The effect of land fragmentation on labor allocation and the economic diversity of farm households: The case of Vietnam

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The effect of land fragmentation on labor allocation and the economic diversity of farm households: The case of Vietnam

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Abstract

This paper investigates the impacts of land fragmentation on economic diversity of farm households in Vietnam. To develop the empirical analysis, a model is presented in which the estimated impact of land fragmentation on economic diversification allows for non-neutral technical change. The paper tests the theoretical predictions of this model by providing empirical evidence of the impact of land fragmentation on farm and nonfarm outcomes such as labour supply, profits, labour intensity and productivity. By using different methods aimed at verifying and checking the consistency of the results, we find that land consolidation may reduce on farm labour supply, labour intensity and improve farm profits and productivity. Similarly, it may release more farm labour to nonfarm sectors and increase nonfarm profits. The empirical results show that factor-biased technical change plays an important role in explaining the impact of agricultural technical change on economic diversification in Vietnam.

Key words: Agricultural technical change, land fragmentation, land consolidation, labour allocation, and elasticity of substitution, nonfarm sectors, and economic diversification.

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"Vietnam needs to adopt the seemingly paradoxical stance of giving a high priority to raising agricultural productivity while recognizing that success can come only as agriculture declines as an employer of labour"

(World Bank, 2000, p12)

1. Introduction

The development experience shows that the success of countries is accompanied by agricultural growth and economic structural change, where labour and resources are reallocated from the traditional sector toward other sectors where it can be used more productively (Lewis 1954, Perkin et al. 2006, Warr 2009). The governments of many developing countries emphasize the role of research, public investments and credit programs in agriculture and the promotion of mechanization in order to improve productivity. However, these policies may be hindered if land holdings of household are too scattered and small (McPherson 1982). Thus land reforms play a vital role in productivity growth and structural change. Several studies on agricultural growth show that the reduction of land fragmentation results in the productivity gain in agriculture (Blarel 1992; Wan and Cheng 2001; Hung et al. 2007; Kompas et al. 2012). As a result, land consolidation has policy relevance for governments in promoting agricultural productivity. In an analysis of annual crop yield in Northern Vietnamese farm households, Hung et al. (2007) conclude that land consolidation may release more labour for other sectors of the economy. Tan et al. (2008) have the same conclusion for Chinese farm households. If these findings are correct, land consolidation can not only improve agricultural productivity, but also reduce agricultural surplus of labour, which is one of the challenges facing Vietnam.

The question is whether this policy really works and whether land consolidation may also foster economic diversification. Does the application of land consolidation reduce labour supply and induce labour reallocation in farm households? Or do land reforms such as land consolidation free up labour to be put to work in other sectors and to be invested in the creation of human capital? The key variable that is used to explore the effect of agricultural development is measured by agricultural technical change. All previous studies find that the reduction of land fragmentation improves agricultural technical efficiency. Many models analyze the role of agricultural productivity growth in releasing labour from agriculture and generating demand for the output of nonfarm sectors (Johnson 2000, Haggblade et al. 2007). However, there have been a lot of debates

related to this finding. Matsuyama (1992) indicates that the growth of agricultural productivity can slow down structural change in open economies because labour reallocates toward the agricultural sector, which reduces the size of the non-agricultural sectors. Similarly, Foster and Rosenzweig (2004 and 2008) find that growth of income from the nonfarm sector in rural India has been substantial and the primary source of this growth is not predicated on the expansion of agricultural growth. On the other hand, Johnson (2000) emphasizes that increasing the productivity of agriculture is essential for both poverty reduction and the development of the nonagricultural sector. Although there have been many theoretical studies, empirical evidences testing these linkages is still rare, particularly using household data.

Land fragmentation is defined as the existence of a number of spatially separate plots of land, which are farmed as single units (McPherson, 1982). The existence of fragmented landholdings is considered an important feature of Vietnam and other developing countries in Asia (Blarel et al. 1992). It can be an obstacle to agricultural development because it hinders agricultural mechanization, and results in time loss in travel and inconvenience and inefficiencies in production. The reduction of land fragmentation consequently improves agricultural productivity (McPherson 1982, Wan et al. 2001, Tan et al. 2006, Hung et al. 2007, Kompas et al. 2012). The reduction of land fragmentation can improve technical efficiency in agricultural production, according to studies using stochastic production frontier approach (Rahman et al. 2008, Kompas et al. 2012). In view of these considerations, many Asian countries have introduced land consolidation programs and land reforms to reduce fragmentation. The literature documents that land consolidation helps to improve agricultural productivity and reduce time wastage.

Regarding the impact of land fragmentation on labour allocation, there have been only a few studies. Hung, MacAulay and Marsh (2007) find that land consolidation may release more labour for other sectors in Vietnam. Similarly, Wan and Cheng (2001), and Tan et al. (2008) conclude that more liberal land policies in China allowing land consolidation may reduce agricultural surplus labour. Conversely, Jia and Petrick (2013) show that land consolidation has a positive impact on farm labour and may slowdown the release of farm labour. The coefficients are statistically insignificant. As a result, studies provided different evidence on the linkages between land consolidation and labour allocation. There is no paper analyzing the impact of land consolidation on economic diversification of households. In addition, these studies do not provide a theoretical framework for their analysis. Jia et al. (2013) show that the effects of scattered landholdings on the

marginal product of labour and labour allocation are theoretically undetermined despite the positive relationship between land consolidation and productivity. However, the linkage is determined if there is a clear production function with different assumptions related to technical change.

The overall objective of this paper is to test the validity of the above-mentioned areas of thought in rural Vietnam with a concentration on the role of land policies in facilitating structural transformation from the farm to the nonfarm economy. First, it aims to address the issue of whether agricultural technical change through land consolidation, which improves agricultural productivity, leads to economic diversification and raises the incomes of households. McCaig and Pavcnik (2013) show that no study formally examines the impact of agricultural productivity growth on the "labour push" explanation for the observed movement of labour out of agriculture in Vietnam. Prior studies have used adoption rates of high-yielding variety seeds and measured the effects of these adoption rates on economic diversification. In this paper, we use land consolidation as a measure of agricultural technical change. Second, we test whether land consolidation is considered as factor-biased technical change or Hick-neutral technical change. If land consolidation reduces farm labor, factor biased technical change should be considered. Conversely, if land consolidation increases farm labor, Hicks neutral technical change should be selected.

To do empirical tests, we develop a model for studying the effect of agricultural productivity growth through land consolidation. We expand the model developed by Jia and Petrick (2013) by capturing the land consolidation parameter measuring the efficiency of labour uses on the farm plot and ability to apply it to mechanization in rice production and factor-biased technical change. As shown in Matsuyama (1992), it can be predicted that agricultural productivity growth, which takes the form of Hicks-neutral technical progress, induces a reduction of labour relocation. The theoretical model, thus, predicts that the effect of agricultural technical change through land consolidation on labour allocation depends on the factor biased technical change. Thus, we use empirical work to test the predictions of the model.

We employ a panel data set of Vietnam Household Living Standard Survey in 2004 and 2006 to test my hypothesis. Our empirical strategy includes different methods to verify the consistency of the results such as first difference, double hurdle model and model of sample selection correction. There are two systems of equations including the impact of land consolidation on farm and nonfarm outcomes. This study contributes to the literature in several ways. First, this is apparently the first paper looking into the joint treatment of two issues, which have previously

been treated separately: the effects of land consolidation on farm, nonfarm employments and income in Vietnam. Land consolidation has two separate effects: a direct productivity effect that is the main focus of much of the empirical literature, and an indirect labour allocation effect that we study here.

Second, many studies in the literature focus on the impacts of land consolidation on agricultural productivity, crop inputs and crop diversification, but this study discusses the linkages between agricultural technical change and labour allocation. Next, there is a further contribution to the current literature by taking into account the potential spillovers of land consolidation as a "push" factor in the determinants of nonfarm employment and income after controlling human capital assets and locational factors. Finally, this study provides the theoretical framework of linkages between agricultural technical change and labour allocation, which the earlier literature ignores.

The rest of this paper is organized as follows: Section 2 provides the background of the research, and gives a descriptive analysis about trends of employment. It provides an overview of land fragmentation in Vietnam due to egalitarian reallocation in the initial years of land reform in the late 1980s. Section 3 analyzes the reasons for land fragmentation in Vietnam and situation of current land consolidation programs. The next section covers the literature review and summarizes previous studies, which support the discussion of variables in the model. Section 5 introduces the theoretical framework and empirical methodologies. This section introduces regression models that quantify the relationship between farm profits, farm labor supply, labor intensity, nonfarm labor supply, and nonfarm profits and the variable of land fragmentation, which captures agricultural technical change, and compares the results of different methods that control unobserved fixed effects and selection bias. Section 6 analyzes the data and variables. Section 7 describes the empirical results. Finally, the paper draws conclusions with a summary of the main findings.

2. Background and context

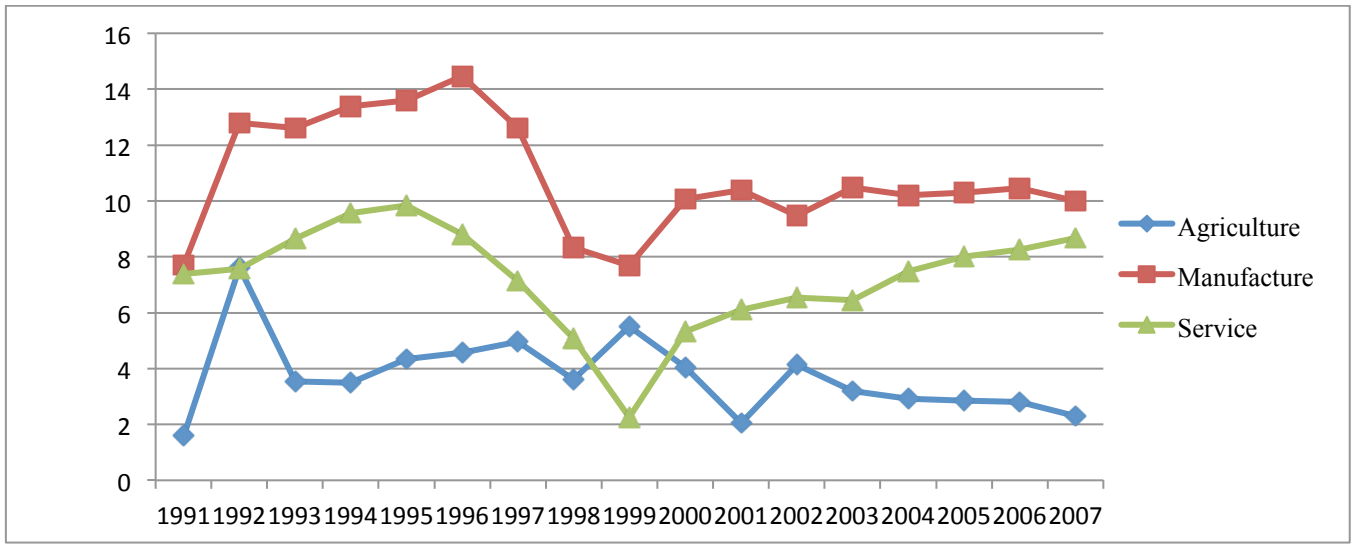
** Agricultural growth and trends of land reforms*

Vietnam started its economic reforms in 1986. The *DoiMoi* has transformed Vietnam from a poor country to become a middle-income country in nearly two decades (World Bank 2011). According to World Bank (2011), Vietnam's GNI per capita was USD 1,010 in 2011, compared with USD 790 in 2007. Economic growth has brought about great achievement in poverty

reduction. The number of people living below poverty line fell from 58 per cent in 1993 to 14 percent in 2011. In addition, this prolonged economic growth has also enabled Vietnam to improve social welfare and living standard of most of the households (Glewwe et al., 1994).

Agricultural reform played an important role in the development process of Vietnam. Minot and Goletti (1998), Benjamin and Brandt (2004), and Dang et al. (2006) argue that agricultural reforms in late 1980s contributed greatly to raising both food production and rural households' welfare. From a net food consumer in the early 1980s, Vietnam has become a leading food exporter. This country has transferred from central planning to dynamic market agricultural sector. The reform started by establishing the household responsibility system and increasing the state purchase prices for agricultural products, which led to large improvement in agricultural production. The process of decollectivizing the agricultural system under Resolution 10 in 1988, which allocated land to farm households, resulted in the boost in the agricultural output and improved the living standard of farmers. The Land Law 1993 and the Decree 64 (1993) allocated agricultural land to farmers in long-term with stable use and proved farmers with five rights of land use including the rights of transfer, exchange, lease, inheritance and mortgage. The most important principle of the land allocation was to maintain equality. Kompas (2004) shows that land and market reforms in Vietnam induced farmers to work harder and more incentives to invest in land in spite of a relatively modest growth of most inputs and little or no technological change.

Figure 1. Growth rates by sectors, 1991-2007



Source: General Statistics Office (GSO), 2002, 2003, 2008, and 2009, *The statistical yearbooks*, The Statistics Publishing House, Hanoi.

However, agricultural growth has been reducing recently in Vietnam. As can be seen in Figure 1, in the period 1986-2007, average growth rate of agriculture was 4.2 per cent (GSO 2006), which helped Vietnam maintain food security and remarkable poverty alleviation. The agricultural growth in the period 2000-2005 reduced to 3.7 per cent per year and 2.3 per cent in 2007 (GSO 2008). The declines in agricultural growth and falling demand for rice have threatened the sustainability of food security and poverty reduction in rural Vietnam.

There are some reasons for the reduction of agricultural growth. The agricultural production is constrained by small and scattered land holding (World Bank 2006, and 2008). Many studies on Vietnamese agriculture find that land fragmentation is one of main reasons for the reduction of agricultural growth (Hung et al. 2007; Kompas et al. 2012). These studies show that land fragmentation had a negative impact on crop productivity, increased family labour uses, and expenses of crop inputs. Since the cooperatives was abolished under Resolution 10 in 1988 which recognized the farm household as an autonomous economic unit, the agricultural land of a commune had been redistributed to individual household on egalitarian basis. Each household was reallocated some plots in different areas based on the different qualities of the field plots as well as access to water sources or other infrastructure. The land reallocation process has been remarkably equitable (Ravallion and van de Walle, 2003). As a result, farmland has been deliberated fragmented. In the whole country, there are about 75 million plots, an average of seven to eight plots per farm household (Vy, 2002).

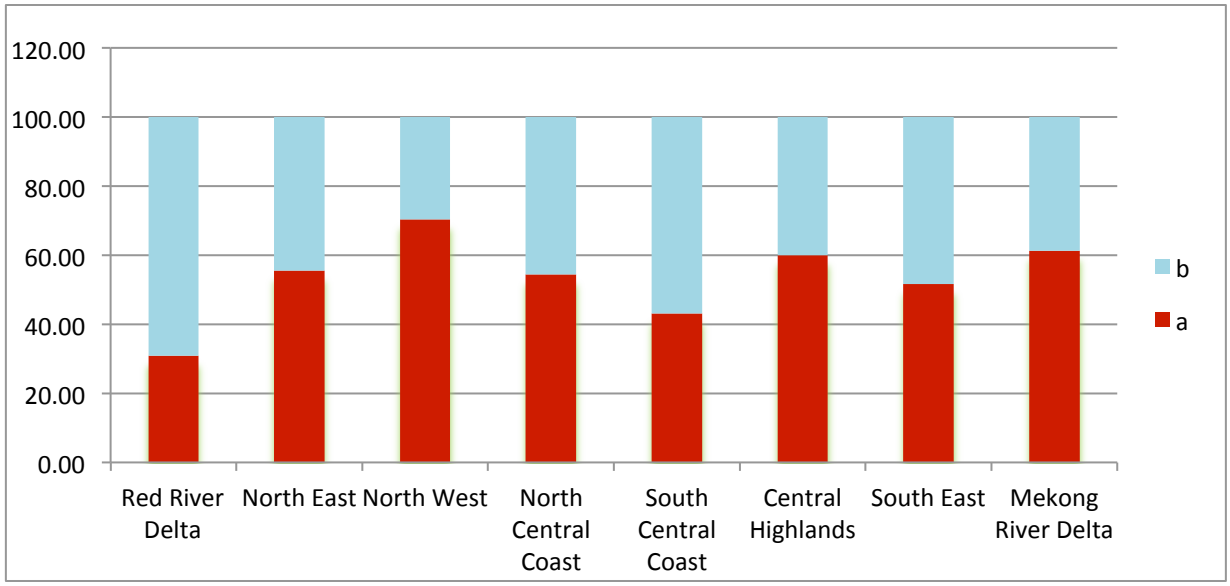
In the past decades, paddy land has been reduced significantly due to the increasing impacts of urbanization, industrial growth and climate change (Dang et al. 2006). In Vietnam, the area of paddy land was 4.1 million of ha. Households, whose farm sizes were smaller than 0.5 hectares represented over 65 per cent of households in rural areas (Agricensus, 2006). In the period of 2001-2005, paddy land was reduced by 70,000 hectare annually due to the impact of urbanization, the expansion of industrial zones and climate changes (MARD, 2008). In the period 2001-2005, 366,400 hectares of agricultural land were recalled by local governments; by 2010 the total rose to roughly 745,000 hectares, affecting some nine million farming people, or about 10 percent of the country's population (World Bank, 2011). Clearly, land fragmentation, increasing recall of paddy land, and landlessness, adverse impact of climate changes and rising costs of crop inputs due to high inflation in the past few years are threatening the sustainable growth of agricultural

production and livelihoods of farm households in rural Vietnam. Therefore, land reforms have becoming the most important institutional challenge facing Vietnam.

