (-1.78)
Available savings (*yuan*)	-0.000 (-0.49)
Available credit (*yuan*)	-0.000 (-1.50)
Constant	6.764 *** (43.6)
R^2	0.34
Adj. R^2	0.31
F-statistic	12.0

Notes: The dependent variables are in logarithm.

t-statistics are between brackets; *Significant at 10% level, **significant at 5% level and ***significant at 1% level.

Appendix 4.5 Results for rice production cost category (*yuan*/ton)

Independent variables	Labor	Fertilizer	Seed	Herbicides & pesticides	Oxen
Constant	6.20***	5.47***	3.37***	3.74***	3.98***
	(32.32)	(26.8)	(13.2)	(16.0)	(19.0)
Shangzhu village	0.62***	-0.63***	0.72***	-0.42***	0.85***
	(8.42)	(-7.97)	(7.32)	(-4.22)	(10.5)
Gangyan village	0.19***	-0.19***	0.30***	-0.28***	0.49***
	(2.68)	(-2.61)	(3.25)	(-3.30)	(6.45)
Plot size	-0.07*	-0.07	0.08	0.08*	0.05
	(-1.83)	(0.266)	(1.58)	(1.77)	(1.36)
Farm size (*mu*)	-0.01*	-0.03	-0.02***	-0.02***	-0.01**
	(-1.90)	(-0.20)	(-2.97)	(-3.19)	(-2.10)
Average distance (minute)	0.01***	-0.005	0.00	0.01*	0.01*
	(3.28)	(1.35)	(0.97)	(1.75)	(1.82)
Age (year)	0.005**	-0.001	-0.01*	0.002	0.001
	(2.10)	(-0.51)	(-1.69)	(0.63)	(0.52)
Education (year)	-0.02**	-0.001***	-0.03**	-0.006	0.003
	(-2.43)	(-2.72)	(-2.16)	(-0.42)	(-0.33)
Household size (person)	-0.01	0.000*	-0.01	0.04*	-0.02
	(-0.59)	(0.077)	(-0.66)	(1.77)	(-0.84)
Share good irrigated land	-0.001	0.000	0.00	0.000	0.00
	(-1.12)	(-0.005)	(-0.52)	(0.51)	(-1.03)
Forest land (*mu*)	0.01	0.000	0.01	-0.01*	-0.01
	(0.91)	(-0.61)	(1.56)	(-1.66)	(-0.96)
Own oxen	-0.09*	0.001	0.11	-0.02	0.03
	(-1.81)	(-1.20)	(1.61)	(-0.29)	(0.54)
Available savings (*yuan*)	0.00	0.004	0.00	-7.88E-06	-2.27E-06
	(-0.13)	(-1.34)	(1.92)	(-1.46)	(-0.47)
Available credit (*yuan*)	0.00	0.010*	0.00	-6.86E-06	-1.45E-06
	(-1.07)	(-1.69)	(-0.30)	(-0.83)	(-0.20)
R^2	0.39	0.25	0.25	0.14	0.33
Adj. R^2	0.36	0.22	0.22	0.10	0.30
F-statistic	14.9	7.93	8.09	3.69	11.6

Notes: All the dependent variables are in logarithm.

t-statistics are between brackets; *Significant at 10% level, **significant at 5% level and ***significant at 1% level.

CHAPTER 5

LAND FRAGMENTATION AND TECHNICAL EFFICIENCY[38]

5.1 Introduction

Technical efficiency is a core issue in economic research. China's entry into WTO puts an increasing pressure on productivity and efficiency in Chinese agriculture. Significant increases in productivity and efficiency for the main crops in China are needed to meet the challenges of increased foreign competition. The small-scale of farms and their scattered plots, a striking phenomenon especially in the Southern rice growing areas of China, may be a major bottleneck in this respect (Fleisher and Liu, 1992; Wan and Cheng, 2001; Zhang, 2001).

In this chapter, we intend to investigate the extent to which rice production in China can be improved under existing technologies. We do this by examining the factors responsible for technical inefficiency in rice farming, and the relative importance of land fragmentation in this respect. Empirical research on the impact of land fragmentation on agricultural productivity and efficiency in China is scarce. Available studies include Nguyen *et al*. (1996), who use data from a household survey among 1200 households held in Jilin, Shandong, Jiangxi, Sichuan and Guangdong Provinces in 1993-94 to examine the impact of land fragmentation on the productivity of three major grain crops. Results indicate that, controlling for total holding size, there is a significant positive relationship between plot size and output for maize, wheat and rice. Wan and Cheng (2001) use the same rural household survey data to explore the impact of land fragmentation and returns to scale in the Chinese farming sector. Their main finding is that, given total holding size, an increase in the number of plots by one leads to output

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[38] A paper based on this chapter will be published in the proceedings of the "International Symposium on China's Rural Economy: Problems and Strategies", organized by the Chinese Economists Society (CES) in Hangzhou, P. R. China, June 25-28, 2004. I want to thank Subal Kumbhakar, Spiro Stefanou, Ravi Kanbur and an anonymous referee of the symposium proceedings paper for their constructive comments.

losses in the order of 9.8% for tubers, 6.5% for wheat and less than 2% for other crops. Earlier research undertaken by Fleisher and Liu (1992) used a survey dataset of 1200 households collected in Jilin, Jiangsu, Henan, Hebei and Jiangxi Provinces in 1987-88. A Cobb-Douglas production function was applied to examine the effect of land fragmentation, measured by the number of plots, on productivity. They found that a 10% increase in the number of plots induces a 5.7% decline in output.

All these studies use simple partial measures of efficiency and fail to control for the productivity differential caused by other factors like farmer's age and education. If these omitted variables correlate with land fragmentation, this will bias the results for land fragmentation. Methods are therefore needed that take these factors into account as well. During the last two decades, many studies have analyzed agricultural efficiency with parametric methods (Kalirajan and Shand, 1986; Battese and Coelli, 1992; Najafi and Bakhshoodeh, 1992; Kumbhakar, 1994; Battese and Coelli, 1995; Kebede, 2001; Daryanto *et al.*, 2002). Efficiency analysis with non-parametric methods has also become popular in recent years (Chavas and Aliber, 1993; Sharma, 1997; Wadud and White, 2000; Krasachat, 2003). Coelli *et al*. (2002) provide a very good example of non-parametric methods to analyze rice cultivators' efficiency in Bangladesh. Although they use one of the most exhaustive lists of farm-specific variables that any efficiency analysis has applied, they do not include land fragmentation in their research.

Among the numerous empirical analyses of agricultural efficiency, only a few have taken land fragmentation into account. A study by Hazarika and Alwang (2003) shows that plot size has a significant positive effect on the cost efficiency of tobacco cultivators in Malawi. Research in Bangladesh (Wadud and White, 2000) indicates that on average farmers with greater plot size or less land fragmentation operate at a higher level of technical efficiency. Sherlund *et al*. (2002) test smallholder technical efficiency controlling for plot-specific environmental conditions for traditional rice plots in Cote d'Ivoire. They find, surprisingly, that technical efficiency is higher among those who cultivate three or more rice plots.

Recent research by Chen *et al*. (2003) examines the technical efficiency of Chinese grain farms, using a stochastic production frontier. The model is fitted to a panel data set covering almost 600 farm households in 9 provinces during the late 1990s. Land fragmentation (measured by the number of plots) is found to be detrimental to technical efficiency. In our study, we focus on rice production only. We distinguish between double-rice (i.e. early rice and late rice) and one-season rice cultivation, as production technologies and technical efficiency may differ considerably between them. Moreover, while Chen *et al*. (2003) included total fertilizer use (in kg) in the production frontier part, we will subdivide fertilizer use into pure N, P and K contents. This is expected to give more accurate technical efficiency scores, because nutrient requirements differ between different crops and rice types. Actual fertilizer applications very often do not reflect these differences in nutrient requirements, leading to either overuse or underuse of specific fertilizer components in certain crops (see e.g. Huang, 1997).

The aim of this chapter is therefore to estimate technical efficiency in different rice types and examine the impact of land fragmentation on rice producers' technical efficiency, while controlling for other factors. The remainder of the chapter is structured as follows. Section 5.2 sets out the theoretical model. The empirical analysis of the model is conducted in section 5.3. Regression results are presented and discussed in section 5.4. Section 5.5 summarizes the major conclusions and discusses the main implications.

5.2 Methodology

Three issues will be discussed with respect to the methodology: firstly, the choice between a non-parametric and parametric approach; then, given selected approach, the choice of a functional form for the production function; and lastly, the selection of an estimation method. We discuss the first problem in sub-section 5.2.1 and treat the second and the third issues in sub-section 5.2.2.

5.2.1 Basic model

Choosing between a parametric and a non-parametric approach to measure efficiency has been controversial: each has its strengths and weaknesses (Olesen, 1996; Coelli and Perelman, 1999). The parametric analysis deals with stochastic noise, and allows hypothesis testing on production structure and efficiency, etc. However, this method has to specify a functional form for the production frontier and imposes a distributional assumption on the efficiency term. The non-parametric method does not impose such restrictions, but it assumes the absence of measurement or sampling error. The choice between these approaches, therefore, depends upon the objective of the research, the type of farms that are analyzed, and data availability.

In this chapter, we choose the stochastic frontier approach - a parametric method - to analyze the impact of land fragmentation on rice producers' technical efficiency. The main reason for this choice is that rice production in China is subject to weather disturbances and heterogeneous environmental factors like soil quality and irrigation access; moreover, the respondents might not always answer all the questions precisely, due to e.g. varied perceptions, and this will affect measured efficiency (Chen *et al.*, 2003).

The stochastic frontier function was developed independently by Aigner, Lovell and Schmidt (1977) and Meeusen (1977). Jondrow *et al.* (1982) extended it by incorporating producer-specific efficiency effects. Greene (1993) proposed various specifications for the distributional assumption. Following Battese and Coelli (1995), and assuming a half normal distribution of the one-sided error, the basic structure of the model for a cross-sectional data set can be expressed as

$$q_i = f(x_i; \beta) + \varepsilon_i \quad (i=1, 2, \ldots\ldots, N) \qquad (5.1)$$

where

N is the number of household farms

q_i is the production of the i-th farm

x_i is a (j×1)-vector of the input quantities of the i-th farm

β is a (1×j)-vector of unknown parameters

$f(.)$ is the production frontier function

ε_i is a composed error term, which can be decomposed as

$$\varepsilon_i = v_i - u_i \qquad (5.2)$$

where

v_i are stochastic random errors, which are assumed to be independently and identically distributed (iid) as N (0, $\sigma_v{}^2$) and independent of the u_i;

u_i are non-negative random errors accounting for technical inefficiency (*TIE*) in production; they are assumed to be iid as half normal $N^+(0, \sigma_u^2)$.

Parameters β, σ_v and σ_u and technical inefficiency for each household can be estimated, provided suitable empirical data are available. Then technical efficiency (*TE),* with *TE*=1-*TIE*, can be used for the purpose of this study, namely to test the relative importance of land fragmentation. To this purpose, we estimate the following equation:

$$TE_i = z_i \delta + \eta_i \qquad (5.3)$$

where TE_i is the predicted technical efficiency score of each farm household; z_i is a (1×k)-vector of variables which may influence the efficiency of a farm, including land fragmentation in our case; δ is a (k×1)-vector of unknown parameters; and η_i is a random disturbance term assumed to be idd as $N(0, \sigma_\eta^2)$.

5.2.2 Model choice and estimation techniques

The choice of a functional form in parametric models has also been subject to debate (Bravo-Ureta, 1993). Two production functions, Cobb-Douglas and translog, are commonly used in production frontier analysis. Some authors, Kopp and Smith (1980), for example, argue that functional specification has a discernible, though rather small, impact on estimated efficiency. Taylor *et al.* (1986) also argue that as long as interest rests on efficiency measurement and not on the analysis of the general structure of the production technology, the Cobb-Douglas production function provides an adequate representation of the production technology. Therefore, following Fleisher and Liu (1992) and Nguyen *et al*. (1996), we choose the Cobb-Douglas production function because of its simplicity, its apparently good fit to Chinese agricultural data, and the relatively large number of inputs that we use in our analysis[39].

Typical agricultural inputs like land area, labor and material inputs used in rice

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[39] Our research distinguished nine inputs. The translog function requires that quadratic terms and cross-products are included in the function as well.

production are included in the production function[40]. Fertilizer is separated into the three macro-nutrients (N, P, K) required for crop growth. Fertilizer application in China is commonly believed to be severely imbalanced. Farmers tend to use too much nitrogen and too little phosphorus and potassium[41]. Some years ago, a so-called K-compensation project has therefore been launched in some areas of Eastern China with assistance from agricultural extension agents.

We estimate the specified model with a two-step technique. In the first stage, we estimate the frontier model by assuming a half-normal distribution of the inefficiency term to predict the technical efficiency scores and estimate the β's; then we examine the determinants of technical efficiency by means of a censored normal (Tobit) model. Alternatively, the so-called one-step method may be used, which incorporates farm-specific factors affecting technical efficiency in the estimation of the production frontier (Kumbhakar, 1991; Huang and Liu, 1994; Battese and Coelli, 1995). Although this method is preferable from a theoretical point of view, it leads to highly unstable results when applied to our data set.

5.3 Empirical analysis

5.3.1 Specification of the production frontier function

The production frontier model that will be estimated can be specified as:

$$\begin{aligned}\ln(OUT) &= \beta_0 + \beta_1 \ln(LAND) + \beta_2 \ln(LABOR) + \beta_3 \ln(SEED) + \beta_4 \ln(UREA) + \beta_5 \ln(PERT)\\ &+ \beta_6 \ln(KCL) + \beta_7 \ln(CHEM) + \beta_8 \ln(OXEN) + \beta_9 \ln(SOIL) + v - u\end{aligned} \tag{5.4}$$

where *ln(OUT) is* the logarithm of rice output (either early, late or one-season rice) on

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[40] A problem with using a Cobb-Douglas or translog function is that input quantities cannot have zero values. We follow Battese (1997) to treat the observations with zero values.

[41] A survey conducted by the "Mechanism and control of red soil degradation in China research group" in Jiangxi shows that the ratio of N: P_2O_5: K_2O in chemical fertilizer use was 1: 0.41: 0.04 in 1980, and 1: 0.37: 0.28 in 1995. The increase in K_2O is mainly contributed to the K-compensation project (Mechanism and control of red soil degradation in China research group, 1999).

each farm; *LAND, LABOR, SEED, UREA, PFERT, KCL, CHEM* and *OXEN* represent rice planting area, labor used, seed, urea, P fertilizer, K fertilizer, chemical inputs (herbicides and pesticides) and oxen use, respectively (see Table 5.1). Tractor use is converted into oxen days on the basis of its cost (rent), because tractors and oxen can easily be substituted. *SOIL* is a soil quality index. In our survey, farmers were asked to distinguish their plots into good (with score 1), medium (with score 2) and bad land (with score 3) in terms of their perceptions on soil color, top soil depth, soil texture and workability. The soil quality index is derived by multiplying the size of a plot planted with rice by its soil fertility score and dividing this score by the total land area planted with early (or late, one-season) rice[42]. This index ranges from 1 to 3; the larger the value is, the poorer the soil fertility is. v and u are error terms as specified in equation (*5.2*).

Table 5.1 Variable definitions and expected signs in production function

Variable explanation	Variable name	Unit	Expected sign
Rice production per type of rice	*OUT*	*jin*	
Land area used	*LAND*	*mu*	+
Labor used	*LABOR*	day	+
Seed used	*SEED*	*jin*	+
Urea used	*UREA*	*jin*	+
P fertilizer used	*PFERT*	*jin*	+
K fertilizer used	*KCL*	*jin*	+
Herbicides and pesticides	*CHEM*	*yuan*	+/-
Oxen and tractor used	*OXEN*	day	+
Soil quality index	*SOIL*		-

All inputs in the Cobb-Douglas production function are expected to have a positive impact, except for the soil quality index. Herbicides and pesticides, however, may be related negatively to rice production if they are used for curative instead of preventive purposes, i.e. if they are used to control the damage caused by weeds and pests.

5.3.2 Specification of the technical efficiency equation

The most frequently used variables in empirical analyses of technical efficiency are farmer’s education and experience, contact with extension services, access to credit, farm

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[42] For example, if a farm household used 3 plots with soil fertility 1, 2 and 3 and the corresponding area of each plot is 2, 3 and 4 *mu*, respectively, the soil quality index equals (1*2+2*3+3*4)/(2+3+4)=2.22.

size, land tenure, and factors like information and supervision, which may influence the capability of a producer to utilize the available technologies. The indicators chosen for any model depend on the relevant conditions in the research area and the availability of data.

