

**THE ECONOMICS OF LAND FRAGMENTATION
IN THE NORTH OF VIETNAM**

by

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Abstract

Land fragmentation, in which a single farm household operates more than one separate piece of land, is a significant issue in Vietnamese agriculture, especially in the North. For the whole country, there are about 75 million plots of land, an average of 7-8 plots per farm household. Such fragmentation can be seen to have negative and positive benefits for farm households and the community generally. The negative impacts can be reduced mechanisation, higher costs, loss of land due to boundaries, increased negative externalities, and more limited application of new technologies. On the other hand, land fragmentation may have some benefits to farmers such as spreading output risk, seasonal labour use, and crop diversification. Comparative static analysis and analysis of survey data have led to the conclusion that small sized farms are likely to be more fragmented and the number of plots held by a household is not a significant determinant of yield and output risk spreading but is a significant factor in crop diversification. Policies which allow the appropriate opportunity cost of labour to be reflected at the farm level may provide appropriate incentives to trigger farm size change and land consolidation. Policies which tip the benefits in favour of fewer and larger plots such as strong and effective research and development, an active extension system and strong administrative management may also lead to land consolidation and thus allow some of the benefits which will accrue to the economy more generally to be obtained by farmers.

Introduction

Land fragmentation where “a single farm consists of numerous parcels, often scattered over a wide area” (Binns 1950) is a common phenomenon and one of the important features of agriculture in many countries, especially in developing countries. For example, land fragmentation is present in Jordan, Ghana, Rwanda and China (Blarel et al. 1992; Jabarin and Epplin 1994; Nguyen et al. 1996; Wan and Cheng 2001) Fragmentation is a phenomenon of agriculture not only in Asia, and Africa, but in European countries as well (Sabates-Wheeler 2002). In Vietnam, land fragmentation is common especially in the North. For the whole country, there are about 75 million parcels of land, an average of 7-8 plots per farm household (Marsh and MacAulay 2002). Land fragmentation is considered an impediment to efficient crop production which is the reason why many countries have implemented policies encouraging land consolidation. Such policies have been implemented in Kenya, Tanzania, Rwanda (Blarel et al. 1992), Albania, Bulgaria (Lusho and Papa 1998; Sabates-Wheeler 2002) and are now being considered in Vietnam. In the larger context, if land fragmentation means that more labour and other resources are used than is necessary and that these resources can be used more effectively elsewhere in the economy, then there is likely to be an overall economic gain from reduced fragmentation. However, even though land fragmentation may have negative impacts on farms and the overall economy, there are reasons why it may be beneficial to farmers so that they attempt to keep some degree of fragmentation. Some of these

issues will be examined.

The aim of the paper is to investigate the current situation of land fragmentation in the North of Vietnam, its effects and relationship to crop productivity. Comparative static analysis approaches are proposed to examine the relationship between land fragmentation and farm size, agricultural production ability, off-farm jobs, and the amount of land rented in and out. The role of land fragmentation in spreading output risk is also considered. In order to work toward these objectives, the specific issues to be examined are: (1) what is the level of land fragmentation in the North of Vietnam; (2) whether land fragmentation does or does not have an effect on crop productivity; (3) whether land fragmentation does or does not reduce output risks of crop production; and (4) which policies are needed to facilitate land consolidation in the future.

The paper is organised as follows. In section two some background to Vietnamese agriculture and the issue of land fragmentation in the North of Vietnam is presented. Causes, advantages and disadvantages of land fragmentation are discussed in section three. Evidence of land fragmentation in the North of Vietnam and its relationship to crop productivity, farm size and other factors are mentioned in section four. The comparative static analysis is presented in section five. In sections six and seven empirical models are proposed which allow the examination of effects of land fragmentation on crop productivity and diversification and risk spreading. Conclusions and policy implications are drawn in the last section.

Background

Vietnam started on its path of overall economic reforms with the introduction of the *Doi Moi* (renovation) policy in 1986. The *Doi Moi* was launched and aimed to shift the Vietnamese economy from a central planning model to a largely market based one. In the agricultural sector, the Resolution 10 of the Politburo of the Central Committee of the Communist Party of Vietnam in 1988, which was commonly known as *Khoan 10* (Contract 10) system, was a radical reform. The main ideas of this policy were to recognise the farm household as an autonomous economic unit and free markets for inputs and outputs as well as the means of production (except land), liberalise prices, provide longer terms for land use rights and more freedom for farmers in choosing the crops to be produced, reduce land use tax, and the demise of the agricultural cooperatives (Pingali and Xuan 1992; Hung and Murata 2001; Nakachi 2001; Marsh and MacAulay 2002; Ministry of Agriculture and Rural Development 2002). Under the *Khoan 10* policy, farmers were allocated land for stable use for 15 years and assigned 'contract levels' for inputs used, outputs, and labour which was stable for five years. Since then, most of the means of production (machines, buffaloes, cattle and agricultural instruments) have been recognised as privately owned. This policy was the main factor that mobilised farmers to use production resources more efficiently. Another component of this policy was that the income of farmers depended on how many stages they were responsible for, but it could not be less than 40 percent of total production output (Ministry of Agriculture and Rural Development 2000). This meant that labour was transferred from hired labour to self-employed, which also mobilised farmers to use all their capacity. Since then, Vietnam's agriculture has entered a new and relatively more stable development

stage. However, the duration of land allocation was short and other land use rights still were not supported by the legal system (Nakachi 2001). This meant that farmers did not have incentives for long-term investment in their land.

The 1993 Land Law was enacted in response to the above mentioned demands. Under the Land Law, farmers were allocated land for long term and stable use and they were granted five rights of land use including the rights of transfer, exchange, lease, inheritance and mortgage. The duration of land allocation was 20 years for land used for annual crops and aquaculture, and 50 years for land used for perennial crops and it could be renewed if the holder still had a need for the land (Ministry of Agriculture and Rural Development 2000). Thus, this could allow the state to make adjustments or a reallocation (Kerkvliet 2000). The Land Law also put a ceiling on the land areas allocated to farm households. The limit for annual crop land was two hectares in the central and northern provinces and three hectares in the southern provinces. For perennial crop land the land limit was 10 hectares in communes with flat fields and 30 hectares in midland or mountainous communes (Ministry of Agriculture and Rural Development 2000; Marsh and MacAulay 2002). Actually, these limits were not constraints in many provinces in the deltas, especially in the Red River Delta. In these areas, farmers were not concerned about land limits because their land holdings were much lower than this ceiling¹.

The most important principle of the land allocation was to maintain equality, but there were different procedures in different provinces. Commonly, many localities in the north allocated a certain amount of land to each *Dinh Suat* (per capita equivalent)² (Hung Yen People's Committee 2002). Moreover, land was allocated not only on the basis of the number of household members (per capita equivalent) but also on the basis of social policies. Households with members who had been wounded or had died during the wars, received an additional amount of land (Kerkvliet 2000). For example, in Hung Yen province the additional amount of land was one *sao*³ (360 m²) for each wounded soldier and martyr (Hung Yen People's Committee 2002). In addition, households with members who had retired from government organizations or the state-owned enterprises could receive an additional amount of land which was dependent on the availability of land in the commune⁴. Other conditions that were also taken into consideration for the amount of land allocated were land quality, the irrigation system, distance to plots, and capacity for crop rotation. In Vietnam, annual crop land was divided into six categories⁵. Therefore, in order to maintain the principle of equality each household may have plots with different categories, locations and quality of land. As a result, a household had a number of plots, often scattered over a wide area. For example, in the Red River Delta each farm household, on average, had eight or nine plots often less than 200 to 500 m² each (World Bank in

¹ In 1998, average farm size was 0.25 and 1.18 hectares in the Red River and Mekong River Delta, respectively.

² A *Dinh Suat* (per capita equivalent) is generally a person in the agricultural population.

³ *Sao* is a common unit of land areas in the north of Vietnam.

⁴ In Vietnam, people who work in private companies do not usually receive a pension or other payment when they retire.

⁵ In the upland and mountainous areas, land was more scattered and the number of categories of land could be more than six.

Vietnam 1998). That is why land fragmentation is a significant issue in this delta in particular and in the north and in the north central part of Vietnam in general.

Land allocation in the Central Highlands, the South and some provinces in the northern mountainous areas was different. Based on historical considerations, in these areas land was returned to previous ‘owners’. In fact, in these regions land allocation was not really present as in the Red River Delta. Land cultivated by farmers was recognised by the government as belonging to them if there were no conflicts over the land. Farmers were given land use certificates (the Red Book) on the basis of the actual situation of their fields and negotiation between farmers (Ministry of Agriculture and Rural Development 2002). This is likely to be one of the reasons why in these areas (except the northern mountainous areas) land fragmentation is not a serious problem. However, other social issues have appeared such as landless farmers and a tenant class. Another issue occurs in the North, especially in the Red River Delta, where people who were born after the land allocation (1993) have not been allocated land and the land of people who died after this point of time has not been withdrawn. This is why some farmers in these areas have requested a re-allocation of land. However, new land allocation is still not accepted by the central and local governments (Ministry of Agriculture and Rural Development 2002).

The issue of land fragmentation, which resulted from this ‘equitable’ allocation of agricultural land, has emerged in recent years. According to data from the Statistical Register Department, Land Management Office, in 1998, on average, a farm in the Red River Delta and the Northern Mountainous and Midlands region had seven and 10-20 plots respectively, while this figure for a farm in the Mekong River Delta was only three parcels (Lan 2001). However, within a region there were different degrees of land fragmentation. Some locations were more serious, others not. Data from 42,167 farm households in 27 communes in Hung Yen province show that after the land allocation was made in 1993, on average a farm had 7.58 plots (Hung Yen People's Committee 2002). In 1993, land allocations were made to 34,346 farm households in Kim Son district, Ninh Binh province⁶ and resulted in 67,250 plots. On average, there were only 1.96 plots per household. Some 12,573 households, or 36.6 percent, had only one plot, 13,540 households (39.4%) had two plots, 5,525 households (16.1%) had three plots, 2,542 households (7.4%) had four plots; 142 households (0.4%) had five plots, and 24 households (0.1%) had six plots (Khoa 2003).

During the *Doi Moi* period, a series of policies and laws especially concerned with land use in the agricultural sector were issued. The most important policies were the Ordinance 64/CP (1993) and 02/CP (1994) of the government on the regulation of agricultural and forestry land allocation. In addition, there were revised versions of the Land Law in 1998, 2001, and 2003. There were also other policies related directly to land issues: such as the Ordinance 17/CP (1999) of the government on the procedure of exchange, transfer, lease, release, heritage, mortgage of land use rights, and ‘joint capital’⁷ by using the value of land use rights; the Resolution 03/NQ-CP (2000) of the government on the allocation, lease, assignment and accumulation of land; and the Decision 661/QD-TTg (1998) of the Prime Minister on the task, target,

⁶ Hung Yen and Ninh Binh province are both located in the Red River Delta.

⁷ ‘Joint capital’ means that land user can use land use rights as capital in joint venture arrangements.

and implementation of the Five Million Hectares Reforestation Programme (Programme 661). These policies contributed significantly to efficient land use and stable land relations in Vietnam and the undeniable achievements in the agricultural and rural sectors during recent years.

In 1998, the government issued a policy to promote the exchange of land plots so as to encourage larger plot areas. This policy was known as *Don Dien, Doi Thua* (plot exchange). Since then, provinces in the North, especially in the Red River Delta, have established steering committees for conducting pilot studies on plot exchange. Throughout the whole country, there are 700 communes in 20 provinces where plot exchanges were and are being implemented, but progress is still slow. In these areas land was effectively re-allocated to farmers with a target to reduce the number of plots. In Thanh Hoa province, for example, the number of plots decreased by 51.5 percent after three years implementation of the policy (1998-2001) in 391 communes in 16 flat field districts of a total 27 districts. On average, the number of plots per farm household decreased from 7.8 to 3.8 plots (Ministry of Agriculture and Rural Development 2002). In 1998, three communes were chosen to implement plot exchange in Hung Yen province. At the end of 2001, the Hung Yen People's Committee decided to expand this process to 35 communes in 10 districts. Each commune was supported by an amount of 20 million Vietnamese Dong (VND) to organise this work. After implementing the policy, the total number of plots of land decreased by 57.9 percent from 319,453 to 134,508 plots. The average number of plots per household decreased from 7.58 to 3.42. Fifty one percent of households had three plots or less. In some communes, there were on average around two plots per farm household, such as in Dan Tien 2.12 (decreased from 5.57 plots) and Chi Dao 2.43 (decreased from 5.11 plots). The highest average numbers of plots per household were 4.81 and 4.79 (decreased from 7.97 and 7.0 plots) in Trung Dung and Hung An communes respectively (Hung Yen People's Committee 2002).