** Trend of employments*

In addition to the need of further land reforms, there has been a structural change in rural Vietnam. More households abandoned agriculture or reduced agricultural production and took part in the rural nonfarm economy. Figure 2 depicts the participation rate in nonfarm activities by farm households in 8 regions in Vietnam. Two main rice-producing regions are Red River Delta and Mekong River Delta. Regions in northern Vietnam suffer from higher land fragmentation than ones in the South. The Simpson index in Red River Delta is 0.6, three times higher than the Simpson index in Mekong River Delta. Interestingly, nearly 70 percent of farm households in Red River Delta have at least one member working in nonfarm activities. Whereas, only 40 per cent of farm households in the South have extra nonfarm jobs. However, the figure can show that farm households tend to diversify their income in light of increasing uncertainties in agricultural production.

Figure 2. The structure of two groups of households by regions from the VHLSS 2004-2006



Notes: (a) Households working only on the farm; (b) Households with at least one member working in nonfarm activities

Source: calculated from VHLSS 2004 and 2006.

** Trends of earning diversification*

Table 1 provides information on incomes by farm sizes in the period 2004-2006. Clearly, households with smaller farm sizes are more engaged into nonfarm activities. More than 60 percent of rural households have farm size that is less than 0.5 hectare. Nonfarm income represents the largest share of off-farm incomes of rural household in Vietnam. The share of total household income derived from nonfarm activities falls with farm size. In addition, among off-farm-incomes, nonfarm incomes are far much larger than agricultural wages. All categories of off-farm activities are relatively more important for households with fewer land assets. Thus, the ability to participate in nonfarm activities is fundamental for the land-poor. Many households with small farm sizes are more engaged to off-farm activities. Small landholding households have diversified their livelihoods in light of increasing costs of inputs and the declining trend of rice prices.

Table 1. Sources of income in rural Vietnam by farm size, 2004-2006

	<0.5 ha	0.5-1 ha	1-2ha	2-3ha	>3ha
Share in total income					
Total farm income	35.33	62.12	71.39	76.53	78.72
Total off-farm income[1]	64.65	37.87	28.61	23.47	21.28
Nonfarm income	47.63	25.52	18.56	15.20	14.63
Nonfarm wages	29.93	16.92	12.91	9.78	9.77
Self-nonfarm income	17.67	8.59	5.64	5.42	4.86
Agricultural wages	1.70	0.77	0.81	0.41	0.12
Remittances	9.12	7.19	5.75	4.62	3.32
Public transfers	4.08	2.65	1.99	1.94	1.74
Others	2.15	1.74	1.49	1.30	1.47
Number of household (%)	61.44	17.17	11.84	4.64	4.91

Source: Calculated from VHLSS panel data 2004-2006
Note: All incomes deflated to January 2000 prices

Similarly, table 2 provides information on sources of income by quintiles of per capital expenditure in the period 2004-2006. For the middle and richest groups, off-farm incomes are more important than farm incomes. Richer households are, the higher share of nonfarm income

[1] According to the questionnaire from VHLSS of 2004 and 2006, remittances are income from people, who are not household members. Therefore, they are not considered as nonfarm incomes of rural households. Other incomes in this paper are income from education, health, and others from section 4D2 of the questionnaire. Nonfarm incomes

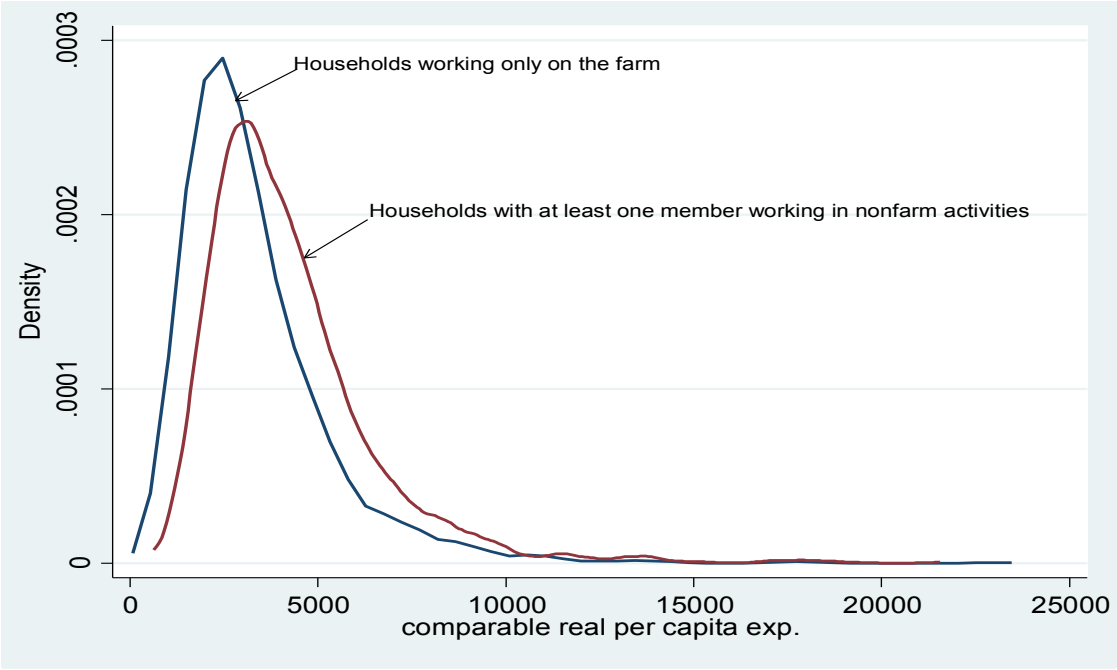
is. These results are consistent with the findings of previous studies shown in the literature review of this paper. For the poor groups, farming is the main activity of the sample. Agriculture emerges as the driving factor in determining the evolution of expenditure in poor groups. Nonfarm incomes only represent 28.29 percent of the total income of the poorest households. Clearly, there is upward mobility in labour markets in rural Vietnam. When households' incomes improve, households tend to move toward nonfarm activities. Haggblade et al. (2007) show that there are barriers for poor households to enter nonfarm activities due to constraints of education and assets. However, in the context of rural Vietnam, nonfarm employment contributes to improving livelihoods of these households. Small farm sizes, land fragmentation and increasing costs of production can be one of arguments explaining the "push" factor for the participation into nonfarm activities in rural Vietnam (Pham et al. 2010).

Table 2. Sources of income in rural Vietnam by quintiles of per capital expenditure, 2004-2006

	Poorest	Poor-mid	Middle	Middle-upper	Richest
Share in total income (%)					
Total farm income	59.85	50.90	47.86	39.23	29.08
Total off-farm income	40.14	49.05	52.14	60.75	70.92
Nonfarm income	28.39	37.73	38.48	42.94	44.17
Nonfarm wages	23.79	24.24	22.07	24.08	25.11
Self-nonfarm income	4.59	13.44	16.40	18.84	19.06
Agricultural wages	2.24	1.25	0.70	1.03	0.84
Remittances	5.08	6.12	7.84	10.10	16.86
Public transfers	2.58	2.66	3.56	4.41	4.92
Others	1.87	1.34	1.57	2.29	4.13
Number of household (%)	22.69	24.24	23.44	19.88	9.74

Source: Calculated from VHLSS panel data 2004-2006
Note: All incomes deflated to January 2000 prices

Figure 3. The density function of real per capita expenditure of two groups of households



Source: calculated from VHLSS 2004 and 2006.

Many studies have shown that participation in rural nonfarm economy is positively correlated to household welfare (Haggbalde et al. 2007; Lanjouw and Lanjouw, 2001; Reardon, 1997). However, studies of determinants of nonfarm participation indicate that typically rich households have better access to remunerative nonfarm activities (de Janvry & Sadoulet 2001). In the context of rural Vietnam, households with at least one member in nonfarm activity have higher expenditure than ones with only farming activities (Figure 3).

3. Reasons for land fragmentation and trend of land consolidation in Vietnam

** Reasons for land fragmentation in Vietnam*

In the literature review, reasons for land fragmentation are classified into two strands including supply-side and demand-side (Bentley 1987; Blarel et al. 1992). The supply-side reasons are referred to an exogenous imposition on farm households of a pattern of land areas, while the later covers varying levels of land fragmentation selected by farm households (Blarel et al. 1992). In rural Vietnam, land fragmentation has mainly resulted from the land reallocation policies (Hung and MacAulay 2002). In addition, imperfect land markets such as lack of regulatory frameworks

and high transaction costs have restricted transactions in land markets (World Bank 2003 and 2006; ADB 2004).

As regards demand-side reasons, farm households may retain some certain degrees of land fragmentation if they realize some benefits. In this case, the private benefits of land fragmentation may exceed the private costs (Blarel et al. 1992). The positive benefits include the effects of land fragmentation on risks spreading, seasonal labor spreading and crops diversification. However, land fragmentation results in many negative impacts such as higher costs, increased negative externality, loss of land due to boundaries and disputes between farm households (Blarel et al. 1992).

The most important cause of land fragmentation in Vietnam is the land allocation process of the government. The decollectivization of agricultural system in the late 1980s under the Resolution 10 of the government, which transferred land to farm households, has caused land fragmentation since 1988. Land was reallocated based on two main criteria: the number of individuals in the household and land quality with consideration of irrigation system, distance among plots and other farming conditions. Consequently, equality policy resulted in serious land problems in Vietnam.

In rural Vietnam, a production team or village typically is distributed around the village. It is unlikely for natural disasters to strike one block while not others within such a small vicinity/locality. Therefore, the only potential benefit possibly associated with land fragmentation, namely risks reduction, and is not really applicable to Vietnam. World Bank (2006) shows that household with more fragmented landholdings was more likely to cultivate rice, spending more time on the farm, and achieving a lower productivity.

> *"Land consolidation helped farmers reduce labor and time requirement. Before, due to manual techniques, much labor and working days needed, With the application of technology, it takes only average two weeks per household to harvest in comparison to one and a half of month before"*
>
> *"Before I had twenty plots in different positions… There are five people in my family… When necessary, I need to mobile all my family members to visit fields or ask for the help of my cousins. However, now with three plots, only I and my husband can do everything in one afternoon"*
>
> (Ta, T. T. 2010, p.27)

Similarly, McPherson (1982) find that land fragmentation hinders the improvement in agricultural productivity. Given the continued decline in cultivated area, diminishing productivity, the prevalence of labour surplus and continued increases in the cost of production, rural

households' profit ability rice production is decreasing. Moreover, Wan and Cheng (2001) finds that land fragmentation often results in problems of increased labour time, land loss, need for fencing, transportation costs and restrictions to human, machinery, and irrigation access. The limit of technological application is likely a main disadvantage of land fragmentation in Vietnam. Table 3 provides the summary of advantages and disadvantages of land fragmentation. In the literature, studies show that the disadvantages outweigh the advantages. Hence, a reduction in land fragmentation through consolidation will enable the problems of land fragmentation to be reduced.

Table 3. Costs and benefits of land fragmentation

Costs of land fragmentation		Benefits of land fragmentation	
Private cost	Public cost	Private benefit	Public cost
- Increases in costs - More labor used - Land loss due to boundaries - Disputes between neighbors - Cumbersome water management - Difficulties in technological application and mechanization	- Less labor released - Higher transaction costs - Delay of mechanization and technological application - Difficulties in crops planning and land use planning	- Risk spreading - Crop rotation - Seasonal labor spreading	- Equality of land redistribution (egalitarian principle) - Implicit insurance

Sources: Summarized from studies in the literature review related to land fragmentation.

** Measurement of land fragmentation*

The measurement of land fragmentation is desired to provide a relatively complete picture of fragmented land holdings of rural households and can be used for policy analysis. This present paper uses the Simpson index to measure land fragmentation. This approach has been used by some studies in the literature[2]. According to Blarel et al. (1992), Simpson index is defined as:

[2] Studies applied the Simpson index as the measurement of land fragmentation (Blarel et al, 1992; Tan et al. 2008; Hung et al. 2007).

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

Where *a* is the area of each plot, and *n* is the number of plots. *SI* lies between zero and one, with a higher value if Simpson index (*SI*) shows a larger degree of land fragmentation. The average plot area, the distribution of plot area and the number of plot form *I*. It does not capture the average distance from home to plots. Hence, it ignores the spatial distribution of plots. This is a limitation of data. However, there is no section of spatial distribution in the VHLSS of 2004 and 2006. Simpson index has been used in previous studies on land fragmentation in Vietnam (Kompas et al., 2012; Hung et al., 2007, Makussen et al. 2013), which can be compared with the results in this study. In this paper, we use both Simpson index and plots as a measure of land fragmentation.

** Land consolidation from survey data*

This part is to explore whether land consolidation occurred and, if so, whether the process was driven by the land market in Vietnam. Table 4 provides statistics of land fragmentation in Vietnam using the VHLSS 2004 and 2006. As can be seen in the table, there is a reduction in the degree of land fragmentation. All indicators have shown the tendency of land consolidation consistently. The reduction of Simpson index means that more plots are consolidated. Meanwhile, the farm sizes also increase. Thus, land consolidation and accumulation take place at the same time[3]. Marsh et al. (2006) show that land can be consolidated through plot exchange or through transactions in the land markets. The plot exchange programs have been implemented since 1998 and limited land use rights to farmers as the foundation of land markets were formalized in Land Law in 1993. Land consolidation programs have considered as a strategy to maintain food security and support rural industrialization in Vietnam[4].

[3] The reduction of plots can eliminate the barriers between plots and irrigational systems. Due to the lack of data on land barriers and irrigational systems, the paper cannot provide evidences on this argument.

[4] Land consolidation is a key strategy in the Communist Party's Resolution No. 26-NQ/TW (2008) on agriculture, farmers and rural development in Vietnam. In this resolution, the government emphasized the role of land consolidation and slow progress due to rising corruption and cumbersome procedure.

Table 4. Land fragmentation in the period 2004-2006

Indicators	2004	2006	Panel
Farm size (ha)			
Mean	0.45	0.48	0.47
Median	0.27	0.28	0.27
Average size of plot (m2)			
Mean	1112.1	1530.7	1326.2
Median	437.5	540.0	494.3
Plots			
Mean	6.0	5.2	5.6
Median	5.0	4.0	5.0
Simpson index	*Percentage of households (%)*		
0-0.2	10.18	13.70	11.94
0.2-0.4	13.70	13.31	13.51
0.4-0.6	25.67	27.46	26.56
0.6-0.8	34.46	33.57	34.01
0.8-1.0	15.99	11.97	13.98
Number of households	*2014*	*2014*	*4028*

Source: calculated from VHLSS 2004 and 2006

In rural Vietnam, farm households can reduce land fragmentation through the exchange of plots or transfer of certificates of land use rights (LUC) in land markets. The government issued a policy to encourage the plot exchange through decentralized land consolidation programs[5] in 1998. However, this process is slow and mainly focused in some northern provinces (World Bank 2006; Hung et al. 2007). In addition, administrative constraints represent another obstacle. Credit constraints can also prevent or slowdown market-based land consolidation (World Bank 2006).

The plot exchange in rural Vietnam is based on some principles such as voluntarism, equity, transparency, and proactive participation of local authorities. This process is likely to cause interest conflicts if land governance is weak (Palmer et al. 2009). Therefore, the quality of land governance is a key determinant of successful land consolidation programs.

Kerkvliet (2000) finds that land transactions took place in some regions, but many illegally. He shows that costs with registering land-use-right transactions, time consuming, cumbersome

[5] "Land consolidation is defined as an exchange of the private ownership and location of spatially dispersed plots of farms to form new holdings containing a single (or a few as possible) plot(s) with the same or similar value as the original area" (Oldenburg 1990, p. 183).

procedures, unclear regulations and opportunistic rent-seeking behaviors are attributed to illegal transfers. In addition, restrictions on land markets have made rental and land transfer values not reflect true market prices. These values are determined within pricing frameworks set by the central government with the actual prices fixed by the local governments. Thus, most rural households are reluctant to sell their land-use-right unless they have better prospects with reasonably low risk..

Above studies show the opposite results to conclusions of Deininger and Jin 2005), who find that the emerging land rental market in China provide a more efficient way to reduce land scattered holdings. In Vietnam, according to the Land Law 1993, private land ownership is prohibited. Thus, most of the studies have covered the development of land-use-right markets in Vietnam. Ravallion and van de Walle (2003) show that although a land-use-right transfer is emerging in Vietnam in response to reforms that have given a degree of security and tenure to land holdings, it is still constrained. They claim that there are official restrictions for land-use-right transactions, which control the circumstances under which, and to whom, land-use-rights can be transferred. Deininger and Jin (2003) use data of the 1992/93 and1997/98 VLSS to estimate factors affecting rental and sales market in Vietnam. They confirm that both markets have a positive impact on productivity and provide opportunities for households with higher levels of ability to access land.