In our case, the following factors will be used for explaining efficiency:

(1) Household characteristics: age and education of household head, household size, savings;

(2) Farm characteristics: land fragmentation indicators[43] (number of plots, average plot size and average distance of plots to the homestead), oxen ownership and tractor use.

Households within the same village face almost the same conditions with respect to extension and infrastructure. We therefore use village dummies to capture the impact of extension, infrastructure and other village-level variables.

The model explaining efficiency is specified as

$$\begin{aligned} TE = \delta_0 + \delta_1 AGE + \delta_2 EDU + \delta_3 HHSIZE + \delta_4 NPLOT + \delta_5 PSIZE + \delta_6 DIST \\ + \delta_7 DSAVE + \delta_8 DCAT + \delta_9 DTRACT + \delta_{10} D_1 + \delta_{11} D_2 + \eta \end{aligned} \qquad (5.5)$$

where TE represents the efficiency score of each household obtained from Equation *(5.4)* and η denotes error term of efficiency function. The expected signs for each explanatory variable are given in Table 5.2.

Age may have both a positive and a negative impact on technical efficiency, depending on whether older farmers are more experienced or slower to accept new technologies than young farmers. A higher level of education can lead to a better assessment of the importance and complexities of production decisions, resulting in a better farm management. Farmers with higher education, however, may also pay more attention to off-farm work, leading to a lower efficiency. The impact of education may therefore be positive as well as negative. A larger household size usually implies more laborers and thus more time that can be devoted to timely irrigation, pest management, and harvesting etc. In addition, larger families have more children or old persons to

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[43] Instead of using the Simpson index, we use the single dimension indicators to measure land fragmentation. This allows us to obtain the explicit impact of each single dimension indicator on technical efficiency.

participate in agricultural production at peak times. Both situations can have a positive impact on technical efficiency. Savings can reduce constraints on production, facilitating obtaining the inputs needed for production on a timely basis. Hence, it is supposed to improve the efficiency of farmers.

Table 5.2 Variable definitions and expected signs in technical efficiency equation

Variable explanation	Variable name	Unit	Expected sign
Age of household head	*AGE*	year	+/-
Education of household head	*EDU*	year	+/-
Household size	*HHSIZE*	person	+
Number of plots	*NPLOT*		+
Average plot size	*PSIZE*	*mu*	+
Average distance from plots to homestead	*DIST*	minute	-
Dummy, =1 if household saves money	*DSAVE*		+
Dummy, =1 if household owns oxen	*DCAT*		+
Dummy, =1 if tractor is used in rice production	*DTRACT*		+
Shangzhu village dummy	*D1*		-
Gangyan village dummy	*D2*		+/-

Empirical studies of technical efficiency normally use farm size as one of the explanatory variables. In this study, we decompose farm size into the number of plots and average plot size. Given the average plot size, the number of plots measures the scale effect, while the average plot size captures the information of land fragmentation. At a given average plot size, an increase in the number of plots is expected to have a positive scale effect on technical efficiency, because larger farms have better opportunities to realize economies of scale. For a given number of plots, average plot size is expected to have a positive impact on technical efficiency. Some technologies are inappropriate for use on (very) small plots. A larger average distance to the plots means less convenience in farm management, and therefore is expected to have a negative impact on technical efficiency. When a farm household owns oxen, it can prepare land at the optimum times and with more care than when it needs to rent oxen, and hence is expected to be more efficient. Mechanization is generally assumed to increase technical efficiency, thus the expected impact of tractor use on technical efficiency is positive.

Data from the household survey described in section 4.3 are used to estimate technical efficiency and its determinants. Dummy variables are added to control for differences in village-level factors between the three villages where the survey was held. Shangzhu village has a poorer infrastructure, lower temperatures and more sloping land than Banqiao village. Farmers in Shangzhu village may therefore be less efficient than their counterparts in Banqiao. Gangyan village has no major differences in infrastructure, climate, or market access with Banqiao village, although the share of sloping land is higher in Banqiao (but much lower than in Shangzhu). The value for the dummy variable for Gangyan village may therefore be either positive or negative. The variable definitions and anticipated signs of the impact of the explanatory variables on technical efficiency are summarized in Table 5.2.

Table 5.3 Descriptive statistics of variables used

	Early rice				**One-season rice**				**Late rice**			
	Max	Min	Mean	Stdev	Max	Min	Mean	Stdev	Max	Min	Mean	Stdev
Variables for production function												
OUT	8000	250	**2863**	1767	26400	150	**2923**	2551	14000	200	**3634**	2400
LAND	16.0	0.4	**5.03**	3.03	33	0.40	**4.70**	3.63	23.0	0.30	**5.62**	3.47
LABOR	179	5	**60.94**	32.4	269	1	**65.5**	47.7	307	4.59	**59.6**	39.6
SEED	34.0	0	**7.05**	5.16	62.8	0.07	**6.41**	6.79	47.1	0.35	**7.46**	6.79
UREA	1047	4	**207**	161	656	0	**145**	124	1486	0	**227**	194
PFERT	1500	0	**295**	298	2343	0	**165**	251	2086	0	**271**	335
KCL	500	0	**76.0**	94	787	0	**44.2**	70.5	783	0	**101**	133
CHEM	437	0.99	**60.9**	50	524	0	**56.2**	56.4	467	0.00	**79.4**	72.6
OXEN	17.5	0.31	**4.13**	2.97	62.1	0.52	**5.73**	7.03	26.8	0.33	**4.07**	3.03
SOIL	3.00	1.00	**1.75**	0.53	3.00	0.42	**2.32**	0.59	3.00	1.00	**1.79**	0.52
Production function variables per ha												
OUT	8500	1731	**4286**	905	13125	1650	**4873**	1433	10500	1172	**4786**	1190
LABOR	829	58.8	**211**	110	1320	37.5	**247**	165	1265	30.3	**187**	125
SEED	57.4	1.23	**12.0**	7.9	49.7	0.57	**10.7**	7.45	50.6	0.46	**10.9**	7.11
UREA	1271	22.7	**315**	168	1125	0	**262**	169	1013	0	**291**	152
PFERT	2720	0	**442**	385	1594	0	**280**	260	3651	0	**369**	405
KCL	626	0	**109**	107	707	0	**74.4**	78.5	1003	0	**117**	118
CHEM	1170	10.1	**195**	143	1025	0	**202**	145	915	0	**217**	134
OXEN	37.5	1.58	**13.4**	6.77	77.6	1.88	**18.2**	11.5	100	1.12	**12.3**	8.80
Variables for technical efficiency model												
AGE	75	23	**47.0**	10.3	75	27	**47.2**	9.94	75	23	**47.0**	10.1
EDU	12	0	**4.70**	2.75	13	0	**4.71**	2.84	12	0	**4.69**	2.70
HHSIZE	14	1	**4.55**	1.55	14	1	**4.54**	1.57	14	1	**4.56**	1.56
NPLOT	15	1	**3.13**	2.10	9	1	**3.21**	2.12	15	1	**3.69**	2.34
PSIZE	9	0.25	**1.90**	1.11	8.00	0.34	**1.55**	0.94	9	0.30	**1.79**	1.10
DIST	35	1	**12.6**	6.76	75	0	**20.5**	12.4	45	1	**12.8**	7.35
DSAVE	1	0	**0.52**	0.5	1	0	**0.52**	0.5	1	0	**0.53**	0.50
DCAT	1	0	**0.64**	0.48	1	0	**0.64**	0.48	1	0	**0.65**	0.48
DTRACT	1	0	**0.13**	0.33	1	0	**0.07**	0.25	1	0	**0.20**	0.40

Sources: Based on the survey conducted by the SERENA project.

5.3.3 Descriptive statistics of data used

Table 5.3 shows the descriptive statistics for the variables used in the analyses. Inputs and output on a per hectare base are added for comparative purpose. The average area used for rice cultivation is about 0.3 ha per household, with large variations among households. The corresponding rice production varies from about 100 kg to more than 10,000 kg, with an average value of around 1500 kg for a 4-5- person household. This suggests that most of the farms are producing for their own consumption while only a few farms are market-oriented.

Average yields equal 4.3, 4.9 and 4.8 ton/ha for early, one-season and late rice, respectively. Labor and oxen input are relatively intensive, while fertilizer application is relatively low in one-season rice production. Early rice needs more applications of fertilizer and seed and slightly less herbicides and pesticides than late and one-season rice. Land fragmentation and soil quality show substantial variation between the three rice types. On average, the respondent households used 3.13 plots to cultivate early rice, and 3.21 and 3.69 plots for one-season and late rice production, respectively. Households tend to use the best plots for early rice production, i.e. the plots with best soil quality, closest to the homestead and with the largest plot sizes. On the other hand, they tend to use the worst plots with smallest average size, largest distance and lowest soil quality for one-season rice production[44].

5.4 Empirical results

We first briefly discuss the results of the frontier function, and then discuss in more detail the results for technical efficiency.

5.4.1 Production frontier and technical efficiency

The results of the three frontier models are presented in Table 5.4. Land has a very significant impact on the production of all three types of rice, confirming the fundamental

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[44] Similar conclusions can be drawn for each of the three villages.

Table 5.4 Results of frontier function

Independent variables	Early rice	One-season rice	Late rice
Constant	6.260***	6.89***	6.66***
	(48.7)	(42.3)	(47.0)
ln(*LAND*)	0.972***	0.963***	0.914***
	(24.5)	(18.2)	(19.9)
ln(*LABOR*)	-0.033	-0.073**	-0.057**
	(-0.10)	(-2.08)	(-1.97)
ln(*SEED*)	-0.037*	-0.022	-0.001
	(-1.82)	(-1.14)	(-0.04)
ln(*UREA*)	0.012	0.062**	0.057**
	(0.53)	(2.19)	(2.05)
ln(*PFERT*)	0.048***	-0.022	-0.024
	(2.63)	(-0.67)	(-1.12)
ln(*KCL*)	-0.0003	0.031	0.051***
	(-0.02)	(0.96)	(2.31)
ln(*CHEM*)	0.055***	0.006	0.002
	(2.74)	(0.24)	(0.12)
ln(*OXEN*)	-0.043*	-0.065**	0.07***
	(-1.85)	(-1.99)	(2.67)
ln(*SOIL*)	-0.018	-0.084*	-0.184***
	(-0.45)	(-1.43)	(-3.71)
$\ln \sigma_v^2$	-3.74***	-3.59***	-3.66***
	(-17.1)	(-13.50)	(-16.0)
$\ln \sigma_u^2$	-3.15***	-2.21***	-2.41***
	(-8.85)	(-9.22)	(-10.7)
σ_v	0.154	0.166	0.16
σ_u	0.207	0.332	0.30
Log likelihood	53.92	-10.86	5.07
Likelihood-ratio test of σ_u =0	4.59	10.12	13.03
Prob ≥ chibar2	0.000	0.001	0.000
Number of observations	264	204	261

Note: z-values are between the brackets. * represents significance at 10% level, ** at 5% level and *** 1% level.

importance of land availability for agricultural production in China. The estimated elasticity for one-season rice (0.914) is lower than that estimated for early and late rice (0.972 and 0.963). Most other variables are highly correlated (0.70 or higher) with land area, making it difficult to estimate their separate impacts from that of land. This probably explains why some explanatory variables (particularly labor and oxen & tractor use) seem to have an impact opposite to what production theory tells us. For obtaining accurate estimates of technical efficiency, however, these inputs should be left in the model.

Subdividing fertilizer use into its three major nutrient components gives some interesting results. The results indicate that the marginal productivity of N is positive in late rice and one-season rice, but not in early rice. Likewise, the marginal productivity of P is positive in early rice only, while the marginal productivity in K is positive only in late rice production.

The sum of the estimated input coefficients, excluding soil quality, is close to one for early rice (0.97). For one-season rice and late rice, the sum are 0.88 and 1.01, respectively. This means that the hypothesis of constant returns to scale may be rejected for one-season rice but not for early and late rice[45]. For early rice, this conclusion is consistent with the constant returns to scale in grain production found by Chen *et al*. (2003) and in Fleisher and Liu (1992).

Table 5.5 Elasticity estimates for household agricultural production in China

		Land	Labor	Fertilizer			Seed	Chem[1]	Capital[2]	Scale elastic-ity
				Urea	P fert	K fert				
Chen *et al*. (2003)	Grain	0.679	0.035		0.06			-	0.125	0.90
Park (1989)	Grain	0.46	0.04		0.30			-	0.00	0.80
Fleisher & Liu (1992)	Grain	0.70	0.20		0.09			-	0.06	1.05
This study (rice)	Early	0.97	-0.03	0.01	0.05	-0.00	-0.04	0.06	-0.04	0.97
	One-season	0.96	-0.07	0.06	-0.02	0.03	-0.02	0.01	-0.01	0.88
	Late	0.91	-0.06	0.06	-0.02	0.05	-0.00	0.00	0.07	1.01

Note: [1]Chem means herbicides and pesticides use.

[2]Capital means oxen and tractor use in the rice production of the current season, which is a variable input.

A comparison is made with results from available studies on Chinese farm agriculture in Table 5.5. Park (1989) finds that in the earlier period of the land reform, fertilizer was

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[45] Formal t-tests of economies of scale confirm that constant returns to scale are present in early rice and late rice, but not in one-season rice.

one of the main contributors to grain production. Land was relatively less important then, with an elasticity of 0.46. With the passing of time, fertilizer use became less and less important; land, however, became more important, as shown by the results of Fleisher and Liu (1992), Chen *et al.* (2003) and this study. This is consistent with our introductory discussion about cropland area becoming a major challenge to Chinese grain production.

Table 5.6 summarizes the technical efficiency scores obtained from the frontier model. The average technical efficiency for our sample is 0.85 for early rice, 0.79 for one-season rice, and 0.83 for late rice. This suggests that on average the respondents are able to obtain about 82 per cent of the potential output by using the given mixture of production inputs. It also implies that in the short run, considerable room exists to improve rice yields for many households. The minimum efficiency levels are 0.61 for early rice, 0.57 for one-season rice and 0.54 for late rice, respectively. For households with the lowest efficiency levels, substantial output increases can still be reached with the amounts of inputs they are currently using.

Table 5.6 Technical efficiency scores of rice producers

Rice type		Technical efficiency		0.50-0.60	0.60-0.70	0.70-0.80	0.80-0.90	0.90-1.00
Early rice	max	1.00	Cases	0	9	55	131	69
	min	0.61						
	mean	**0.85**	Percentage	0	3	21	50	26
	Stdev	0.07						
One season rice	Max	1.00	Cases	3	23	78	96	4
	Min	0.57						
	mean	**0.79**	Percentage	1	11	38	47	2
	Stdev	0.07						
Late rice	Max	1.00	Cases	2	16	68	130	45
	Min	0.54						
	mean	**0.83**	Percentage	1	6	26	50	17
	Stdev	0.08						

Table 5.6 also shows the frequency distribution of technical efficiency per rice type. Around 50% of the farmers for all three rice types have technical efficiency scores between 0.80 and 0.90. Very few one-season rice farmers have technical efficiency scores of more than 0.90, compared to early and late rice farmers, and there are relatively more farmers in this group with technical efficiency scores below 0.70.

5.4.2 Determinants of technical efficiency

The technical efficiency model, equation (*5.5*), is estimated with a censored normal Tobit model. Regression results are presented in Table 5.7. The number of plots and average plot size are found to be strongly significant and have the anticipated positive values. This means that an increase in the number of plots, with average plot size remaining constant, has a positive (scale) effect on technical efficiency. Likewise, for a given number of plots, an increase in average plot size has a positive effect on technical efficiency. Distance to the plots does not have a significant impact on technical efficiency for all the three kinds of rice. The results show that farm households with large average distances to the plots are as efficient as farms with small average distances to the plots.

Table 5.7 Results for technical efficiency determinants (censored normal Tobit model)

Independent variables	Early rice	One-season rice	Late rice
Constant	0.754***	0.620***	0.722***
	(34.0)	(21.7)	(31.29)
Age of household head	-0.001***	0.000	-0.001***
	(-2.96)	(0.11)	(-3.41)
Education of household head	-0.002**	0.000	0.000
	(-1.98)	(0.02)	(-0.23)
Household size	0.004***	0.005***	0.005***
	(2.25)	(2.40)	(2.60)
Number of plots	0.024***	0.024***	0.021***
	(16.0)	(13.74)	(14.26)
Average plot size	0.035***	0.040***	0.033***
	(11.5)	(10.77)	(10.57)
Average distance from plots to homestead	0.000	0.000	0.000
	(-0.87)	(0.08)	(-0.26)
Dummy, =1 if household saves money	0.005	0.005	0.002
	(0.87)	(0.80)	(0.35)
Dummy, =1 if household owns oxen	-0.006	-0.010	0.008
	(-1.00)	(-1.40)	(1.28)
Dummy, =1 if tractor is used in rice production	-0.014*	-0.008	-0.009
	(-1.66)	(-0.56)	(-1.21)
Shangzhu village dummy	-0.050***	0.003	-0.055***
	(-5.23)	(0.18)	(-5.51)
Gangyan village dummy	-0.002	0.002	0.007
	(-0.21)	(0.10)	(0.80)
Adjusted R-square	0.669	0.595	0.668
Log likelihood	4.59	340	447
Number of observations	263	204	261

Note: z-values are between brackets; * represents significance at 10% level, ** at 5% level and *** 1% level.