In reports made to the central and local governments, the conclusion is that the policy of plot exchange should be implemented where farmers realise there is a problem of fragmentation and land relations are in order (Ministry of Agriculture and Rural Development 2002). This means that plot exchange should not lead to new conflicts related to land allocation. The most important principle is that farmers should voluntarily exchange land to result in larger plot areas for each individual (Ministry of Agriculture and Rural Development 2002). However, in many provinces the land re-allocation process occurs without much input from farmers. Farmers are only involved in the assessment of land quality in order to determine the exchange coefficients⁸. Farmers still believe that land is owned by the state (the people as a whole), so they believe they do not have rights to be involved in the process and discuss how land use planning should be in general.

⁸ In some communes in Hung Yen province, the coefficient is 1.9 between the lowest and highest quality of land. This means that a farmer can be allocated one *Sao* (360 m²) of land of class one (the highest quality) or 1.9 *Sao* of land of class six.

Reasons for Land Fragmentation

In the literature, researchers have preferred to classify causes of land fragmentation into two broad categories: *supply-side* and *demand-side* (Bentley 1987; Blarel et al. 1992). The supply-side causes refer to an exogenous imposition on farmers of a pattern of land areas, while the second reflects varying degrees of fragmentation chosen by farmers (Blarel et al. 1992).

A supply-side explanation of land fragmentation the view is that it may happen involuntarily as a result based on historical, geographical issues, population pressure and patterns of inheritance (Bentley 1987). Historical issues may be more significant where land is scarce. In most developing countries in Africa and Asia where labour is cheap, crop production is mainly carried out by hand cultivation and animal traction. This is suited to small-scale and self-sufficient production. In such cases, fragmentation is a certain result. Where production volume is large, fragmentation may become a barrier to modern mechanisation and lead to increases in inefficiency. Fragmentation is also a result of geographical conditions where the terrain is hilly and upland areas exist. In these areas, land fragmentation is common. Historical and geographical problems of land fragmentation are hard to overcome and it may take a long time to consolidate such land areas.

Land fragmentation can also be explained by pressure of population growth (Bentley 1987; Blarel et al. 1992). Farms in regions where population growth is high and farmers have less off-farm opportunities, may be more fragmented. This explanation is common in the north of Vietnam where the population density is high, especially in the Red River Delta. In 1998, the population density was 1,319 persons per square kilometre for the Red River Delta and 229 for the whole country. There were 2,647,000 farm households in the Red River Delta while the figure for the whole country was 10,981,000 (General Statistical Office 2000 and 2001). As a result, the average farm sizes were 2,538 and 7,358 m² for the Red River Delta and the whole country respectively. Another cause of land fragmentation can be inheritance, where farmers want to give their children land of similar quality. The above mentioned explanations are observed in many developing countries, such as China (Nguyen et al. 1996), Ghana and Rwanda (Blarel et al. 1992).

In Vietnam, land fragmentation has mainly been caused by the land allocation process. After the Resolution 10 and especially the Land Law and the Ordinance 64/CP of the Prime Minister had been introduced in 1993, agricultural land was officially allocated to the farm household for stable and long-term use. How to allocate land to farmers was a question not only for the central government but also for local governments and between farmers. In order to satisfy the needs of farmers on an equitable basis, agricultural land was allocated equally on a per capita or per 'capita equivalent' basis. This is why each household may have several plots in different areas even though some plots are very small, sometimes only about 100 m². The situation is similar to China where farmers signed contracts with local government authorities to utilise land after the Chinese government had introduced the Household Responsibility System in the early 1980s (Nguyen et al. 1996).

Another cause of land fragmentation is the failure of land markets to operate effectively because of government regulations on land transactions (Bentley 1987;

Blarel et al. 1992). If the land market is under control of the government, fragmentation may also be a result. In Vietnam, the market for the exchange of land use rights is still complicated and not well developed. Farmers who want to use their land as collateral for borrowing money from banks need the permission and seal of authority from the local government. Other transactions such as ‘selling’ or ‘buying’ land use rights are completed only if they are recorded and certified by the local government. In many cases this is not done (Kerkvliet 2000). In Can Tho, a farm household reported that they bought three plots of land each in 1992, 1996 and 1998. For recording these transfers in the *Red-book* (land use certificate) they paid VND 480,000 (\$US 40 in 1998) per *cong*⁹ for a parcel bought in 1992¹⁰. This amount of money is not small for farmers. This is one of the reasons, why in some provinces farmers may not want to record their land transactions with the local government.

‘Demand-side’ causes of land fragmentation arise when farmers consider that land fragmentation may have some benefits. In this case it is possible for the private benefits of land fragmentation to exceed its private costs (Blarel et al. 1992; Hung and MacAulay 2002). It is also possible that the transaction costs for reducing fragmentation are sufficiently high for farmers not to undertake the set of land transactions that would be needed to reduce the degree of fragmentation. Moreover, farmers may realise some additional benefits from fragmentation. By cultivating plots in different geographical areas, variation in output may be less because the risks caused by drought, flood and diseases are spread. Another reason farmers want to keep fragmented farms is that they may be able to use their seasonal labour more effectively. Although labour is generally in surplus in Vietnam, especially in the Red River Delta, in peak times (transplanting and harvesting periods) and during the winter crop growing period, more labour is demanded, and even child labour is very common in these periods. Therefore, farmers may reduce peak time labour periods by diversifying crops in different plots.

The above demand-side explanations are based on the choice of farmers to choose to retain certain levels of fragmentation that they perceive are beneficial to them. These positive benefits are the impacts of fragmentation on risk-spreading, seasonal labour spreading, and crop diversification. Another impact is that the land user can mortgage or sell a portion of their land use rights easily and anytime. If land is not fragmented, it is not easy to sell a half or a portion of their total land. They may also give land to their children as an inheritance more easily when the children want to live separately.

However, land fragmentation causes many negative effects including higher costs, prevention of mechanisation, increased negative externalities, loss of land due to boundaries, and a greater potential for disputes between neighbouring farmers (Blarel et al. 1992; Lan 2001; Hung and MacAulay 2002). Production costs may also be higher due to higher costs for labour. For example, it takes more time to travel from plot to plot and to operate an activity for a unit of land. Higher costs for labour also are reflected in more time needed for irrigation, especially during a drought period. A major source of higher production costs is the higher transport costs of inputs and outputs. If land is fragmented, transportation distances will be higher and there is

⁹ *Cong* is a common unit of land in the Mekong Delta and equal to 1000 m².

¹⁰ The author was an interviewer for the second survey of the ACIAR project in the South of Vietnam in July and August 2002 and noted this case.

more fuel and labour needed.

Other problems caused by fragmentation may be higher negative externalities which can happen when farmers cultivate different crops or varieties (Bentley 1987). This leads to greater potential for disputes between neighbours. Land fragmentation also causes an increased land loss due to plot boundaries or bunds and access routes (because more plots have more boundaries so each plot can retain water and be distinguished from neighbouring plots). This loss of land is directly related to the number of plots. In addition, it is hard to apply new technologies in the case of small and fragmented farms. This is likely to be a main disadvantage of land fragmentation in Vietnam.

Although, there are the above mentioned disadvantages of land fragmentation, farmers in many provinces especially in the north and north central regions of Vietnam still keep their parcels of land indicating they may not want to exchange small plots for larger ones. This means that farmers probably benefit from some degree of land fragmentation, by reducing risks from flood, drought and diseases, making more efficient use of seasonal labour, and enabling crop diversification.

Land Fragmentation in the North of Vietnam: Evidence from Survey Data

Measuring land fragmentation

There is an absence of a standard measurement of land fragmentation. This leads to difficulties in determining when farm households are ‘too fragmented’ or ‘less fragmented’. Bentley (1987) reports that most authors have used two simple measurements of land fragmentation: the number of plots per farm and the average farm size. However, the distance to plots is ignored in these measurements. Some authors have considered that land fragmentation should be measured by six parameters: farm size, the number of plots, plot size, plot shape, spatial distribution, and the size distribution of the fields (King and Burton 1982; Bentley 1987). Bentley (1987) also cites three other measures of land fragmentation. Simmon’s index of land fragmentation is measured by the sum of the squares of the plot sizes, divided by the square of the farm size or total plot areas. This index is likely to be similar to Simpson’s diversification index. Januszewki’s index is given by the square root of the farm size, divided by the sum of the square root of the plot areas. Igbozurike’s index is the total distance travelled to reach all of the plots, multiplied by the average plot size, divided by 100. There is also the possibility of using other diversification indexes to measure fragmentation, because there is evidence that if farmers have more plots their production may be more diversified. However, each measure has advantages as well as disadvantages when it is used alone.

In this paper, two main measures of fragmentation are used: the number of plots per farm household and Simpson’s diversification index. Blarel, Hazell et al. (1982) have also used these two indicators to measure land fragmentation in Ghana and Rwanda. Other measures such as farm size, plot sizes, and distances are also considered. The number of plots per farm is simple and easy to understand for a public audience, but it ignores other important factors such as plot and farm sizes and the distance to plots.

Simpson's index is defined as $(1 - \frac{\sum a_i^2}{A^2})$ where a_i is the area of the i th plot, A is the farm size and $A = \sum a_i$. This index has a value between zero and one. A value of zero means that the farm household has only one parcel or plot of land, which indicates complete land consolidation, while a value close to one means the household has numerous plots and the farm is 'very fragmented'. A disadvantage of this index is that it is sensitive to the number of plots as well as their sizes. Fragmentation will decrease when the area of big plots increases or/and that of small plots decreases.

Fragmentation Evidence from Survey Data

Two provinces, Ha Tay and Yen Bai, in the North were chosen as research sites for the ACIAR project¹¹. In each province, two districts, one where farm sizes were smaller than average and the other where farm sizes were larger than average, were chosen. This same procedure was followed in selecting two communes in each district. In Ha Tay province located in the Red River Delta, Dai Dong and Thach Hoa commune in Thach That district were selected for surveying, while in Dan Phuong district the two communes were Song Phuong and Tho Xuan. In Yen Bai province located in the midland area, the four communes were Dai Dong and Bao Ai in Yen Binh district, and Mau Dong and Dong Cuong in Van Yen district. Data for two years (2000 and 2001) were collected by using prepared questionnaires. Staff and fourth year students at the Faculty of Economics and Rural Development, Hanoi Agricultural University helped the research team members to conduct the survey.

Ha Tay province is characterised by low land and a small farm size while the Yen Bai province is located in the upland region and has a larger farm size. Part of Ha Tay has some upland area, therefore, the average farm size is likely to be larger than that of other provinces in the Red River Delta. Land in Vietnam, especially in the North and in the Red River Delta is scarce so farm size is small in comparison with that in other developing countries. However, farm size also varies even in a province, or a district. According to data from the first survey, average farm sizes including resettlement land, agricultural land, ponds, and forestry land in Ha Tay and Yen Bai were 6,300.9 and 25,128.7 m² in 2000, respectively (Table 1). At the commune level, average farm sizes in Dai Dong and Thach Hoa commune (both in Ha Tay) were 3,832 and 10,506 m², respectively. In Yen Bai, these figures were 11,972 m² in Bao Ai commune and 53,149 m² in Dai Dong commune (Tables 2 and 3). More than 93 percent of the surveyed farms in Ha Tay had a farm size between 1,001 and 5,000 m², while this figure for Yen Bai was only 38 percent. On the other hand, only 2.1 percent of the surveyed farms in Ha Tay had farm size larger than the land limit (two hectares) while in Yen Bai the figure was 37.4 percent, and even higher in some communes such as Dai Dong (55 percent) (Figures 1 and 2). This has led to the conclusion that the higher the average farm size in a commune, the larger the variation of farm size (Marsh and MacAulay 2003).

Yen Bai province is located in an upland and mountainous area. This is why it has a larger farm size than other provinces, especially than those in the Red River Delta.

¹¹ The ACIAR project ADP 1/97/092 was entitled "Impacts of the alternative policy options on the agricultural sector of Vietnam"

However, annual crop land and rice fields were not significantly different in size in comparison with those in the delta. The biggest difference was in the size of hill and forestry land. Therefore, the average farm size in the region was larger. In 2000, the average farm sizes for Dai Dong, Bao Ai, Mau Dong, and Dong Cuong commune were in turn 53,149, 11,972, 23,603, 18,929 m² respectively (Table 3). The distribution of households by farm size in four communes was also different, but most of the households had farm sizes between 5,001 to 10,000 m² and larger than 20,000 m². For example, 80, 64, 79, and 80 percent of households had a farm size falling into these two groups in Dai Dong, Bao Ai, Mau Dong, and Dong Cuong commune, respectively (Figure 2).