To have an insight of the change in land fragmentation in rural Vietnam, the correlation between land fragmentation and farm sizes is explored. If the relationship is uncorrelated or very weakly correlated, the change in land fragmentation is likely to be driven by the factors such as plot exchange. Conversely, if scattered landholdings and farm sizes are negatively correlated or become less positively related, land consolidation can be driven by land markets. In order to measure the relationship between land fragmentation and farm size, the Spearman's rank correlation coefficient is used[6]. The Spearman coefficient is selected because it has many advantages in terms of distributional nonparametric method (Kozak et al. 2012). The Spearman rank correlation is estimated by the following expression:

$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)}$, where d_i is the difference between the rank of corresponding variables, n is the number of pairs of values.

[6] In Stata13, the Spearman's rank correlation coefficient can be calculated by using the command *spearman*. See Kozak et al. (2012) for further discussion of the Spearman's rank correlation coefficients in agricultural research.

Table 5. The Spearman correlation coefficient between land fragmentation and farm sizes

Pair of variables	2004	2006
Number of plots-farm size	0.1748 (0.000)	0.2117 (0.000)
Plot size-farm size	0.6345 (0.000)	0.610 (0.000)
Simpson index-farm size	0.0937 (0.000)	0.0449 (0.044)

Notes: number in parathesis is P value of the test H_0: two variables are independent

Source: calculated from VHLSS 2004 and 2006

Table 5 shows the Spearman correlation coefficients between land fragmentation and farm sizes in annual crop production in Vietnam using the VHLSS 2004 and 2006. As can be seen from the table, the process of land consolidation is unlikely to be driven by the land market. If farm households consolidate plots that are close to their existing plots, there would be an opposite direction between farm sizes and land fragmentation. It means that the Spearman correlation coefficient would be negative or less positive overtime. The statistics from Table 5 provide clear evidence that the correlation between scattered land holdings is weak (the coefficient is less than 0.5). As a result, land consolidation in surveyed years should be attributed to plot exchange rather than the land market.

In the survey data from 2004 to 2006, there is no evidence from the data that the emerging land markets support land consolidation. Farm households may have not realized the negative effects of land fragmentation on agricultural production. In other words, the costs of severe scattered land holdings is unlikely to overweight the expense of consolidating annual plots that are located next to their plots. Therefore, in the present paper, land consolidation is assumed to be exogenously driven, reflecting imperfect functions of the land market or credit constraints in land consolidation.

4. Literature review

4.1. Agricultural growth and labor allocation

Considering the determinants of labor allocation, to date, there are three strands of thoughts that trace this process. The first strand, the role of infrastructure, and locational factors views that labor move toward the rural nonfarm economy in the areas where infrastructure is well developed (Haggblade et al. 2007; Isgut, 2004). The second strand is the importance of human

capital, and assets, which are well asserted in all studies related to the nonfarm sectors (Fafchamps and Quisumbing 1999; Haggblade et al. 2007; Kijima and Lanjouw, 2005). The final strand is the role of agricultural growth linkages, which emphasize that agricultural development resulting from technological advances, could spur the development of the nonfarm sector through many forward and backward linkages (Johnson 2000, Haggblade et al. 2007).

While many studies evaluated the effects of infrastructure and locational factors and human capital assets on poverty reduction[7], the third strand has not been explored deeply. The agricultural growth linkages hypothesis postulates that modern agricultural technology propels the development of the nonfarm economy through production and consumption linkages (Haggblade et al. 2007). On the production side, improved agricultural technologies and land reallocation, which allows more mechanization, may spur the birth and development of industries and service-related support to the agricultural sector. In addition, it releases rural workers to participate in nonfarm activities. On the consumption side, increase in farm income brought about by increased agricultural productivity stimulates the consumption of locally produced nonfarm goods and services (Haggblade et al. 2007).

One that is close to this paper is the research of Foster and Rosenzweig (2004 and 2008). The authors investigated the effects of agricultural technical change as the adoption of high yielding varieties (HYV) on economic diversification and income growth in rural India and proved the strong conclusion of Johnson (2000, AER) that the increase in agricultural productivity leads to the development of non-agricultural sectors. Foster and Rosenzweig (2004, 2008) found the opposite evidences that the substantial expansion of the nonfarm sectors in India was not resulted from the growth of agricultural productivity. They, however, assume the technical change as Hicks-neutral. In my theoretical model, I predict that if the technical change is Hicks-neutral, increase in farm productivity leads to more farm labor intensity. Thus, the conclusion of Foster and Rosenzweig is consistent with the predictions in the theoretical studies. The authors do not analyze the effect of increased agricultural productivity under the factor-biased technical change.

As regards the impact of land fragmentation on labour allocation and income diversification, there is a missing link in the literature. The main focus of the literature is the linkage between land fragmentation, farm sizes and farm productivity or farm output. Many studies show that

[7] Other studies emphasized the importance of human capital asset and locational factors (de Janvi and Sadoulet 2001; Lanjouw 2001; Quizon and Sparrow 2001; Micevska and Raut 2008; Cunugara et al. 2011).

small and fragmented farm size hampers technology application, leading to more farm labour and costs for farming production, which reduces productivity in agricultural production (Hung et al 2004, Blarel et al 1992, Bentley 1987). McPherson (1983) and Bentley (1987) find that land fragmentation keeps labour on farms and increase farming labour supply. Jia and Petrick (2013) conclude that land consolidation makes on-farm work more attractive and thus decreases off-farm labour supply. However, they show that the impact of land-consolidated policies on off-farm labour supply is statistically insignificant.

Markussen et al. (2013) provide a detailed analysis of inter and intra farm land fragmentation in Vietnam. They use a different sample, which is Vietnam Access to Resources Household Survey of 12 provinces (VARHS) in 2008. They find that consolidating land will facilitate some kinds of mechanization in farming activities and more fragmented farms use more labour. Thus, land consolidation has potentials to release farm labour surplus to other sectors. Hung et al. (2007) have the same finding that less fragmented land holdings result in more release of labour out of agriculture. However, these studies do not investigate the mechanisms of labour allocation any further, particularly theoretical framework for this allocation.

4.2. The literature on the determinants of rural economic diversification and nonfarm employment

Regarding the identification of the determinants of rural income diversification, Ellis (1998) shows that the determinants of rural income diversification are necessity and choice, which are the same as the push and pull factors of migration. The author finds that asset categories and its structure determine the choice of livelihoods. These categories include natural capital such as land, physical capital, human capital, financial capital and social capital. Barrett et al. (2001) argue that the diverse mix of assets available to households typically produces a wide range of different asset allocation choices. These papers argue that asset structure has an important role in the choice of livelihood diversification in rural areas.

Similarly, Reardon et al. (2007) show that the motives of rural households for diversification differ significantly across settings and income groups, suggesting an important distinction between diversification driven mainly by “pull” factors for accumulation objectives, and “push” factors for coping with shocks and escape from low growth in agriculture. The coping literature examines how rural households in low-potential and risky environments adapt by deploying

household resources to a range of farm and nonfarm activities. Many rural households turn to a more diversified portfolio of activities due to increasing risks in their livelihood in farm activities (Carter 1997, and Ellis 1998).

In recent years, the role of assets in economic diversification has been the subject of many empirical studies. Schultz (1988) emphasizes that rural households with more schooling are more likely to participate into off-farm activities. On the whole, the empirical findings show the significant role of education as human capital asset in diversifying income sources (Kijima and Landjouw 2005). Both theoretical and empirical results, however, have been different. Van de Walle and Cratty (2003) find that land holdings have a negative impact on nonfarm employment in Thailand and Vietnam. Whereas, Reardon et al. (1992) show a positive impact in Burkina Faso.

In addition to the literature, there is an additional area of thought that traces the development of the rural nonfarm economy. Several studies emphasize the effect of infrastructure on economic diversification in rural areas (Haggblade et al. 2007; Renkow 2007, Lokshin and Yemtsov 2005). The improvement in roads facilitates the nonfarm opportunities. Moreover, the expansion of electricity results in a wide range of nonfarm employment opportunities in Indonesia (Gibson and Olivia 2010).There is no doubt about the remarkable progress in the previous studies. There have been extensive papers discussing about push and pull factors. However, previous studies ignore the linkages between nonfarm labour supply and incomes and land policies, particularly in countries with high land fragmentation like Vietnam.

5. Methodology

5.1. Theoretical framework

We begin by introducing a simple conceptual framework for investigating the impact of agricultural technical change on the marginal product of on-farm labour, and labour allocation. Consider rural households who derive their livelihood from agricultural production.

5.1.1. Theoretical research on the impact of agricultural technical change on labor allocation of farm households

As shown by both theoretical and empirical evidences, there is a mixed empirical evidence of the effect of agricultural technical change on labour use and allocation in the household. That is the main interest in this paper. The marginal product of farm labour is a key factor that can influence

the labour allocation process in microeconomic perspectives. We have an output function Y(L, A, θ), where L denotes labour, A is a vector of other factors of production, and θ is a vector of technologies. Acemoglu (2010) shows that technology is strongly labour saving if an increase in θ reduces the marginal product of labor and it strongly labour complementary if it increases this

Because the focus is on labour reallocation due to the impacts of agricultural technical changes, we consider two kinds of production function, Cobb-Douglas and CES, y=f(L,A), which is the same type of model used by Benjamin (1995) and Urdy (1996). We introduce the technical parameter in the function to evaluate its impacts on the marginal product of farm labour, $y=\alpha_1 f(L,A)$ (Hicks-neutral technical change), $y=f(\alpha_2 L, A)$ (labour augmenting technical change like the approach of Jia and Petrick (2013)), and $y=f(L,\alpha_3 A)$ (land augmenting technical change). McMillan, Whalley and Zhu (1989) used the same approach, which α is defined as the effort of farmers due to institutional reforms and αL is measured as efficiency units. This model is considered as the Hicks factor-biased labour augmenting.

We start the CES production function, which is based on the specification developed by Acemoglu (2010), we extent the production function as follows[8]:

$$Y = \alpha_1[\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}} + (1-\gamma)(\alpha_3 A)^{\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}} \qquad (3)$$

Where Y denotes the production of agricultural product. There are two input factors as labour (L) and land (A), α_1 represents Hicks-neutral technical changes; α_2 labour augmenting technical changes; α_3 is land or capital augmenting technical changes. The parameter α_2 is the same approach used by Jia and Patrick (2013). The share parameter $\gamma \in (0,1)$, and the parameter σ measure the elasticity of substitution between labour and land. If $\frac{\sigma-1}{\sigma}$ approaches to zero, we get the Cobb-Douglass production function.

We get marginal product of labor (MPL) by differentiating the agricultural production function (the equation 3) with respect to labour: $MPL = \frac{\partial Y}{\partial L}$

[8] The main development of my model compared with that used by Acemoglu (2010) is the introduction of agricultural technical parameter. In addition, I analyze three cases of technical change in details that are ignored in previous studies. I also develop further the condition of labor savings in Acemoglu (2010). Technology is strongly labour saving if technological change reduces the farm marginal product of labour. This condition only holds if we have low enough elasticity of substitution as shown in the equation (5).

$$MPL = \alpha_1[\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}} + (1-\gamma)(\alpha_3 A)^{\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}-1}\gamma L^{\frac{\sigma-1}{\sigma}-1}\alpha_2^{\frac{\sigma-1}{\sigma}}$$

Set $\omega = [\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}} + (1-\gamma)(\alpha_3 A)^{\frac{\sigma-1}{\sigma}}]$

We have $MPL = \alpha_1 \omega^{\frac{\sigma}{\sigma-1}-1}\gamma L^{\frac{\sigma-1}{\sigma}-1}\alpha_2^{\frac{\sigma-1}{\sigma}}$

The ratio of marginal product of land to marginal product of labour is:

$$\frac{MPA}{MPL} = \frac{1-\gamma}{\gamma}\left(\frac{\alpha_3}{\alpha_2}\right)^{\frac{\sigma-1}{\sigma}}\left(\frac{A}{L}\right)^{\frac{1}{\sigma}} \quad (4)$$

Therefore, if labour and land are complements in agricultural production ($\sigma<1$), labour augmenting technology, which increases in α_2, will raise the marginal product of land relative to labour. Similarly, the technical change is labour saving if technical changes decrease the MPL. We now evaluate the impact of agricultural technical changes on the farm marginal product of labor and labour allocation in the household under two types of technical change.

Case 1: Hicks neutral technical change[9]

We extend Jia and Petrick (2013) by introducing further the case of Hicks neutral technical change. This is the same type of functional form developed by Lau and Yotopolous (1971) in their discussion of technical efficiency. The Cobb-Douglas production function has been used extensively in the literature and has the property of Hicks neutral technical change and the elasticity of substitution is unity. Thus, under the Cobb-Douglas production function, productivity is always Hicks neutral, which improvements in productivity do not affect the relative marginal products of land and labour and so do not alter the relative allocations of the factors (Acemoglu 2010; Raval 2011). In case of the Cobb-Douglas production function, the increase in agricultural productivity has a positive impact on the MPL and thus slowdowns the process of labour transformation.

Using the assumption of Hicks neutral technical change, the agricultural technical change affects production processes rather than a particular input. It adds to the production process through its effects on productive efficiency (Wan and Cheng, 2001). The increase in α_1 toward unity means

[9] The technical progress is classified as Hicks neutral if the ratio of marginal products remains unchanged for a given factor input ratio (Hicks, 1936).

that more productivity and thus results in the increase in the farm marginal product of labour because $\frac{\partial MPL}{\partial \alpha_1} > 0$. As a result, less farm labour are released to other sectors.

If Hicks-neutral technical change is applied in agricultural production, then $\frac{\partial MPL}{\partial \alpha_1} > 0$, we have

$$\frac{\partial MPL}{\partial \alpha_1} = [\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}} + (1-\gamma)(\alpha_3 A)^{\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}-1} \gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}-1} \alpha_2 > 0$$

where $\gamma \in (0,1)$, and $\alpha_2>0$, $\alpha_3>0$, L and A are positive.

Case 2: Labour augmenting technical change

The impact of agricultural technical change depends on the elasticity of substitution. If the elasticity of substitution meets the conditions in the equation (5), labour augmenting technical change is strongly labour saving (Acemoglu 2010). Benjamin (1995) shows that if the elasticity of substitution is low enough, and labour's share is high enough, factors that improve productivity such as better land quality could decrease labour uses. This would happen because fewer labour (L) are required to achieve the optimal amount of effective labour $\alpha_2 L$. In addition, technical change causes a change in the MPL, $\frac{\partial MPL}{\partial \alpha_2} < 0$ and $\frac{\partial L}{\partial \alpha_2} < 0$

In the case of labour augmenting technical change, $\frac{\partial MPL}{\partial \alpha_2} < 0$ if and only if the condition in the equation (5) is satisfied or the elasticity of substitution is low enough. We have:

$$\frac{\partial MPL}{\partial \alpha_2} = \alpha_1 \omega^{\frac{\sigma}{\sigma-1}-1} \gamma L^{\frac{\sigma-1}{\sigma}-1} \alpha_2^{\frac{\sigma-1}{\sigma}-1} \frac{\sigma-1}{\sigma} + \alpha_1 \omega^{\frac{\sigma}{\sigma-1}-2} (\frac{\sigma}{\sigma-1}-1) \gamma L^{\frac{\sigma-1}{\sigma}} \alpha_2^{\frac{\sigma-1}{\sigma}-1} \frac{\sigma-1}{\sigma} \gamma L^{\frac{\sigma-1}{\sigma}-1} \alpha_2^{\frac{\sigma-1}{\sigma}}$$

$$\frac{\partial MPL}{\partial \alpha_2} = \alpha_1 \omega^{\frac{1}{\sigma-1}} \gamma L^{\frac{-1}{\sigma}} \alpha_2^{\frac{-1}{\sigma}} \frac{\sigma-1}{\sigma} [1 + \frac{1}{\sigma-1} \omega^{-1} \gamma (\alpha_2 L)^{\frac{\sigma-1}{\sigma}}]$$

where $\omega = [\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}} + (1-\gamma)(\alpha_3 A)^{\frac{\sigma-1}{\sigma}}]$

If $\sigma<1$ and $\frac{\sigma-1}{\sigma} < 0$, $\frac{\partial MPL}{\partial \alpha_2} < 0$ if and only if $[1 + \frac{1}{\sigma-1} \omega^{-1} \gamma (\alpha_2 L)^{\frac{\sigma-1}{\sigma}}] > 0$. This condition holds when σ satisfies the condition (5) as follows:

$$\sigma < \frac{(1-\gamma)(\alpha_3 A)^{\frac{\sigma-1}{\sigma}}}{\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}} + (1-\gamma)(\alpha_3 A)^{\frac{\sigma-1}{\sigma}}} < 1 \qquad (5)$$

Proof: the expression must satisfy the condition $[1+\frac{1}{\sigma-1}\omega^{-1}\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}}]>0$ if we expect $\frac{\partial MPL}{\partial \alpha_2}<0$ in the case of σ<1 (labour and land are complements in agricultural production). In order to have $[1+\frac{1}{\sigma-1}\omega^{-1}\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}}]>0$, we have:

$$1 > -\frac{1}{\sigma-1}\omega^{-1}\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}} \quad \text{where } \omega = [\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}} + (1-\gamma)(\alpha_3 A)^{\frac{\sigma-1}{\sigma}}]$$

$$-\omega^{-1}\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}} < -(1-\sigma) \Rightarrow \sigma < 1-\omega^{-1}\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}}$$

I have $\sigma < 1-\frac{\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}}}{\omega}$

$$\sigma < 1-\frac{\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}}}{[\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}} + (1-\gamma)(\alpha_3 A)^{\frac{\sigma-1}{\sigma}}]} = \frac{(1-\gamma)(\alpha_3 A)^{\frac{\sigma-1}{\sigma}}}{[\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}} + (1-\gamma)(\alpha_3 A)^{\frac{\sigma-1}{\sigma}}]}$$

As a result, $\frac{\partial MPL}{\partial \alpha_2}<0$ if and only if $\sigma < \frac{(1-\gamma)(\alpha_3 A)^{\frac{\sigma-1}{\sigma}}}{\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}} + (1-\gamma)(\alpha_3 A)^{\frac{\sigma-1}{\sigma}}} < 1$

If the elasticity of substitution fails to satisfy the condition (5), and is smaller than one, labour augmenting technical change is not strong labour saving. Hence, an increase in α_2 will have a positive impact on the farm marginal product of labour, $\frac{\partial MPL}{\partial \alpha_2}>0$

* *Empirical prediction*

The theoretical framework predicts that a Hick-neutral increase in agricultural productivity slow the labor allocation toward nonfarm sectors. However, if the condition (5) is satisfied, technical

change is strongly labor saving, there will be a reduction of labor demand in farm production. Hence, the predictions of the theoretical model show that the impacts of agricultural productivity on labor allocation are subject to the factor-biased technical change.