Variables with either a plus-sign or a minus-sign in Tables 5.1 and 5.2 are tested one-sided.

The age of the household head has a significant negative effect on technical efficiency in early rice and late rice. This suggests that older farmers operate farms in a less efficient way compared to their younger counterparts in double rice production. Compared to one-season rice, double rice production needs more complicated and timely decisions in nursery, harvesting (early rice) and transplanting (late rice).

Education is also found to have a significant negative effect on technical efficiency in early rice, but no significant effect on technical efficiency in one-season and late rice. This may be because farmers with higher education levels are more involved in off-farm employment and pay less attention to agricultural production. Due to climatic reasons, early rice needs special care during the growing season.

Household size has a significant positive impact in all three rice models. This is in line with findings from research in Mali (Audibert, 1997) that larger families tend to be more efficient than smaller ones. In our research area, the assistance provided by children or old persons during peak seasons may explain this finding.

Savings and oxen ownership also do not have a significant effect on technical efficiency. This suggests that the impact of these two factors on more timely management is negligible. Use of a tractor has a significant negative effect on technical efficiency in early rice. A possible explanation for this counterintuitive result is that use of tractors at the start of the agricultural season causes soil compaction, a well-known problem in the research area.

Finally, the dummy variable for Shangzhu, the remote village, has a significant negative impact on technical efficiency in early rice and late rice, but not on technical efficiency in one-season rice. Because Shangzhu is located in a mountainous area, the growing season is shorter and one-season rice is much more common than double-rice as compared to the other two villages. The regression results indicate that, if other relevant factors are controlled, farmers growing one-season rice in Shangzhu are as efficient as farmers growing the same crop in the two villages, which benefit from much better market access.

5.5 Discussion and concluding remarks

This chapter applied detailed household, crop and plot level data to investigate the impact of land fragmentation on rice producer's technical efficiency in three villages. The so-called two-stage method is applied to estimate efficiency and its determinants for double-rice and one-season rice production[46]. A stochastic frontier model is applied in which rice production is explained from traditional agricultural inputs and soil quality. The resulting technical efficiency scores are then explained from farm household specific factors using a censored normal Tobit model.

Frontier model results show that technical efficiency in one-season rice is lower than in double-rice production. The average technical efficiency scores (0.85 for early rice, 0.83 for late rice, and 0.79 for one-season rice) suggest that output increases in the order of 15-20% can still be reached with the presently used levels of inputs. New technologies will have to be introduced to realize further increases in rice productivity. This also indicates that, if the average farmer in the sample was to achieve the technical efficiency level of its most efficient counterparts, then the average farmer could realize a 15%, 17% and 21% cost savings in early, late and one-season rice production, respectively. Likewise, if the farmer with the poorest performance was to achieve the technical efficiency level of its average counterparts, the farmer could realize a 28%, 35% and 28% cost savings in early, late and one-season rice production, respectively.

Results from the technical efficiency model suggest that land fragmentation plays an important role in explaining technical efficiency. Given the number of plots, increases in average plot size have a significant positive impact on technical efficiency. Distance to the plots, however, has no significant impact on technical efficiency. This suggests that farm households with large average distances to the plots are as efficient as farm households with small average distances to the plots.

As Carnahan (2002) has pointed out, over the longer term increased rice production in China is expected to be achieved through biotechnology-based techniques, integrated management of low- to medium-yielding rice fields (namely those with higher soil quality

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[46] Although this procedure is regarded to be inconsistent with its assumptions regarding the independence of the inefficiency effects in the two-stage estimations, it has been recognized to be a useful method (Binam *et al.,* 2004).

index), pest management and diseases and weed control, mechanization and improved irrigation and water conservation. All these measures are, to some extent, related to land fragmentation. If fragmented plots can be consolidated, the above technology improvements can be implemented more easily. A reduction of land fragmentation can therefore substantially increase rice productivity and promote the international competitiveness of rice cultivation in China, and thereby reduce rural poverty.

CHAPTER 6

LAND FRAGMENTATION, FARM MANAGEMENT AND SOIL QUALITY[46]

6.1 Introduction

Recent years have seen a growing interest in examining relations between agricultural development and the environment, both in developed and developing countries (Shiferaw and Holden, 1997; Abalu and Hassan, 1998; Oudendag and Luesink, 1998; Kim *et al.*, 2001; Heerink *et al.*, 2001; Ali and Byerlee, 2002; Pacini *et al.*, 2004). In China, resource degradation in agriculture is also receiving increased attention (Wen *et al.,* 1992; Edmonds, 1994; Rozelle *et al.* 1997; Prosterman, 2001). Many researchers (Hu, 1997; Deininger and *Jin*, 2003; Tan *et al.,* 2004) point out that capital investment in farmland and maintenance of irrigation facilities has been neglected since the introduction of the HRS reform. According to Hu (1997), farmers are "mining" their land resources for short and immediate benefits, and the resulting soil degradation is threatening the sustainability of agriculture in China.

Soil is a vital natural resource. It is regarded as the base of sustainable agricultural and economic development (Lindert, 1999; Yu, 2002; Struif Bontkes and van Keulen, 2003; Sanchez, 2002). It is important for sustaining long-term agricultural productivity, water quality, and the habitats of all organisms including people. Soil quality can be changed by farm management. Appropriate use of crop production technologies like crop rotation, residue management, and use of conservation buffers and structures can maintain or enhance soil quality (Magleby, 2002). Inappropriate farming practices, on the other hand, can lead to on-site soil degradation. Farm management, therefore, not only affects current crop output levels, but also has important implications for future agricultural productivity through its effects on soil quality. This is especially important in China

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[46] A paper based on this chapter will be published in the proceedings of the 7th "European Conference on Agriculture and Rural Development in China (ECARDC)" held in Greenwich, UK, September 8-10, 2004. I want to thank Herman van Keulen for his constructive comments on this chapter.

which has over one-fifth of the world’s population but only about one-twelfth of the world’s arable land. Any reduction in the size and quality of its agricultural soil resources may threaten China’s long-standing goal of food security (Lindert, 1999).

Many factors affect actual farm management (Grepperud, 1997). Institutional factors like land tenure arrangements and land use policies affect farmers’ behavior by providing incentives (Lafrance, 1992; Katz, 2000; Deininger and Jin, 2003). Household characteristics, such as education level and age, play a role as well. For example, educated farmers have been found to be more likely to perceive soil degradation as a problem and to conserve their soils (Thampapillai and Anderson, 1994).

In turn, farm management decisions affect agro-ecological processes such as nutrient and water supply, and thus productivity. The outcomes of these processes (changes in soil quality, for example), in their turn, can influence farmers’ decisions. Thus, socio-economic factors, farm management decisions, and soil quality interact in agricultural practice (Kuyvenhoven *et al.,* 1995).

Among the factors affecting farm management, land fragmentation may play an important role. Empirical analyses (Li *et al.,* 1998; Yan, 1998) have shown that farmers tend to apply more manure, a very important aspect of farm management, to plots closer to the homestead than to plots at larger distances. Previous chapters and other research have shown that land fragmentation causes an increase in rice production costs, a decline in technical efficiency of rice farmers, and a reduction in agricultural production (Blarel *et al.,* 1992; Nguyen *et al.,* 1996; Wan and Cheng, 2001; Su and Wang, 2002). Some researchers (Hu, 1997; Zhang *et al.,* 1997) have pointed out that over-fragmented land with many ridges and ditches has hampered the functioning of irrigation and drainage systems and aggravated the impact of natural disasters.

The scientific literature has thus far largely neglected the relation between land fragmentation and soil quality management. A major exception is a study of a village in the Philippines, where farm households with more fragmented holdings were found to pay more attention to land conservation practices (Pattanayak and Mercer, 1998). The impact of land fragmentation on farm management, and thus on soil quality and agricultural productivity, requires more attention in China because:

(1) Land fragmentation is very serious in China due to the prevailing system of land allocation (see Chapters 2 and 3);

(2) Farm households are the main and direct land users; their decisions on land management have important implications for soil quality and thus for agricultural sustainability and food security; and

(3) Empirical research on land fragmentation, soil quality and farm agricultural production is lacking.

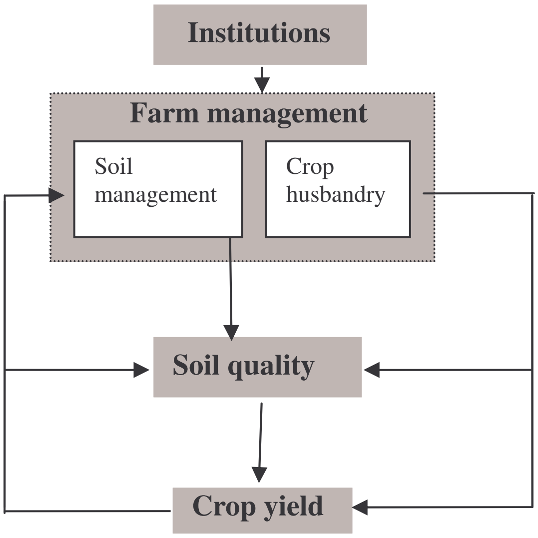
The objective of this chapter is to examine the impact of land fragmentation on farm management, soil quality and crop yield, taking into account their interrelations. In addition to land fragmentation, we also consider the impact of land tenure. The prevailing system of land distribution and land property rights not only plays a major role in land fragmentation, but may also have important direct implications for farm management decisions.

The remainder of this chapter is structured as follows: section 6.2 presents a framework of how institutions (land tenure and land fragmentation), farm management, soil quality and crop yield are interlinked. Based on this framework, an analytical model for examining the relationships is developed. Section 6.3 describes how the analysis of this chapter is implemented. The results are presented in section 6.4. Section 6.5 reviews the chapter and summarizes the main conclusions.

6. 2 Analytical framework

The analytical framework to be used in this chapter is presented in Figure 6.1. It shows how agricultural production interacts with soil quality and farm management. The interaction mainly takes place at farm household level in China. In this section, we will explore the relationships by examining the determinants of each major component, i.e. farm management, soil quality and crop yield, shown in Figure 6.1.

Figure 6.1 Analytical framework



6.2.1 Farm management

Farm management refers to decisions about choice of activity, e.g. crop grown, use of chemical inputs, labor, animal traction, machinery, and so on. Farm management affects the yield of a crop either through soil management (nutrients, water) or through crop husbandry (weeding, crop protection, harvesting, and so on). Institutional factors, such as land tenure and land fragmentation may affect farmer's production decisions. According to the theory, more secure land tenure can stimulate selection of efficient cropping patterns and increase the willingness to invest in agriculture (Feder *et al.,* 1988; Li *et al.*, 1998; Yao, 1998; Place *et al.,* 2001). It can offer incentives for investments attached to land (e.g. perennial crops, physical anti-erosion measures), non-attached investment (i.e. farm implements), and use of material inputs (i.e. quality seed and fertilizers) and labor. In short, like other factors influencing the socio-economic environment faced by farm households such as prices, markets, services and infrastructure, land tenure arrangements will influence farm households' decisions on land use and resource allocation in agriculture and thus the outcomes, in terms of agricultural production. Empirical studies assessing the implications of land tenure for fixed investment, material input use and labor use, however, provide rather mixed results (Ruben *et al.*, 2001).

Land fragmentation affects farm management directly and indirectly. It directly causes an increase in travel time, leaving less labor available for cropping activities. It may also cause difficulties in management. For example, small and scattered plots need more supervision due to crop theft risk and damage by wild animals. It discourages the use of machines and other new technologies, and may affect household decisions on the use of improved seed, chemical fertilizers, and pesticides. Farm households often tend to cultivate the more scattered plots relatively extensively. Land fragmentation may also contribute to the neglect of farming facilities, because it is more difficult for farmers to irrigate and drain the fields at the optimum times. Construction and maintenance of farming facilities involve higher costs when the plots are scattered.

Yields obtained from a plot may influence farm management decisions. For instance, farmers may use more labor and fertilizers on plots with higher productivity. Or, they may use fewer fertilizers, labor and other inputs for improving the productivity of low-yielding plots.

Household characteristics may affect farmers’ capacities of decision-making. More educated farmers are often more efficient in managing fields. Likewise, older, more experienced farmers are likely to better manage the soil. Other important exogenous variables affecting farm management decisions are agro-climatic factors and soil types. These factors tend to be relatively constant within villages or small regions, but may vary greatly between regions.

The farm management function can thus be expressed as:

$$M = f(I, Y, X) \tag{6.1}$$

where M denotes farm management activities; I represents institutions like land tenure and land fragmentation; Y is crop yield and X denotes other exogenous variables, including household and village characteristics.

6.2.2 Soil quality

Soil quality is a multi-faceted notion that can be broadly described as the capacity of a soil to function, within natural or managed ecosystem boundaries, to sustain plant and/or animal production, maintain or enhance water and air quality, and support human health and habitats. Different people have different ideas of what a good quality soil is, because they have different objectives. For people active in agriculture, it means a highly productive soil, sustaining or enhancing crop land/or animal productivity, maximizing profits, and conserving its quality for future generations.

Soil has both inherent and dynamic qualities. Inherent soil quality is a function of soil parent material and prevailing climatic conditions. For instance, sandy soil drains faster than clayey soil. The inherent soil characteristics do not change easily. Dynamic soil quality is affected by soil management. For example, chemical fertilizer use directly affects the macro-nutrient contents in the soil; manure application and crop residue incorporation may increase soil organic matter content. Soil tillage can improve soil air and water conditions and increase top soil depth, but accelerate the decomposition of soil organic matter.

Differences in crop yield due to both farm management (e.g. fertilizer application) and non-farm management causes (such as unfavorable weather conditions or pests) can have different impacts on soil quality. On the one hand, higher yields will remove more nutrients from the soil; on the other hand, higher yields often mean more crop residues that, when left on the land, decompose into soil organic matter and thus improve soil quality.

Relatively stable soil characteristics such as soil pH and clay content affect nutrient availability. Soil pH influences the nitrogen form taken up by the crops and volatilization losses, and thus the nitrogen left in the soil. Soil pH also affects the form and availability of soil phosphorus (P) and the fixation of potassium (K). Clay content may affect plant-available N, P and K. Clay provides ‘protection’ to organic matter in the soil and thus hampers decomposition, necessary to transform N and P into plant-available inorganic forms. K is mobile and vulnerable to leaching. Clay may adsorb it and reduce the loss, and therefore may increase the K available for plant growth.

The dynamic component of soil quality can therefore be expressed as:

$$S = h\,(M, Y, U) \qquad (6.2)$$

where S denotes the dynamic component of soil quality, M denotes farm management decisions (i.e. soil management), Y denotes crop yield, and U represents the inherent soil characteristics, such as soil pH[47] and soil clay content.

6.2.3 Crop yield

From a biophysical point of view, crop yield is determined by the available energy from the sun (for photosynthesis which forms CH_2O), the quantity of water available from the soil, the content of nutrients in the soil, the extent to which these nutrients can be taken up by the plants, the incidence of yield-reducing factors such as pests and diseases and labor input for farm management. Crop growth (biomass production) can schematically be expressed as follows:

$$CH_2O \;+\; \begin{matrix}\text{Other essential elements}\\ \text{(N, P, K, Ca, Mg, S…)}\end{matrix} \longrightarrow \text{Biomass = yield + crop residues}$$

Essential elements are usually divided into two categories depending on the concentration within the plant tissues: macronutrients and micronutrients. Plants require macronutrients in relatively large amounts. They include three nutrients supplied by the atmosphere: carbon, hydrogen and oxygen, and six nutrients supplied by the soil: nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur. The most critical one is often referred to as the ‘yield-limiting factor’. This means that further increases in yield are limited by the availability of this nutrient, with the concentrations of the other nutrients being sufficient for further yield increases.

Micronutrients are required in much smaller quantities than macronutrients, i.e. 10 to 1000 times less. Crop yield and/or quality will be negatively affected if a crop is deficient

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[47] pH is only 'relatively' stable. pH can also be affected by management, for example continuous application of certain forms of fertilizers may result in 'acidification' thus lowering of soil pH. The focus of the analysis in this chapter, however, is on changes in dynamic soil quality.

in these nutrients. But micronutrients are generally provided in sufficient quantities from natural sources, such as soil parent material or soil organic matter.