Based on the survey data, farm size is closely related to plot size (Hung and MacAulay 2002; Marsh and MacAulay 2002, 2003). When farm size is small, on average, individual plot areas cannot be very large, especially in the case where land is allocated to family members. In Ha Tay, the average farm size and plot size in Dai Dong commune were in turn 3,831.9 and 453.0 m² respectively, while these figures for Thach Hoa commune were 10,506.5 and 1,358.0 m² respectively (Table 2). The same situation was also observed in Yen Bai province. The average farm size and plot size in Dai Dong commune were 53,149.2 and 5,509.4 m² respectively, while in Bao Ai these were in turn 11,972.3 and 1,688.4 m² respectively (Table 3). The same situation is observed in the average sizes of smallest and largest plots in the four communes (Table 2 and 3).

Households in the surveyed areas had an average of 7.09 plots or parcels of land, of which the figures for Ha Tay and Yen Bai were in turn 6.48 and 7.73 plots, respectively (Table 1). The average number of plots also varied from region to region and commune to commune. Seventy six percent of farms in Ha Tay had three to eight plots while this figure for Yen Bai was 56 percent. There were only 6.6 percent of farms in Ha Tay that had more than 11 plots while this figure for Yen Bai was more than 17 percent. If the degree of fragmentation is measured by the number of plots, Yen Bai's farms were "more fragmented" than those in Ha Tay while if the degree of fragmentation is measured by Simpson's index the conclusion is the reverse. This means that Yen Bai's farms were "less fragmented" when measured with Simpson's index. Farms in Yen Bai had, on average, a value for Simpson's index of 0.53 while this figure for Ha Tay was 0.75. More than 90 and 48 percent of farms in Ha Tay had a value of the index higher than 0.6 and 0.8 respectively, while for Yen Bai it was 45 and 18 percent respectively. This means that in Yen Bai there were more larger plots and/or smaller plots because this index is sensitive to the area of the largest or smallest plots.

The degree of fragmentation measured by the above mentioned indicators also varied from commune to commune (Tables 2 and 3). In Dai Dong commune (Yen Bai province), 30 percent of households had more than 11 plots while this figure was only five percent in Dong Cuong commune. Ten and 28 percent of farms in these two communes had between three and five plots. In Ha Tay province, 20 percent of households in Dai Dong commune had more than 11 plots but no households in Tho Xuan and Song Phuong had this many plots. Twenty percent of farms in Dai Dong had three to five plots while these figures for Tho Xuan and Song Phuong were 69 and 62 percent respectively (Figure 3 and 4). This means that even within a province or region the level of fragmentation may be different and fragmentation can be

dependent on natural geography.

The number of plots and farm size appear not to be significantly related (Hung and MacAulay 2002). Figures 7, 8 and 9 show the relationships for the two provinces. This means that land consolidation may occur without land accumulation through plot exchanges. Figures 5 and 6 show the distribution of the number of plots by the area of plots. The distribution was similar in the two provinces. Fifty four and 55 percent of the total number of plots in Ha Tay and Yen Bai respectively had areas of less than 400 m², although the average areas of a plot in the two provinces were different (831 and 3,233 m² in Ha Tay and Yen Bai respectively) (Table 1). However, the data by commune shows that the distributions are different. For example, 70 percent of plots in Dai Dong commune (Ha Tay province) had areas of less than 400 m² while this figure for Song Phuong commune was only 36 percent. In Yen Bai province, 26 percent of plots in Dai Dong commune had areas larger than 1000 m² while this figure for Mau Dong commune was 15 percent only.

Some authors assert that fragmentation seems to be a serious problem for agricultural production in Vietnam (Lan 2001; Ministry of Agriculture and Rural Development 2002). In order to investigate this, the correlation between fragmentation and costs and returns (yields and revenues) was calculated and tested on five main crops (first and second rice crops, maize, soybeans, and vegetables and flowers) and 6 crop rotations (Tables 4 and 5). The fragmentation variable (number of plots per household) was not significantly correlated with yields from the five crops or the revenue from the crop rotations, with the exception of two rotations of rice-rice and rice-rice-maize. Thus, without taking into account other interacting variables, fragmentation appears to have little or no effect on land productivity. In general, there were also no significant correlations between fragmentation levels and total expenses or the use of nitrogen fertiliser. However, it was found that there were significant correlations with labour use (both family and hired labour). The rice-rice rotation appears to be significantly correlated with labour, and also two other rotations of rice-rice-soybeans and vegetables and flowers. Correlations were particularly strong with hired labour, with correlation coefficients greater than 0.78 (Table 4 and 5). Therefore, fragmentation is unlikely to have significant effects on yields, revenues and the costs related to crops but may be significant in relation to labour use. In the Red River Delta, agricultural labour is still in surplus, however, in the future when the opportunity for off-farm jobs is greater land fragmentation may become a more serious problem.

The effects of land fragmentation will also be affected by the distance from the farmer's home to plots. In Ha Tay province, the distance to parcels is on average about 700 metres (Table 1). Fifty percent of plots had a distance less than 500 metres (except for farmers in Song Phuong). For 25 and 17 percent of plots in Dan Phuong and Thach That respectively, farmers must travel more than one kilometre to reach their parcels (Figure 10). In Yen Bai province, an average distance from home to annual land plots varied from commune to commune; for example, it was on average 411 metres in Mau Dong and 729 metres in Dong Cuong (Table 2). In Yen Bai, the number of plots located far from the farmer's home was less than that in Ha Tay. There were only five and six percent of the total plots in which farmers must travel more than one kilometre to reach their plots in Yen Binh and Van Yen district, respectively (Figure 11). This implies that the annual crop land in Yen Bai is often

located in a valley floor or low land close to the farmer's home and village. Distance to plots may not be a problem specific to fragmented farms. In the case of consolidation or accumulation of land, that is, a farmer may still travel a similar distance.

Comparative Static Farm Model

In this paper, a household model related to the crop production of the household is used. It is assumed that a labour market exists in which households can hire labour and be employed. There is also assumed to be a market for land use rights, that is, farmers can rent out their land or rent in land (Marsh and MacAulay 2004). Credit is constrained. A household must pay some transaction costs for their entry into the land transaction and credit markets. Land fragmentation (the number of plots) is given and assumed to affect production costs. Let household i be endowed with a fixed amount of labour (\bar{L}_i), capital (\bar{K}_i), land \bar{A}_i , a number of plots (\bar{N}_i), and a given level of agricultural ability (α_i)¹².

Assume that household i has j plots, Q_{ij} is output obtained in plot j ($j=1, N$) of household i ($i = 1, M$). The production function for plot j of household i , therefore, is

$$(1) \quad Q_{ij} = F_{ij}(l_{fij}, l_{hij}, x_{ij}, a_{ij})$$

Where: l_{fij} = family labour used in plot j , household i , and $\sum_j l_{fij} = L_{fi}$
 l_{hij} = hired in labour, and $\sum_j l_{hij} = L_{hi}$
 x_{ij} = a vector of inputs used in plot j of household i , $\sum_j x_{ij} = X_i$
 a_{ij} = area of plot j of household i , and $\sum_j a_{ij} = A_i$ (A_i is operating areas of household i)

A householder will be assumed to maximise his/her income from three sources, being agricultural production outputs from all plots, off-farm work and renting out (or in) land. This for household i :

$$(2) \text{ Max } (\pi) = \sum_j P_i \alpha_i F_{ij}(l_{fij}, l_{hij}, x_{ij}, a_{ij}) + w_1 L_{oi} - w_2 L_{hi} \\ + G^{\text{out}} (\bar{A}_i - A_i)(r_2 - T_2) - G^{\text{in}} (A_i - \bar{A}_i)(r_2 + T_2) \\ - \sum_j (P_{xi} + T_3) x_{ij} \\ - G^{\text{bor}} [\sum_j (P_{xi} + T_3) x_{ij} + G^{\text{in}} (A_i - \bar{A}_i)(r_2 + T_2) + w_2 L_{hi} - \bar{K}_i](r_1 + T_1) \\ (i = 1, M = \text{number of households}; j = 1, N = \text{number of plots})$$

For notation simplicity, i is ignored.

Where: P = price of output
 α = agricultural production ability of household
 $\bar{L} = L_f + L_o = \sum_j l_{fj} + L_o = \text{total household labour}$
 $L_f = \sum_j l_{fj} = \text{total working on farm}$
 $L_o = \bar{L} - L_f = \bar{L} - \sum_j l_{fj} = \text{total working off-farm}$

¹² This variable was introduced by Deininger and Jin (2003)

$$L_h = \sum_j l_{hj} = \text{total hired in labour}$$

w_1 and w_2 are wages of off-farm jobs and hired in labour respectively

$$\begin{aligned} K &= \sum_j (P_x + T_3) x_j + G^{\text{in}} (A_i - \bar{A}_i)(r_2 + T_2) + w_2 L_{hi} \\ &= (P_x + T_3) X + G^{\text{in}} (A_i - \bar{A}_i)(r_2 + T_2) + w_2 L_{hi} \\ &= \text{total operating capital} \end{aligned}$$

$G^{\text{bor}} = 1$, if the household borrows money, and 0 otherwise

$G^{\text{out}} = 1$, if the household rents out land, and 0 otherwise

$G^{\text{in}} = 1$, if the household rents in land, and 0 otherwise

If $G^{\text{out}} = 1$, then $G^{\text{in}} = 0$ and $G^{\text{in}} = 1$, then $G^{\text{out}} = 0$

$G^{\text{out}} = G^{\text{in}} = 0$, if the household has no land transaction (no renting in or out)

r_1 and T_1 are interest rate and credit transaction costs respectively

r_2 and T_2 are rental rate and transaction costs respectively

T_3 is the transaction cost of fragmentation. It is assumed that an increase in the number of plots may increase some costs of transportation and other costs so that it increases the direct costs.

Assume that the production function, F , satisfies the standard assumptions:

$$\frac{\partial F}{\partial z} = F_z > 0 \text{ (where } z = l_f, l_h, x, \text{ and } a \text{ (for simplicity, hereafter } l_f \text{ and } l_h \text{ are written as } f \text{ and } h \text{ only))};$$

$$\frac{\partial^2 F}{\partial z^2} = F_{zz} < 0; \text{ and } F_{zz^*} > 0 \text{ (where } z^* = f, h, x, a \text{ and } z \neq z^*)$$

This means that positive marginal products and diminishing marginal returns are required. In solving the maximisation problem (2) a household will choose optimum levels of l_{fj}^* , l_{hj}^* , x_j^* and a_j^* . The first-order conditions of the problem (2) are:

$$(3) \quad \sum_j P \alpha \frac{\partial F_j}{\partial l_{fj}} - N w_1 = 0$$

$$(4) \quad \sum_j P \alpha \frac{\partial F_j}{\partial l_{hj}} - N w_2 = 0$$

$$(4') \quad \sum_j P \alpha \frac{\partial F_j}{\partial l_{hj}} - N w_2 - N w_2 (r_1 + T_1) = 0$$

for households who borrow money

$$(5) \quad \sum_j P \alpha \frac{\partial F_j}{\partial x_j} - N (P_x + T_3) = 0$$

$$(5') \quad \sum_j P \alpha \frac{\partial F_j}{\partial x_j} - N (P_x + T_3) - N (P_x + T_3) (r_1 + T_1) = 0$$

for households who borrow money

$$(6) \quad \sum_j P \alpha \frac{\partial F_j}{\partial a_j} - N (r_2 - T_2) = 0$$

for households who rent out

$$(6') \quad \sum_j P \alpha \frac{\partial F_j}{\partial a_j} - N (r_2 + T_2) = 0$$

for households who rent in

$$(6'') \quad \sum_j P \alpha \frac{\partial F_j}{\partial a_j} - N (r_2 + T_2) - N (r_2 + T_2) (r_1 + T_1) = 0$$

for households who rent in and borrow money

Thus, for households who do not rent out or in land (no land transactions):

$$(7) \quad N (r_2 - T_2) < \sum_j P \alpha \frac{\partial F_j}{\partial a_j} < N (r_2 + T_2)$$

$$\text{or} \quad N (r_2 - T_2) < \sum_j P \alpha \frac{\partial F_j}{\partial a_j} < N (r_2 + T_2) (1 + r_1 + T_1)$$

for households who borrow money

The first order conditions allow the derivation a set of comparative static conclusions (see the Appendix for a more detailed derivation).

Equation (3) implies that the total value of the marginal product of family labour from all plots of a household should be equal to the off-farm wage multiplied by the number of plots. If the total returns to family labour are maintained at some level, an increase in the off-farm wage will reduce the number of plots. Thus, the opportunity for off-farm labour is one of the key factors that will encourage land consolidation.