In this paper, we test the prediction of the theoretical framework by investigating the impacts of the reduction of land fragmentation on farm and nonfarm outcomes such as labor supply and profits. To hypothesize the effects of different agricultural technical changes on household's labour allocation, we develop a model based on Jia and Petrick (2013)[10]. In Jia and Petrick (2013), an exogenous land consolidation parameter $\alpha \in (0,1)$ is introduced. This parameter captures the efficiency of labour use on the plot. If α is closer to unity, the farmer spends more time on farming activities. Conversely, if α is closer to 0, more time is spent for travelling due to scattered plots and distance from home to plots, or for other unproductive activities such as difficulties in water management and mechanization in agricultural production (Blarel et al. 1992; Tan et al. 2008; Wan and Cheng 2001, Hung et al. 2007). The negative effects of land fragmentation on productivity are analyzed deeply in the literature review of this paper. Because of land fragmentation problems, there is a reduction of the productive labour used in agricultural production. Jia and Petrick (2013) only introduce the production function Y = f(αL, X), where αL is the level of effective labour.

Nevertheless, Jia and Petrick (2013) argue that the impact of land fragmentation on the marginal product of labour is theoretically undetermined when taking partial derivative of labour augmenting production function with respect to farm labour, L. This present paper provides a different view. Based on the framework of the level of effective on-plot labour in the presence of land fragmentation, the effects of land fragmentation on the marginal product of farm labour can be determined by showing a clear production function and the assumptions of the elasticity of substitution and technical changes[11]. By using the approach of Acemoglu (2010), we extend the

[10] The main development of my model compared with that used by Jia and Petrick (2013) is the arguments and discussion related to production functional forms and elasticity of substitution, which can determine the effects of land fragmentation on the marginal product of farm labour. In addition, we further develop the labour optimization problem under imperfect land market, which is prominent in developing countries. In Jia and Petrick (2013), authors argue that the effects of land fragmentation on the marginal product of farm labour are undetermined.

[11] The scope of this paper will introduce two forms of production function including the Cobb-Douglas and CES functions. These functions have been used extensively in the literature when studying the issues of households. The idea of the elasticity of substitution was originated from Hicks (1936) in "The theory of wages". Elasticity of substitution is defined as the elasticity of the ratio of two inputs to a production function with respect to the ratio of their marginal products. It measures how easy it is to substitute one input for the other.

model by capturing the land consolidation parameter α. All cases including Hicks neutral, labour augmenting and land augmenting technical change have the same property that more land consolidation, leads to more agricultural output. What differs between the models is the way in which the relative marginal products of land and labour are affected, which then affect the labour allocation in the household.

As shown by many studies in the literature, land consolidation enables farmers to mechanize and save time. Therefore, this technology is characterized as labour-augmenting technical change. Wan and Cheng (2001) tested the non-neutral effects if land fragmentation. They could not reject the hypothesis of non-neutral effects. The impacts on labour allocation depend on the elasticity of substitution between labour and land. If land and labour are complementary and meet the condition of equation (5), then land consolidation is expected to reduce the labour intensity in agricultural production and more labor allocation toward the nonfarm activities[12]. Otherwise, the prediction can be opposite if the complementarity between land and labour is weak. Before testing the predictions, we develop the framework for empirical studies and model specifications in the next section. If the empirical evidence shows that policies toward more land consolidation will release farm labor to other sectors and reduce labour intensity, we can conclude that Hicks non neutral technical change plays an important role in the relationship between the growth of agricultural technical change and economic structural change in rural Vietnam.

5.1.2. Model framework for the impact of land fragmentation on the labour allocation

We begin by presenting a theoretical framework that the farm household's optimal labour allocation to main activities. We extend the approach of Jolliffe (2004)[13] and consider the household's resource allocation problem as:

$$\text{Max} \quad U[\bar{L}(X_{h,t}) - \sum_a L_{a,t}, \sum_a Y_a(L_{a,t}, A_{k,t}, \alpha_t, X_t, LF, \varepsilon_{a,t})]$$

$$L_{a,t}, Z_{a,t}, A_{k,t} \qquad (6)$$

---

[12] See Acemoglu (2010) for further discussion about the labor saving.

[13] Jolliffe (2004) uses the same model to measure the effects of education on labour allocation and profits in farm and off-farm activities in Ghana. The main development of our model compared with that used by Jolliffe (2004) is the introduction of land fragmentation and adding more land consolidation parameter such as Simpson index or log of plots..

Subject to $\bar{L} \geq \sum_a L_a, L_a \geq 0, A = \sum_k A_k = \bar{A}$, *a = f(farm), nf(nonfarm)*

U(.) is the farm utility function in the period t over leisure ($\bar{L}(X_h) - \sum_a L_a$), and restricted profits (income minus cost of inputs Z_a). The restricted profits are a sum of profits in two activities: farm (f) and nonfarm (nf). Profits in two activities are a function of household endowments such as assets, education and access to infrastructure, X, household labour supply, L_a, allocated to farm and nonfarm activities. A_k is the land use of different annual crops, which is constrained by the total endowment of land, and locational factors such as infrastructure conditions, LF. Household labour supply depends on household characteristics, X_h. The number of plots or the Simpson index measures the land consolidation parameter. Random shocks to production are defined as ε_a.

If labour and land markets were perfect, equation (6) would lead to a separable decision between production and preferences (Singh, Squire, and Strauss 1986). The marginal product of farm and nonfarm activities equates exogenously market wages. However, many studies show that perfect labour and land markets are rarely found in developing countries (Benjamin 1992; Urdy 1996; Jolliffe 2004). Le (2009) also rejected the perfect market assumption in the sample of Vietnamese farmers when he estimated the labour supply function in rural Vietnam. The land markets also have the same pattern (World Bank 2006). Therefore, in the case of incomplete labour and land markets, de Janvry et al. (1991), and Skoufias (1994) showed that household labour is allocated such that the marginal product of labour is equal to endogenous shadow cost of labour, w*. The household labour supply can be formed by identifying the factors that affect w* in the case of utility maximization.

We have: $$\frac{\partial Y_{a,t}(L_{a,t}, A_{k,t}, \alpha_t, X_t, LF_t, \varepsilon_{a,t})}{\partial L_{a,t}} = w_t^* \qquad (7)$$

The allocation of family labour to farm and nonfarm activities thus depends, through w*, on household characteristics and other factors that affect profits (de Janvry et al. 1991). The reduced form of household labour supply into farm and nonfarm activities is as follows[14]:

$$L_a = f(X_t, A_{k,t}, \alpha_t, LF_t, \varepsilon_{a,t})\ a=f,\ nf \qquad (8)$$

Substitution the equation (8) into farm and nonfarm profit functions, I have:

$$Y_{a,t} = f(L_a^*(X_t, A_{k,t}, \alpha_t, LF_t, \varepsilon_{a,t}), X_t, A_{k,t}, \alpha_t, LF_t, \varepsilon_{a,t}) \qquad a=f,nf \qquad (9)$$

$$Y_{a,t} = f(X_t, A_{k,t}, \alpha_t, LF_t, \varepsilon_{a,t}) \qquad (9')$$

We add up profit function from each activity into a single household profit function yields:

$$Y_t = f(L_a^*(X_t, A_{k,t}, \alpha_t, LF_t, \varepsilon_{a,t}), X_t, A_{k,t}, \alpha_t, LF_t, \varepsilon_{a,t}) \qquad (9'')$$

Therefore, the equation (8) measures the extent to which land fragmentation affects the labour allocation between farm and nonfarm activities. Similarly, the equation (9') measures the direct effect of land fragmentation on farm and nonfarm income. These equations thus guide the framework for econometric specification.

5.2. Empirical models

The purpose of empirical models is to address the issue of whether the agricultural technical change, which results from the reduction of land fragmentation, actually leads to labor allocation in a farm household and economic diversity in rural Vietnam. This study design allows us to examine whether exogenous shocks to crop productivity lead to changes in labor allocation and economic diversification of a farm household. This step permits to characterize the factor biased technical change as shown by (Wan and Cheng 2001). Previous studies show the role of the reduction of land fragmentation on farm productivity and the improvement of technical efficiency. This section studies the effect of land fragmentation on labour allocation and economic diversification including the participation in the rural nonfarm economy in Vietnam. An implication of this result is that investigating the impact on the farm both underestimates the value of the reduction of land fragmentation and ignores the importance of land consolidation to the allocation of labour into higher return activity.

[14] X_t includes household characteristics, X_h. Benjamin (1992) shows that if X_h can have a significant impact on sectoral choice, then this finding can provide evidence for incomplete labour market and the separable assumption can be rejected.

For this purpose, we first estimate two reduced forms of farm and nonfarm labour supplies from equation (8) and farm and nonfarm profits from equation (9'). Next, we study the effect of land fragmentation on the agricultural productivity and labour intensity in farm and nonfarm activities. This paper uses different methods to measure the extent of the reduction of land fragmentation on labour allocation and test the prediction that this change is characterized as labour-augmenting technical change.

Based on the equation (8) and (9'), the dependent variables are estimated by using the same set of independent variables, which control incentives and constraints affecting the participation in farm and nonfarm activities (Reardon et al. 2006). We have reduced form equations as follows:

$$L_{it,a} = \beta_0 + \beta_1 S_{it} + \beta_2 X_{it} + \beta_3 A_{it} + \beta_4 LF_{it} + \beta_5 R_k + \beta_6 T + \varepsilon_{it,a} \ , \ a = f, nf \qquad (10)$$

$$Y_{it,a} = \lambda_0 + \lambda_1 S_{it} + \lambda_2 X_{it} + \lambda_3 A_{it} + \lambda_4 LF_{it} + \lambda_5 R_k + \lambda_6 T + \varepsilon_{it,a} \qquad (11)$$

And the effect of land consolidation on agricultural productivity and factor intensity in farm and nonfarm activities are captured by the following reduced form equation:

$$P_{it,a} = \delta_0 + \delta_1 S_{it} + \delta_2 X_{it} + \delta_3 A_{it} + \delta_4 LF_{it} + \delta_5 R_k + \delta_6 T + \varepsilon_{it,a} \qquad (12)$$

Where L_a and Y_a represents the farm, nonfarm labour supply and profits respectively. P_{it} is defined as either (i) agricultural output per ha; (ii) the number of individuals in the household who derive their main income from farm or nonfarm activity, *a* represents farm and nonfarm outcomes. S_{it} is a vector of variables capturing land fragmentation, which includes the Simpson index or the number of plots. The direct effect of land fragmentation on farm, nonfarm labour supplies and farm and nonfarm profits is β_1. The hypothesis of the coefficient β_1 is positive in case of the estimation of farm labour supply function and negative if the reduced form is nonfarm labour supply function. A similar pattern is applied for the profit functions. If we cannot reject these hypotheses, we can argue that the impact of agricultural technical change through land consolidation is subject to the factor biased technical changes. Thus, the variable of interest in the paper is S_{it}. The paper also control other variables that can affect farm and nonfarm labour supply and profits, which include household characteristics, X_{it} (education, demographics and social networks of household members), total land area of annual crops[15], A_{it}, locational factors, LF_{it} (infrastructure, business

[15] World Bank (2006) show that land fragmentation mainly focuses on annual crops.

environments)[16], regional dummies, R_k, and year dummies, T. The error term ε_{it} includes two components. The first one is unobserved time-constant heterogeneity η_i, which affect outcomes such as land quality, farm household's management ability, and degree of risk aversion. The second one is unobserved time-varying factors that impacts dependent variables like health shocks.

We start investigating how land consolidation relates to changes in farm production and labour allocation between farm and nonfarm activities in the equations (10), (11), and (12). In the first section in estimation strategies, we introduce different equations related to farm results including farm labour supply and profits, farm output per hectare, and share of farm employment. In the second section, we also show estimates of equations related to nonfarm outcomes including nonfarm labor supply, nonfarm profits and number of individuals in nonfarm activities.

The next section discusses the problems that may arise when estimating the models.

5.3. Controlling the bias in econometric models

** Controlling for unobserved heterogeneity η_i*

The estimation of equations (10), (11) and (12) pose some econometric challenges. A potential problem may arise from the effect of unobserved heterogeneity η_i, which can cause biased estimation of the models (due to omitted variable bias). Therefore, we need to control η_i to get consistent estimates. In addition, we use a vector of exogenous household and communal characteristics[17]. Equations (10), (11) and (12) can be estimated using a fixed effect model. First difference is applied to control the unobserved heterogeneity η_i.

Alternatively, we need to capture the efficiency gain by using a random effect model. Due to low variation of the measure of land fragmentation, an approach proposed by Mundlak (1978) is applied. This method allows unobserved heterogeneity to be correlated with independent variables.

In the correlated random effect model, we denote $\bar{X}_h$ as the mean of time varying independent variables in the models. Using the approach of Mundlak (1978), let unobserved heterogeneity $\eta_i = \bar{X}_h\gamma + \mu_h$, where γ is a vector of coefficients capturing possible correlation between η_i and

[16]Isgut (2004) emphasizes the importance of location factors such as infrastructure and business environment on nonfarm income and employment in Honduras. This paper shows that locational factors play a very important role in moving toward nonfarm activities. The importance of human capital and infrastructure is analyzed in the section of literature review in this paper.

[17] Van de Walle and Cratty (2003) also used exogenous variables to reduce the potentials of biased estimates in their study on the role of nonfarm economy on poverty reduction in Vietnam.

household characteristics and μ_h is an error term that is not correrlated with $\bar{X}_h$. We substitute $\varepsilon_{it,a} = \eta_i + \tau_{it,a}$ and $\eta_i = \bar{X}_h\gamma + \mu_h$ into equations (10), (11), and (12) to yield the Mundlak specifications (for more on the correlated random effects model, see Wooldridge 2012)

as follows:

$$L_{it,a} = \beta_0 + \beta_1 S_{it} + \beta_2 X_{it} + \beta_3 A_{it} + \beta_4 LF_{it} + \beta_5 R_k + \beta_6 T + \beta_7 \bar{X}_h + \omega_{it,a} \quad (10'')$$

$$Y_{it,a} = \lambda_0 + \lambda_1 S_{it} + \lambda_2 X_{it} + \lambda_3 A_{it} + \lambda_4 LF_{it} + \lambda_5 R_k + \lambda_6 T + \lambda_7 \bar{X} + \omega_{it,a} \quad (11'')$$

$$P_{it,a} = \delta_0 + \delta_1 S_{it} + \delta_2 X_{it} + \delta_3 A_{it} + \delta_4 LF_{it} + \delta_5 R_k + \delta_6 T + \delta_7 \bar{X} + \omega_{it,a} \quad (12'')$$

Where $\omega_{it,a} = \mu_h + \tau_{it,a}$

** Controlling for unobserved shocks*

One of problems, which may arise even after controlling the correlation between S_{it} and η_i, is the correlation between S_{it} and unobservable time-varying variables. In the section 2, land fragmentations measured by the Simpson index and log of plots are assumed to be exogenous, and thus serve as their own instruments due to restrictions of the Vietnamese land markets[18]. Farmland was reallocated to households by the egalitarian principle during the process of decollectivizing the agricultural system. In addition, land markets are imperfect, which resulted from uncertainties related to land institutions and restrictions, both sales and rental markets. Therefore, land fragmentation is assumed to be exogenous in the models. All prior studies assume independence between land fragmentation and unobserved time varying variables. According to VHLSSs, there were 67.3 percent of plots that have land use right certificates. Only 4.03 per cent of plots were exchanged through the land rental market. Thus, rural households could not reduce scattered land holdings by land markets. In the previous section, we reject the hypothesis that land consolidation in the surveyed data was attributed by the operations of land market including rental and sales markets.