The extent to which the essential nutrients are available to the plants depends not only on the nutrient concentration in the soil, but also on the chemical (e.g. soil pH; see above) and physical (top soil depth and structure, for example) characteristics of soil. Deep soils allow more extensive rooting than shallow soils and, if the nutrient concentrations are the same for both, will provide more nutrients.

Soil organic matter is linked to many aspects of soil quality. It provides nutrients to plants and their production environment. Moreover, it improves the soil structure, facilitating plant root extension and making tillage easier for farmers and increasing the capacity to retain water.

In addition to the limiting factors discussed above, yield may also be negatively affected through ‘yield-reducing factors’, like weeds, pests and disease. Crop protection (weeding, pesticides and herbicides) can reduce the impact of these factors. Pesticides and herbicides may be used either in a preventive way, to avoid damage by pests and diseases, or in a curative way.

Labor input is not a direct factor in biomass formation. However, labor input in weeding, fertilizer application, plant protection, harvesting, and so on, indirectly contributes to higher yields through crop husbandry.

The production function explaining crop yield can thus be expressed as:

$$Y = g(M_1, S, V) \qquad (6.3)$$

where Y denotes crop yield, M_1 denotes farm management decisions on crop husbandry (i.e. labor input, crop protection), S denotes the dynamic component of soil quality, V represents the external factors which may affect yield, including agro-climatic factors (such as rainfall, radiation, and temperature) and yield-reducing factors (like weeds, pests and diseases).

This production function differs in one essential way from production functions commonly used by agricultural economists. Chemical fertilizers and manure affect crop yield only indirectly through their impact on the dynamic component of soil quality. The reason is that the relation between (chemical and organic) fertilizer application rate and crop yield is not constant, but depends crucially on soil chemical characteristics and processes[48]. The resulting production function reflects some important insights gained from agronomic science.

6.3 Empirical analysis

6.3.1 Sampling and data collection

Data used for this chapter were collected in the three villages described in Chapter 4. Plot level data include institutional factors, farm management, soil quality, and rice yield. Institutional factors cover: (1) land fragmentation, as indicated by the distance of the plot to the homestead and the plot size; and (2) plot tenancy, i.e. whether a plot is contracted or rented-in (from other farmers or from the collective). Plot level management data include labor, herbicides, manure and chemical fertilizer use in (single-crop or double-crop) rice production[49]. Soil quality data include soil organic matter content, soil physical characteristics like topsoil depth and soil clay content, soil chemical characteristics such as soil total nitrogen, available phosphorus, available potassium, and pH value. The rice yield obtained from a plot refers to either a single rice crop or a double rice crop. Farm household characteristics include information on the plot size, the number of plots and on the age and education level of the household head.

Farm household characteristics were collected for the year 2000 as part of the survey held in the three villages. Plot-specific data, however, were not collected during that survey. Out of the 339 households in the original survey, 47 households were randomly selected for plot-level data collection with respect to their rice plots[50]. They were

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[48] The impact of pesticides and herbicides application may be modeled in a similar way, by specifying their impact on yield-reducing factors. Such an analysis, however, is beyond the scope of this study.

[49] Data are also available on seed, animal traction, and pesticide use. These management variables do not significantly affect rice yield in our sample and are therefore left out for simplicity.

[50] Only plots cultivated with rice are included in the sample. Rice plots planted with green manure or other crops during the 2002 season are not included.

interviewed in January 2003 about the previous agricultural season[51]. The resulting number of plots in the data set is 154; 29 plots in Banqiao, 50 in Shangzhu, and 75 in Gangyan. The soil samples of these plots were analyzed at the College of Resources and Environmental Sciences at Nanjing Agricultural University.

6.3.2 Choice of variables

In this subsection, we discuss the indicators used to estimate the relationships shown in Figure 6.1. With respect to land tenure, three forms can be distinguished in the surveyed villages: reserved, contracted and rented in land. Reserved land was allocated to individual households many years ago and can be cultivated for a long time, but only makes up a very small of total land. In principle, around 5% of the total farmland area can be reserved, but in many villages this share is even lower. Most plots in the three villages in our survey are contracted by households from the village committee. Renting of land from other farm households or from the village (group) collective has only recently become popular. The rice production dataset used in this study contains only contracted plots and rented-in plots. The contracted land accounts for 75% and the rented in land for 25% of the plots. A dummy variable is used to indicate whether a plot is rented (value is one) or contracted (value is zero).

The land fragmentation indicators used in this chapter differ from those used in previous chapters, because the analysis in this chapter is at the plot level. We therefore use plot-specific information on plot size and distance of the plot to the homestead, and supplement it with farm-level information on the number of plots as a measure of the fragmentation at the farm level.

The farm management variables included in this study are the use of labor, chemical fertilizers and manure use. Chemical fertilizers are subdivided into nitrogen, phosphorus, and potassium fertilizers, based on nutrient contents (N, P_2O_5, and K_2O) of different fertilizer types. Manure is used on 38% of the plots in our sample. We use a dummy variable to indicate whether it is used on a specific plot (value is one) or not. Rice yield is

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[51] The interviews and soil sampling were carried out in the beginning of January, because both enumerators and farmers had time available then. Moreover, there is no water in the field in that month, making soil sampling easier.

measured per *mu*. It indicates the paddy yield of either a single rice crop or a double rice crop on a plot.

Dynamic soil quality indicators include soil organic matter content, total soil nitrogen, available soil phosphorus and available soil potassium. They were selected upon the advice of soil scientists. Soil organic matter content is an important indicator of soil fertility. It provides many macro- and micro-nutrients to crops. Moreover, soil with adequate organic matter is characterized by a good structure, high stability, and high nutrient retention. Soil nitrogen, phosphorus and potassium represent the most important macro-nutrients for crops. Total soil nitrogen, most of which is incorporated in soil organic matter, is an important indicator of long-term soil fertility. Available phosphorus and available potassium indicate the soil phosphorus and potassium stocks that are available for crop uptake within one growth cycle.

Inherent soil characteristics include soil pH, soil clay content, and depth of the topsoil. Soil scientists regard these as the most important soil characteristics in the research area. Soil pH is an indicator of the acidity or alkalinity of soil. Its neutral point is at pH 7. With decreasing value below 7, the soil is increasingly acid, and with increasing value above 7, the soil is increasingly alkaline.

The age and education level of the household head are selected as farm household characteristics that are likely to affect farm management decisions. The education variable is defined as a dummy variable that indicates whether a household head has received any formal education (value is one) or not.

Differences between the three villages in soil parent material, landscape, agro-climatic factors, access to extension, input/output prices, and other relevant factors are indicated by means of two village dummy variables indicating whether a plot is located in either Shangzhu village (value is one, zero otherwise) or in Gangyan (value is one, zero otherwise).

Table 6.1 shows the descriptive statistics of the variables used in the analysis. The average paddy yield is 930 *jin* per *mu*, i.e. 6,975 kg per ha[52]. Yields are extremely variable, ranging from 250 to 1,725 *jin* per *mu*. Similarly, the variation in the farm management variables is large. Nitrogen fertilizer is applied to all plots, but some plots do

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[52] As shown in Table 4.1, most of the paddy land in two villages (Banqiao and Ganyan) and almost 30% of the paddy land in the third village (Shangzhu) is double-cropped.

not receive any phosphorus or potassium fertilizer. The average number of plots per farm is 8.94, with plots in the sample having an average size of 1.85 *mu*, and an average distance to the homestead of 14 minutes.

Table 6.1 Descriptive statistics of the variables used in the regression analyses

	Number of observations	Unit	Mean	Max	Min	Stdev
Endogenous variables						
Farm management activities						
Labor used (*LB*)	154	man days/*mu*	56.8	249	10.0	31.7
Herbicides used (*HB*)	154	*yuan*/*mu*	2.34	10.0	0.33	1.51
Pure nitrogen (*NP*)	154	*jin*	24.0	86.4	2.25	14.4
P_2O_5 phosphorus (*PP*)	154	*jin*	11.5	73.0	0.00	9.70
K_2O potassium (*KP*)	154	*jin*	14.8	100	0.00	12.6
Manure use dummy (*DM*)	154	0 or 1	0.38	1.00	0.00	0.49
Dynamic soil quality						
Soil organic matter (*SO*)	154	%	3.80	6.21	1.27	1.02
Total nitrogen (*NT*)	154	%	0.26	0.48	0.10	0.07
Available phosphorus (*PA*)	154	g/kg	13.4	63.6	1.36	11.2
Available potassium (*KA*)	154	mg/kg	94.4	385	19.8	54.6
Crop yield						
Rice yield (*RY*)	154	*jin*/*mu*	930	1725	250	353
Exogenous variables						
Institutional factors						
Rented in land dummy (*DH*)	154	0 or 1	0.25	1.00	0.00	0.44
Plot area (*PA*)	154	*mu*	1.85	9.00	0.20	1.35
Plot distance (*PD*)	154	minutes	14.3	60.0	1.00	12.1
Number of plots in a farm (*PN*)	154	plots	8.94	16.0	3.00	3.43
Soil characteristics						
Clay content (*CL*)	154	%	14.2	27.6	4.77	4.76
Topsoil depth (*TD*)	154	cm	17.1	35.0	9.0	4.45
pH value (*PH*)	154	pH units	5.15	5.90	4.60	0.22
Farm household characteristics						
Age of household head (*AG*)	154	years	46.6	75.0	30. 0	11.7
Education dummy (*DE*)	154	0 or 1	0.81	1	0	0.40
Village characteristics						
Shangzhu dummy (*DV1*)	154	0 or 1	0.32	1.00	0.00	0.47
Gangyan dummy (*DV2*)	154	0 or 1	0.49	1.00	0.00	0.50

Sources: Calculated from the survey data.

6.3.3 Model specification and estimation method

The variables listed in Table 6.1 will be used to estimate the model shown in Figure 6.1. The equations that will be used for estimating the factors explaining farm management decisions are:

$$FM_i = \alpha_{0i} + \alpha_{1i}DT + \alpha_{2i}PA + \alpha_{3i}PD + \alpha_{4i}PD^2 + \alpha_{5i}PN + \alpha_{6i}RY + \alpha_{7i}AG + \alpha_{8i}AG^2 + \alpha_{9i}DE + \alpha_{10i}DV1 + \alpha_{11i}DV2 + \upsilon_{1i} \qquad (6.4a\text{-}4f)$$

with

FM_i = *LB*, *HB*, *NP*, *PP*, *KP*, and *DM*, respectively

where $\alpha_{0i},\ldots,\alpha_{11i}$ are unknown coefficients;
υ_{1i} is a disturbance term with standard properties.

The definitions of the variables can be found in Table 6.1. In this specification, farm management decisions depend on institutional factors (land tenure, land fragmentation), rice yield, household characteristics (age and education of the household head) and village characteristics (measured by village dummies). Quadratic terms are added for plot distance (*PD*) and for age of the household head (*AG*) to account for potential nonlinearities in the impact of these variables.

The dynamic component of soil quality depends on the quantity of nutrients and manure applied in rice production, the yield obtained, and soil chemical processes. For soil organic matter (*SO*), the following equation will be used:

$$SO = \beta_0 + \beta_1DM + \beta_2RY + \beta_3CL + \beta_4DV1 + \beta_5DV2 + \upsilon_2 \qquad (6.5a)$$

where $\beta_0,\ldots,\beta_5$ are unknown coefficients;
υ_2 is a disturbance term with standard properties.

Soil organic matter contents in this specification depend on the application of manure (*DM*), the biomass removed by harvesting rice (*RY*), the soil clay content (*CL*: clay soils can retain more soil organic matter by reducing its decomposition) and on village-specific factors (represented by dummy variables *DV1* and *DV2*).

The equation for total nitrogen is as follows:

$$NT = \gamma_0 + \gamma_1 NP + \gamma_2 DM + \gamma_3 SO + \gamma_4 RY + \gamma_5 DV1 + \gamma_6 DV2 + \upsilon_3 \qquad (6.5b)$$

where $\gamma_0,\ldots,\gamma_6$ are unknown coefficients;
υ_3 is a disturbance term with standard properties.

The application of nitrogen fertilizer (*NP*) and manure (*DM*) can increase the nitrogen content in the soil. Soils with a high soil organic matter content (*SO*) tend to have lower nitrogen losses from leaching and volatilization. Harvesting of crops (*RY*) removes nitrogen from the field and hence reduces the nitrogen stock. Finally, village-specific factors (*DV1*, *DV2*) such as differences in soil types may also play a role.

For available phosphorus, the following equation will be estimated:

$$PA = \delta_0 + \delta_1 PP + \delta_2 DM + \delta_3 RY + \delta_4 PH + \delta_5 CL + \delta_6 DV1 + \delta_7 DV2 + \upsilon_4 \qquad (6.5c)$$

where $\delta_0,\ldots,\delta_7$ are unknown coefficients;
υ_4 is a disturbance term with standard properties.

Phosphorus fertilizer (*PP*) and manure (*DM*) can supplement the available phosphorus in the soil, while crop harvesting (*RY*) removes available phosphorus. Soil pH (*PH*) also affects the form and availability of soil phosphorus. Phosphorus availability is lower both in soils with low pH (formation of insoluble Al-phosphates) and in soils with high pH (formation of insoluble Ca-phosphates). Soils with high clay content (*CL*) provide ‘protection’ to organic matter in the soil and thus hamper decomposition and reduce the P available for plant growth. Again, village-specific factors (*DV1*, *DV2*) such as soil types may play a role as well.

The same equation, with phosphorus application replaced by potassium application (*KP*), is used for available potassium:

$$KA = \varepsilon_0 + \varepsilon_1 KP + \varepsilon_2 DM + \varepsilon_3 RY + \varepsilon_4 PH + \varepsilon_5 CL + \varepsilon_6 DV1 + \varepsilon_7 DV2 + \upsilon_5 \qquad (6.5d)$$

where $\varepsilon_0,\ldots,\varepsilon_7$ are unknown coefficients
υ_5 is a disturbance term with standard properties

Soil pH is again expected to have a negative impact. An increase in acidity (lower value of *PH*) will increase the concentration of aluminum in the soil solution. This in its turn could make more potassium available for crop growth. The expected impact of clay content (*CL*) is opposite to its impact on available phosphorus. Potassium is relatively mobile and vulnerable to leaching. A clayey soil may reduce the loss, and therefore increase the availability of potassium for plant growth.

Finally, a Cobb-Douglas production function is used for estimating the rice yield equation:

$$\begin{aligned} ln(RY) = {} & \zeta_0 + \zeta_1 ln(LB) + \zeta_2 ln(HB) + \zeta_3 ln(PA) + \zeta_4 ln(SO) + \zeta_5 ln(NT) + \zeta_6 ln(PA) \\ & + \zeta_7 ln(KA) + \zeta_8 ln(TD) + \zeta_9 ln(PH) + \zeta_{10} DV1 + \zeta_{11} DV2 + \upsilon_6 \qquad (6.6) \end{aligned}$$

where $\zeta_0, \ldots, \zeta_{11}$ are unknown coefficients;
υ_6 is a disturbance term with standard properties.

In this specification rice yield depends on the labor used in growing rice (*LB*), the herbicides applied (*HB*), the area of the plot (*PA*), soil organic matter content (*SO* which is used as a proxy for the availability of water), the macro-nutrients available for plant growth (*SO*, *NT*, *PA*, and *KA*), the depth of the topsoil (*TD*), the soil pH-value (*PH*), and soil type, ago-climatic factors and other village-specific factors captured in the village dummies (*DV1* and *DV2*). All factors except plot area are expected to have a positive impact on rice yield. The variables in this production function are expressed on a per *mu* basis. Plot area is therefore added to the equation to estimate whether there are decreasing ($\zeta_3 < 0$), constant ($\zeta_3 = 0$), or increasing ($\zeta_3 > 0$) returns to scale in crop husbandry.

Equations *(6.4a-6.4f)*, *(6.5a-6.5d)* and *(6.6)* together make up the model. It consists of 11 equations, explaining 11 endogenous variables. All equations are identified, except for the yield equation. In section 6.4.3, we will explain how the identification problem for the yield equation was solved.

A simultaneous-equations technique is needed to estimate the model. If the equations in the system are related through the residuals, three-stage least squares (3SLS) should be applied in order to obtain unbiased and efficient estimates. Any misspecification of a single equation, however, can contaminate the 3SLS- estimates of the other equations in the system. In our model, we have no reasons to assume that the residuals of the equations are related to each other. Moreover several equations, particularly the soil quality equations, are of an exploratory nature, requiring further research to improve their specification. We therefore use two-stage least squares (2SLS) to estimate the model.