Equation (A7) implies that farm land operated by the household increases with increasing agricultural production ability of the household, α . The amount of land rented in also increases with increasing agricultural production ability of the household and decreases for households with a higher land endowment, \bar{A}_i (Equations A12 and 13). Therefore, rental markets will transfer to “*poor but efficient*” crop producers (Deininger and Jin 2003). However, farm land operated by the household and the amount of land rented in increases with increasing capital endowment, \bar{K}_i (Equation A20). Thus, “rich” farmers may be more active in the rental market than “poor” farmers. These two results suggest that both farmers with relatively small and large areas of farm land could be expected to be active in the rental market (as observed by Marsh and MacAulay, 2004). Currently, most of the rural population is still involved in agricultural production because the opportunity for off-farm jobs is limited. However, in the future when the opportunity for off-farm employment is greater, land may transfer to small-sized farms with high agricultural ability.

Equation (A14) implies that small-sized farms are likely to be “more fragmented” than large sized farms. Thus, land fragmentation will be present for small, subsistence oriented production (Bentley 1987). Land fragmentation as measured by the number of plots decreases with increasing agricultural production ability of the household (Equation A16). Therefore, a system of extension and training is needed to facilitate land consolidation.

Equations (A22 and A24) imply that the amount of land rented in and out decreases with increasing transaction costs in land rental market, T_2 . As a result, this leads to a reduction in the number of households who participate in the rental markets.

Therefore, a reduction in the transaction costs or a simpler procedure for land registration (the land transaction record) may result in a stronger market for land use rights.

The number of plots, N , increases as transaction costs associated with the credit market, T_1 , the market for land use rights, T_2 , and land fragmentation, T_3 , increase (Equations A27, A28, and A29). If the procedure for loans and/or land transactions is simpler, the number of plots or land fragmentation may decrease. Reforms in the administration sector will reduce transaction costs and, therefore, may encourage land consolidation. Additionally, a reduction in transaction costs will increase the profit and income of the farm household. This leads to the conclusion that administration reforms are needed, and will make all farmers better off.

A reasonable assumption is that households with a high agricultural production ability who specialise in agricultural production will continue to rent in land and their off-farm opportunities remain the same as before. Those households with low agricultural ability who join the off-farm labour force will take advantage of an increase in off-farm wages, w_1 . The amount of land rented out increases as off-farm wages increase (Equation A31). Thus, an increase in the wage rate for off-farm employment may increase land transacted in the rental market. As a result, this may lead to a decrease in the equilibrium rental rate which will make everybody better off (Deininger and Jin 2003). Therefore, an increase in the opportunity for off-farm jobs may be a key policy to encourage not only an active market for land use rights but also agricultural production and an increase in farmers' income.

An Empirical Model and Results

If the production function in (2) follows constant returns to size, then the output function is equivalent to the yield function. When returns to size are unclear, instead of the output function, the yield function can be estimated with the adjusted land areas.

The yield function can be written as:

$$(8) \quad \begin{aligned} Y &= f(L_f, L_h, x). h(A) \\ h(A) &= \mu_0 A^{\mu_1} e^{\mu_2 A} \end{aligned}$$

Where yield, Y is assumed to be separable into functions f and h . Function f is the yield per unit of land area while function h incorporates economies of farm size (MacAulay and Hertzler 2000). If there are no economies or diseconomies of size, μ_0 and μ_1 will be one, μ_2 will be zero and function h will equal the area A ¹³. Function f can be designed with the variables in different forms. MacAulay and Hertzler (2000) suggested that the variable inputs can be designed in the transcendental form while the labour input may be in the Cobb-Douglas form. In Vietnam, agricultural labour is still in surplus, therefore, in the empirical model, hired labour is designed in a Cobb-Douglas form while the family labour input is a transcendental form. Fertiliser inputs are expressed in the translog form while other variable inputs (seed application and

¹³ In cases where the household cultivates one crop, otherwise A may be a plot area.

money expenses) and land area (farm size) are also assumed to be in the transcendental form. Land fragmentation, measured by the number of plots, is included in the model with a Cobb-Douglas form. Other discrete variables (number of crops and education level) are in a semi-log form. The intercept can be separated into two elements, of which one reflects household characteristics or the effect of each household, which is considered as an agricultural production ability of the household. Another element represents other factors such as access to infrastructure and markets, soil quality, and climate (Deininger and Jin 2003).

In logarithmic linear form the function becomes:

$$(9) \quad \text{Ln}(Y) = (\alpha_1 + \alpha_2) + \beta_1 \text{Ln}(X_1) + \beta_2 \text{Ln}(X_2) + \beta_3 \text{Ln}(X_3) \\ + \beta_4 \text{Ln}(X_1)\text{Ln}(X_2) + \beta_5 \text{Ln}(X_1)\text{Ln}(X_3) + \beta_6 \text{Ln}(X_2)\text{Ln}(X_3) \\ + \beta_7 \text{Ln}(X_4) + \beta_8 X_4 + \beta_9 \text{Ln}(X_5) + \beta_{10} X_5 + \beta_{11} \text{Ln}(X_6) \\ + \beta_{12} X_6 + \beta_{13} \text{Ln}(X_7) + \beta_{14} \text{Ln}(X_8) + \beta_{15} X_8 + \beta_{16} \text{Ln}(X_9) \\ + \beta_{17} X_{10} + \beta_{18} X_{11} + \delta_1 D_1 + \delta_2 D_2 + U$$

Where: Y = equivalent rice yield of a crop rotation (kg/ha/year)
 X_1 = Nitrogen input (kg/ha/year)
 X_2 = Phosphorus input (kg/ha/year)
 X_3 = Potassium input (kg/ha/year)
 X_4 = expenditure of seed application (VND '000/ha/year)
 X_5 = Other money expenses (VND '000/ha/year)
 X_6 = Family labour input (person days/ha/year)
 X_7 = Hired labour input (person days/ha/year)
 X_8 = Farm area ($sao = 360 \text{ m}^2$)
 X_9 = Number of plots per farm household (no.)
 X_{10} = Number of crops in a rotation ($X_{10} = 1 - 3$)
 X_{11} = Level of education of household head ($X_{11} = 0 - 5$ that are equivalent to illiterate, primary, secondary, high school, college, and university level)
 D_1 = Province dummy variable; $D_1 = 1$, if household located in Ha Tay
 $D_1 = 0$, otherwise
 D_2 = Dummy variable for land use change;
 $D_2 = 1$, if household change to cultivate flowers or high value cash crops
 $D_2 = 0$, otherwise
 U = disturbances; Ln = natural logarithm
Let $\beta_0 = (\alpha_1 + \alpha_2)$
 α_1 = agricultural ability
 α_2 = village-level characteristics
 β_i ($i = 0 - 18$), δ_1 and δ_2 are coefficients to be estimated

Multiple crops are often produced on a single plot (one rotation). In order to aggregate yields of different crops, an average of price ratios between rice and other crops was used so that the dependent variable was a price weighted average representing the equivalent rice yield of a rotation per hectare.

In the model, it was expected that fragmentation, represented by the number of plots, would have a negative sign while other money expenses, number of crops in a

rotation, education level, and dummy for land use change would have positive signs. Results are given in Table 6.

Table 6. Annual crop yield function in Ha Tay and Yen Bai Province, 2000

Estimates	Coefficients	T – value	Significance level
β_0 Intercept	7.9490	31.539	***
β_1 Nitrogen input	0.0462	3.162	***
β_2 Phosphorus input	-0.0180	-1.033	ns
β_3 Potassium input	-0.0213	-1.214	ns
β_4 Nitrogen * Phosphorus	0.0028	0.998	ns
β_5 Nitrogen * Potassium	0.0066	2.238	**
β_6 Phosphorus * Potassium	-0.0007	-0.590	ns
β_7 Seed application	0.0267	2.130	**
β_8 Seed application (exp)	0.0001	1.016	ns
β_9 Other money expenses	0.0564	3.355	***
β_{10} Other money expenses (exp)	0.0000	3.091	***
β_{11} Family labour	-0.0492	-2.154	**
β_{12} Family labour (exp)	0.0005	6.305	***
β_{13} Hired labour	0.0307	1.845	*
β_{14} Farm area	0.0634	1.376	ns
β_{15} Farm areas (exp)	-0.0004	-0.933	ns
β_{16} Number of plots	-0.0823	-1.339	ns
β_{17} Number of crops (exp)	0.2672	4.745	***
β_{18} Education level (exp)	0.0527	1.757	*
δ_1 Province dummy (Ha Tay = 1)	0.0518	0.607	ns
δ_2 Dummy for land use change	0.2530	1.732	*
Sample size, n	303		
Log likelihood function	-162.92		
F value	24.14		***
R ²	0.63		
Adjusted R ²	0.60		

Note: ***, **, and * are significant at 1, 5 and 10 percent, respectively.
Ns is none-significant

The production function in (9) was estimated using frontier regression methods. The software used was FRONTIER 4.1 (Coelli 1994). From the results it would seem that a reasonable response function has been estimated (trans-log form in fertiliser variables, transcendental form in other variable inputs, except hired labour and also land area with appropriate signs on all the variables except the non-significant phosphorus and potassium. The R² values were reasonable and significantly different from zero at one percent (F value = 24.14). The coefficient β_1 and the trans-log term β_5 were significantly different from zero. This meant that an increase in nitrogen used would increase the yield. Both coefficients β_9 and β_{10} were positive and significantly different from zero at one percent. This implies that the other money expenses

(excluding expenses for seed and application of the three fertilisers) seem to be a factor that increases the yield with increasing marginal product. Coefficients on the farm area variable were not significant supporting the idea that there were no economies of size for the range of areas considered.

For the estimated model, the coefficient β_{16} (number of plots) was not statistically different from zero. This meant that, statistically, the number of plots has not been shown to have an effect on productivity as reflected in the equivalent rice yield. Although this result suggests that there is no effect of plot number on farm performance, this may not imply that fragmentation has no effects at all on crop productivity because it was earlier shown to be correlated with the revenue from two rotations (rice-rice and rice-rice-maize) and also with labour use. Using a higher significance level (of about 17 percent) the equivalent yield was negatively related to the number of plots (fragmentation level). This would seem to imply that the effects of fragmentation on productivity may be weak, and affect factors such as labour use more significantly than the output. Secondly, it may also imply that farmers have adjusted to the use of fragmented holdings. They may choose crop patterns suitable for fragmented land given the technology and other conditions. Another reason could be that the average plot size is so small (749 m²) and the current technology chosen by most of the farmers is similar and cannot be adjusted within the plot numbers being considered. The results may also imply that the private costs for changing the land fragmentation situation may be higher than the private benefits resulting from such changes.

The labour variables, including both family and hired labour, were statistically significant. This implies that they were a major factor which affected crop yields and revenue of a rotation. As a result, increases in hired labour of 10 percent were found to increase crop yield by 0.31 percent. The coefficient β_{11} (family labour) was negative when in its transcendental term, β_{12} was positive and both of them were statistically different from zero. However, within the range being considered the elasticity of crop yield with respect to family labour was positive¹⁴. An increase in family labour of 10 percent was found to increase the yield, on average, by 2.24 percent. Other research on rice productivity in the Red River Delta has found that family labour used in rice production may be overused¹⁵. In this paper, the model is for a rotation that includes winter crops and 'cash' crops such as vegetables, flowers and annual industrial crops (soybeans and peanuts). These crops may be more labour intensive, so that an increase in labour would increase crop yield and revenue.

The coefficient β_{17} (number of crops) was statistically significant at one percent. This was the number of crops cultivated in a rotation, which is dependent on soil quality and good irrigation conditions. Therefore, areas with good soil will increase the equivalent yield and revenue.

The coefficient β_{18} was also statistically significant and positive. This implies that in

¹⁴ The elasticity is equal to $(-0.0492 + 0.0005 X_6)$ where X_6 is family labour and its mean is 547 man-days per hectare giving a value of 0.224.

¹⁵ This work was on pesticide use and rice productivity in Hanoi province (Hung 1998) and by Cuong (2002).

the surveyed areas the equivalent crop yield increases as the level of education of the household head increases. However, the yield increases by only 0.0527 per cent as the household head moved from the first to the second level of education (for example, from primary to secondary school). The reason could be that all members of the household, and not only the household head, contribute to crop production.