[18] Section 2 in this paper discusses the problems of land markets and history of land fragmentation in Vietnam in details. In this paper, we use log of plots as another measure of land fragmentation, which is similar to previous studies (Jia and Petrick 2013; Wan and Cheng 2001, Hung et al. 2007).

However, the assumption of independence between the land fragmentation and unobserved shocks may be strong. Therefore, in this paper, the land fragmentation may be correlated with unobserved time-varying factors that affect farm and nonfarm. As discussed earlier, land consolidation from the data is attributed by the plot exchange, not by land markets. The land consolidation programs are implemented by voluntary plot exchange and reallocation with comprehensive planning. Tran (2006) finds that voluntary plot exchange is carried out at the household level and the scope as well as the effect of this program is low. This method of land consolidation requires close coordination among a large number of households and plots. As a result, it takes time and efforts to achieve consent among all members. This is one of challenges facing voluntary land consolidation programs. In addition, it is attributed to explain the difficulties in land consolidation in rural Vietnam (Tran 2006). Thus, the reduction of land fragmentation represents a decision made by local authorities and related households in the rather than a household decision.

In addition, the control of the correlation between land fragmentation and unobserved shocks requires an instrumental variable. This instrumental variable is correlated with the potentially endogenous variable, but not correlated with unobserved shocks in the structural models. We experimented some instrumental variables such as number of land use right certificates transferred in the commune, communal population density, annual land titled by certificates of land use right in the commune[19]. However, the results are not useful due to a lack of suitable instruments. Ma et al. (2013) studied the effect of perceived land tenure security on land investments. The authors used some instrumental variables that are correlated with perceived land tenure such as opinions about policy. A good instrumental variable is linked to land governance or perception of households related to the benefits of land fragmentation, which are ignored in household surveys designed by the World Bank. This is the reason why all previous papers, which study the problem of land fragmentation, assume that it is exogenous. Based on arguments from this section and the imperfect land markets in rural Vietnam, it is plausible to consider land fragmentation as exogenous in this paper. This may be one of limitations in this paper (for more information on the exogenous land fragmentation, see Jia and Petrick 2013; Rahman 2008; Markussen et al. 2013).

[19] In the communal surveys, section 4 covers agriculture and land types. However, it does not provide information related to land consolidation programs. In Vietnam, land ownership does not exist. Local government issues a certificate of land use right for all plots which households use. In this certificate, it shows the information on the number of plots, areas, and locations for each plot.

We test the exogenous condition of land fragmentation by appling the control function approach to solve the problem. The control function is implemented by taking the residuals from a reduced form model of land fragmentation. These residuals are included in the labor supply and profit functions as a covariate. The significance of the coefficients on the residuals will test and control for the correlation between land fragmentation and unobserved shocks (Lewbel 2004; Parke and Wooldridge 2008). In order to apply the control function, the first step is to model the reduced form for land fragmentation by using the first difference and Tobit for the correlated random effect models. The instrumental variable is the number of land use right certificates was transferred in the commune in the past years. Although the coefficient of this instrumental variable is significant, the coefficient of residuals on the structural farm and nonfarm equations is statistically insignificant, which indicates that the land fragmentation is not endogenous in both farm and nonfarm outcome equations[20].

** Controlling the sample selection bias*

In order to control the unobserved heterogeneity η_i, correlated random effects (CRE), which are followed by the works of Mundlak (1978), can be applied. Although we can control the unobserved heterogeneity η_i, we face sample selection bias due to the incidental truncation of the nonfarm labour participation (Cunguara et al. 2011). Therefore, Wooldridge (2012) argues that the problem of sample selection bias needs to be tested. Because of the change in household's selection status overtime, the within estimator aiming at eliminating the unobserved time-constant heterogeneity cannot be applied due to changes in household composition overtime by the group of selected households. In order to solve both problems of sample selection and η_i, we use the estimating procedure introduced by Wooldridge (1995), who developed the level equation to obtain consistent estimations with a pooled method by parameterizing the conditional expectations.

Tests and correction for sample selection are performed following the procedure introduced by Wooldridge (1995). I first obtain the inverse Mills ratio from a reduced form selection probit equation as follows:

$$s_{it} = 1[x_i \gamma_{t2} + \varepsilon_{it} > 0] \quad \text{(A2)}$$

[20] See the appendix for the test of using control function.

where *s* is a dummy variable, which is equal to one for households with positive nonfarm labour supply or profits and zero for otherwise; $x_i = (x_{it}, \bar{x})$ is consist of the value of an independent variable for household *i* in period t and its mean value for household i across periods of time. We use the approach of Mundlak (1978) to control household fixed effect for the selection equation. The independent variables are showed in the equation (10''), (11'') and (12''). The Wooldridge (1995) estimator requires at least a time varying variable, which affects selection, but not the level equation. The two-step estimation could be unreliable in the absence of exclusion restriction (Wooldridge 2012).

We pool time periods together and treat the data set as a cross section. Pooling of all panel observations is a shortcoming of this approach. It is unfortunately the only way in this case. We include the inverse Mills ratio, which is computed from the participation equation, as an additional variable to control sample selection bias. However, we will have some exclusion restrictions related to the models of nonfarm outcomes. We include at least one time varying variable in the selection equation that does not affect nonfarm labor supply and incomes. In this case, we use unearned incomes followed by Gupta and Smith (2002) in the participation equation but not in the nonfarm labor supply and incomes.

5.4. Functional forms

** The effect of land fragmentation on farm outcomes: productivity, labour supply, profits, and share of farm employment*

The effect of land fragmentation on four farm outcomes is investigated in order to answer the question of whether more people moving off the farm result from policies related to the reduction of land fragmentation or land consolidation. Firstly, farm productivity change is measured as the farm annual crop output per hectare. The second is farm labour supply measured by working hours spent by household members on farming activities. The third outcome is farm profits[21]. The final one is the number individual in farm employment in the household. In this paper, the impact of land fragmentation on farm outcomes can be estimated using different methods.

[21] Farm profits are the difference between total revenue and costs of annual crop production. Farm profits equal to zero if total costs are greater than total revenue.

While the pre-determined initial values may be considered exogenous, the same cannot be said of the changes in those variables. Thus, we take the first difference of these equations and obtain the following reduced forms:

$$\Delta L_{it,a} = \beta_1 \Delta S_{it} + \beta_2 X_{it-1} + \beta_3 A_{it-1} + \beta_4 LF_{it-1} + \beta_5 R_k + \Delta \varepsilon_{it,a} \quad (10')$$

$$\Delta Y_{it,a} = \lambda_1 \Delta S_{it} + \lambda_2 X_{it-1} + \lambda_3 A_{it-1} + \lambda_4 LF_{it-1} + \lambda_5 R_k + \Delta \varepsilon_{it,a} \quad (11')$$

$$\Delta P_{it,a} = \delta_1 \Delta S_{it} + \delta_2 X_{it-1} + \delta_3 A_{it-1} + \delta_4 LF_{it-1} + \delta_5 R_k + \Delta \varepsilon_{it,a} \quad (12')$$

Equations (10'), (11') and (12') show the effects of agricultural technical change through land consolidation on labor and economic diversification of farm households. X_{it-1}, A_{it-1} and LF_{it-1} are initial characteristics of households, land and communes that may affect the farm and nonfarm outcomes. The use of the initial period (and thus pre-determined) variables may eliminate the potential endogeneity of the some household characteristics. Moreover, it may also mitigate the simultaneity problem caused by some unobservable variables. This method removes unobserved heterogeneity η_i such as land quality, management skills or ability.

** The effects of land fragmentation on nonfarm outcomes: labour supply and profits*

We now turn to the question of whether moving toward nonfarm activities increased due to the impact of land fragmentation. There are two equations for three outcomes including nonfarm labour supply measured by the number of hours spent by household members on nonfarm work, and nonfarm profits[22]. As mentioned earlier, one of the challenges associated with estimating nonfarm labor supply and profits is that a large of the households in the sample do not participate into nonfarm activities. It may seem plausible that Wooldridge (1995) would be appropriate

However, the exclusion restriction is not easy to accept on a priori ground. Van de Walle and Cratty (2003) argue that given the imperfect markets in rural Vietnam such as land markets such an exclusion restriction would seem far-fetched. Therefore, we use another method, which do not require imposing exclusion restrictions. The method is called double hurdle model for nonfarm labour supply and profits. We follow recent studies related to nonfarm participation and income such as Matshe and Young (2004), Atamanov and Van den Berge (2012) by applying the same approach. The two-step double hurdle model (DHM) developed by Cragg (1971) is chosen in this case to estimate censored dependent variables. This model is more flexible than the Tobit

[22] Nonfarm profits are the aggregate of nonfarm wages and profits of self-nonfarm employments of farm households.

because it takes into account of the possibility that the factors affecting the participation in farm activities and factors affecting the level of farm labour supply and profits may be different. In hurdle 1, farm households decide whether or not to participate into farm activities, and if household members agree to take part in, hurdle 2 take consideration of the amount of profits earned by household. The maximum likelihood estimator in the first hurdle can be obtained by using a probit regression. The maximum likelihood estimator for hurdle 2 can, then be estimated using a truncated normal regression model. The test to choose between Tobit and double hurdle model is implemented by using a likelihood ratio test.

Moreover, the independent error term assumption in the double hurdle model is relaxed in this paper following recent studies (Matche and Young 2004). The double hurdle model allows the same factor to affect the participation and levels in different ways. Cragg's (1971) original model assumes that conditional on the explanatory variables, the errors between hurdle 1 and hurdle 2 are independent and normally distributed and that the covariance between the two errors equals zero. This present paper maintains Cragg's original assumption.

6. Data and variables

The paper uses the Vietnam Household Living Standard Survey (VHLSS) of 2004 and 2006 for empirical analysis. These surveys are nationally representative, and consist of questionnaires at both household and communal levels. The Vietnamese General Statistics Office (GSO) undertook them with technical support from the World Bank and UNDP since 1997/1998. VHLSSs provide rich information on household and commune characteristics such as demography, education, health, employment, land, assets, income and expenditure. The commune survey covers information on infrastructure and institution at the communal level. There were 9,189 households in 2,216 communes surveyed in each VHLSS 2004 and 2006, which forms a panel dataset including 4193 households for each year. The cluster-sampling technique is used to represent the entire country. To concentrate on labour allocation of rural households, from the full sample, we follow the approach of Jolliffe (2004) by selecting farm households with at least one member who describes the main jobs as farming and which have positive farm profits. In addition, households with no annual crop outputs were excluded from the analysis (the number of excluded households is 2179). The sample of panel data used in this paper thus includes pure tenant households, and land rental households.

As regards attrition bias resulted from households leaving the panel in different waves, we found that of the 2,289 households sampled in the second wave, 2,032 of those households had been sampled in the first wave. Thus, a balanced panel of 2014 households was established by removing households with missing data and apparent enumerator errors and available for only one time period, which create 4,028 households over the two waves of the survey.

Table 3.1 provides the information on the summary statistics of variables using in models. Farm profits are measured by the difference between the total revenue of annual crops and their costs in a year. The measure of rice output is the quantity harvested during the previous 12 months. To better compare the profits and value of assets of households between two years, these values were deflated to January 2000 prices as the base year. The deflators used in this paper are collected from GSO (2010).

VHLSS of 2004 and 2006 has an attractive feature that provides key detailed information on employments of household members aged above 15 years olds[23]. From this information, we compile the household data on the amount of labour allocated to each of the following two main activities: (a) only self-employment in agriculture, (b) self-employment in agriculture and nonfarm employment. In the VHLSS, nonfarm employment is divided into nonfarm wage and self-nonfarm employment, which only 12.43 percent of the households engage in nonfarm self-employment, and 39.58 percent engage in nonfarm wage activities. In order to carry out regressions, we follow Jolliffe (2004) by using an aggregate measure of wage income and self-employment profits into nonfarm profits[24]. Similarly, nonfarm hours consist of hours in nonfarm wage and self-nonfarm employment. The decisions to aggregate these sources of nonfarm employment clearly result in the cost of confounding two distinct types of economic activity. In addition, the estimation of censored variables becomes less severe if merging two types of

[23] In the VHLSS 2004 and 2006 questionnaire, section 4A – Employment, a question "For the last 12 months, have you worked for wage, salary?" is asked. Then the following question, "Have you self-employed in agriculture?" is asked and finally the question, "Have you self-employed in non-agriculture?" is interviewed. The sample used in this analysis includes individuals aged above 15 years old. The lower age limit of 15 years old is chosen because we follow the classification of GSO (2010). More than 90 per cent of the rural population aged 15 years old has had lower secondary as their highest educational level. As the same time, the survey showed that those who had no work, or could not find a job, or did not know how and where to find a job, ranging from 1 to 2 per cent in the VHLSSs. We also include household members over 65 year's old accounting for seven percent of the economically active labour participation. We only choose the employment type that household members spend most time for classification so I can compare my results with previous studies.

[24] Restricted profits are used instead of incomes. Lau and Yotopoulos (1971) discussed details on the restricted profits. Hence, we will use this term in this paper. Profits here mean restricted profits.

nonfarm activities together. As a result, there are 48 per cent of households that work only on the farm and 52 percent of farm households with at least one member working on nonfarm activities. In addition, farm and nonfarm hours are the sum of individual's hours for each activity.

Table 6. Summary statistics

Variable	Mean	Std. Dev.
**** Farm outcomes***		
Farm profits/ha/year, 1000 VND	34879.69	96583.81
Rice output/ha, tons/ha	5.6	4.3
Farm hours	2446.90	1822.19
Share of individuals in farm activities of the household (%)	33.8	0.34
**** Nonfarm outcomes***		
Nonfarm profits, 1000 VND	6833.25	11266.63
Nonfarm hours	1573.37	2034.10
Share of individuals in nonfarm activities of the household (%)	29.4	0.41
**** Explanatory variables***		
Simpson index	0.54	0.25
Age of the head of household, years	46.96	14.40
Age of the head of household squared, years	2412.45	1372.62
Gender of the head of household, 1 for male	0.59	0.49
Marital status of the head, 1 for married	0.83	0.37
Ethnic status of the head, 1 for majority	0.81	0.39
Household members, from 15 to 60 years old, people	2.75	1.32
Dependency ratio (%)	0.33	0.23
Mean education of working age men (from 15 to 60, years)	3.85	2.40
Mean education of working age women (from 15 to 60, years)	3.66	2.38
Head of household has primary education, 1 for primary education	0.25	0.43
Head of household has lower secondary education	0.38	0.49
Head of household has university education	0.01	0.09
Days of illness	19.52	43.81
Access to asphalt road	0.60	0.49
Access to electricity	0.85	0.35
Access to post office	0.77	0.42
Access to extension	0.49	0.24
Inland delta areas	0.58	0.49
Remote areas	0.15	0.36
Having business units in commune	0.62	0.48
Having craft villages in commune	0.14	0.34
Disasters in commune	1.16	1.25
Having employment programs in commune	0.24	0.43
Having infrastructure programs in commune	0.42	0.49
Having educational and vocational programs in commune	0.14	0.34

Households working only on the farm (%)	48
Households with at least one member working in nonfarm activities (%)	52
No of observations	4028.00