6.4 Regression results

For most equations, it is not clear *a priori* which functional form should be used. The only exception is the yield equation where we specify a Cobb-Douglas function. For the other equations, we estimated both a linear and a double-logarithmic functional form[53], and compared the results for the (second-order) Ramsey-test as well as for the Jarque-Bera normality test and the F-test. The results are reported in Appendix 6.1. The double-logarithmic specification performed better than the linear specification for all equations except for manure and soil organic matter. We therefore use double-logarithmic specifications for all equations except equations *(6.4f)* and *(6.5a)*. Each equation is estimated by 2SLS. For equation *(6.4f)*, a Probit model is applied with rice yield, the only endogenous explanatory variable in that equation, replaced by its estimate obtained from the first stage of 2SLS. Insignificant explanatory variables and variables with coefficients with wrong signs are left out of the equations. Results of the full equations are reported in Appendices 6.2 to 6.7. One-sided tests are applied to those explanatory variables that can only have a positive impact on a dependent variable (such as labor use in the yield equation).

6.4.1 Determinants of production activities

Tables 6.2 and 6.3 present the regression results for the farm management variables. The use of labor, herbicides, manure, and nitrogen does not differ significantly between rented-in plots and contracted plots. This supports the findings of Li *et al*. (1998). However, controlling for the yield level, rented-in plots are found to receive significant higher quantities of phosphorus and potassium fertilizer. A possible explanation could be that farmers have to use more P and K fertilizers to compensate for the poorer land quality

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[53] Dummy variables were not transformed in the double-log equations. This also holds for the dependent variable in the manure use equation.

of rented land. A comparison of soil quality indicators between rented-in and contracted plots, however, shows that the differences are not statistically significant (see Appendix 6.8).

Table 6.2 Regression results for labor and manure use

	Labor use per *mu* (2SLS)	Herbicides use per *mu* (2SLS)	Manure dummy (Probit)
Constant	-1.29 (-0.56)	-24.5** (-2.60)	-4.07** (-2.35)
Rented in plot dummy	-	-	-
Plot area	-0.10* (-1.82)	-0.21*** (-3.86)	-
Plot distance	0.49*** (2.76)	-	-0.03*** (-2.57)
Plot distance squared	-0.12*** (-3.17)	-	-
Number of plots	-	0.23** (2.02)	-
Yield	0.68** (2.16)	0.88*** (4.93)	-
Age	-	9.81** (1.98)	0.16** (1.92)
Age squared	-	-1.27* (-1.97)	-0.001** (-2.06)
Education dummy	-	-	-
Shangzhu dummy	0.68*** (3.85)	-	1.48*** (3.98)
Gangyan dummy	-	-0.19** (-2.04)	1.15*** (3.12)
R^2	0.39	0.36	
Adj. R^2	0.37	0.33	
McFadden R^2			0.14
Number of observations	154	154	154

Note: Double-log specifications for labor use and herbicides use.

z-values are between brackets; * significant at 0.1 level; ** significant at 0.05 level and *** significant at 0.01 level.

An alternative explanation could be that farmers who rented the plots out did not apply P and K during the last one or two years before they started to rent out the plots. This normally does not affect yields in the short run. Farmers who rent-in the land know this, and apply extra P and K to compensate for this. Informal interviews during the field work suggested this explanation[54]. Evidence from Mandel (1970) also supports this explanation. Short-term lease of land discouraged farmer to invest in land, even with (a lease of) nine years. It is reported that “the farmer had too often to spend the first three-year rotation reconstituting the fertility impaired by his predecessor; he cultivated the land normally during the second three-year period, and then spent the last three years exhausting the land in one way or another.”

Of the land fragmentation indicators, plot size is found to have a negative impact on labor input, herbicides use and nitrogen application. Larger plots are easier to manage and therefore have higher input use efficiency. A one percent increase in plot size reduces the inputs of labor, herbicides, and nitrogen per *mu* by 0.10, 0.21 and 0.12%, respectively. The use of manure, phosphorus and potassium is not affected by plot size. Plot distance has a positive impact on labor use on relatively nearby plots, and a negative impact for far-away plots. The turning point is at travel times of around 8 minutes. The labor use data collected in our survey include the time required to travel to the plots. So, for far-away plots the reduction in labor input on more distant plots exceeds the time involved in traveling to the plots, while for nearby plots it does not.

Manure application is a rather strenuous activity. As expected, the distance of a plot negatively affects manure use. Nitrogen fertilizers are used to replace manure on distant plots, as indicated by the positive impact of plot distance on nitrogen use. Plot distance does not affect the use of other chemical fertilizers and herbicides. The number of plots on a farm only affects levels of herbicides and phosphorus use. Farms with a larger number of plots experience more weed invasion from neighboring non-cultivated land, necessitating a higher use of herbicides. Application of phosphorus is a relatively long-term investment. A higher probability of land reallocation for farmers with a large number of plots may explain the reluctance of such farmers to invest in soil quality through phosphorus application.

Yield is found to have a positive impact on all farm management variables except manure use. So, controlling for the technical relationship between input use and rice yield (as estimated by the production function), plots with higher yields receive higher quantities of inputs. The estimated elasticities range from 0.68 for labor to 1.68 for

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[54] Some farmers even apply salt instead of fertilizer when they know that they will cultivate their land for the last time. The Na^+ in the salt can displace the K^+ on the soil particles, and hence make K^+ available for crop growth. But in the long-run, this will damage the soil structure and cause a decrease in yield.

nitrogen use.

Table 6.3 Regression results for chemical fertilizer use, 2SLS

Independent variables	Nitrogen use per *mu*	Phosphorus use per *mu*	Potassium use per *mu*
Constant	-8.32*** (-5.11)	-3.16 (-1.23)	-5.81* (-1.86)
Rented in plot dummy	-	0.31** (2.17)	0.34** (2.00)
Plot area	-0.12* (-1.85)	-	-
Plot distance	-	-	-
Plot distance squared	0.15*** (2.45)	-	-
Number of plots	-	-0.37*** (-2.49)	-
Yield	1.68*** (7.02)	0.97*** (2.63)	1.21*** (2.70)
Age	-	-	-
Age-squared	-	-	-
Education dummy	-0.29*** (-2.55)	-	-
Shangzhu dummy	-	-0.71*** (-3.02)	-0.44* (-1.74)
Gangyan dummy	-0.26** (-2.13)	-0.64*** (-4.12)	-
R^2	0.43	0.40	0.35
Adj. R^2	0.41	0.38	0.33
Number of observations	154	154	154

Note: Double-log specifications for all equations.

z-values are between brackets; * significant at 0.1 level; ** significant at 0.05 level and *** significant at 0.01 level.

The age of the household head only affects herbicide and manure use. Older farmers are more likely to use herbicides and manure than younger farmers, but the impact of age becomes less at higher ages (and declines after the age of 48 for herbicides use). Education only affects levels of nitrogen use: when the household head has received some formal education, nitrogen application tends to be lower. For the other management variables, farming experience is probably more important than formal education in making decisions.

Keeping other factors constant, farmers in Shangzhu, the remote and mountainous village, use more labor and manure and less phosphorus and potassium fertilizers than farmers in Banqiao village, the village that is closest to a major market. Farmers in Gangyan, the village in the plain area, use more manure and less herbicides and nitrogen and phosphorus fertilizers than farmers in Banqiao village.

6.4.2 Determinants of soil quality

Table 6.4 presents the regression results for the soil organic matter and soil total nitrogen equations. In the equation explaining soil organic matter (SOM) it is found that manure use has a very significant positive impact, as expected. On plots where manure is applied, the SOM content is on average 1.42 / 3.80= 37% higher. Clay content does not have a significant impact on the rice yield obtained from a plot. In Gangyan village, the SOM content in the soil is slightly higher than in the other two villages, controlling for the impact of manure use.

Total soil nitrogen is strongly affected by the soil organic matter content. The main reason is that that the larger part of total soil nitrogen is in organic form in soil organic matter. Moreover, higher SOM contents prevent nitrogen losses through leaching and volatilization. A one percent higher soil organic matter content increases total soil nitrogen by 0.65%. Total soil nitrogen content is not significantly influenced either by nitrogen fertilizer use or by manure application. Total soil nitrogen formation is a relatively slow process, and the observed differences levels of nitrogen and manure application in one agricultural season would not significantly affect this[55]. It may be noted, however, that manure use has an indirect impact on soil nitrogen formation in our model through its contribution to SOM formation. Yield is again found to have an insignificant impact on total soil nitrogen, as was the case for SOM content.

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[55] As shown by Heerink (1994), cross-section observations can be used to provide close approximations of long-term processes provided (a) the correlation coefficients of an explanatory variable and its lagged values over the sample are close to one for the relevant time period, and (b) the standard deviation of the explanatory variable is relatively constant over time. In our case this means that nitrogen (manure) application on each plot should be relatively constant for the period that it contributes to total soil nitrogen build-up. This assumption may not be justified.

Table 6.4 Regression results for SOM and soil total nitrogen, 2SLS

Independent variables	Soil organic matter	Soil total nitrogen
Constant	3.13*** (18.9)	-1.97*** (-29.7)
Pure nitrogen use per *mu*	n.a.	-
Manure use dummy	1.42*** (4.51)	-
Yield	-	-
Soil organic matter	n.a.	0.65*** (12.4)
Clay content	-	n.a.
Shangzhu dummy	-	-
Gangyan dummy	0.28* (1.70)	-
R^2	0.01	0.74
Adj. R^2	-0.00	0.74
Number of observations	154	154

Note: Double-log specifications for soil total nitrogen. n.a. means not applicable.

t-statistics are between brackets; * significant at 0.1 level; ** significant at 0.05 level and *** significant at 0.01 level.

Regression results for soil available phosphorus and potassium are shown in Table 6.5. Phosphorus fertilizer use is found to have a significant impact on soil available phosphorus. A one percent increase in phosphorous fertilizer application increases the available phosphorus in the soil by 0.41% on average. Potassium fertilizer, however, does not have a significant impact on soil available potassium content. The inadequacy of our one-season data set for explaining long-term processes may again explain the latter result.

Manure use has a significant positive impact on both available phosphorus and available potassium in the soil. On plots with manure application, the content of soil available phosphorus is 54% (7.2 g/kg) higher and the content of soil available potassium is 43% (40.6 mg/kg) higher on average compared to plots without manure application. Rice yield does not have significant effects on soil available phosphorus and potassium contents. None of the soil quality variables therefore seems to be affected by differences in rice yields between plots.

Soil pH is found to have no significant impact on soil available phosphorus, but has a significant negative impact on soil available potassium. The latter result can be explained from the fact that fixation of potassium and entrapment at specific sites between clay layers tends to be higher under alkaline conditions.

Table 6.5 Regression results for soil available phosphorus and potassium, 2SLS

Independent variables	Soil available phosphorus	Soil available potassium
Constant	1.26 (1.33)	6.70*** (6.45)
Phosphorus use per *mu*	0.41* (1.60)	n.a.
Potassium use per *mu*	n.a.	-
Manure use dummy	0.54** (1.68)	0.43*** (3.00)
Yield	-	-
Soil pH	-	-1.98** (-2.19)
Soil clay content	-0.31* (-1.79)	0.48*** (4.34)
Shangzhu dummy	0.87** (2.10)	-
Gangyan dummy	0.91*** (3.23)	-0.40*** (-5.21)
R^2	0.08	0.22
Adj. R^2	0.04	0.19
Number of observations	154	154

Note: Double-log specifications for both equations. n.a. means not applicable.

t-statistics are between brackets; * significant at 0.1 level; ** significant at 0.05 level and *** significant at 0.01 level.

Soil clay content has a significant negative impact on soil available phosphorus but a positive impact on soil available potassium. For phosphorus no obvious explanation is available, while potassium is very mobile and susceptible to leaching, so that soil clay particles can reduce potassium losses to some extent.

Plots in Shangzhu and Gangyan villages have around 90% higher soil available phosphorus on average than those in Banqiao, keeping other factors constant. Plots in Gangyan have about 40% lower soil available potassium than those in Banqiao and Shangzhu. Soil characteristics that are not included in the model, such as moisture characteristics or parent materials in these villages, may explain these results.

6.4.3 Determinants of yield

The results of the previous two sub-sections indicate that several explanatory variables have insignificant effects on soil management decisions and on soil quality. After dropping these variables from the model as presented in *(6.4a-6.4f)*, *(6.5a-6.5d)*, and

(6.6), the rice yield equation can be identified[56].

Table 6.6 Regression results for rice yield, 2SLS

Independent variables	Yield
Constant	4.62*** (7.50)
Labor use per *mu*	0.27*** (2.64)
Herbicides use per *mu*	0.34*** (3.25)
Plot area	0.07* (1.63)
Soil organic matter	-
Soil total nitrogen	-
Soil available phosphorus	0.13** (2.17)
Soil available potassium	0.16** (1.74)
Top soil depth	-
Soil pH	-
Shangzhu dummy	-0.52*** (-6.03)
Gangyan dummy	-
R^2	0.46
Adj. R^2	0.45
Number of observations	154

Note: Double-log specification.

t-statistics are between brackets; * significant at 0.1 level; ** significant at 0.05 level and *** significant at 0.01 level.

Table 6.6 presents the regressions results for rice yield. Labor use is found to have a significant positive impact on yield. In other words, marginal labor productivity is greater than zero. This means that there is no labor surplus, and that labor cannot be withdrawn from agriculture without reducing agricultural production (as many studies on China assume) in our research area. In the production frontier results of Chapter 5, the labor input was also not significant. It should be noted that labor is measured in this chapter on a per-plot basis and only covers the time worked in the field, not the time involved in traveling to the plot. It therefore gives a more precise estimate of the actual labor input than the data used in previous chapters (which included travel time). Plot area has a small but significant impact on rice yield. Hence, there is some evidence of increasing returns to

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[56] The other ten equations can also be identified when these variables are dropped.

scale in rice crop husbandry[57]. Rewriting the Cobb-Douglas function in terms of total production (and total labor and herbicides use) gives us the elasticity for plot area: 1.00 - 0.27 + 0.34 + 0.07 = 0.32. This elasticity is considerably lower than the elasticity of area with respect to total area (0.97) estimated in Chapter 5.

Of the soil quality indicators, only available phosphorus and potassium have a significant effect on rice yield. This suggests that available phosphorus and available potassium are the yield-limiting factors in rice production in the research area. Variations in nitrogen and soil organic matter between the plots apparently do not matter, either because nitrogen is available in the soil in sufficient quantities or nitrogen is in an unavailable form in the soil.

Top soil depth and pH-value do not affect rice yield either. The average topsoil depth of 17 cm in our research area is more than enough for the extension of rice roots. Rice does not have strict requirements for pH value. The range of 4.6 to 5.9 for the soil pH value in our research area is somewhat low, but when flooded, this value will tend to be close to 7.0.

Compared to plots in Banqiao and Gangyan village, plots in Shangzhu village have lower yields in rice production. Taking into account differences in crop husbandry and dynamic soil quality between the villages, plots in Shangzhu (the remote village) are on average 52% lower than in the other villages. Differences in climate, slope, position in the landscape, and access to extension services may be important factors in this respect. This is consistent with the higher production cost per ton of grain and the lower technical efficiency in Shangzhu village that we found in Chapters 4 and 5.

6.5 Discussion and concluding remarks

Soil quality has important implications for sustainable agricultural development and food security in many developing countries. One of the components of soil quality is total soil nutrient stocks. As argued by Cassman and Harwood (1995), a decrease in soil nutrient stocks necessitates more inputs and greater management skills in order to compensate for the reduction in nutrients availability. This is why the interaction of agricultural

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[57] Because production and management variables are measured on a per *mu* basis, the area variable indicates the presence of economies of scale in a Cobb-Douglas production function.

development and soil quality management attracts widespread attention from researchers (e.g. Koning *et al.,* 2001, Sanchez, 2002; Heerink, 2005). This chapter attempts to identify the major links among management practices, observable soil characteristics, and productivity.

Applying plot level data on input/output, and a selected number of soil quality indicators and farm household level information, from the three villages described in Chapter 4, this chapter examines the impact of land fragmentation and land tenure on soil management, the dynamic component of soil quality, crop husbandry and rice yield at plot level. A 2SLS econometric approach is applied to simultaneously estimate the interlinked relationships between these variables.

Referring back to the theoretical model shown in Figure 6.1, the findings in this chapter identify a number of interactions between the factors considered.