The coefficient δ_1 (provincial dummy) was not significantly different from zero. This suggests that the equivalent yield from annual crops per unit of land in the two provinces is not different from each other. In general, the gross margins of annual crop rotations in the Red River Delta have been found to be higher than in the upland and mountainous areas. However, based on the use of a stochastic production frontier it was predicted that the technical efficiency levels for rice production would be 72 percent in Yen Bai while in Ha Tay it was only 66 percent for the year 1999 (Kompas 2002). This means that in the mountainous areas farmers may cultivate just as intensively as those in the low land areas.

The dummy for land use change was also significant. Those households who have cultivated flowers rather than rice or changed their land use purposes (from annual crop land to growing fruit trees or fish farming) were classified into this group. This suggests that if the government allows farmers to cultivate perennial crops (fruit trees) or 'cash' crops (high value crops) instead of traditional annual crops (rice and maize), the equivalent yield will increase.

The Relationship of Land Fragmentation to Output Risk Spreading and Crop Diversity

Risk reduction is one of the benefits of land fragmentation. Risk reduction can be a reduction in the variance of crop output obtained from cultivating several plots. In this section, a model of Blarel et al. (1992) which measures the effect of land fragmentation on the variance of output is used.

It is assumed that the yield for farmer i on plot j is separated into three parts, the village average yield and its random effect ($y_o + \mu$), household effect ($h_i + \eta_i$), and plot effect ($k_{ij} + \varphi_{ij}$). In mathematical form, it can be written:

$$(10) \quad Q_{ij}/a_{ij} = (y_o + \mu) + (h_i + \eta_i) + (k_{ij} + \varphi_{ij})$$

Where: Q_{ij} is the output of the j th plot of household i ; a_{ij} is the area of plot j of household i ; y_o is the village average yield for all plots and households; μ is a random village-level effect; h_i is a fixed household effect; η_i is a random household effect; k_{ij} is a fixed effect of plots; and φ_{ij} is a random plot effect.

The derivation of the variance yields (see Appendix C for more detailed derivation):

$$(11) \quad \text{Var} [(\sum_j Q_{ij})/A_i] = \text{Var}(\mu) + \text{Var}(\eta_i) + (1 - S) \text{Var}(\varphi_{ij})$$

Where A_i is the farm area (farm size) of household i ; Var is the variance; S is the

Simpson's index of land fragmentation ($S = 1 - \sum_j \frac{a_j^2}{A^2}$), and others are denoted as before.

The variance of the household farm output decreases linearly as land fragmentation measured by Simpson's index, S , increases. This means that fragmented farms may reduce their output risk.

The equation (11) can be estimated by using simple regression.

$$(12) \quad Y = \alpha_0 + \alpha_1 X + U$$

where $Y = \text{Var}[(\sum_j Q_{ij})/A_i]$
 $\alpha_0 = \text{Var}(\mu)$
 $\alpha_1 = \text{Var}(\varphi_{ij})$
 $U = \text{Var}(\eta_i)$
 $X = (1 - S)$

In order to calculate the variance of output, multiple observations of a household are needed and time series data is best for estimation (Blarel et al. 1992). In this paper, the authors used cross-sectional data, because each household may cultivate a different rotation in different plots. Thus, a household may have more than one observation allowing short-term variance to be estimated. Therefore, the variance of the equivalent yield in each plot was used in this research¹⁶. However, data on output for some households was available for a single rotation only. Thus, the number of observations has been reduced compared to the full survey. Results are given in Table 7.

The model was estimated using ordinary least squares and was not statistically significant. The relationship between reduction of output risk and the land fragmentation index in the research sites was found to be unclear. This meant that households in the research sites may not have benefited from output risk spreading due to land fragmentation. The reason could also be that the farm area was small and farm households intensively farm the same crops on all plots. However, to reach a clear conclusion time series data are needed to estimate equation (12). This is an area for further research.

Farmers can benefit from numerous parcels of land because their crop patterns can be more diversified and flexible because of differing land types and land qualities on different plots. In order to test the relationship between fragmentation and the level of crop diversity, a simple model was used. In linear form, the model proposed can be written as:

$$(13) \quad Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + U$$

where: Y is the number of land uses (no.)

¹⁶ The variance was estimated based on the formula ($\frac{n \sum x^2 - (\sum x)^2}{n(n-1)}$) where x is the equivalent rice yield of a rotation of the household and n is the number of rotations of the household.

X_1 is Simpson's index of land fragmentation of a household
 X_2 is percentage of cultivated land (%)
 X_3 is the average crop pattern of the household (average number of crops/year)
 X_4 is the level of education of household head ($X_4 = 0 - 5$ that are equivalent to illiterate, primary, secondary, high school, college, and university level)

X_5 is the age of household head (years)
 U is disturbances
 β_i ($i = 0-5$) are coefficients to be estimated

Crop diversity is defined as the number of land uses. There were complicated crop patterns in the research sites such as multiple crops cultivated in a rotation, mixed orchards, perennial crops. In this paper, the same crops in different seasons were counted as different land uses, for example, spring and summer rice count as two land uses; mixed orchards and forests were counted as one land use; and fish farming was also counted as a land use. The dependent variable is the number of land uses which varied from two to ten. Therefore, the truncated estimation was used. The average crop pattern was the average number of crops cultivated in a plot of a household per year. The level of education was defined as in Table 6. Results are given in Table 8.

From the results it would seem that the model was reasonable with the F value of 7.87 which was significantly different from zero at one percent. All coefficients were statistically significant with the exception of two variables, the education level and age of the household head. The number of land uses increased as the crop pattern increased and decreased as the percentage of annual crop land increased. This means that households having a higher percentage of different land types such as perennial and pond land will have greater production diversity. Land fragmentation measured by Simpson's index was positively related to crop diversity. In the context of a subsistence oriented agricultural production, this may lead to security of not only food but also farmers' incomes. This is why in some provinces farmers may want to keep existing levels of land fragmentation. Therefore, the trade off between the level of crop diversity or land fragmentation and commercial production should be questioned and is a needed area for future studies.

Conclusion

From a theoretical point of view, fragmentation of plots on farms has both benefits and costs. These have been identified as shown in Table 9. The relative values of these benefits and costs, which will be different for different farm households, will affect the economics of land fragmentation for individual households and for the public more generally.

In this paper, a number of different methods have been used to investigate the economics of land fragmentation, including both theoretical comparative statics analysis and empirical analysis of survey data from farm households in the North of Vietnam.

Table 9. Costs and Benefits Associated with Land Fragmentation

Benefits of many plots		Costs of many plots	
Private benefits	Public benefits	Private costs	Public cost
+ Risk spreading - Flooding - Diseases and pests - Output	+ Implicit insurance + Equality of treatment	- Cost increases - More labour used - Border land loss	- Less labour released - Mechanisation delayed
+Inheritance flexibility	+ Increased biodiversity	- Access difficult - Disputes increased - Irrigation difficult	- Application of new technology delayed
+ Crop rotation flexibility/diversity		- Mechanisation difficult	- Planning of commercial production zones difficult
+ Small parcels to transfer/sell/mortgage		- Application of new technology difficult	- Higher transaction costs when used as collateral
+ Seasonal labour spreading			- Management
+ Management			

Using survey data from 303 plot-based observations from 179 farm households in the North of Vietnam it was found that the number of plots per household did not appear to be correlated with the rice equivalent crop yields or revenue earned from various types of rotations. However, labour use did appear to be related to the number of plots. Other factors such as fertiliser and other costs did not appear to be related. Data analysis also showed that fragmentation was not a significant determinant of output risk spreading but it did appear to be a significant factor for crop diversity.

As Vietnam appears to have surplus agricultural labour, at least for much of the production year, the real benefits to farm households from land consolidation may not be apparent until the real opportunity cost of farm labour begins to rise. This opportunity cost will clearly be affected by a number of factors such as the availability of employment opportunities for the farm family members and the wage rate associated with these opportunities, the level of education and age of the rural workforce, the time of year and season. The transactions costs involved in job search will be an issue as will the reliability of the employment. Therefore, creation of new off-farm jobs and movement of the agricultural labour force to other sectors of the economy will be a key policy for agricultural and rural development in the future.

Administration reforms are being considered in Vietnam. This may lead to a reduction in the transaction costs associated with the credit market, the market for land use rights and land fragmentation. Comparative statics analysis suggests that if this were the case then land consolidation would be encouraged and the market for land use

rights would also likely to be more active. Therefore, reforms in the administration sector are needed not only for the whole of society, but also for agricultural and rural development that will make all farmers better off.

In the future, agricultural land may be concentrated in the hands of households who have a high agricultural ability. Comparative statics analysis also shows that land fragmentation is likely to decrease with increasing agricultural production ability. Therefore, expansion and improvement of the extension and training systems in rural areas will be very important and needed to facilitate land consolidation.

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Appendix A

Table 1. Fragmentation in Ha Tay and Yen Bai province (percentage of households)

Provinces	Yen Bai	Ha Tay	Total
Number of households*	88	91	179
Simpson's Index			
0-0.2	15.9	2.2	8.9
0.2-0.4	19.3	1.1	10.1
0.4-0.6	19.3	6.6	12.9
0.6-0.8	27.3	41.8	34.6
0.8-1.0	18.2	48.3	33.5
Mean**	0.53	0.75	0.64
Median**	0.56	0.80	0.74
Number of plots			
<= 2	5.7	1.1	3.3
3 – 5	26.1	45.0	35.8
6 – 8	29.5	30.8	30.2
9 – 11	21.6	16.5	19.0
> 11	17.1	6.6	11.7
Mean**	7.73	6.48	7.09
Median**	7	6	6
Farm size (m²)			
Mean	25,128.7	6,300.9	15,557.0
Median	11,919.0	4,284.0	5,104.0
Areas of plot (m²)			
Average areas of a plot	3,233	831	2,126
Average areas of smallest plots	2,001	246	224
Average areas of largest plots	18,168	2,710	10,309
Distance (m)			
0-300	29.5	19.8	24.6
300-700	48.9	39.5	44.1
700-1000	15.9	20.9	18.4
> 1000	5.7	19.8	12.9
Mean (m)**	496.0	676.6	587.8
Median**	440.0	560.0	500.0

Note: * Households which had no data on land and annual crop production were deleted; therefore, the number of observations may be different from previous reports.

** Expressed in relevant units, not percentages.

Source: Household survey data 2000: ACIAR Project ADP 1/97/092.

Table 2. Land fragmentation in Ha Tay province

District	Communes	Thach That		Dan Phuong	
		Dai Dong (n=24)	Thach Hoa (n=19)	Song Phuong (n=22)	Tho Xuan (n=26)
Farm size (m ²)					
	Mean	3,831.9	10,506.5	6,920.9	4,982.1
	Max	6,612.0	42,128.0	20,000.0	14,970.0
	Min	2,052.0	930.0	1,440.0	1,494.4
Number of plots					
	Mean	8.46	7.74	5.41	4.65
	Max	14	12	11	9
	Min	3	3	1	3
Simpson's index					
	Mean	0.84	0.69	0.74	0.75
	Max	0.91	0.86	0.89	0.86
	Min	0.51	0.10	0.00	0.55
Average areas of a plot (m ²)					
	Average areas of a plot (m ²)	453.0	1,358.0	1,279.5	1,070.5
	Average areas of the smallest plot	131.3	206.2	348.9	298.3
	Average areas of the largest plot	1,035.0	5,747.2	2,717.3	2,032.0
Average distances to a plot (m)					
	Average distances to a plot (m)	652.8	582.2	682.4	794.7
	Average distances of nearest plots	469.6	423.4	387.7	253.1
	Average distances of furthest plots	1,166.7	1,513.2	931.8	1,551.9

Table 3. Land fragmentation in Yen Bai province

District	Communes	Yen Binh		Van Yen	
		Dai Dong (n=17)	Bao Ai (n=22)	Mau Dong (n=25)	Dong Cuong (n=24)
Farm size (m ²)					
	Mean	53,149.2	11,972.3	23,603.4	18,929.7
	Max	254,898.0	31,700.0	175,946.0	145,040.0
	Min	1,676.0	1,320.0	1,464.0	1,515.0
Number of plots					
	Mean	9.65	7.09	7.96	6.71
	Max	16	14	14	16
	Min	5	2	3	2
Simpson's index					
	Mean	0.41	0.59	0.53	0.54
	Max	0.85	0.87	0.89	0.88
	Min	0.08	0.24	0.09	0.06
Average areas of a plot (m ²)					
	Average areas of a plot (m ²)	5,509.4	1,688.4	2,965.2	2,821.8
	Average areas of the smallest plot	130.7	251.8	152.6	253.6
	Average areas of the largest plot	38,910.0	7,028.7	16,756.1	15,157.7
Average distances to a plot (m)					
	Average distances to a plot (m)	592.4	397.2	440.3	611.2
	Average distances of nearest plots	292.9	337.3	292.4	341.7
	Average distances of furthest plots	1,711.8	886.4	1,244.0	1,658.3

Table 4. Correlation coefficients between fragmentation and yields and costs of main annual crops

Crops	Yield	Costs per hectare			
		Family Labour	Hired Labour	Total expenses	Nitrogen
First Rice (n=233)	0.0703	0.1089*	0.1901***	-0.030	-0.0295
Second Rice (n=231)	0.0648	0.2032***	0.1712**	-0.0567	-0.0679
Maize (n=102)	0.0246	-0.1549*	-0.0660	-0.0064	-0.0557
Soybean (n=44)	0.0025	0.0695	-	-0.1886	0.2758*
Vegetables & Flowers	0.2147 ^a	0.1339	0.9672***	0.1891	-0.0640

Note: ***, **, and * are significantly different from zero at 1, 5 and 10 percent, respectively.