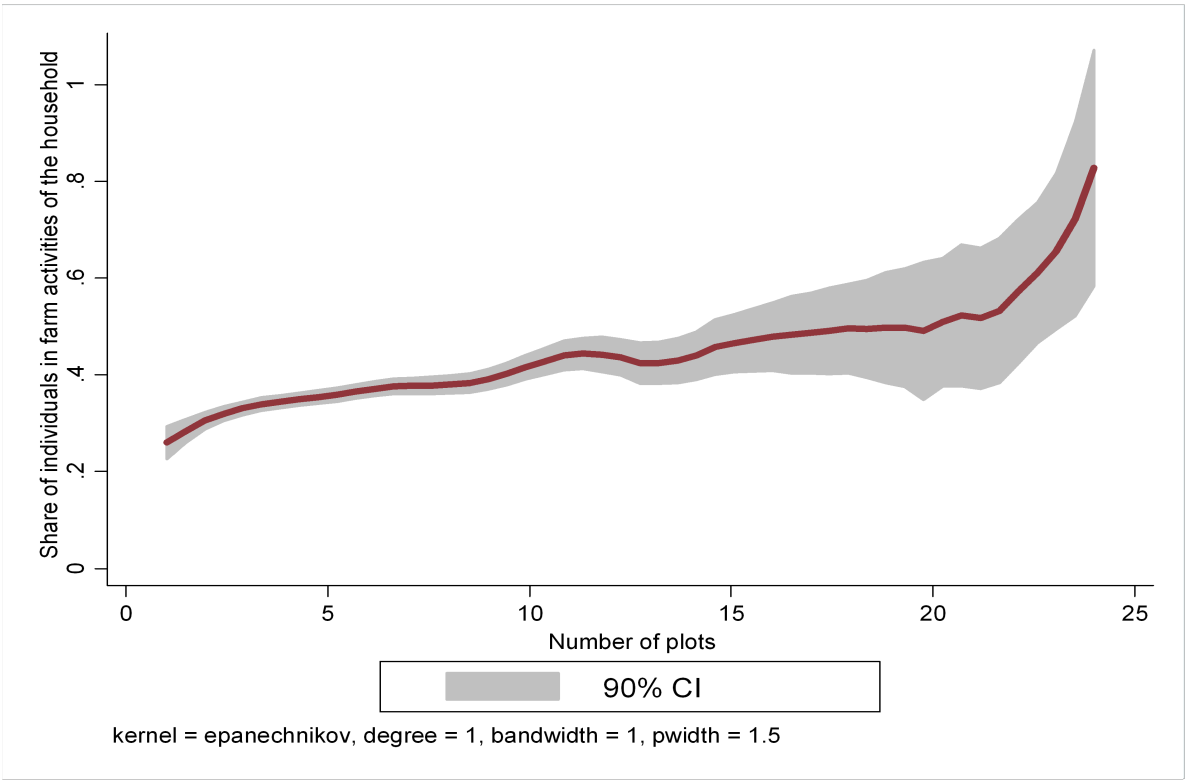
7. Empirical results

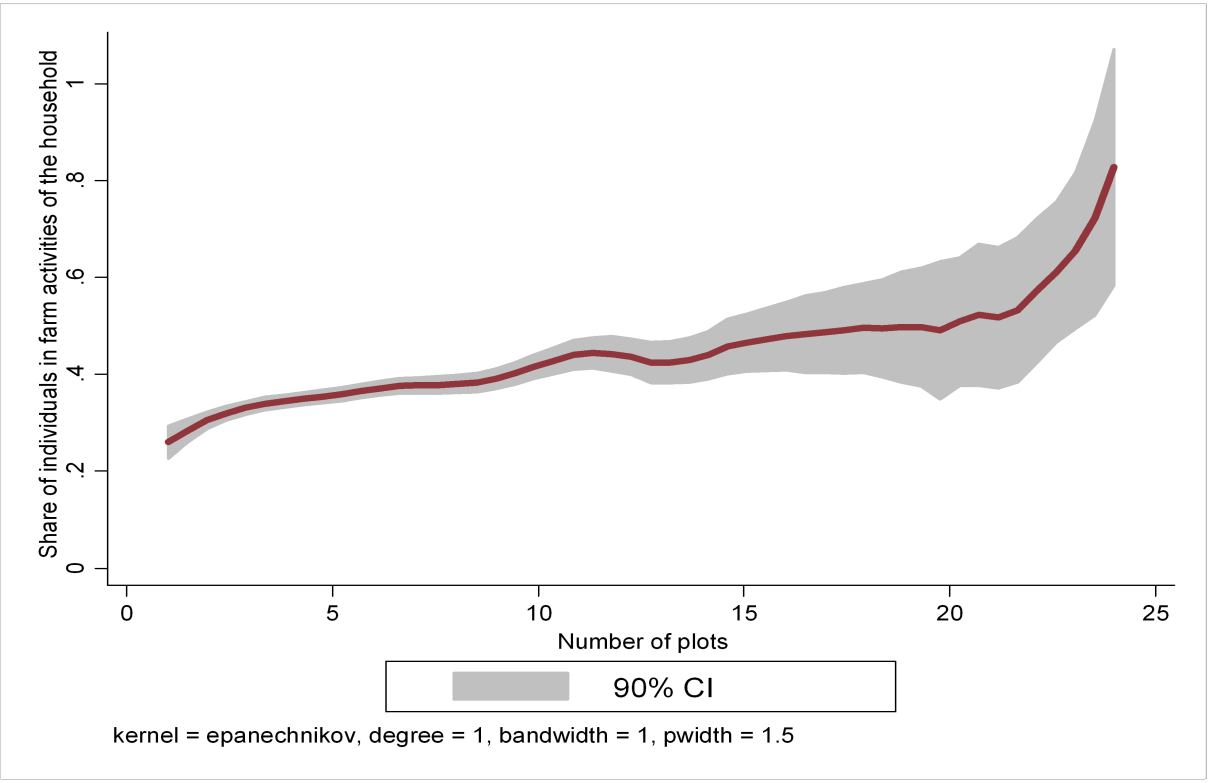
The purpose of this section is to obtain empirical results of the relationship between changes in land fragmentation and economic diversification. We answer the question of whether policies related to land consolidation would lead to more economic diversity, which include the growth of farm and nonfarm incomes and labor supplies. We also provide the result of farm outputs and profits, which confirm further the evidence of agricultural productivity growth as a result of the reduction of land fragmentation. We do not estimate the production function as prior studies did. Deaton (1997) points out that the most concern in the estimation of production function is the endogeneity of inputs. In order to solve the problem of endogeneity, papers in the literature instrumented inputs (Jacoby 1993, Barrett et al. 2008). In addition, due to data limitations, using the values instead of quantities of farm inputs and outputs may bias the estimation because of price changes (Jacoby 1993). Hence, we use the common factors that determine both outputs and farm profits.

7.1. Non-parametric regression

Comparison of the farm labor supply and level of land fragmentation indicates that households who have fewer plots work less on the farm. Figure 4 presents nonparametric regression of farm labor intensity on the number of plots as a measure of land fragmentation for households who produce annual crops. The Kernel-weighted polynomial regression indicates a statistically significant positive relationship between farm labor intensity (including farm labor supply and share of individuals in farm activities) and the degree of land fragmentation. Households who have less land fragmentation experience lower farm labor intensity. This nonparametric result seems to confirm the hypothesis of non-neutral effect of land fragmentation by Wan and Cheng (2001).

Figure 4. Kernel weighted local polynomial smoothing





7.2. Multivariate regression estimation

** Farm outcomes: productivity, labour supply, profits, and share of farm employment*

We examine the impact of land fragmentation on farm labour supply and profits. In order to investigate the relationship, we estimate equations (10'), (11') and (12') using first difference. Table 7 provides the results of estimating reduced-form equations using different methods. The main explanatory variable of interest is the Simpson index and log of plots, which is exogenous as discussions in the section 2. We use some specifications in Table 7 with four farm outcomes as the dependent variable, and control household characteristics, locational factors and regions. Column (1) presents the Simpson index, column (2) log of plots. All four dependent variables are estimated on the same set of explanatory variables in the equations (10) and (11) using the methods of panel data to control the fixed unobserved heterogeneity. The log of plots and Simpson index are used to measure land fragmentation. We control household characteristics such as education of adults, assets, participation into different nonfarm activities and demographic information of a farm household. In addition, location factors such as business environment related to infrastructure, and regional characteristics are also controlled.

Table 7. The effect of land fragmentation on farm outcomes using first difference

Dependent variables: Farm outcomes	Log of plots (1)		Simpson index (2)	
	Coef.	SE	Coef.	SE
No. of individuals in farming activities	0.051	0.041	0.200*	0.097
Farm labour supply	0.355***	0.129	0.533*	0.315
Farm profits per ha	-0.115***	0.031	-0.109	0.082
Farm output per ha	-0.055***	0.007	-0.092***	0.019

Notes: Standard errors are robust through the *cluster* option; All dependent variables are expressed in the log, except number of individuals in farming activities; ∗, ∗∗, ∗∗∗ indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively; In first difference method, the regression include all of the control variables: the initial characteristics of households and communes, a dummy for regions (see Table A1 and A2 in the Appendix for full estimation).

As can be seen in the Table 7, the estimated coefficients show that the reduction of land fragmentation (land consolidation) resulted in the reduction in farm labour supply and number of individuals working in farming activities. Farmers with more fragmented land holdings switch to more labor-intensive methods. Although the model is estimated using different methods, the

trend of the effects is consistent. This finding is also consistent with previous studies such as Hung et al. (2007), Tan et al. (2008), and Markusen et al. (2013). Land consolidation releases more labour to other sectors, all else equal. Similarly, the findings of the impact of land on farm profits and output per hectare are consistent with studies using stochastic production frontiers. The decline in land fragmentation, therefore, improves farm productivity, which then reduces the labour intensity in agriculture. The advantage of land consolidation is to save labour time and allows saving labour costs. As a result, this finding is consistent with the characterization of the expansion of land consolidation as non-Hick neutral technical change, which is consistent with the hypothesis of non-neutral effects in Chen and Wang (2001). Both measures of land fragmentation have the same effect on farm outcomes.

** Nonfarm outcomes: labour supply, income, and share of nonfarm employment*

This section provides the empirical results of the effect of land fragmentation on nonfarm outcomes including nonfarm labour supply and nonfarm profits and number. The purpose of this section is to answer whether an exogenous shocks to agricultural productivity leads to an economic diversity in a farm household. The same approach in the estimation of farm outcomes, we follow different specifications to check the consistency of the impact. Table 8 and 9 indicate the effect on nonfarm outcomes without selection corrections. As can be seen in the table, all estimated coefficients have negative signs. This finding means that the reduction of land fragmentation results in the increase in nonfarm labour supply and nonfarm profits.

The column (1) presents the result of double hurdle model of level equation. The selection equation of hurdle 1 is in the Appendix. We can compare the results between column (1) and column (2). For robustness, the likelihood ratio test (LR) is carried out to determine whether the double hurdle model fits the model of factors affecting nonfarm labour supply and profits than the model estimated by Tobit. Like Matshe and Young (2004), all the Tobit models can be rejected in favour of the double hurdle model at 5 per cent significant level. we provide the estimates in both cases with or without the specification of Mundlak (1978) approach and tests of Mundlak fixed effects for nonfarm supply and profits. We aggregate nonfarm self-employment profits and nonfarm wages, which make the estimation of censored variables becomes less severe if merging two types of nonfarm activities together. The null hypothesis of fixed effect test for nonfarm profits is rejected at 5 per cent significant level. Using log of plots as a measure of land

fragmentation, column (2) in Table 3.8 shows that land fragmentation tends to have negative effects on nonfarm labor supply and nonfarm profits. The variable of Simpson index is statistically significant at 5 percent significant level.

Table 8. The effect of land fragmentation on nonfarm outcomes without selection correction using Simpson index

Dependent variables: Nonfarm outcomes	Hurdle 2 (1)		First difference (2)	
	Coef.	SE	Coef.	SE
Nonfarm labour supply[a]	-0.120*	0.063	-0.646*	0.344
Nonfarm profits[a]	-0.307***	0.096	-0.233	0.408

Notes: Standard errors are robust through the *cluster* option. DHM standard errors are bootstrapped with 500 replications. DHM is double hurdle model (only report the hurdle 2 of level equation, the hurdle 1 is in Appendix); All dependent variables are expressed in the log; ∗, ∗∗, ∗∗∗ indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively; [a] The model specification follows the Mundlak (1978) approach; Mundlak fixed effects test for nonfarm labor supply: $\chi^2(9)=12.58$ (0.1697); Mundlak fixed effects test for nonfarm profits: $\chi^2(9)=65.87$ (0.000); In first difference method, the regression include all of the control variables: the initial characteristics of households and communes, a dummy for regions (The full set of parameter estimates are presented in Table in the appendix).

Table 9. The effect of land fragmentation on nonfarm outcomes without selection correction using log of plots

Nonfarm outcomes	Hurdle 2 (1)		First difference (2)	
	Coef.	SE	Coef.	SE
Nonfarm labour supply[a]	-0.026	0.027	-0.324**	0.143
Nonfarm profits[a]	-0.154***	0.038	-0.225	0.168

Notes: Standard errors are robust through the *cluster* option. DHM standard errors are bootstrapped with 500 replications; DHM is double hurdle model (only report the hurdle 2 of level equation); All dependent variables are expressed in the log; ∗, ∗∗, ∗∗∗ indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively; [a] The model specification follows the Mundlak (1978) approach; Fixed effects test for nonfarm labor supply: $\chi^2(9)=12.51$ (0.1863); Fixed effects test for nonfarm profits: $\chi^2(9)=64.64$ (0.000); In first difference method, the regression include all of the control variables: the initial characteristics of households and communes, a dummy for regions (The full set of parameter estimates are presented in Table in the appendix).

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Although specifications have the same trends of estimated coefficients and indicate that policies toward more consolidated land holdings may release more agricultural labour surplus, these equations also may suffer from a selection bias. Therefore, in the next section, we will examine the effect of land consolidation on nonfarm outcomes with selection corrections.

Table 9 and 10 indicate the effect of land consolidation on nonfarm outcomes with the correction of sample selection bias. To control the sample selection, we estimate (10''), (11'') and (12'') with pooled data. The tests for sample selection bias and fixed effects were obtained by employing F-test. The results reveal that both nonfarm labor supply and profits suffer from sample selection at 5 per cent significant level. Thus, the approach of controlling sample selection bias is demanding. As a result, using the method of Wooldridge (1995) results in the same conclusion, that more land consolidation may release more labour to nonfarm sectors in the future. All the coefficients of the Simpson index and log of plots in equations are significant and have the same sign. The increase in agricultural productivity as a result of land consolidation leads to an increase in farm households' income, combined with non-homothetic preferences, will generate the demand for non-agricultural goods and services. Consequently, this process will pull farm labor to nonfarm sectors. This may be an argument for the impact of the reduction of land fragmentation on nonfarm labor supply and labor reallocation in the household.

Table 10. The effect of land fragmentation on nonfarm outcomes with selection correction using Simpson index

Dependent variable: Nonfarm outcomes	Wooldridge (1995)	
	Coef.	SE
Nonfarm labour supply[a]	-0.122*	0.063
Nonfarm profits[a]	-0.297***	0.080

Notes: Standard errors are robust through the *cluster* option; All dependent variables are expressed in the log; ∗, ∗∗, ∗∗∗ indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively; [a] the model specification follows the Mundlak (1978) approach. Mundlak fixed effect test for nonfarm labor supply and nonfarm profits: F(9,1956)=1.31 (0.2282) and F(9,1956)=2.96 (0.0017) at 5% significant level respectively; Sample selection bias test for nonfarm labor supply and profits: F(2,1956)=0.60 (0.548) and F(2,1956)=4.44 (0.0120) at 5% significant level respectively (The full set of parameter estimates are presented in Table in the appendix).

Table 11. The effect of land fragmentation on nonfarm outcomes with selection correction using log of plots

Nonfarm outcomes	Wooldridge (1995)	
	Coef.	SE
Nonfarm labour supply[a]	-0.023	0.027
Nonfarm profits[a]	-0.143***	0.037

Notes: Standard errors are robust through the *cluster* option; All dependent variables are expressed in the log; ∗, ∗∗, ∗∗∗ indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively; [a] The

model specification follows the Mundlak (1978) approach. Fixed effect test for nonfarm labor supply and nonfarm profits: F(9,1956)=1.28 (0.2434) and F(9,1956)=2.79 (0.0030) at 5% significant level respectively; Sample selection bias test for nonfarm labor supply and profits: F(2,1956)=0.57 (0.564) and F(2,1956)=4.67 (0.0094) at 5% significant level respectively (The full set of parameter estimates are presented in Table in the appendix).

To sum up, the estimates of farm outcomes clearly indicate that moving land consolidation increases farm incomes. When the fixed effect is controlled, the estimates show that an increase in land consolidation reduces labor intensity and farm labor supply and improve nonfarm profits and nonfarm labor supply. This finding indicates that the agricultural development and nonfarm economy are complements rather than substitutes. There is a linkage between the agricultural development and rural nonfarm economy. Regression results show that the reduction of land fragmentation would improve productivity, which then increase the probability of rising nonfarm incomes. The fact that agricultural technical change led to increases in nonfarm incomes, which means that investments in agricultural technical changes pay off.

6.3. Robustness to controlling for market wages

Another potential concern is that results might be driven by the evolution of market wages in the nonfarm sectors, and not by technical change. For example, an increase in the wage in nonfarm sectors could induce an expansion of employment in these sectors. To address this concern, we add the variable of hour wages[25] into the following equation:

$$\Delta L_{it,a} = \beta_1 \Delta S_{it} + \beta_2 W_{it-1} + \beta_3 X_{it-1} + \beta_4 A_{it-1} + \beta_5 LF_{it-1} + \beta_6 R_k + \Delta\varepsilon_{it,a} \text{ , } a=farm, nonfarm \quad (10''')$$

The equation (10''') is the same as the one (10'). The only difference is that hour wages in the initial period ($W_{i,t-1}$) are controlled. As can be seen in the Table 12, the reduction of land fragmentation leads to the reduction of farm labour supply and increase in nonfarm labor supply after controlling hour wages. Using hour wages in the initial period will reduce the endogeneity problem of this variable in the regression. The results obtained using data from VHLSS survey are consistent. We also test the effect of hour wages on nonfarm labor supply and the result is still consistent like the case without hour wages.