(1) Increase use of labor and herbicides have a direct positive impact on crop yield;
(2) conversely, yield is found to have a significant positive feedback effect on crop husbandry decisions;
(3) manure application has a positive impact on the stock and availability of macro-nutrients in the soil; however, the impact of chemical fertilizers on macro nutrients, cannot be confirmed due to data limitations;
(4) only phosphorus and potassium availability in the soil affect rice yields; nitrogen and soil organic matter content, soil pH and topsoil depth do not play a role;
(5) the biomass removed through rice harvesting does not significantly affect the macronutrients in the soil;
(6) rice yield is found to have a significant positive impact on fertilizer application, but not on manure use;
(7) the tenure status of a plot affects the application of phosphorus and potassium, but not the other farm management variables examined in this study;
(8) land fragmentation has mixed effects on farm management decisions:
    - on far-away plots, labor and manure use is lower but application of nitrogen fertilizers is higher,

- on large plots, use of labor, herbicides, and nitrogen fertilizers per unit area is lower, and economies of scale in crop husbandry can be realized, and
- on farms with a large number of plots, the use of herbicides per unit area is higher and the use of phosphorus fertilizers per unit area is lower.

From these results we conclude that land fragmentation does play a role in farm management practices and decisions. Consolidation of small, fragmented plots into a smaller number of larger plots increases input-efficiency by inducing lower quantities of labor and herbicides use at given yield levels. Moreover, if these plots are located closer to the homestead, more manure will be used. Increased manure use contributes to soil quality improvement and increases the availability of the two major yield-limiting factors in rice production in the research area, the available phosphorus and potassium in the soil.

The land tenure status of a plot does not affect crop husbandry decisions on labor and herbicide use. Farmers on rented-in plots do, however, use more chemical fertilizers (phosphorus and potassium). Probably they do so to compensate for the lack of application of such fertilizers in previous seasons by farmers renting out the land.

This implies that farmers care more about short-term yields than about the built-up of long-term soil productivity. In order to sustain long-term soil productivity, measures should be taken to ensure that the prices for renting land reflect such soil investments.

Appendix 6.1 Comparison of the main tests of functional forms (full equations)

		Labor	N fert	P fert	K fert	Dman	Yield	SOM	Soil tot. N	Soil av. P	Soil av. K
Linear	Jarque-Bera (prob.)	533 (0.00)	497 (0.00)	3434 (0.00)	3127 (0.00)	73.2 (0.00)		3.33 (0.20)	156 (0.00)	19.0 (0.00)	186 (0.00)
	Ramsey (2) (prob.)	0.54 (0.58)	0.10 (0.90)	0.31 (0.73)	0.11 (0.90)			1.43 (0.24)	0.65 (0.52)	1.45 (0.24)	0.11 (0.89)
	F-test (prob.)	5.43 (0.00)	5.45 (0.00)	7.17 (0.00)	5.90 (0.00)	-65.6[1] (0.00)		7.04 (0.00)	17.9 (0.00)	2.82 (0.01)	5.58 (0.00)
Double log	Jarque-Bera (prob.)	4.24 (0.12)	6.54 (0.04)	46.6 (0.00)	125 (0.00)	499 (0.00)	0.19 (0.90)	20.9 (0.00)	16.8 (0.00)	1.29 (0.52)	2.27 (0.32)
	Ramsey (2) (prob.)	2.25 (0.11)	0.69 (0.50)	0.60 (0.55)	0.30 (0.74)		2.41 (0.12)	2.53 (0.08)	0.46 (0.63)	0.88 (0.42)	0.11 (0.89)
	F-test (prob.)	5.39 (0.00)	11.8 (0.00)	5.96 (0.00)	6.12 (0.00)	-65.9 (0.00)	8.83 (0.00)	9.59 (0.00)	24.0 (0.00)	4.86 (0.00)	5.47 (0.00)

Note: The tests are for the simplified equations

Manure use is estimated with a Probit model; here the log form is only for right-hand variables.

[1] is log likelihood for manure equation estimated by Probit model.

Appendix 6.2 Comparison of some tests of functional forms (reduced equations)

		Labor	N fert	P fert	K fert	Yield	SOM	Soil total N	Soil av. P	Soil av. K
Linear	Normality	0	0	0	0	0.22	0.36	0	0	0
	Ramsey	0.38	0.41	0.48	0.17	0.93	0.26	0.75	0.40	0.12
	R-square	0.32	0.33	0.37	0.16	0.26	0.01	0.52	0.09	0.16
	Adj. R-square	0.30	0.31	0.35	0.13	0.24	-0.003	0.51	0.05	0.13
	F-test	8.25	9.18	14.3	17.8	14.7	11.5	28.8	3.03	8.45
Double log	Normality	0.05	0.001	0	0	0.16		0.01	0.01	0.92
	Ramsey	0.43	0.40	0.67	0.35	0.59		0.85	0.37	0.38
	R-square	0.39	0.43	0.40	0.35	0.46		0.67	0.08	0.22
	Adj. R-square	0.37	0.41	0.38	0.33	0.45		0.67	0.04	0.19
	F-test	11.0	12.1	12.3	21.0	22.4		62.2	7.08	10.9

Note: The tests are for the simplified equations

Manure use is estimated with Probit model and is not reported here.

Appendix 6.3 Results for labor and manure use

Independent variables	Labor use per *mu* (2SLS)	Manure dummy (Probit)
Constant	-8.01 (-0.79)	-26.59*** (-2.74)
Rented in plot dummy	0.09 (0.99)	-0.03 (-0.30)
Plot area	-0.12** (-2.10)	0.05 (0.83)
Number of plots	-0.10 (-0.87)	-0.08 (-0.76)
Plot distance	0.41** (2.18)	0.25 (1.38)
Plot distance squared	-0.11*** (-2.79)	-0.05 (-1.37)
Yield	0.45 1.15)	1.13*** (3.03)
Age	4.08 (0.80)	9.96** (2.04)
Age-squared	-0.48 (-0.71)	-1.31** (-2.04)
Education dummy	0.19 (1.22)	-0.07 (-0.47)
Shangzhu dummy	0.48** (2.19)	1.01*** (4.79)
Gangyan dummy	-0.07 (-0.65)	0.33*** (3.18)
R^2	0.39	0.27
Adj. R^2	0.35	
Number of observations	154	154

Note: Double log specification for labor use. McFadden R^2 for manure use.

t-statistics and z-values are between brackets; * significant at 0.1 level; ** significant at 0.05 level and *** significant at 0.01 level, same for Appendices 6.4 to 6.7.

Appendix 6.4 Results for chemical fertilizer use, 2SLS (Double log specifications)

Independent variables	N use per *mu*	P use per *mu*	K use per *mu*
Constant	-4.52 (-0.39)	-26.49* (-1.70)	22.61 (1.19)
Rented in plot dummy	0.11 (1.05)	0.36*** (2.45)	0.31* (1.74)
Plot area	-0.13** (-2.05)	-0.12 (-1.33)	-0.12 (-1.14)
Number of plots	0.07 (0.51)	-0.42*** (-2.50)	0.20 (0.97)
Plot distance	0.06 (0.27)	0.38 (1.31)	0.21 (0.58)
Plot distance squared	0.02 (0.44)	-0.07 (-1.16)	-0.06 (-0.79)
Yield	1.56*** (3.50)	1.28** (2.14)	0.86 (1.17)
Age	-1.06 (-0.18)	11.09 (1.42)	-13.87 (-1.45)
Age-squared	0.08 (0.11)	-1.46 (-1.41)	1.81 (1.43)
Education dummy	-0.46*** (-2.55)	-0.16 (-0.64)	0.20 (0.66)
Shangzhu dummy	-0.13 (-0.50)	-0.61 (-1.80)	-0.69* (-1.68)
Gangyan dummy	-0.37*** (-2.93)	-0.70 (-4.17)	-0.10 (-0.47)
R^2	0.48	0.42	0.38
Adj. R^2	0.44	0.37	0.33
Number of observations	154	154	154

Appendix 6.5 Results for SOM and soil total nitrogen, 2SLS

Independent variables	Soil organic matter	Soil total nitrogen
Constant	3.49*** (3.32)	-2.58 *** (-2.91)
Pure nitrogen use per *mu*	-0.02 (-1.09)	-0.04 (-0.60)
Manure use dummy	0.84 (1.47)	-0.06 (-0.65)
Yield	0.00 (0.00)	0.05 (0.38)
Clay	0.00 (0.00)	
Shangzhu dummy	0.59 (1.02)	0.05 (0.56)
Gangyan dummy	0.74 *** (2.82)	-0.01 (-0.23)
Soil organic matter		0.74 *** (6.40)
R^2	0.20	0.71
Adj. R^2	0.17	0.70
Number of observations	154	154

Note: Double log specification for soil total nitrogen.

Appendix 6.6 Results for soil available phosphorus and potassium, 2SLS

Independent variables	Soil available phosphorus	Soil available potassium
Constant	0.41 (0.09)	3.84 (1.13)
Phosphorus use per *mu*	0.38 (1.42)	
Potassium use per *mu*		-0.30 (-1.46)
Manure use dummy	0.54 (1.08)	-0.01 (-0.03)
Soil pH	0.34 (0.18)	-3.16*** (-2.48)
Soil clay content	-0.32* (-1.78)	0.59*** (4.12)
Yield	0.05 (0.07)	0.74 (1.31)
Shangzhu dummy	0.86 (1.35)	0.34 (0.97)
Gangyan dummy	0.89*** (3.13)	-0.30* (-1.82)
R^2	0.09	-0.01
Adj. R^2	0.04	-0.07
Number of observations	154	154

Note: Double log specifications for the two equations.

Appendix 6.7 Results for agricultural yield, 2SLS

Independent variables	Yield
Constant	6.20*** (2.88)
Labor use per *mu*	0.18 (1.34)
Soil organic matter	-0.42 (-0.81)
Soil total nitrogen	0.42 (0.70)
Soil available phosphorus	0.22** (2.19)
Soil available potassium	0.09 (0.70)
Soil pH	0.49 (0.66)
Top soil depth	-0.17 (-1.17)
Shangzhu dummy	-0.69*** (-5.15)
Gangyan dummy	-0.10 (-0.82)
R^2	0.39
Adj. R^2	0.35
Number of observations	154

Note: Double log specification. t-statistics are between brackets.

Appendix 6.8 Comparison of soil quality in rented-in and contracted plots

		Soil organic matter	Soil total nitrogen	Soil available phosphorus	Soil available potassium
Rented-in	Mean	3.858	0.251	14.73	83.38
	Stdev	1.067	0.064	10.66	48.15
Contracted	Mean	3.779	0.264	12.89	98.19
	Stdev	1.003	0.072	11.35	56.33

Sources: Calculated from the survey data.

CHAPTER 7

DISCUSSION AND CONCLUSIONS

7.1 Introduction

In order to reverse the declining trend in food production in China since the end of the 1990s, the Chinese government has recently implemented a series of measures designed to support the incomes of rural households, raise grain production, and promote the overall production capacity of the agricultural sector (see State Council, 2004, 2005; Gale *et al*., 2005). Reducing land fragmentation could make a significant contribution to these policy objectives by increasing the size of the effectively cultivated land area, enabling economies of scale, reducing management inconvenience (including time lost in traveling between plots), and promoting the adoption of modern technologies like improved breeds, water-saving irrigation technologies, and mechanization.

Despite the high degree of land fragmentation in China (see section 2.3), little research has been done so far on the consequences of land fragmentation for food production in China. Research to date has mainly focused on the impact of land fragmentation on production efficiency using simple partial measures of efficiency and not controlling for other factors affecting productivity differentials between farmers (see section 5.1). There is an urgent need for a more in-depth analysis of the impact of land fragmentation on food production in China.

The objectives of this study were therefore to examine how, and to what extent the high degree of land fragmentation affects food production in China. These general objectives were realized by addressing the five research questions:

(1) What are the characteristics of land fragmentation in China? What drives differences in the degree of fragmentation?
(2) What is the impact of land fragmentation on smallholder rice production costs?
(3) What is the impact of land fragmentation on rice producers’ technical efficiency?
(4) What is the relative importance of land fragmentation in smallholder farm

management decisions compared to other factors?

(5) How do the resulting farm management decisions affect rice yield and soil quality?

We discuss the answers to these research questions in the next section.

7.2 Main findings

7.2.1 Land fragmentation and its driving forces in China

The first part of the study examines how fragmentation in China has changed over time since the mid-1980s, and analyses the driving forces of the fragmentation process. Using data for China as a whole and for its three major regions, we find that land fragmentation is most severe in the Western part (with relatively large number of plots and small plot sizes) and the Eastern part (with small farm sizes and plot sizes). During the 1990s, land fragmentation decreased slightly (with a move towards larger plot sizes and fewer plots) in all regions. Compared to other countries for which data are available, we find that farm size and average plot size are much smaller in China.

Factors inducing land fragmentation are analyzed empirically with data from 860 households in 11 villages in Jiangxi Province. The results show that the egalitarian principles used in distributing and reallocating land use rights to households has contributed significantly to land fragmentation in China. Land within each village is classified into different classes, with each household receiving land from each class. Moreover, land is basically assigned on the basis of household size, with large households receiving substantially more (and slightly bigger) plots than small households. We further find that land renting activities and involvement in off-farm employment reduce land fragmentation, but their impact is small. Missing markets or limited market access does not induce land fragmentation, as 'demand-side' explanations of fragmentation suggest. Instead, we find that landholdings in suburban areas are more fragmented than landholdings in remote areas, probably because farmers cultivate a wider range of (high value-added) crops in these areas.

7.2.2 Production costs

Data from a household survey among 322 households in three villages in Northeast Jiangxi Province are used to examine the impact of land fragmentation on the variable cost of household rice production. The main finding is that, given other factors, farm size and distance to the plots have a significant impact on rice production costs. A 1% increase in farm size causes a 0.16% decrease in the total production costs per ton. One minute less of walking time to a plot reduces production costs by around 0.8% lower. There is no significant correlation between the Simpson index (an indicator integrating number of plots, average plot size and distribution of plot sizes) and total production costs. Interestingly, however, we find that an increase in the Simpson index of fragmentation induces a shift from the use of fertilizer, seed and oxen/tractors towards a higher use labor. This finding indicates that farmers with highly fragmented plots switch to more labor-intensive methods and use fewer modern technologies, but that the net impact of this switch on the total production costs is negligible.

7.2.3 Technical efficiency

The same household survey data set for three villages in Jiangxi Province was used to investigate the impact of land fragmentation on rice producers' technical efficiency, using a stochastic frontier function. Empirical results show that technical efficiency in one-season rice is lower than in double-rice production. The average technical efficiency scores (0.85 for early rice, 0.83 for late rice, and 0.79 for one-season rice) suggest that output increases in the order of 15-20% can be attained with the current levels of inputs. New technologies will have to be introduced to realize further increases in rice productivity.

The number of plots and the average plot size of a landholding have a significant impact on the technical efficiency of the farm household. An increase in the number of plots, with average plot size remaining constant, has a positive (scale) effect on technical efficiency. Likewise, for a given number of plots, an increase in average plot size has a positive effect on technical efficiency. Distance to the plots does not have a significant impact on technical efficiency for all the three kinds of rice. This indicates that farm household with large average distances to the plots are as efficient as farm with small average distances to the plots.

7.2.4 Farm management

Differences in the management of plots were analyzed for a sub-set of 47 households in the same three villages in Jiangxi Province. Plot-specific data for 154 plots that were collected among these households were used to estimate a simultaneous-equations model reflecting interactions between management decisions, soil quality and rice yield. Controlling for other factors affecting farm management decisions, we find that land fragmentation has mixed effects:

- on far-away plots, labor and manure use is lower but application of nitrogen fertilizers is higher;
- on large plots, use of labor, herbicides, and nitrogen fertilizers per unit area is lower, and economies of scale in crop husbandry can be realized; and
- on farms with a large number of plots, the use of herbicides per unit area is higher and the use of phosphorus fertilizers per unit area is lower.

From these results we conclude that land fragmentation does play a role in influencing farm management. Consolidating small, fragmented plots into a smaller number of large plots increases input-use efficiency. If the average distance of plots to the homestead is smaller, more labor and manure are likely to be used.