The Student's t-test is used ($t^* = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$, where r is the correlation coefficient, n is sample size).

a. Revenue

Table 5. Correlation coefficients between fragmentation and revenues and costs of main crop rotations

Rotations/year	Revenue	Costs			
		Family Labour	Hired Labour	Total expenses	Nitrogen
Rice – Rice (n=123)	0.1675*	0.2506***	0.1828**	-0.0915	0.0377
Rice–Rice–Maize (n=49)	0.2945**	-0.0962	0.1408	0.2449*	0.0794
Rice-Rice-Soybean (n=30)	0.0055	-0.0429	0.7768***	-0.1225	-0.0300
Rice-Rice-Vegetables (n=13)	0.3072	0.6275***	-	0.0114	0.1496
Vegetables & Flowers (n=13)	0.2894	0.0586	0.9672***	0.4878*	-0.0257
2 or 3 maizes (n=27)	-0.2299	-0.2228	0.1027	-0.1890	-0.1429

Note: ***, **, and * are significantly different from zero at 1, 5 and 10 percent, respectively.

Table 7. Variance of output function

	Estimates	Coefficients	T – value	Significance level
α_0	Intercept	370696100	1.451	ns
α_1	Fragmentation (1 – S)	-92028940	-0.125	ns
	Sample size, n	98		
	F value	0.02		ns
	R ²	0.01		
	Adjusted R ²	-0.01		

Note: ns is non-significant.

Table 8. Crop diversity function

	Estimates	Coefficients	T – value	Significance level
β_0	Intercept	2.241	2.41	**
β_1	Simpson's index	1.883	2.99	***
β_2	Cultivated land	-0.023	-5.37	***
β_3	Crop pattern	0.851	3.29	***
β_4	Education level of household head	0.106	0.76	ns
β_5	Age of household head	0.011	0.93	ns
	Sample size, n	179		
	Log likelihood function	-330.3		
	F value	7.87		***
	R ²	0.19		
	Adjusted R ²	0.16		

Note: *** and ** are significantly different from zero at 1 and 5 percent, respectively.
ns is non-significant.

Figure 1. Distribution of farm sizes in Ha Tay province

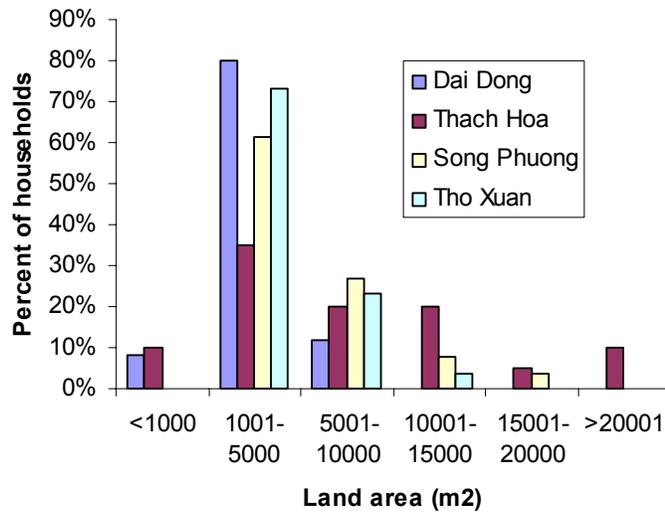


Figure 2. Distribution of farm sizes in Yen Bai province

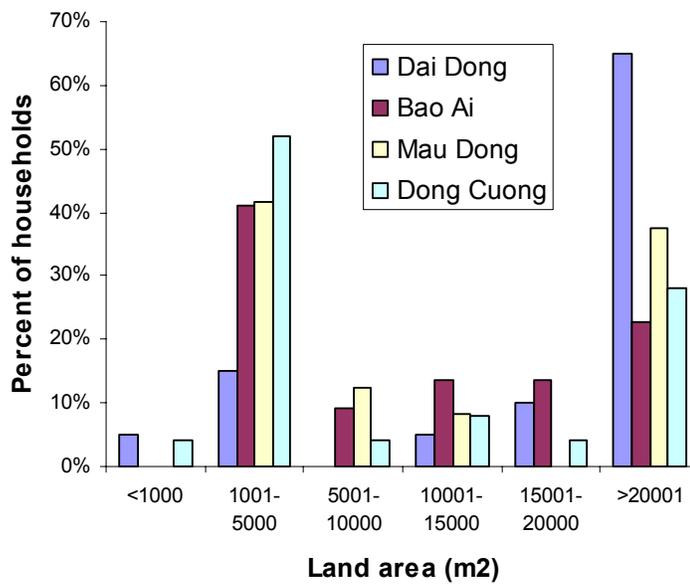


Figure 3. Distribution of households by plot numbers in Ha Tay province

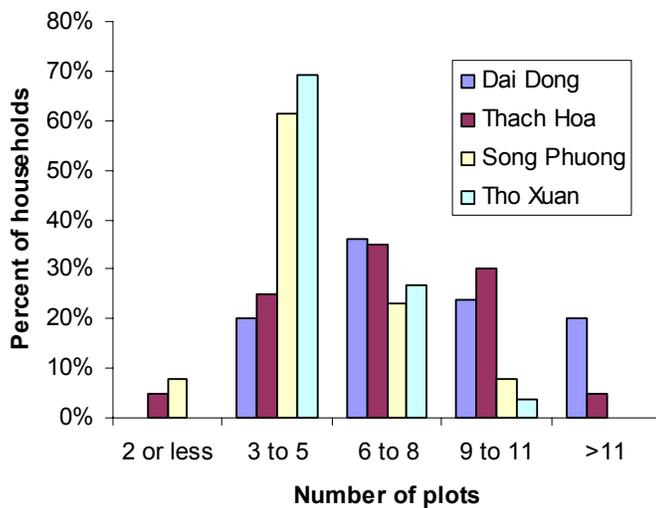


Figure 4. Distribution of households by plot numbers in Yen Bai province

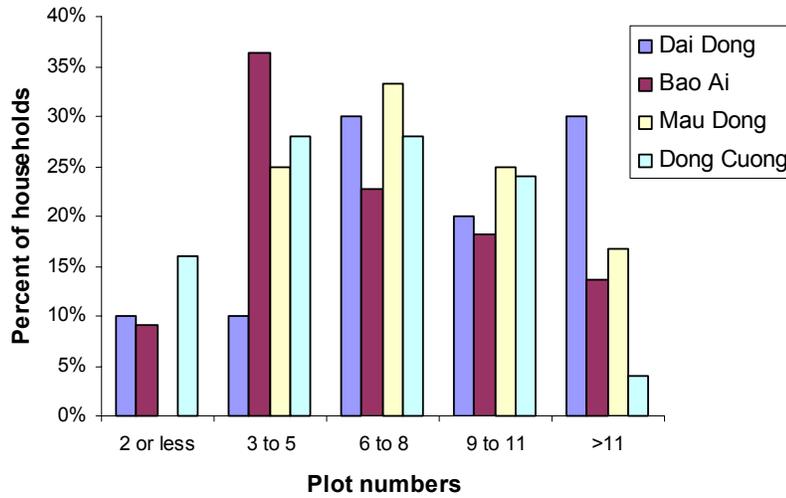


Figure 5. Distribution of plot numbers in Ha Tay province

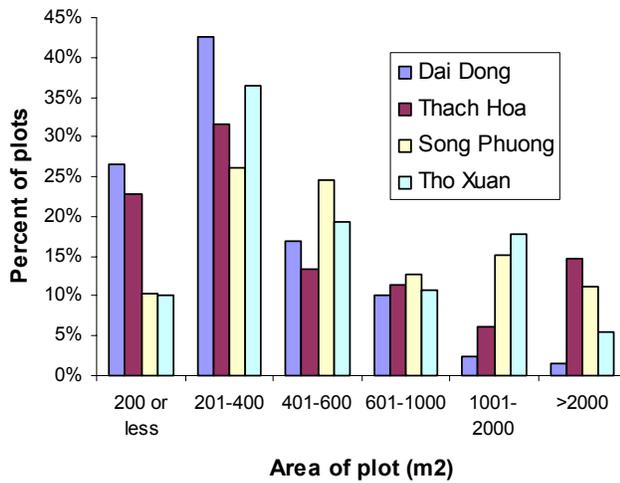


Figure 6. Distribution of plot numbers in Yen Bai province

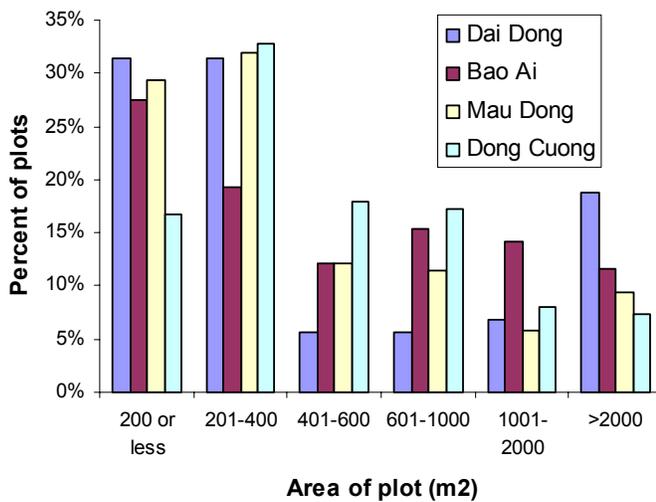


Figure 7. Distribution of the number of plots by farm size in Ha Tay

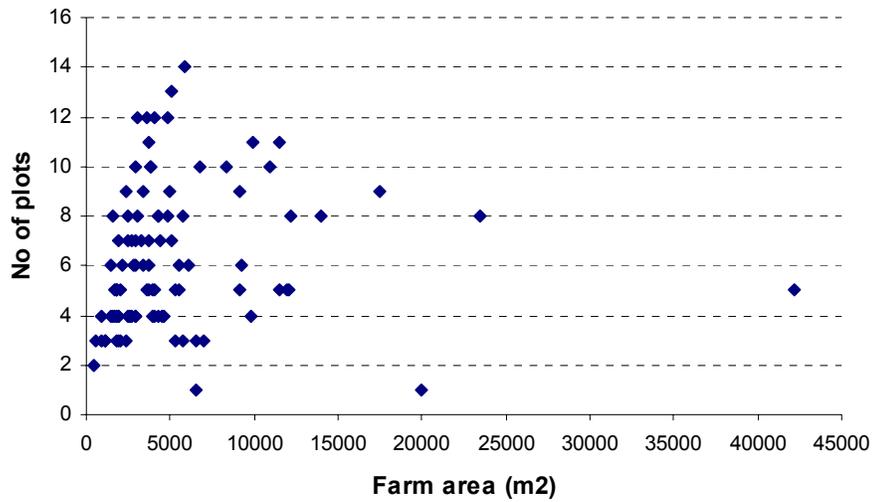


Figure 8. Distribution of the number of plots by farm size in Yen Bai

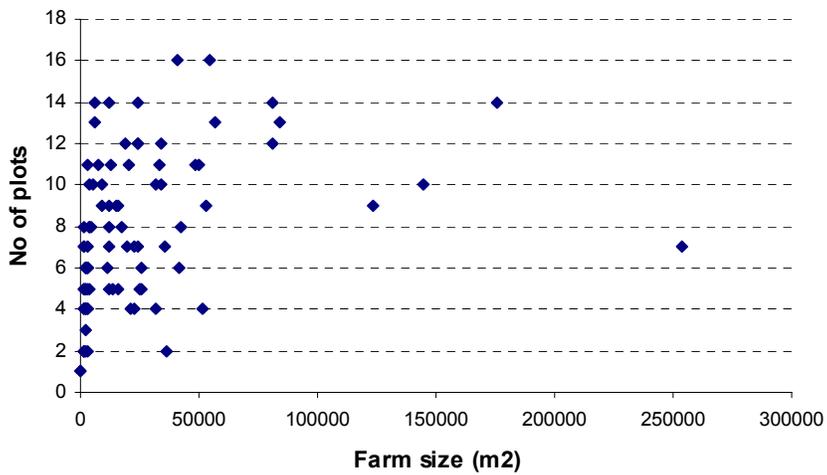


Figure 9. Distribution of the number of plots by farm size in Yen Bai (only for farm size less than 50,000 m²)