[25] Mean hourly real wages (thousand VND) for farm households who have at least one member participating nonfarm employment are 2.75, respectively. Wages are deflated to January 2000 prices. This mean is much lower compared with 4.56 if we use the whole sample.

Table 12. Determinants of farm and nonfarm labour supply using first difference method

	Farm labor supply		Nonfarm labor supply	
	Coef.	SE	Coef.	SE
Simpson index	0.531*	0.314	-0.362	0.319
Hour wages	-0.313**	0.133	1.716***	0.091
Annual crop land	0.035	0.049	-0.093*	0.052
Age	-0.049***	0.006	-0.030***	0.005
Household members, from 15 to 60 years old, people	0.316***	0.076	0.327***	0.072
Dependency ratio (%)	4.382***	0.370	1.098***	0.346
Mean education of working age men	0.178***	0.036	0.163***	0.034
Mean education of working age women	0.062*	0.034	0.085**	0.034
Access to formal credit	-0.024	0.155	0.067	0.154
Log of assets	-0.030	0.022	0.005	0.022
Access to asphalt road	0.419**	0.167	0.388**	0.167
Access to electricity	0.107	0.199	-0.193	0.197
Access to post office	-0.348*	0.205	0.097	0.212
Access to extension	-0.283	0.359	-0.262	0.359
Having business units in commune	0.162	0.176	0.316*	0.178
Having craft villages in commune	-0.438*	0.249	0.474*	0.251
Disasters in commune	0.082	0.069	-0.037	0.068
Having employment programs in commune	-0.073	0.192	-0.125	0.192
Having infrastructure programs in commune	-0.029	0.158	-0.046	0.157
Having educational and vocational programs	-0.505**	0.210	-0.110	0.202
Having member working in state economic sector	-0.480	0.329	0.592*	0.308
Having member working in private economic sector	-0.146	0.424	0.692*	0.380
Having member working on household's own business	-1.280***	0.184	-0.609***	0.207
North East	-0.278	0.250	-0.724***	0.240
North West	0.734*	0.399	-0.431	0.424
North Central Coast	0.012	0.239	-0.638***	0.239
South Central Coast	0.311	0.282	0.221	0.272
Central Highlands	0.228	0.454	-0.201	0.456
South East	0.586	0.399	-0.371	0.459
Mekong River Delta	0.436*	0.261	-0.515**	0.262
Constant	4.593***	0.568	3.222***	0.570
N	2014		2014	
R^2	0.172		0.246	

Notes: Standard errors are robust; The dependent variables is expressed in the log; ∗, ∗∗, ∗∗∗ indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively.

7. Conclusions

Economic growth in developing countries is accompanied by moving farm labour out of agriculture. It is widely recognized that improving agricultural productivity leads to rising rural income and poverty reduction (Warr 2006). Although Vietnam is one of the leading rice exporters in the world, rice farmers are being kept in poverty and low incomes. In addition, rice consumption is falling in nearly all of Asia and potential expansion of rice exports in some Asian countries, which may result in crisis in rice prices and exports (Timmer 2013). Therefore, it is no surprise that increased attention has been given in recent years in development institutions such as the World Bank, ADB and governments to the potential for expansion of the rural nonfarm economy as a source of income growth and poverty reduction and economic diversification. This argument has raised a question whether the improvement of agricultural productivity leads to structural change and economic diversification in rural areas. Although there have been many studies on agricultural productivity or the rural nonfarm economy separately, there is little evidence answering this question. Thus, the objective of this paper is to fill the gap by answering the above question in the case of Vietnamese agriculture. Furthermore, it also tests the hypothesis that the impacts of agricultural productivity growth on economic diversification depend on the factor bias of technical change.

Many studies apply Hicks neutral technical change when setting up the model to evaluate the relationship between farm and nonfarm sectors or agricultural productivity growth and rural transformation. Theoretically, using this assumption of technical change results in the conclusion that the increase in agricultural productivity slows the rural structure transformation. Conversely, if the technical change is factor-biased, opposite conclusions can be drawn.

By expanding the theoretical framework of Jia and Petrick (2013), Acemoglu (2010) and arguments in Foster and Rosenzweig (2004 and 2008), we develop the theoretical analysis using the Cobb-Douglas and CES production functions with different assumptions on technical changes. If the technical change is Hick-neutral, land consolidation leads to more on farm labour supply. Conversely, if technical change is factor-biased and the elasticity of substitution is low enough, the technical change can be labor saving, which may reduce farm labour supply and release more labour to other sectors. Technology is labor saving if technological advances reduce the farm marginal product of labor. The paper tests these theoretical predictions by developing

empirical analysis of the impact of land consolidation on farm and nonfarm outcomes such as labour supply, profits and labour intensity, and productivity.

By using different methods aimed at verifying and checking the consistency of the result, we find that the reduction of land fragmentation will reduce farm labour supply, labour intensity and improve farm profits and productivity. Similarly, land consolidation may release more farm labour to nonfarm sectors and increase nonfarm profits. The paper uses the methods of panel data and correlated random effect model to control the unobserved heterogeneity, and sample selection bias. The empirical evidences also show that factor biased technical change plays an important role in explaining the effect of agricultural productivity on economic diversification and income in Vietnam. If technical change is labour saving as in the case of land consolidation, the agricultural technical change results in the release of more farm labour. Therefore, these results are consistent with theoretical prediction that the application of labour saving agricultural technical changes reduces labour demand and induces labour reallocation in farm households.

The paper also finds that there is a linkage between the farm and nonfarm sector. The productivity improvement in farm sector will promote the development of the nonfarm economy and economic diversification of households. Evidence provided by the paper indicates that land consolidation is an appropriate public policy in light of declining agricultural growth in Vietnam. The issues of land use have become an important threshold that Vietnam needs to reform despite increasing public investment in agriculture in recent years. Thus, if land polices encourage more consolidated land holdings, they will release more farm labour and result in economic diversification of farm households. The finding of this paper shows that land reforms such as land consolidation programs frees up labor to be put to work in other sectors and to be invested in the creation of human capital. As Warr (2009) finds, these released resources are used more productively in other sectors and improve the productivity of the country. In addition, the expansion of and intuitions to develop land markets are key factors in the next reforms if Vietnam accelerates the land consolidation programs, which are mainly implemented through plot exchange that much depends on the quality of land governance.

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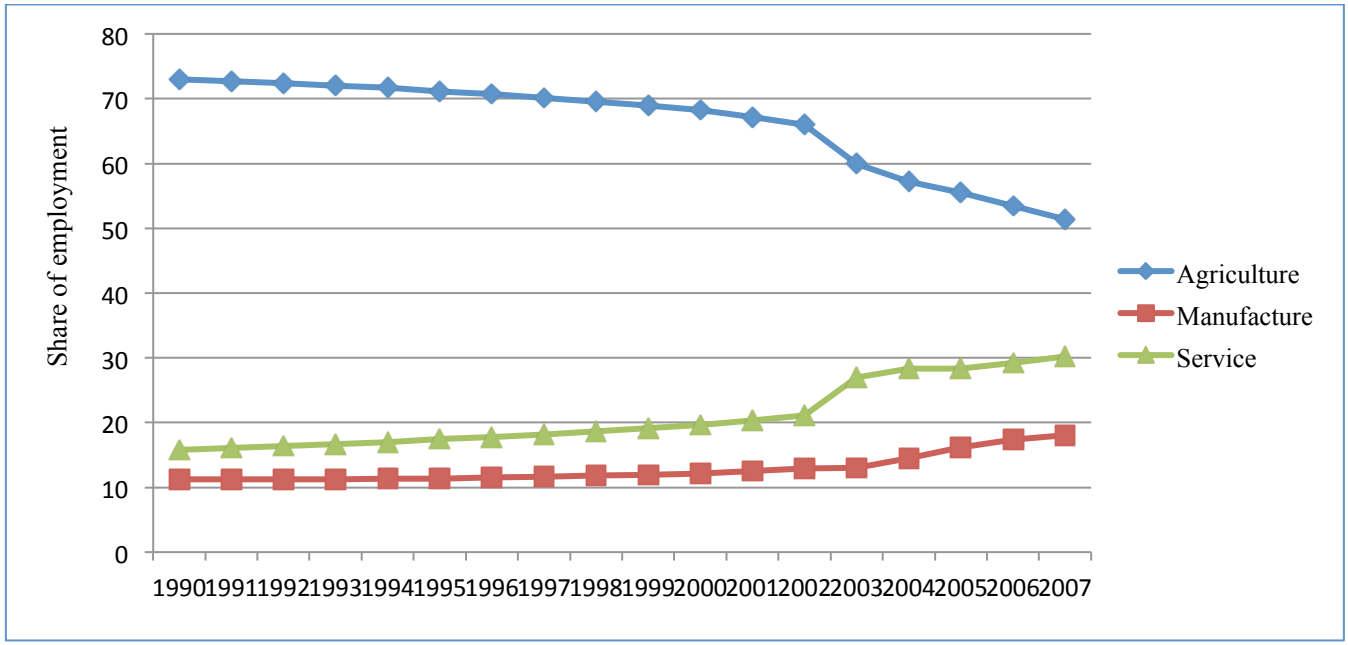
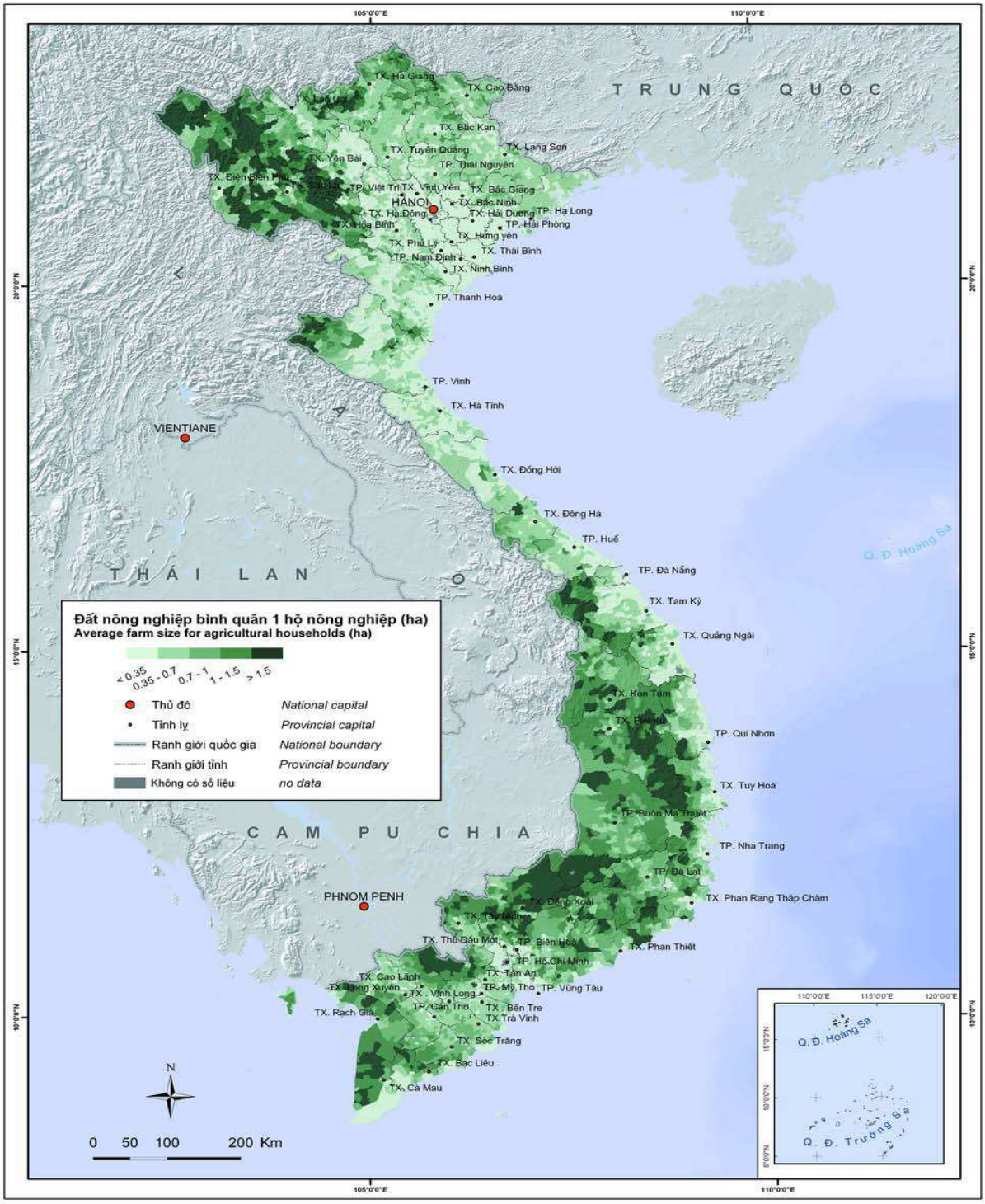
Figure A1. Shares of employment by sectors, 1990-2007



Source: General Statistics Office (GSO), 2002, 2003, 2008, and 2009, *The statistical yearbooks*, The Statistics Publishing House, Hanoi.

Figure A2. Average farm size for agricultural household (ha)



Source: FAO

Table A1. The effects of land fragmentation on farm outcomes using the first difference method

	Farm labor supply	Farm profits	Farm output	No of individuals in farming activities
Log of plots	0.355***	-0.115***	-0.055***	0.051
Annual crop land	0.048	0.194***	-0.022***	-0.016
Age	-0.047***	-0.003**	0.000	-0.007***
Household members, from 15 to 60 years old, people	0.260***	-0.020	0.003	0.010
Dependency ratio (%)	4.408***	-0.080	-0.016	0.358***
Mean education of working age men	0.180***	0.005	0.003	0.024**
Mean education of working age women	0.065*	0.015*	0.002	0.008
Access to formal credit	-0.012	0.048	0.008	-0.027
Log of assets	-0.025	-0.016***	0.002	0.003
Access to asphalt road	0.407**	-0.032	-0.001	-0.039
Access to electricity	0.111	-0.025	-0.002	-0.070
Access to post office	-0.341*	0.057	-0.010	0.057
Access to extension	-0.233	0.027	0.003	-0.013
Having business units in commune	0.172	-0.016	0.001	-0.123**
Having craft villages in commune	-0.452*	-0.051	-0.003	0.000
Disasters in commune	0.088	-0.027*	0.005	0.022
Having employment programs in commune	-0.101	-0.037	-0.007	0.084
Having infrastructure programs in commune	-0.049	-0.051	0.002	0.017
Having educational and vocational programs	-0.524**	0.033	-0.025*	-0.058
Having member working in state economic sector	-0.890***	-0.105	0.001	-0.054
Having member working in private economic sector	-0.463	-0.051	-0.021	-0.007
Having member working on household's own business	-1.139***	-0.118***	0.005	-0.540***
North East	-0.293	-0.011	-0.001	-0.058
North West	0.768*	-0.482***	-0.004	0.249
North Central Coast	0.066	0.075*	0.001	-0.076
South Central Coast	0.326	0.024	-0.016	-0.176**
Central Highlands	0.356	-0.128	-0.022	0.251
South East	0.537	-0.095	-0.028	0.156
Mekong River Delta	0.467*	-0.038	0.001	0.125
Constant	4.346***	-0.231	0.131***	0.793***
N	2014	1937	2014	2014
R^2	0.171	0.095	0.067	0.073

Notes: Standard errors are robust through the *cluster* option; All dependent variables are expressed in the log change;

*, **, *** indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively;

Table A2. The effects of land fragmentation on farm outcomes using the first difference method

	Farm labor supply	Farm profits	Farm output	No of individuals in farming activities
Simpson index	0.533*	-0.109	-0.092***	0.200**
Annual crop land	0.049	0.189***	-0.022***	-0.012
Age	-0.048***	-0.003**	0.000	-0.007***
Household members, from 15 to 60 years old, people	0.266***	-0.021	0.002	0.010
Dependency ratio (%)	4.423***	-0.086	-0.018	0.356***
Mean education of working age men	0.174***	0.007	0.004*	0.023**
Mean education of working age women	0.063*	0.016**	0.002	0.008
Access to formal credit	-0.020	0.050	0.009	-0.027
Log of assets	-0.025	-0.016***	0.002	0.003
Access to asphalt road	0.422**	-0.035	-0.003	-0.034
Access to electricity	0.125	-0.032	-0.003	-0.074
Access to post office	-0.353*	0.062	-0.009	0.058
Access to extension	-0.247	0.031	0.005	-0.015
Having business units in commune	0.152	-0.009	0.004	-0.126**
Having craft villages in commune	-0.468*	-0.047	-0.001	-0.002
Disasters in commune	0.088	-0.026*	0.005	0.023
Having employment programs in commune	-0.077	-0.045	-0.010	0.087
Having infrastructure programs in commune	-0.033	-0.058*	-0.001	0.017
Having educational and vocational programs	-0.518**	0.031	-0.026**	-0.057
Having member working in state economic sector	-0.877***	-0.107*	-0.002	-0.051
Having member working in private economic sector	-0.477	-0.049	-0.019	-0.006
Having member working on household's own business	-1.129***	-0.122***	0.004	-0.539***
North East	-0.222	-0.034	-0.012	-0.049
North West	0.807**	-0.492***	-0.009	0.248
North Central Coast	0.075	0.073*	-0.001	-0.075
South Central Coast	0.315	0.024	-0.014	-0.183**
Central Highlands	0.294	-0.112	-0.012	0.233
South East	0.550	-0.093	-0.030	0.158
Mekong River Delta	0.463*	-0.028	0.002	0.127
Constant	4.280***	-0.175	0.142***	0.772***
N	2014	1937	2014	2014
R^2	0.17	0.087	0.053	0.074