7.2.5 Rice yield and soil quality

The same plot-level data set and simultaneous-equations model are used to analyze the impact of farm management decisions on rice yield and soil quality. The production function specified in the model differs in one essential way from production functions commonly used by agricultural economists. Chemical fertilizers and manure affect crop yield only indirectly through their impact on the dynamic component of soil quality. The resulting production function reflects some important insights gained from agronomic science. The regression results for the resulting model indicate, among other things, that:

- labor use and herbicides application have a direct positive impact on crop yield;
- manure application has a positive impact on the stock and availability of macro-nutrients in the soil; the impact of chemical fertilizers on macro nutrients, however, could not be confirmed due to data limitations;
- only phosphorus and potassium availability in the soil affect rice yields; nitrogen and soil organic matter content, soil pH and topsoil depth are not significant;

Bearing in mind the mixed effects of land fragmentation on farm management decisions discussed above, we can conclude that land fragmentation has significant indirect effects on rice yields and soil quality. Consolidation of small, fragmented plots into a smaller number of larger plots increases input-efficiency by inducing lower quantities of labor and herbicides use at given yield levels. Moreover, if these plots are located closer to the homestead, more manure will be used. Increased manure use contributes to soil quality improvement and increases the availability of the two major yield-limiting factors in rice production in the research area, the available phosphorus and potassium in the soil.

7.3 Conclusions and policy implications

The following four major conclusions can be drawn from the findings of this study:

- Although land fragmentation has slightly declined during the 1990s, it is likely to remain high in China if the current principles underlying land distribution within villages are maintained. Increases in off-farm employment and land renting may reduce land fragmentation, but our results indicate that their impact is relatively modest.
- Increasing the average farm size and reducing the distance between the homestead and the plots can provide a significant contribution to the reduction of production costs in rice cultivation.
- Under existing technologies, a considerable productivity improvement can be achieved by addressing the factors constraining technical efficiency. Land consolidation can be an important option in this respect, as average plot size is

found to have a significant positive impact on technical efficiency in the three villages examined in this study.

- Land fragmentation also plays a role in farm management. Increasing the average plot size and/or reducing the distance of plots to the homestead increases input-use efficiency, improves the availability of two major yield-limiting factors in rice production in the research area (the available phosphorus and potassium levels in the soil), and improves soil quality.

Our findings have important policy implications. The empirical analysis on land fragmentation in this study indicates that small and highly scattered land plots will remain an important obstacle to cost reduction and productivity in rice production, and possibly even to soil quality improvement in the near future. A number of policy options can be suggested for reducing land fragmentation and promoting smallholder agricultural productivity in China:

1. The first is to reform the land distribution system so that land is assigned in terms of value instead of physical units. This can substantially reduce land fragmentation, because households no longer need to obtain at least one plot of each land class. At the same time, it will maintain equity among households. A major disadvantage is that evaluation of plot values may involve considerable cost.
2. A second option is to provide tradable land use rights to all farmers, so that they can freely transfer their agricultural land in the market. Currently, the development of a land rental market is severely hindered by the *hukou* system and other institutional bottlenecks. A recent survey held in eight provinces found that, although land transfers are encouraged by the government, only 3 - 4 % of the land is leased (Yao, 2000b). With further development of the economy, the liberalization of the *hukou* system, and increased off-farm employment opportunities, tradable land use rights are expected to provide an important contribution to the development of the land rental market. As argued in Chapter 3, however, the impact of land rental market development on land fragmentation under the current institutional environment is likely to be modest.

   Spontaneous land renting between farmers is currently characterized by a series of shortcomings, such as high transaction costs, short-term leases, and lack of formal contracts. It therefore hardly contributes to land consolidation in practice. In contrast, land markets organized by village collectives can reduce transaction costs and effectively promote land consolidation. However, as argued by Tian *et al.* (forthcoming), the involvement of village committees in land markets may lead to corruption and damage farmers' interests. In the future, introducing a democratic system of decision-making on land markets may be a feasible way to guarantee farm household benefits and at the same time contribute to land consolidation.

3. A third policy option is to promote the establishment of small, non-state-owned, local enterprises throughout the country that will absorb large numbers of rural laborers, and encourage migration of rural population to urban areas. This will not only create off-farm employment and increase non-agricultural incomes, but will also stimulate the trading of land use rights between households. If combined with the first two suggested policies, such a policy may lead to a substantial reduction in land fragmentation and hence to lower production costs and higher productivity.

Boosting the long-term agricultural production capacity has become a major policy focus since the beginning of 2005. To make this policy successful, large-scale investments in irrigation facilities, transport infrastructure, agricultural science and technology, and processing industries should be supplemented with measures providing farm household incentives to strengthen the long-term production capacity of their farms. The results of this study indicate that promoting land consolidation can play an important role in this respect. It will not only reduce production costs and increase the technical efficiency of farmers, but may also contribute to improved soil quality, and hence a stronger long-term production base.

7.4 Retrospect and suggestions for further research

This study has examined the impact of land fragmentation on agricultural production from several angles and at different levels (village, farm household, crop and plot level). The methods used and the choices made in this study, however, have certain limitations which may be addressed in future research:

(1) Factors driving land fragmentation were examined for Jiangxi Province, using the number of plots and average plot size as indicators of land fragmentation. Further research in this field might examine the extent to which the results obtained also hold for other regions within China. The other chapters in this study indicate that the distance between plots and the homestead also has important effects on rice production costs and input use efficiency. Future research may examine whether the factors explaining average plot distance to the homestead differ from those of the other two fragmentation indicators.

(2) The impact of land fragmentation on agricultural production is examined by partial analyses on rice production costs and technical efficiency, and by a simultaneous equations model of farm management decisions, agricultural yield and soil quality in rice production. The focus of the analysis is on production decisions. However, many households take simultaneous decisions on production, consumption, and investment. In the case of severe market imperfections, these decisions are interdependent (Sadoulet and DeJanvry, 1995). For a fuller understanding of the impact of land fragmentation on farm household decision making, an analysis that takes into account the impact of market imperfections on farm household decision making is desirable.

(3) The present study focuses on rice production. The degree of land fragmentation, however, may also have an impact on activity choices made by the households in our sample. Further research may address the implications of choices between alternative agricultural activities (*e.g.* vegetables, perennials, livestock) and non-agricultural activities for food production (and soil quality).

One important way to proceed may therefore be to develop farm household models that take into account interactions between consumption and production decisions, activity choices as well as the biophysical aspects of agricultural production (particularly soil quality) as a next step in order to derive a more complete analysis of the impact of land fragmentation. A second way may be to examine in more detail the policy options that we suggested above. In particular, the costs and benefits of a land distribution system based on land value and the involvement of village committees in land rental markets are issues that merit further research.

CURRICULUM VITAE

Tan Shuhao was born on February 20th, 1968 in Zhangshu, Jiangxi Province, P. R. China. She studied at the Soil Science Department of Nanjing Agricultural University from 1986 to 1990, obtaining a BSc degree in agronomy. From 1990 to 1994, she worked as a researcher and agricultural technician at Zhangshu Agricultural Bureau. From 1994 to 1997, she studied at the College of Land Management, Nanjing Agricultural University, obtaining an MSc degree with a major in Agricultural Resource Economics and Land Use Management. Her MSc thesis was on the grey linear programming model of land use structural optimization, with a case study of Zhejiang province.

From 1997 to 1999, she was appointed as an assistant, from 1999 to 2004, as a lecturer and since 2005, as an associate professor at the College of Land Management at Nanjing Agricultural University. Her teaching activities focus on Real Estate Economics, Regional Economics, and Resource & Environmental Economics. In 1999, she was at the same time appointed as a Ph.D. researcher at the Development Economics Group of Wageningen University. The Ph.D. research was conducted within the framework of the SERENA project, a cooperation between Nanjing Agricultural University (China), Wageningen University, and the Institute of Social Studies (The Hague), financed by the Netherlands Ministry of Development Cooperation (DGIS). The Ph.D. research included an explorative survey in 24 villages, detailed household surveys in three case-study villages and plot level input/output data collection and soil tests in Jiangxi Province, carried out in close collaboration with other project members both from the Netherlands and from China. In 2004-2005, the Ph.D. research was partly carried out at the Beijing Office of the International Food Policy and Research Institute (IFPRI). During the Ph.D. research, she successfully completed the training and supervision program of Mansholt Graduate School and had more than 15 papers published in national and international journals and books.

SUMMARY

To reverse the declining trend in food production in China since the end of the 1990s, the Chinese Government has recently implemented a series of measures to support the incomes of rural households, raise grain production, and promote the overall production capacity of the agricultural sector. Eliminating land fragmentation can make a significant contribution to these policy objectives by increasing the size of the effectively cultivated land area, economies of scale, reducing management inconvenience (including time lost in traveling between plots), and promoting the adoption of modern technologies like improved breeds, water-saving irrigation technologies, and mechanization.

Despite the high degree of land fragmentation in China, little research has been done so far on the consequences of land fragmentation for food production in China. Available research mainly focuses on the impact of land fragmentation on production efficiency using simple partial measures of efficiency and not controlling for other factors affecting productivity differentials between farmers. There is an urgent need for a more in-depth analysis of the impact of land fragmentation on food production in China.

The objective of this study is therefore to examine how and to what extent the high degree of land fragmentation affects food production in China. This general objective is realized by addressing the five research questions:

(1) What are the characteristics of land fragmentation in China? What drives differences in the degree of fragmentation?
(2) What is the impact of land fragmentation on smallholder rice production costs?
(3) What is the impact of land fragmentation on rice producers' technical efficiency?
(4) What is the relative importance of land fragmentation in smallholder farm management decisions compared to other factors?
(5) How do the resulting farm management decisions affect rice yield and soil quality?

The first part of question (1) is answered by analyzing trends in land fragmentation since the mid-1980s in China and its three major regions, and comparing land fragmentation in China with that in other countries for which data are available. We find

that land fragmentation is most severe in the Western part (with relatively large number of plots and small plot sizes) and the Eastern part (small farm sizes and plot sizes). During the 1990s, land fragmentation has decreased slightly (larger plot sizes and fewer plots) in all regions. Comparing land fragmentation in China with that in other countries for which data are available, we find that farm size and average plot size are much smaller in China.

Factors inducing land fragmentation, the second part of question (1), are analyzed empirically with data from 860 households in 11 villages in Jiangxi Province. The results show that the egalitarian principles used in distributing and reallocating land use rights to households have played a major role in causing land fragmentation in China. Land within each village is classified into different classes, with each household receiving land from each class. Moreover, land is basically assigned on the basis of household size, with large households receiving substantially more (and slightly bigger) plots than small households. We further find that land renting activities and involvement in off-farm employment reduce land fragmentation, but their impact is small. Missing markets or limited market access does not induce land fragmentation, as ‘demand-side’ explanations of fragmentation suggest. Instead, we find that landholdings in suburban areas are more fragmented than landholdings in remote areas, probably because farmers cultivate a wider range of (high value-added) crops in these areas.

The impact of land fragmentation on rice production costs, question (2) is examined on the basis of data from a household survey among 322 households in three villages in Northeast Jiangxi Province. The main finding is that, given other factors, farm size and distance to the plots have a significant impact on rice production cost. A 1% increase in farm size causes a 0.16% decrease in the total production cost per ton. If plots are located one minute walking closer to the homestead, the production cost per ton tends to be around 0.8% lower. The Simpson index (an indicator integrating number of plots, average plot size and distribution of plot sizes), however, does not have a significant impact on total production costs. But interestingly we find that an increase in the Simpson index of fragmentation induces a shift from the use of fertilizer, seed and oxen / tractors towards a higher use labor. This finding indicates that farmers with highly fragmented plots switch to more labor-intensive methods and use fewer modern technologies, but that the net impact of this switch on the total production cost is negligible.

A stochastic frontier function is used to answer question (3), the impact of land fragmentation on technical efficiency. The same household survey data set for three villages in Jiangxi Province is used for estimating this model in two steps. Empirical results show that technical efficiency in one-season rice is lower than in double-rice production. The average technical efficiency scores (0.85 for early rice, 0.83 for late rice, and 0.79 for one-season rice) suggest that output increases in the order of 15-20% can be reached with the current levels of inputs. New technologies will have to be introduced to realize further increases in rice productivity. We further find that the number of plots and the average plot size of a landholding have a significant impact on the technical efficiency of the farm household. An increase in the number of plots, with average plot size remaining constant, has a positive (scale) effect on technical efficiency. Likewise, for a given number of plots, an increase in average plot size has a positive effect on technical efficiency. Distance to the plots does not have a significant impact on technical efficiency for all the three kinds of rice. This indicates that farm household with large average distances to the plots are as efficient as farm with small average distances to the plots.

The relative importance of land fragmentation in farm management decisions, question (4), was analyzed for a sub-set of 47 households in the same three villages in Jiangxi Province. Plot-specific data for 154 plots that were collected among these households were used to estimate a simultaneous-equations model reflecting interactions between management decisions, soil quality and rice yield. Controlling for other factors affecting farm management decisions, we find that land fragmentation has mixed effects:

- on far-away plots, labor and manure use is lower but application of nitrogen fertilizers is higher;
- on large plots, use of labor, herbicides, and nitrogen fertilizers per unit area is lower, and economies of scale in crop husbandry can be realized; and
- on farms with a large number of plots, the use of herbicides per unit area is higher and the use of phosphorus fertilizers per unit area is lower.

From these results we conclude that land fragmentation does play a role in farm management. Consolidating small, fragmented plots into a smaller number of large plots increases input-use efficiency. If these plots are located closer to the homestead, more labor and manure are likely to be used.

The same plot-level data set and simultaneous-equations model are used to answer question (5), the impact of farm management decisions on rice yield and soil quality. The production function specified in the model differs in one essential way from production functions commonly used by agricultural economists. Chemical fertilizers and manure affect crop yield only indirectly through their impact on the dynamic component of soil quality. The resulting production function reflects some important insights gained from agronomic science. The regression results for the resulting model indicate, among other things, that:

- labor use and herbicides application has a direct positive impact on crop yield;
- manure application has a positive impact on the stock and availability of macro-nutrients in the soil; the impact of chemical fertilizers on macro nutrients, however, could not be confirmed due to data limitations;
- only phosphorus and potassium availability in the soil affect rice yields; nitrogen and soil organic matter content, soil pH and topsoil depth are not significant.

Bearing in mind the mixed effects of land fragmentation on farm management decisions discussed above, we can conclude that land fragmentation has significant indirect effects on rice yields and soil quality. Consolidation of small, fragmented plots into a smaller number of larger plots increases input-efficiency by inducing lower quantities of labor and herbicide use at given yield levels. Moreover, if these plots are located closer to the homestead, more manure will be used. Increased manure use contributes to soil quality improvement and increases the availability of the two major yield-limiting factors in rice production in the research area, the available phosphorus and potassium in the soil.

This study contributes to the existing literature in a number of ways. It is the first study providing an in-depth analysis of land fragmentation and its impact on smallholder agricultural production in China. Rural Fixed Observation data are used to examine the dynamic aspects of land fragmentation. Such accurate and large scale data sets can rarely be found in other developing countries where land fragmentation is widespread. These data are used in this study to examine the trends in land fragmentation and to analyze the driving forces behind these trends in order to formulate feasible policy recommendations for reducing land fragmentation. This is the second major contribution of this study.

The third innovation is the use of a broad range of land fragmentation indicators, covering different dimensions of the problem. This study uses not only the number of plots and average plot size, but also the distance of a plot to the homestead to reflect the spatial distribution of the plots. By using indicators of different dimensions of the land fragmentation problem, more detailed insights into its impact on agricultural production can be obtained.

The fourth innovation is the use of a farm household model framework to examine the impact of land fragmentation on production costs and technical efficiency. In this approach, farm households are assumed to maximize their utility given a number of constraints that they are facing. It allows a formal derivation of the control factors to be included in empirical analyses of the impact of land fragmentation.

Fifthly, this study empirically examines the impact of land fragmentation on soil quality, a major factor in (future) agricultural production capacity. It develops a model of interactions between farm management activities, rice yield, and soil quality, and examines how land fragmentation affects farm management decisions, and though this also soil quality and rice yield. The production function used in this analysis differs from traditional functions used in agricultural economics by including soil quality indicators (as proximate determinants of yield) instead of soil management variables. In this approach, which is based on insights from agronomy and soil science, fertilizer use and manure application affect rice yield in an indirect way by changing soil quality. Moreover, fertilizer use is subdivided into N, P and K according to the nutrient content of the applied fertilizers, because different crops or crop varieties generally react differently to different macro-nutrients, and because fertilizer types with different compositions have different effects on soil quality. The separation of fertilizer use into its macro-nutrient components makes it possible to estimate which component is yield-limiting in the research area, and to formulate specific recommendations concerning desired changes in fertilizer applications for farm households in the research area.

The study ends with some policy recommendations for reducing land fragmentation in China. Three policy options are distinguished, namely to replace land distribution based on physical units by a system based on land values, to provide tradable land use rights to all farmers, so that they can freely transfer their agricultural land in the market, and to promote the establishment of a local, small, non-state-owned enterprise sector in rural areas with limited off-farm employment opportunities. A combination of these three policies is likely to lead to a significant reduction in land fragmentation, and thereby reduce production costs and stimulate productivity and soil quality improvement. As such, it can provide important incentives to farm households to strengthen the long-term production capacity of their farms, and make the agricultural sector more capable of meeting the challenges of increased foreign competition.

SAMENVATTING

Sinds het eind van de jaren 90 is er sprake van een dalende trend in de binnenlandse voedselproductie in China. Om deze trend te doen keren heeft de Chinese overheid recentelijk een aantal maatregelen genomen om de inkomens van rurale huishoudens te bevorderen, de graanproductie te verhogen en de productiecapaciteit in de landbouw uit te breiden. Het elimineren van landfragmentatie kan een belangrijke bijdrage leveren aan deze beleidsdoelstellingen doordat het de omvang van het effectief bewerkte landareaal verhoogt, schaalvoordelen realiseert, management ongemakken (inclusief de verloren gegane reistijd tussen de verschillende percelen) terugdringt, en de toepassing van moderne technologieën zoals verbeterde rassen, waterbesparende irrigatie en mechanisatie bevordert.

Ondanks de hoge graad van landfragmentatie heeft er weinig onderzoek naar de gevolgen van landfragmentatie voor voedselproductie in China plaatsgevonden. Beschikbaar onderzoek richt zich met name op de invloed van landfragmentatie op productie-efficiëntie, daarbij gebruik makend van simpele, partiële maatstaven van efficiëntie, en zonder te corrigeren voor andere factoren die van invloed zijn op productiviteitsverschillen tussen boeren. Er bestaat derhalve dringend behoefte aan een meer diepgaande analyse van de invloed van landfragmentatie op voedselproductie in China.

Het doel van deze studie is te onderzoeken hoe, en in welke mate, landfragmentatie van invloed is op voedselproductie in China. Om dit doel te bereiken worden vijf onderzoeksvragen behandeld:

(1) Wat zijn de kenmerken van landfragmentatie in China? Wat bepaalt de verschillen in mate van landfragmentatie?

(2) Wat is de invloed van landfragmentatie op de productiekosten van kleine rijstproducenten?

(3) Wat is de invloed van landfragmentatie op de technische efficiëntie van rijstproducenten?

(4) Wat is het relatieve belang van landfragmentatie vergeleken met andere factoren in managementbeslissingen van kleine producenten?

(5) Hoe beïnvloeden de resulterende managementbeslissingen de opbrengst van rijst en de kwaliteit van de landbouwgrond?

Het eerste deel van vraag (1) wordt beantwoord door de trends in landfragmentatie te analyseren sinds het midden van de jaren 80 in de drie belangrijkste regio's en in China als geheel, en door landfragmentatie in China te vergelijken met andere landen waarvoor data beschikbaar zijn. We concluderen dat landfragmentatie het grootst is in het westelijk deel (relatief veel percelen and kleine omvang van percelen) en het oostelijk deel van China (kleine bedrijfsomvang en kleine omvang van percelen). In vergelijking met andere landen is de bedrijfsomvang en de gemiddelde omvang van percelen veel kleiner in China.

De factoren die van invloed zijn op landfragmentatie, het tweede deel van vraag (1), zijn geanalyseerd met gegevens voor 860 huishoudens in 11 dorpen in de provincie Jiangxi. De resultaten geven aan dat het gelijkheidsprincipe dat wordt gehanteerd bij de toewijzing en de herverdeling van landgebruiksrechten aan huishoudens voor een belangrijk deel verantwoordelijk is voor de hoge mate van landfragmentatie. Het beschikbare land in ieder dorp wordt onderverdeeld in verschillende klassen, waarbij iedere huishouding recht heeft op een stuk land van elke klasse. Bovendien wordt de omvang van het toegewezen land grotendeels bepaald door de omvang van een huishouden, waardoor grote huishoudens meer (en grotere) percelen krijgen toegewezen dan kleine huishoudens. Voorts vinden we dat land- verhuur van land en werkzaamheid buiten het eigen bedrijf leiden tot een lagere mate van landfragmentatie, maar de invloed van deze factoren is gering. Beperkte toegang tot markten of afwezigheid van markten draagt niet bij tot landfragmentatie, zoals 'vraagzijde' theorieën van fragmentatie suggereren. In plaats daarvan vinden we dat bedrijven in semi-urbane gebieden meer gefragmenteerd zijn dan bedrijven in afgelegen gebieden, waarschijnlijk omdat boeren in eerstgenoemde gebieden een groter aantal gewassen (met een hoge toegevoegde waarde) telen.

De invloed van landfragmentatie op rijstproductiekosten, onderzoeksvraag (2), is geanalyseerd op basis van gegevens uit een enquête onder 322 huishoudens in drie dorpen in het noordoosten van de provincie Jiangxi. De belangrijkste uitkomst is dat, gegeven de overige factoren, bedrijfsomvang en afstand tussen het woonhuis en de percelen een significante invloed hebben op rijstproductiekosten. Een toename van 1% in de bedrijfsomvang leidt tot een afname van 0.16% in de totale productiekosten per ton;

productiekosten zijn ongeveer 0.8% lager als de loopafstand van het woonhuis naar een perceel met 1 minuut afneemt. De Simpson Index (een maatstaf die het aantal percelen, de gemiddelde perceelomvang en de verdeling van de perceelomvang binnen een bedrijf integreert) heeft echter geen significante invloed op de totale productiekosten. Wel vinden we dat een hogere Simpson Index van landfragmentatie resulteert in een verschuiving van het gebruik van kunstmest, zaad en trekkracht (ossen, tractoren) naar het gebruik van meer arbeid. Dit resultaat geeft aan dat boeren met sterk gefragmenteerd land meer arbeidsintensieve methodes in plaats van moderne technologieën gebruiken, maar dat de netto invloed hiervan op de totale productiekosten te verwaarlozen is.

Voor de beantwoording van vraag (3), de invloed van landfragmentatie op technische efficiëntie, is gebruik gemaakt van een stochastisch frontier model. Dezelfde huishoud-enquêtegegevens voor 3 dorpen in de provincie Jiangxi zijn gebruikt voor het schatten van dit model in twee stappen. De resultaten geven aan dat technische efficiëntie in één-seizoens rijstproductie lager is dan in twee-seizoens productie. De gemiddelde technische efficiëntie scores (0.85 voor vroege rijst, 0.83 voor late rijst, en 0.79 voor één-seizoens rijst) suggereren dat een productietoename van 15-20% gerealiseerd kan worden met de hoeveelheid productieve inputs die momenteel gebruikt worden. Voor verdere toenames in rijstproductie is de invoering van nieuwe technologieën vereist. We vinden verder dat het aantal percelen en de gemiddelde perceelsomvang op een bedrijf een significante invloed hebben op de technische efficiëntie van een agrarische huishouding. Een toename in het aantal percelen, bij een gegeven gemiddelde perceelsomvang, heeft een positief (schaal)effect op technische efficiëntie. De afstand naar de percelen heeft geen significante invloed op technische efficiëntie voor alle drie soorten rijst. Dit betekent dat huishoudens met relatief grote gemiddelde afstanden naar de percelen even efficiënt zijn als boeren die op kleinere afstand van de percelen wonen.

Het relatieve belang van landfragmentatie in managementbeslissingen van kleine producenten, vraag (4), is geanalyseerd voor een deelgroep van 47 huishoudens in dezelfde drie dorpen in de provincie Jiangxi. Perceel-specifieke gegevens voor 154 percelen, die verzameld zijn voor deze huishoudens, zijn gebruikt om een systeem van simultane vergelijkingen te schatten dat de interacties tussen managementbeslissingen, bodemkwaliteit en rijstopbrengsten weergeeft. Gegeven de andere factoren die managementbeslissingen beïnvloeden, vinden we gemengde effecten voor landfragmentatie:

- op verafgelegen percelen is het gebruik van arbeid en mest lager en het gebruik van stikstof hoger;
- op grote percelen is het gebruik van arbeid, onkruidbestrijdingsmiddelen en stikstof per hectare hoger en kunnen schaalvoordelen worden gerealiseerd; en
- op bedrijven met een groter aantal percelen is het gebruik van onkruidbestrijdingsmiddelen per hectare hoger en het gebruik van fosfor per hectare lager.

Op basis van deze resultaten concluderen we dat landfragmentatie een rol speelt in het management van bedrijven. Consolidatie van een groot aantal kleine percelen in een klein aantal grote percelen verhoogt de efficiënte van het gebruik van productieve inputs. Wanneer deze percelen dichter bij het woonhuis gelegen zijn, wordt er waarschijnlijk ook meer arbeid en mest op deze percelen gebruikt.

Dezelfde gegevens voor 154 percelen en hetzelfde model zijn gebruikt om onderzoeksvraag (5), de invloed van managementbeslissingen op rijstopbrengst en bodemkwaliteit, te beantwoorden. De productiefunctie in dit model verschilt op één belangrijke wijze van productiefuncties die gewoonlijk door landbouweconomen worden gebruikt. Kunstmest en mest beïnvloeden de opbrengst van het gewas op een indirecte manier door middel van hun effect op de dynamische component van bodemkwaliteit. De resulterende productiefunctie geeft een aantal belangrijke inzichten uit de agronomie weer. De regressieresultaten van het model wijzen o.a. uit dat:

- gebruik van arbeid en onkruidbestrijdingsmiddelen een direct positief effect op de opbrengst hebben;
- gebruik van mest een positief effect heeft op de voorraad en beschikbaarheid van macronutriënten in de bodem; de invloed van kunstmest op macronutriënten kon echter niet geverifieerd worden vanwege beperkingen in de beschikbare gegevens;
- alleen de beschikbare fosfor en kalium in de bodem beïnvloeden de rijstopbrengst; de stikstof en het organisch stofgehalte, alsmede pH en de diepte van de bovenste bodemlaag hebben geen significant effect op de rijstopbrengst.

Wanneer we ook de bovengenoemde (gemengde) effecten van landfragmentatie op managementbeslissingen in beschouwing nemen, kunnen we concluderen dat landfragmentatie significante effecten heeft op de rijstopbrengst en op de bodemkwaliteit. Consolidatie van een groot aantal kleine percelen in een klein aantal grote percelen verhoogt de efficiënte van het gebruik van productieve inputs vanwege het gebruik van minder arbeid en onkruidbestrijdingsmiddelen bij gegeven opbrengsten. Bovendien zal meer mest gebruikt worden indien deze percelen dichter bij het woonhuis gelegen zijn. Een toename van het gebruik van mest verhoogt de bodemkwaliteit en de beschikbaarheid van twee belangrijke opbrengstbeperkende factoren in rijstproductie in het onderzoeksgebied, namelijk de beschikbare hoeveelheden fosfor en kalium in de bodem.

Deze studie levert een aantal bijdragen aan de beschikbare literatuur. Het is de eerste studie die een diepgaande analyse maakt van landfragmentatie en de invloed daarvan op de landbouwproductie van kleinschalige producenten in China. Gegevens van een vaste steekproef onder rurale huishoudens zijn gebruikt om de dynamische aspecten van landfragmentatie te analyseren. Een dergelijke grootschalige en nauwkeurige gegevensverzameling is zelden beschikbaar voor andere ontwikkelingslanden waar landfragmentatie een wijdverspreid verschijnsel is. Deze gegevens zijn gebruikt om de trends in landfragmentatie en de drijvende krachten achter deze trends te analyseren, om zodoende beleidsaanbevelingen voor het terugdringen van landfragmentatie te kunnen formuleren. Dit is de tweede belangrijke bijdrage van deze studie.

De derde innovatie is het gebruik van meerdere indicatoren van landfragmentatie die de verschillende dimensies van het probleem weergeven. In deze studie worden niet alleen het aantal percelen en de gemiddelde perceelsomvang gebruikt, maar ook de afstand tussen een perceel en het woonhuis als indicator van de ruimtelijke verdeling van de percelen. Door indicatoren van meerdere dimensies van landfragmentatie te gebruiken, kan een meer gedetailleerd inzicht van de invloed van fragmentatie op landbouwproductie worden verkregen.

De vierde innovatie is het gebruik van een landbouwhuishoudmodel om de invloed van landfragmentatie op productiekosten en technische efficiëntie te analyseren. In deze methode wordt aangenomen dat landbouwhuishoudens hun nut maximaliseren onder een aantal randvoorwaarden. Dit maakt het mogelijk om af te leiden welke factoren meegenomen dienen te worden in een empirische analyse van de effecten van landfragmentatie.

Ten vijfde maakt deze studie een empirische analyse van de invloed van landfragmentatie op bodemkwaliteit, een belangrijk element in de (toekomstige) productiecapaciteit van de landbouwsector. Hiertoe wordt een model van interacties tussen managementbeslissingen, rijstopbrengsten en bodemkwaliteit geschat en gebruikt om de invloed van landfragmentatie op deze variabelen te onderzoeken. De productiefunctie die wordt gebruikt in deze analyse verschilt van traditionele productiefuncties in de landbouweconomie vanwege de opname van bodemkwaliteitsindicatoren (als meest directe determinanten van opbrengsten) in plaats van bodemmanagement variabelen. In deze, op inzichten uit de agronomie en bodemwetenschappen gebaseerde, aanpak, hebben kunstmestgebruik en mestgebruik een indirect effect op de rijstopbrengst door middel van veranderingen in bodemkwaliteit. Bovendien wordt kunstmestgebruik onderverdeeld in N, P en K op basis van de nutriëntengehaltes van de verschillende gebruikte kunstmesttypes. De reden hiervoor is dat verschillende gewassen en gewasvariëteiten verschillend reageren op elk van deze drie macronutriënten, en dat de effecten op de bodemkwaliteit verschillen voor kunstmest van verschillende samenstellingen. Uitsplitsing van kunstmest in de drie macro-nutriënten maakt het mogelijk om te bepalen welke nutriënt de beperkende factor is in het onderzoeksgebied, en om specifieke aanbevelingen met betrekking tot kunstmestgebruik te formuleren voor huishoudens in het onderzoeksgebied.

De studie eindigt met een aantal beleidsaanbevelingen voor het reduceren van landfragmentatie in China. Drie beleidsopties worden hierbij onderscheiden, namelijk om het systeem van landtoedeling aan huishoudens niet te baseren op fysieke eenheden maar op de waarde van de landbouwgrond, om verhandelbare gebruiksrechten toe te kennen aan alle huishoudens zodat landbouwgrond vrijelijk verhandeld kan worden, en om kleinschalige, private bedrijfjes te bevorderen in rurale gebieden met beperkte werkgelegenheid buiten de landbouw. In combinatie kunnen deze drie beleidsmaatregelen waarschijnlijk tot een aanzienlijke reductie van landfragmentatie leiden, en daardoor tot een verlaging van de productiekosten in de landbouw en een verhoging van de productiviteit en de bodemkwaliteit. Dit kan een belangrijke stimulans betekenen voor huishoudens om de lange-termijn productiecapaciteit van hun bedrijven te verhogen, en daardoor de landbouwsector in China in staat te stellen de uitdaging met de toegenomen buitenlandse concurrentie aan te gaan.

COMPLETED TRAINING AND SUPERVISION PLAN

Activities	*Institute*	*Year*	*Credits*[1]
Courses:			
Time planning and project management	Wageningen Graduate School	2003	1
Mansholt multidisciplinary seminar (Does land fragmentation matter for farm management and soil quality?)	Mansholt Graduate School	2004	1
Introductory course of Mansholt Graduate School	Mansholt Graduate School	2003	1
Training on bio-economic modeling	Mansholt Graduate School	2002	1
Parametric analysis on efficiency and productivity	Mansholt Graduate School	2003	2
Non-parametric analysis on efficiency and productivity	Mansholt Graduate School	2003	2
New institutional economics: property rights, contracts and transaction costs	Mansholt Graduate School	2004	2
Farm household economics	Wageningen University	1999	3
Regional agricultural development: analysis and policy	Wageningen University	1999	3
Quantitative analysis of development policy	Wageningen University	1999	3
Macroeconomic analysis and policy	Wageningen University	1999	3
Econometrics II	Wageningen University	1999	4
Presentations at international conferences:			2
2nd International Convention for Asian Scholars	Free University, Berlin, Germany	2001	
International conference on “Economic Transition and Sustainable Agricultural Development in Eastern Asia”	Nanjing Agricultural University, Nanjing, China	2003	
International Symposium on “China’s Rural Economy After WTO: Problems and Strategies”	Zhejiang University, Hangzhou, China	2004	
Teaching activities:			
Real Estate Economics	Nanjing Agricultural University, China	2000/ 2001	
Regional Economics	Nanjing Agricultural University, China	2001/ 2002	
Resource and Environmental Economics	Nanjing Agricultural University, China	2002/ 2005	
Total (min. 20 credits)			28

[1] credit represents 40 hours.

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