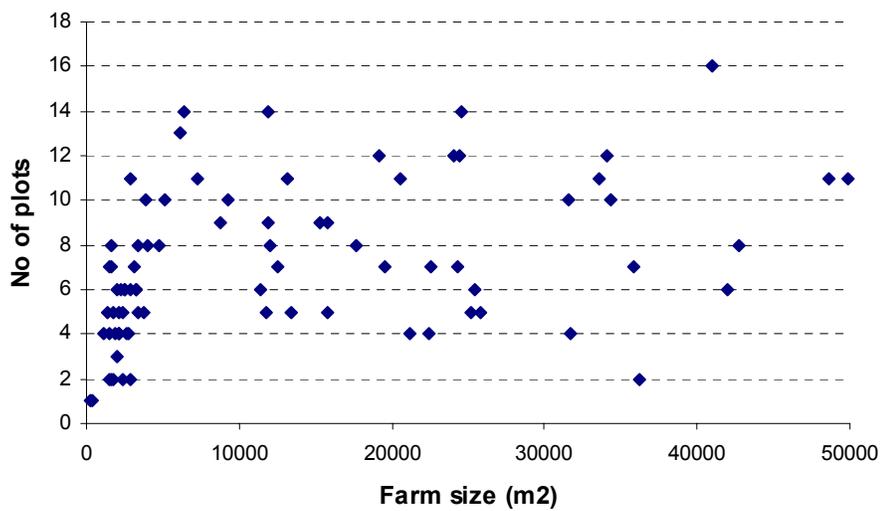


Figure 10. Distribution of distance in Ha Tay province

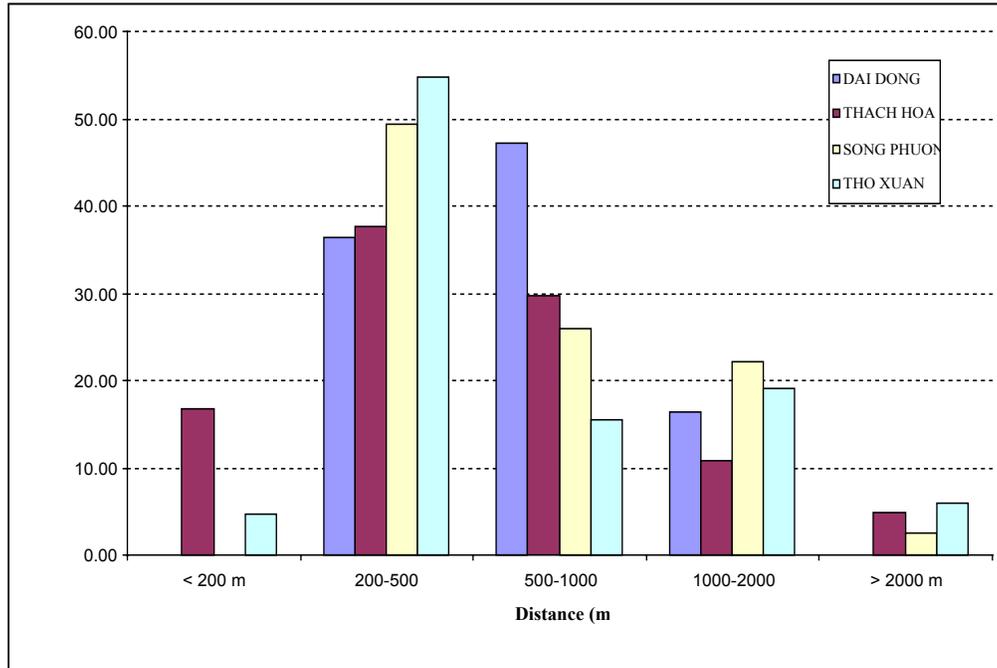
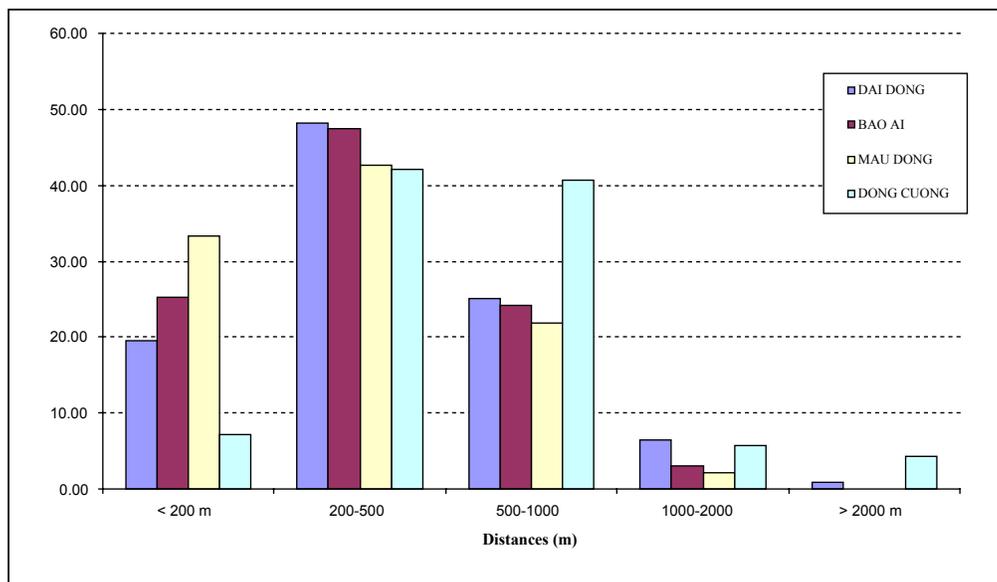


Figure 11. Distribution of distance in Yen Bai province



Appendix B: Derivation of comparative statics

In this appendix the detailed comparative static analysis of the model in equation (2) is given.

Case 1: farm land operated by the household is strictly increasing in agricultural production ability of the household, α . The amount of land rented in is also increasing in production ability, α of the household and decreasing for households with a higher land endowment, \bar{A}_i . Therefore, rental markets may transfer to “*small but efficient*” crop producers.

Total differentiation of both sides of (3), (4), (5), (5') and (6) or (6''), with respect to α , yields:

$$(A1) \quad \sum_j P \frac{\partial F}{\partial l_f} + \sum_j P \alpha \left(F_{ff} \frac{\partial l_f}{\partial \alpha} + F_{fh} \frac{\partial l_h}{\partial \alpha} + F_{fx} \frac{\partial x}{\partial \alpha} + F_{fa} \frac{\partial a}{\partial \alpha} \right) = 0$$

$$(A2) \quad \sum_j P \frac{\partial F}{\partial l_h} + \sum_j P \alpha \left(F_{fh} \frac{\partial l_f}{\partial \alpha} + F_{hh} \frac{\partial l_h}{\partial \alpha} + F_{hx} \frac{\partial x}{\partial \alpha} + F_{ha} \frac{\partial a}{\partial \alpha} \right) = 0$$

$$(A3) \quad \sum_j P \frac{\partial F}{\partial x} + \sum_j P \alpha \left(F_{fx} \frac{\partial l_f}{\partial \alpha} + F_{hx} \frac{\partial l_h}{\partial \alpha} + F_{xx} \frac{\partial x}{\partial \alpha} + F_{xa} \frac{\partial a}{\partial \alpha} \right) = 0$$

$$(A4) \quad \sum_j P \frac{\partial F}{\partial a} + \sum_j P \alpha \left(F_{fa} \frac{\partial l_f}{\partial \alpha} + F_{ha} \frac{\partial l_h}{\partial \alpha} + F_{xa} \frac{\partial x}{\partial \alpha} + F_{aa} \frac{\partial a}{\partial \alpha} \right) = 0$$

For simplicity, $\frac{\partial F}{\partial z}$ is noted as F_z only (where $z = l_f, l_h, x$, and a (and hereafter l_f and l_h are written as f and h , respectively)), $\frac{\partial^2 F}{\partial z^2}$ as F_{zz} , and $\frac{\partial^2 F}{\partial z \partial z^*}$ as F_{zz^*} (where $z^* = f, h, x, a$ and $z \neq z^*$).

In matrix form, expressions (A1-A4) can be written as:

$$\begin{bmatrix} F_{ff} & F_{fh} & F_{fx} & F_{fa} \\ F_{fh} & F_{hh} & F_{hx} & F_{ha} \\ F_{fx} & F_{hx} & F_{xx} & F_{xa} \\ F_{fa} & F_{ha} & F_{xa} & F_{aa} \end{bmatrix} \begin{bmatrix} \sum \frac{\partial l_f}{\partial \alpha} \\ \sum \frac{\partial l_h}{\partial \alpha} \\ \sum \frac{\partial x}{\partial \alpha} \\ \sum \frac{\partial a}{\partial \alpha} \end{bmatrix} = \begin{bmatrix} -\frac{\sum F_f}{\alpha} \\ -\frac{\sum F_h}{\alpha} \\ -\frac{\sum F_x}{\alpha} \\ -\frac{\sum F_a}{\alpha} \end{bmatrix}$$

Solving for $\sum \frac{\partial a}{\partial \alpha}$ by Cramer's rule, yields

$$(A5) \quad \sum \frac{\partial a}{\partial \alpha} = \frac{\begin{vmatrix} F_{ff} & F_{fh} & F_{fx} & -\sum F_f \\ F_{fh} & F_{hh} & F_{hx} & -\sum F_h \\ F_{fx} & F_{hx} & F_{xx} & -\sum F_x \\ F_{fa} & F_{ha} & F_{xa} & -\sum F_a \end{vmatrix}}{|H_4|}$$

where H_4 = Hessian Matrix

For a maximisation problem, $|H_4|$ must be positive, thus, the sign of $\sum \frac{\partial a}{\partial \alpha}$ depends on the sign of the numerator of (A5).

The numerator =

$$(A6) \quad (-1)^{1+4} \frac{-\sum F_f}{\alpha} |C_{14}| + (-1)^{2+4} \frac{-\sum F_h}{\alpha} |C_{24}| + (-1)^{3+4} \frac{-\sum F_x}{\alpha} |C_{34}| \\ + (-1)^{4+4} \frac{-\sum F_a}{\alpha} |C_{44}| > 0, \text{ because}$$

$$|C_{14}| = \begin{vmatrix} F_{fh} & F_{hh} & F_{hx} \\ F_{fx} & F_{hx} & F_{xx} \\ F_{fa} & F_{ha} & F_{xa} \end{vmatrix} > 0$$

And this same procedure yields $|C_{24}| < 0$, $|C_{34}| > 0$, and $|C_{44}| < 0$

So,

$$(A7) \quad \sum \frac{\partial a}{\partial \alpha} = \frac{\partial \sum a}{\partial \alpha} = \frac{\partial A}{\partial \alpha} > 0$$

Expression (A7) implies that the higher the ability in agricultural production of the household the higher the farm area operated by the household. Land is likely to be concentrated in the households with the higher ability.

If households rent out land, the amount of land rented out, A_{out} is equal to the endowed land of the household, \bar{A} subtraction to the operated farm area, A .

$$(A8) \quad A_{out} = \bar{A} - A$$

Total differentiation of both sides of (A8) with respect to α , yields:

$$(A9) \quad \frac{\partial A_{out}}{\partial \alpha} = -\frac{\partial A}{\partial \alpha} < 0 \quad (\text{because } \frac{\partial A}{\partial \alpha} > 0)$$

Expression (A9) implies that a household that rents out will rent out less land as their productive ability increases.

For the households who rent in land, the amount of rented in land, A_{in} is equal to

$$(A10) \quad A_{in} = A - \bar{A}$$

Total differentiation of both sides of (A10) with respect to α , yields:

$$(A11) \quad \frac{\partial A_{in}}{\partial \alpha} = \frac{\partial A}{\partial \alpha} > 0$$

Equation (A11) implies that the amount of rented in land is strictly increasing in the agricultural production ability of the household and households who rent in land will rent more land as their production ability improves.

Total differentiation of both sides of (A10) with respect to \bar{A} , yields:

$$(A12) \quad \frac{\partial A_{in}}{\partial \bar{A}} = -1 < 0$$

Equation (A12) implies that for those farm households who rent in land, the amount of land rented in is strictly decreasing in their land endowment.

Case 2: farm land operated by the household is strictly decreasing in the number of plots. This means that small sized farms are likely to be ‘more fragmented’ than large sized farms. Therefore, land fragmentation is likely to be present for small and self-sufficient producers. Fragmentation as measured by the number of plots also decreases with increasing agricultural ability of the household. Thus, a system of extension and training is needed to facilitate land consolidation.

In the same way as previously, total differentiation of both sides of expressions (3-6 or 6’) with respect to N (the number of plots) and solving for $\sum \frac{\partial a}{\partial N}$ yields:

$$(A13) \quad \sum \frac{\partial a}{\partial N} = \frac{\partial A}{\partial N} < 0$$

Expression (A13) implies that if land is more fragmented the household will operate less land. This also means that small-sized farms are likely to be more fragmented.

Total differentiation of both sides of (A8) and (A10) with respect to N , gives:

$$(A14) \quad \frac{\partial A_{out}}{\partial N} = -\frac{\partial A}{\partial N} > 0, \text{ and}$$

$$(A15) \quad \frac{\partial A_{in}}{\partial N} = \frac{\partial A}{\partial N} < 0$$

Equations (A14 and A15) imply that households who rent in land will rent in less the more fragmented the land. On the other hand, households who rent out land will rent out more the more fragmented the land

Recall equations (A7) and (A13):

$$\frac{\partial A}{\partial \alpha} > 0 \text{ and } \frac{\partial A}{\partial N} < 0,$$

thus, it is possible to derive

$$(A16) \quad \frac{\partial N}{\partial \alpha} < 0$$

Equation (A16) implies that the number of plots is strictly decreasing in agricultural production ability of the household. A system of extension and training may be needed to facilitate land consolidation.

Case 3: farm land operated by the household is strictly decreasing in transaction costs associated with the credit market, T_1 , the market for land use rights, T_2 , and land fragmentation, T_3 . The number of plots, N increases as the above mentioned transaction costs (T_1 , T_2 , and T_3) increase. The amount of land rented in and out decreases with increasing transaction costs for land rental, T_2 .

Total differentiation of both sides of equations (3-6 or 6') with respect to T_1 and solving for

$\sum \frac{\partial a}{\partial T_1}$ yields:

$$(A17) \quad \sum \frac{\partial a}{\partial T_1} = \frac{\partial A}{\partial T_1} < 0$$

Expression (A17) implies that an increase in the credit transaction cost decreases the operating farm size. Households have an incentive to increase farm areas if the transaction costs for credit decrease.

Solving for $\sum \frac{\partial x}{\partial T_1}$ by Cramer's rule yields:

$$(A18) \quad \sum \frac{\partial x}{\partial T_1} = \frac{\partial X}{\partial T_1} < 0$$

Expression (A18) implies that the higher the credit transaction cost the lower the investment of the household in inputs. Farmers may have no incentives to invest inputs in agricultural production if the transaction costs are too high.

Assume that the amount borrowed money for the household is K_{bor} and $K_{bor} = [\sum_j (P_{x_i} + T_3) x_{ij} + (A_i - \bar{A}_i)(r_2 + T_2) + w_2 L_{hi} - \bar{K}_i]$. Differentiation of both sides of this expression with respect to T_1 , yields

$$(A19) \quad \frac{\partial K_{bor}}{\partial T_1} = \frac{(P_x + T_3)\partial X}{\partial T_1} + \frac{(r_2 + T_2)\partial A}{\partial T_1} + \frac{w_2 \partial L_h}{\partial T_1} < 0$$

Expression (A19) implies that the farm household will borrow less money if the credit transaction cost increases.

This same procedure, yields:

$$(A20) \quad \frac{\partial A}{\partial K} > 0 \text{ and } \frac{\partial A_m}{\partial K} > 0$$

Expression (A20) implies that a household with a high capital endowment may be likely to increase their operating land.

In the same way, total differentiation of both sides of expressions (3-6 or 6') with respect to T_2 and T_3 (transaction costs associated with the rental market and land fragmentation) and solving for $\Sigma \frac{\partial a}{\partial T_2}$ yields:

$$(A21) \quad \Sigma \frac{\partial a}{\partial T_2} > 0 \quad \text{or} \quad \frac{\partial A}{\partial T_2} > 0 \quad \text{for households who rent out land}$$

Expression (A21) implies that households who rent out land will tend keep their land rather than rent it out as the transaction cost increases.

Total differentiation of both sides of (A8) with respect to T_2 , gives:

$$(A22) \quad \frac{\partial A_{out}}{\partial T_2} = -\frac{\partial A}{\partial T_2} < 0$$

Equation (A22) implies that the amount of rented out land is strictly decreasing in transaction costs or households who rent out land will rent out less land as the transaction cost increases.

For households who rent in land:

$$(A23) \quad \Sigma \frac{\partial a}{\partial T_2} < 0 \quad \text{or} \quad \frac{\partial A}{\partial T_2} < 0$$

Expression (A23) implies that households who rent in will operate less land as the transaction cost increases or household has reduced incentives to rent in more.

Total differentiation of both sides of (A10) with respect to T_2 , yields:

$$(A24) \quad \frac{\partial A_{in}}{\partial T_2} = \frac{\partial A}{\partial T_2} < 0$$

Equation (A24) implies that the amount of rented in land is strictly decreasing in transaction costs or households who rent in land will rent less land as the transaction cost increases.

In the same way, solving for $\Sigma \frac{\partial a}{\partial T_3}$ by Cramer's rule, yields:

$$(A25) \quad \Sigma \frac{\partial a}{\partial T_3} < 0 \quad \text{or} \quad \frac{\partial A}{\partial T_3} < 0$$

and

$$(A26) \quad \frac{\partial A_{in}}{\partial T_3} < 0$$

Expressions (A25 and A26) imply that the higher the transaction costs associated with land fragmentation the smaller the farm areas operated by the household and the household has reduced incentives to rent in more land.

Recall, $\frac{\partial A}{\partial T_1} < 0$, $\frac{\partial A}{\partial T_2} < 0$, $\frac{\partial A}{\partial T_3} < 0$, and $\frac{\partial A}{\partial N} < 0$

Thus, it is possible to derive

$$(A27) \quad \frac{\partial N}{\partial T_1} > 0, \frac{\partial N}{\partial T_2} > 0, \text{ and } \frac{\partial N}{\partial T_3} > 0$$

Equation (A27) implies that all three transaction costs associated with the credit market, the market for land use rights and land fragmentation are strictly increasing in the number of plots. Land consolidation may be more active if these transaction costs decrease.

Case 4: the farm land operated by the household is strictly decreasing in off-farm wages. The amount of land rented in also decreases while the amount of land rented out increases in relation to off-farm wages. If households who rented in continue to rent in land, an increase of the given wage for off-farm employment may increase land transacted in the rental market. This leads to a decrease in the equilibrium rental rate which will make everybody better off. Therefore, an increase in opportunities for off-farm jobs may be a key policy to encourage an active market for land use rights and land accumulation as well as agricultural production in general.

Using the same procedure, total differentiation of both sides of (3-6 or 6') with respect to the off-farm wage, w_1 and solving for $\sum \frac{\partial a}{\partial w_1}$ yields:

$$(A28) \quad \sum \frac{\partial a}{\partial w_1} = \frac{\partial A}{\partial w_1} < 0$$

Expression (A28) implies that household may reduce operating farm land when off-farm wages increase. Farmers may leave their land more often if more opportunities for off-farm jobs are available.

Total differentiation of both sides of (A8) with respect to w_1 , yields:

$$(A29) \quad \frac{\partial A_{out}}{\partial w_1} = -\frac{\partial A}{\partial w_1} > 0$$

Equation (A29) implies that for those who still rent out land, the amount of rented out land will be more as the off-farm job wage increases.

If it is assumed that the opportunities for off-farm jobs will not affect those households who rented in, an increase in the wage, w_1 will lead to a greater supply of land and the rental rate will decrease. To show this the derivation of Deininger and Jin (2003) will be used.

Let

$$(A30) \quad A_{in} = A_{in}(\alpha, p, w_1^{in}, r_2, T_2) \text{ be the aggregate rent-in curve, and}$$

$$(A31) \quad A_{out} = A_{out}(\alpha, p, w_1^{out}, r_2, T_2) \text{ be the aggregate rent-out curve.}$$

Thus:

$$(A32) \quad A_{in} = A_{out}$$

Total differentiation of both sides of (A32) while varying r_2 and w_1^{out} , yields:

$$(A33) \quad \frac{\partial A_{in}}{\partial r_2} dr_2 = \frac{\partial A_{out}}{\partial r_2} dr_2 + \frac{\partial A_{out}}{\partial w_1^{out}} dw_1^{out}$$

Therefore

$$(A34) \quad \frac{dr_2}{dw_1^{out}} = \frac{\frac{\partial A_{out}}{\partial w_1^{out}}}{\frac{\partial A_{in}}{\partial r_2} - \frac{\partial A_{out}}{\partial r_2}}$$

We know $\frac{\partial A_{in}}{\partial r_2} < 0$, $\frac{\partial A_{out}}{\partial r_2} > 0$, and $\frac{\partial A_{out}}{\partial w_1^{out}} > 0$,

so

$$(A35) \quad \frac{dr_2}{dw_1^{out}} < 0$$

Expression (A35) implies that the equilibrium rental rate for land decreases as the wage rate increases.

Appendix C: Risk Estimation

In this appendix a summary is provided of the model developed by Blarel et al. (1992). It is assumed that the yield for farmer i on plot j is given by

$$(A36) \quad Q_{ij}/a_{ij} = (y_o + \mu) + (h_i + \eta_i) + (k_{ij} + \varphi_{ij})$$

Where: Q_{ij} is the output of the j th plot of household i ; a_{ij} is the area of plot j of household i ; y_o is the village average yield for all plots and households; μ is a random village-level effect; h_i is a fixed household effect; η_i is a random household effect; k_{ij} is a fixed effect of plots; and φ_{ij} is a random plot effect.

It is assumed that random effects are independent of each other. This means that $E(\mu \eta_i) = 0$; $E(\mu \varphi_{ij}) = 0$; and $E(\eta_i \varphi_{ij}) = 0$ for all i and j . In addition, co-variances between η_i and η_{i^*} , φ_{ij} and $\varphi_{i^*j^*}$ (or $E(\eta_i \eta_{i^*})$ and $E(\varphi_{ij} \varphi_{i^*j^*})$ respectively) are equal zero for all $i \neq i^*$ and $j \neq j^*$ (where i^* and j^* are also denoted as i (household) and j (plot), respectively).

Total farm output is

$$(A36) \quad \begin{aligned} \sum_j Q_{ij} &= \sum_j a_j [(y_o + \mu) + (h_i + \eta_i) + (k_{ij} + \varphi_{ij})] \\ &= [(y_o + \mu) + (h_i + \eta_i)] A + \sum_j a_j (k_{ij} + \varphi_{ij}) \end{aligned}$$

where A is farm area and equal to $\sum_j a_j$

The mean of output would be

$$(A37) \quad E(\sum_j Q_{ij}) = (y_o + h_i) A + \sum_j a_j k_{ij}$$

The variance is

$$(A38) \quad \begin{aligned} \text{Var}(\sum_j Q_{ij}) &= A^2 [\text{Var}(\mu) + \text{Var}(\eta_i)] + \sum_j a_j^2 \text{Var}(\varphi_{ij}) \\ \text{or } \frac{1}{A^2} \text{Var}(\sum_j Q_{ij}) &= \text{Var}(\mu) + \text{Var}(\eta_i) + \sum_j \frac{a_j^2}{A^2} \text{Var}(\varphi_{ij}) \end{aligned}$$

Simpson's index of land fragmentation, S is $(1 - \sum_j \frac{a_j^2}{A^2})$

The expression can be written as

$$(A39) \quad \text{Var}(\sum_j Q_{ij}/A) = \text{Var}(\mu) + \text{Var}(\eta_i) + (1 - S) \text{Var}(\varphi_{ij})$$

or

$$\begin{aligned} Y &= \alpha_0 + \alpha_1 X + U \\ \text{where } Y &= \text{Var}[(\sum_j Q_{ij})/A_i] = \text{variance of farm output} \\ \alpha_0 &= \text{Var}(\mu) \\ \alpha_1 &= \text{Var}(\varphi_{ij}) \\ U &= \text{Var}(\eta_i) \\ X &= (1 - S) \text{ and } S \text{ is Simpson's index of land fragmentation.} \end{aligned}$$

The expression (A39) implies that the variance of the household output is linearly decreasing as land fragmentation measured by Simpson's index, S increases.