Notes: Standard errors are robust through the *cluster* option; All dependent variables are expressed in the log change;

*, **, *** indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively;

Table A3. The effects of land fragmentation on nonfarm outcomes without selection correction

Independent variables	Nonfarm labor supply	Nonfarm profits
Simpson index	-0.646*	-0.233
Annual crop land	-0.056	0.105
Age	-0.030***	-0.023***
Household members, from 15 to 60 years old, people	0.323***	0.076
Dependency ratio (%)	1.565***	1.587***
Mean education of working age men	0.236***	0.113**
Mean education of working age women	0.141***	0.120**
Access to formal credit	0.061	0.132
Log of assets	-0.009	0.000
Access to asphalt road	0.531***	0.099
Access to electricity	-0.264	0.253
Access to post office	-0.012	0.073
Access to extension	-0.337	-0.275
Having business units in commune	0.527***	0.507**
Having craft villages in commune	0.064	-0.683**
Disasters in commune	-0.052	-0.118
Having employment programs in commune	-0.023	0.232
Having infrastructure programs in commune	-0.109	0.065
Having educational and vocational programs	-0.216	-0.421
Having member working in state economic sector	-0.239	-2.005***
Having member working in private economic sector	-0.506	-2.910***
Having member working on household's own business	-0.275	-0.594**
North East	-1.042***	0.009
North West	-0.633	0.811
North Central Coast	-0.899***	0.010
South Central Coast	0.469	1.226***
Central Highlands	-0.425	0.325
South East	-0.519	0.228
Mekong River Delta	-0.684**	0.479
Constant	2.729***	-0.077
N	2014	2014
R^2	0.102	0.07

Notes: The first difference method is used; Standard errors are robust through the *cluster* option; All dependent variables are expressed in the log change; ∗, ∗∗, ∗∗∗ indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively;

Table A4. The effects of land fragmentation on nonfarm outcomes without selection correction

Independent variables	Nonfarm labor supply	Nonfarm profits
Log of plots	-0.324**	-0.225
Annual crop land	-0.051	0.103
Age	-0.031***	-0.023***
Household members, from 15 to 60 years old, people	0.326***	0.080
Dependency ratio (%)	1.574***	1.600***
Mean education of working age men	0.230***	0.109**
Mean education of working age women	0.139***	0.118**
Access to formal credit	0.056	0.127
Log of assets	-0.009	0.001
Access to asphalt road	0.548***	0.107
Access to electricity	-0.259	0.266
Access to post office	-0.020	0.062
Access to extension	-0.349	-0.283
Having business units in commune	0.508***	0.494**
Having craft villages in commune	0.049	-0.693**
Disasters in commune	-0.051	-0.120
Having employment programs in commune	-0.001	0.248
Having infrastructure programs in commune	-0.097	0.077
Having educational and vocational programs	-0.210	-0.417
Having member working in state economic sector	-0.225	-1.999***
Having member working in private economic sector	-0.514	-2.921***
Having member working on household's own business	-0.267	-0.588**
North East	-0.979***	0.055
North West	-0.605	0.841*
North Central Coast	-0.893***	0.017
South Central Coast	0.451	1.224***
Central Highlands	-0.493	0.294
South East	-0.507	0.236
Mekong River Delta	-0.685**	0.474
Constant	2.655***	-0.108
N	2014	2014
R^2	0.103	0.07

Notes: The first difference method is used; Standard errors are robust through the *cluster* option; All dependent variables are expressed in the log change; ∗, ∗∗, ∗∗∗ indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively;

Table A5. The effects of land fragmentation on nonfarm outcomes using double hurdle model

	Hurdle 1	
	Probability of participating in nonfarm activities	
Simpson index	0.043	
Log of plots		-0.041
Annual crop land	-0.016	-0.012
Age of the head of household, years	0.011	0.011
Age of the head of household squared, years	0	0
Gender of the head of household, 1 for male	-0.111**	-0.111**
Marital status of the head, 1 for married	-0.178**	-0.178**
Ethnic status of the head, 1 for majority	0.343***	0.343***
Household members, from 15 to 60 years old, people	0.282***	0.282***
Dependency ratio (%)	0.201	0.202
Mean education of working age men	0.034	0.034
Mean education of working age women	0.029	0.028
Head of household has primary education	0.084	0.084
Head of household has lower secondary education	0.064	0.066
Head of household has university education	0.765*	0.766*
Access to formal credit	-0.011	-0.009
Log of assets	0.011	0.011
Days of illness	-0.001	-0.001
Having member working in state economic sector	1.698***	1.697***
Having member working in private economic sector	1.786***	1.788***
Having member working on household's own business	0.175**	0.176**
Access to asphalt road	0.135**	0.133**
Access to electricity	-0.389***	-0.386***
Access to post office	-0.156**	-0.152**
Access to extension	-0.179*	-0.180*
Inland delta areas	0.315***	0.313***
Remote areas	-0.291***	-0.296***
Having business units in commune	0.09	0.091
Having craft villages in commune	0.372***	0.366***
Disasters in commune	-0.021	-0.021
Having employment programs in commune	0.113*	0.114*
Having infrastructure programs in commune	0.117**	0.118**
Having educational and vocational programs	0.07	0.071
Year 2006	0.408***	0.397***
North East	-0.339***	-0.336***
North West	-0.428***	-0.424***
North Central Coast	-0.521***	-0.521***
South Central Coast	-0.157*	-0.171*
Central Highlands	-0.292**	-0.318**
South East	-0.489***	-0.531***
Mekong River Delta	-0.698***	-0.751***
Constant	-1.135***	-1.130***
N	4008	4008

Pseudo R2	0.2765		0.2766	
Mundlak fixed effects	Yes		Yes	
	Hurdle 2			
Independent variables	Nonfarm labor supply	Nonfarm profits	Nonfarm labor supply	Nonfarm profits
Simpson index			-0.120*	-0.291***
Log of plots	-0.026	-0.154***		
Annual crop land (ha)	-0.001	-0.053***	0.012	0.000
Age of the head of household, years	-0.018	-0.022	-0.018	-0.028
Age of the head of household squared, years	0.000	0.000	0.000	0.000*
Gender of the head of household, 1 for male	0.002	-0.007	0.002	-0.008
Marital status of the head, 1 for married	-0.006	0.151**	-0.004	0.148*
Ethnic status of the head, 1 for majority	0.129**	0.438***	0.132**	0.441***
Household members, from 15 to 60 years old, people	0.193***	0.231***	0.195***	0.224***
Dependency ratio (%)	0.371**	0.863***	0.373**	1.005***
Mean education of working age men (years)	-0.009	0.066***	-0.011	0.004
Mean education of working age women (years)	0.004	0.040***	0.003	0.037
Head of household has primary education	0.038	0.138**	0.037	0.145***
Head of household has lower secondary education	0.017	0.103**	0.016	0.099**
Head of household has university education	-0.131	0.011	-0.137	-0.011
Access to formal credit	-0.028	0.029	-0.028	0.031
Log of assets	-0.005	-0.002	-0.005	-0.009
Days of illness	0.000	0.000	0.000	0.000
Having member working in state economic sector	0.237***	0.488***	0.235***	0.480***
Having member working in private economic sector	0.238***	0.290***	0.240***	0.301***
Having member working on their own business	-0.062	-0.077	-0.063*	-0.081**
Access to asphalt road	0.039	0.040	0.040	0.043
Access to electricity	-0.043	-0.024	-0.045	-0.043
Access to post office	-0.038	-0.134***	-0.035	-0.132**
Access to extension	-0.020	-0.057	-0.021	-0.061
Inland delta areas	0.029	0.054	0.031	0.065
Remote areas	-0.033	-0.131	-0.035	-0.118
Having business units in commune	0.063*	0.146***	0.065*	0.154***
Having craft villages in commune	0.050	0.093*	0.048	0.101*
Disasters in commune	-0.003	-0.020	-0.002	-0.015
Having employment programs in commune	-0.023	0.015	-0.025	0.004
Having infrastructure programs in commune	0.002	-0.059	0.003	-0.062
Having educational and vocational programs	-0.033	-0.102*	-0.036	-0.109*
Year 2006	0.200***	0.034	0.200***	0.062***
North East	-0.055	-0.175**	-0.059	-0.191**
North West	-0.280***	-0.250*	-0.287***	-0.282*
North Central Coast	-0.196***	-0.396***	-0.195***	-0.393***
South Central Coast	-0.055	0.095	-0.059	0.108
Central Highlands	-0.015	-0.486**	-0.031	-0.471***
South East	0.023	0.276***	0.004	0.304***
Mekong River Delta	-0.195***	0.015	-0.210***	0.086
Constant	7.766***	8.338***	7.805***	8.596***
N	2008	2008	2008	2008
Pseudo R2				
Mundlak fixed effects	Yes	Yes	Yes	Yes

Table A6. The effects of land fragmentation on nonfarm outcomes using Wooldridge (1995)

Independent variables	Nonfarm labor supply	Nonfarm profits	Nonfarm labor supply	Nonfarm profits
Simpson index	-0.122*	-0.297***		
Log of plots			-0.023	-0.143***
Annual crop land	0.014	0.006	0.011	0.008
Age of the head of household, years	-0.017	-0.025	-0.017	-0.025
Age of the head of household squared, years	0.000	0.000	0.000	0.000
Gender of the head of household, 1 for male	0.006	0.007	0.007	0.008
Marital status of the head, 1 for married	0.002	0.170***	0.001	0.170***
Ethnic status of the head, 1 for majority	0.118**	0.386***	0.116**	0.379***
Household members, from 15 to 60 years old, people	0.186***	0.194***	0.185***	0.190***
Dependency ratio (%)	0.372*	0.997***	0.371*	0.988***
Mean education of working age men	-0.014	-0.003	-0.011	0.003
Mean education of working age women	0.001	0.030	0.002	0.031
Head of household has primary education	0.035	0.138***	0.036	0.142***
Head of household has lower secondary education	0.013	0.090*	0.015	0.095**
Head of household has university education	-0.144	-0.034	-0.141	-0.034
Access to formal credit	-0.026	0.035	-0.026	0.038
Log of assets	-0.006	-0.010	-0.006	-0.010
Days of illness	0.000	0.000	0.000	0.001
Having member working in state economic sector	0.193***	0.332***	0.197***	0.331***
Having member working in private economic sector	0.205***	0.179***	0.204***	0.167**
Having member working on household's own business	-0.062	-0.074	-0.060	-0.069
Access to asphalt road	0.036	0.031	0.036	0.027
Access to electricity	-0.034	-0.007	-0.033	0.003
Access to post office	-0.030	-0.106*	-0.033	-0.103*
Access to extension	-0.016	-0.042	-0.015	-0.036
Inland delta areas	0.021	0.026	0.019	0.017
Remote areas	-0.023	-0.080	-0.018	-0.072
Having business units in commune	0.062*	0.141***	0.061*	0.144***
Having craft villages in commune	0.037	0.062	0.039	0.050
Disasters in commune	-0.002	-0.013	-0.002	-0.013
Having employment programs in commune	-0.029	-0.010	-0.027	-0.005
Having infrastructure programs in commune	0.001	-0.070*	0.001	-0.069*
Having educational and vocational programs	-0.036	-0.109*	-0.034	-0.107*
Inverse Mill ratio (2004)	-0.059	-0.164*	-0.057	-0.177*
Inverse Mill ratio (2006)	-0.090	-0.360***	-0.087	-0.371***
Year 2006	0.204***	0.124**	0.203***	0.095
North East	-0.048	-0.153**	-0.044	-0.130*
North West	-0.275***	-0.239*	-0.265***	-0.188
North Central Coast	-0.180***	-0.338***	-0.181***	-0.335***
South Central Coast	-0.056	0.114*	-0.051	0.100
Central Highlands	-0.022	-0.438**	0.001	-0.412**
South East	0.021	0.365***	0.043	0.350***
Mekong River Delta	-0.187***	0.165**	-0.166***	0.141*

Constant	7.863***	8.789***	7.856***	8.736***
N	2008	2008	2008	2008
R^2	0.249	0.312	0.248	0.314
Mundlak fixed effects	Yes	Yes	Yes	Yes

Table A7. Factors influencing the land fragmentation of a farm household using first difference

	Log of plots		Simpson index	
Independent variables	Coef.	P value	Coef.	P value
Annual crop land	-0.036***	0.000	-0.025***	0.000
Age	0.000	0.711	0.000	0.683
Household members, from 15 to 60 years old, people	0.022*	0.077	0.005	0.320
Dependency ratio (%)	0.096	0.118	0.035	0.188
Mean education of working age men	-0.014**	0.037	0.002	0.439
Mean education of working age women	-0.010*	0.080	-0.002	0.382
Access to formal credit	-0.031	0.250	-0.006	0.560
Log of assets	0.007*	0.078	0.004**	0.028
Access to asphalt road	0.020	0.494	-0.016	0.193
Access to electricity	0.084**	0.010	0.037***	0.008
Access to post office	-0.078**	0.025	-0.026*	0.089
Access to extension	-0.048	0.452	-0.003	0.905
Having business units in commune	-0.059**	0.042	-0.001	0.969
Having craft villages in commune	-0.040	0.317	0.002	0.905
Disasters in commune	-0.021*	0.055	-0.013***	0.006
Having employment programs in commune	0.059*	0.071	-0.003	0.809
Having infrastructure programs in commune	0.058**	0.034	0.012	0.289
Having educational and vocational programs	0.019	0.599	0.000	0.975
Having member working in state economic sector	0.011	0.814	-0.016	0.431
Having member working in private economic sector	-0.067	0.329	-0.022	0.372
Having member working on household's own business	0.031	0.377	0.002	0.896
North East	0.209***	0.000	0.008	0.649
North West	0.162**	0.019	0.041	0.146
North Central Coast	0.043	0.270	0.011	0.517
South Central Coast	0.046	0.349	0.048***	0.010
Central Highlands	-0.039	0.585	0.083***	0.009
South East	0.068	0.408	0.012	0.716
Mekong River Delta	-0.014	0.757	-0.009	0.666
Transfer of land use right certificates in the commune	-0.015***	0.008	-0.006**	0.011
Constant	-0.062	0.562	0.086*	0.058
N	2014		2014	
R^2	0.077		0.052	

Notes: Standard errors are robust through the *cluster* option; All dependent variables are expressed in the log change;

*, **, *** indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively;

Table A8. Testing the endogeneity of land fragmentation using the control function

	Farm labor supply			
Independent variables	Coef.	SE	Coef.	SE
Log of plots	-0.393	2.137		
Residual of log of plots	0.751	2.138		
Simpson index			-0.982	5.349
Residual of Simpson index			1.520	5.358
Annual crop land	0.021	0.092	0.010	0.144
Age	-0.048***	0.006	-0.047***	0.006
Household members, from 15 to 60 years old, people	0.277***	0.087	0.274***	0.078
Dependency ratio (%)	4.478***	0.425	4.475***	0.416
Mean education of working age men	0.169***	0.046	0.177***	0.038
Mean education of working age women	0.057	0.041	0.059	0.036
Access to formal credit	-0.036	0.169	-0.030	0.159
Log of assets	-0.020	0.026	-0.019	0.029
Access to asphalt road	0.421**	0.172	0.397**	0.190
Access to electricity	0.190	0.306	0.193	0.320
Access to post office	-0.393	0.256	-0.388	0.242
Access to extension	-0.260	0.368	-0.245	0.361
Having business units in commune	0.132	0.206	0.154	0.177
Having craft villages in commune	-0.485*	0.268	-0.467*	0.251
Disasters in commune	0.074	0.082	0.069	0.098
Having employment programs in commune	-0.049	0.239	-0.075	0.192
Having infrastructure programs in commune	0.004	0.222	-0.006	0.185
Having educational and vocational programs	-0.511**	0.212	-0.518**	0.209
Having member working in state economic sector	-0.881***	0.283	-0.902***	0.297
Having member working in private economic sector	-0.522	0.431	-0.518	0.422
Having member working on household's own business	-1.116***	0.184	-1.126***	0.173
North East	-0.132	0.528	-0.206	0.258
North West	0.908	0.571	0.885*	0.490
North Central Coast	0.096	0.252	0.089	0.243
South Central Coast	0.351	0.294	0.381	0.365
Central Highlands	0.306	0.472	0.403	0.593
South East	0.564	0.402	0.549	0.399
Mekong River Delta	0.436	0.276	0.433	0.282
Constant	4.313***	0.570	4.421***	0.737
N	2014		2014	
R^2	0.172		0.17	

Notes: Standard errors are robust through the *cluster* option; All dependent variables are expressed in the log change; *, **, *** indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively;