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Land consolidation as technical change: Economic impacts in rural Vietnam ☆

Huy Quynh Nguyen [a], Peter Warr [b,*]

[a] University of Economics, Ho Chi Minh City, Viet Nam
[b] Australian National University, Canberra, Australia

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ABSTRACT

This paper deepens the economic analysis of the effects of land consolidation – reduction of land fragmentation. It does this in the context of rural Vietnam, studying whether land consolidation promotes or hinders the Vietnamese government's policy objectives of encouraging agricultural mechanization and stimulating the off-farm rural economy. The analysis views land consolidation as a form of technical change, making it possible to apply the rich insights developed in the economic literature on that subject. This treatment reveals that the economic impacts of land consolidation depend partly on its factor bias and partly on the degree to which labor is substitutable in production for other factors. At a theoretical level, if a technical change is factor neutral, it will reduce off-farm labor supply and slow rural structural transformation away from agriculture; if it is labor-augmenting and the elasticity of substitution between factors is low enough, the opposite effects are predicted. The paper studies these issues empirically for rice production in Vietnam, focusing on the impact that consolidation of rice land has on rice production, machinery use, and labor allocation. The findings confirm that land consolidation raises both farm productivity and farm income and stimulates increased machinery use. It also reduces farm labor supply, lowers labor intensity in farming, and thereby releases more farm labor to off-farm development, consistent with government policy objectives. Based on these findings, the paper concludes that land consolidation should be encouraged through development of land ownership rights and the promotion of land rental markets.

1. Introduction

Vietnam is a leading rice exporter, but its rice farmers remain poor (World Bank, 2016). Since rice consumption per person is falling in nearly all of Asia (Timmer, 2014), the prospects for rice producers are not encouraging. There are strong economic incentives for rural people to diversify their sources of income, but in many countries the perspective of policy makers is that this market-driven process is occurring too slowly. Accordingly, increased attention has been given to expanding the rural nonfarm economy as a source of income growth and poverty reduction within rural areas (Haggblade, Hazell, & Reardon, 2007; Hazell & Rahman, 2014; Marsh, Macaulay, & Hung, 2006). Structural transformation through expanding the nonfarm rural economy is now an explicit policy objective of the Vietnamese government. Agriculture's contribution to Vietnam's GDP declined from over 45% in 1988 to less than 20% in 2007, but the share of labor in agriculture was 75% in 1990, and remained nearly 60% in 2007 (General Statistics Office of Vietnam, 2012). Agricultural labor productivity (value of output per farm worker) is low, especially in rice production, and needs to be raised, enabling labor to be reallocated from farm to off-farm industries without reducing agricultural output.

It has been argued that in Asia, in response to rising rural wages, government policy should encourage larger farm sizes with less fragmentation of holdings, along with mechanization (Otsuka, Liu, & Yamauchi, 2013; Yamauchi, 2014).[1] Labor shortages within

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* Corresponding author at: Arndt-Corden Department of Economics, Crawford School of Public Policy, College of Asia and the Pacific, Coombs Building (09), Australian National University, Canberra, ACT 2601, Australia.
E-mail address: Peter.Warr@anu.edu.au (P. Warr).

[1] Land fragmentation has been defined as the existence of a number of spatially separate plots of land, which are farmed as single units (McPherson, 1982). Land consolidation is defined by Oldenburg (1990) as an exchange of the ownership of spatially scattered plots of farms to establish new landholdings with fewer plots. In common with most literature on this subject, we shall use the terms 'land consolidation' and 'reduction of land fragmentation' interchangeably to mean a reduction in the number of plots per farm. It is important that 'land consolidation', defined in this way, does not necessarily imply an increase in average farm size. In some studies 'land consolidation' has been used ambiguously to mean either an increase in average farm size or a reduction in the average number of plots per farm, or both.

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agriculture and rising real wages as a result of migration to urban areas create an incentive to substitute machines for increasingly costly labor (Otsuka et al., 2013). Evidence from Africa suggests that land reform, through the reduction of land fragmentation (land consolidation), can raise labor productivity by enabling farmers to have fewer parcels that are larger and better shaped, and possibly to expand the size of their holdings, thereby promoting the adoption of agricultural machinery and thus reducing labor use (Blarel, 1992). Fragmentation of holdings wastes farmers' time by requiring them to travel regularly between sometimes distant plots. It also makes mechanization more difficult. The governments of many developing countries emphasize the role of research, public investments and credit programs in agriculture, as well as the promotion of mechanization to improve productivity and reduce poverty. But these interventions may be hindered if households' land holdings are too scattered and small (McPherson, 1982; Otsuka et al., 2013; Lai, Roe, & Liu, 2015).

The literature is clear that land consolidation raises productivity. But does it promote or impede structural transformation of the rural economy? The literature contains conflicting theoretical arguments about the effect that land consolidation has on the allocation of household labor between on-farm and off-farm employment. We show that these arguments can be clarified and resolved by viewing land consolidation as a form of technical change because this treatment enables the insights of the economic literature on technical change to be applied. At a theoretical level, the effects of a technical change depend partly on its factor bias. If the technical change is factor-neutral, or factor-biased towards augmenting factors other than labor, it will increase on-farm labor use, reduce off-farm labor supply and slow rural structural transformation away from agricultural production. Conversely, if the technical change is factor-biased towards labor-augmentation and, in addition, the elasticity of factor substitution is low enough, the opposite effects are predicted. The paper studies these analytical possibilities by developing an empirical analysis in the context of Vietnam, using three rounds of Vietnam's nationally representative household survey data (2004, 2006, and 2008). It evaluates whether land consolidation increases or reduces the use of labor in Vietnam's rice production, how it affects farm and off-farm incomes and whether it promotes agricultural mechanization.

The paper is organized as follows. Section 2 reviews the literature on the economic effects of land consolidation. Section 3 summarizes the institutional context of land reform in Vietnam. Section 4 presents the theoretical framework. Section 5 describes the data to be used in the empirical analysis and Section 6 summarizes the empirical methodology. Section 7 then presents the main findings, and the conclusions are outlined in Section 8.

2. Literature review

In its treatment of land fragmentation, the main focus of the international literature is its linkage with farm sizes, farm productivity and farm output. Several studies of agricultural growth, including Blarel (1992) on Ghana and Rwanda, and Wan and Cheng (2001) on China, show that small and fragmented farm size hampers application of new technology, leading to higher costs in farming, reducing output and productivity. Wan and Cheng (2001) estimate that the exogenous addition of one plot results in a reduction of annual crop output by 2 to 10 percentage points. Similarly, applying a stochastic production frontier method to data for Bangladesh, Rahman and Rahman (2008) show a negative impact of land fragmentation on agricultural productivity. The reduction of land fragmentation improves agricultural technical efficiency, and contributes to a strengthening of the economic competitiveness of farm households, particularly when costs of labor and other inputs are rising (Rahman, 2009). Otsuka and Estudillo (2010) argue, based on the experience of agricultural transformation in East Asia, that in the middle-income stage of development the comparative advantage of smallholder agriculture will decline in the face of rising part-time farming and rising rural wages unless the problems arising from inefficient land use arrangements are addressed.

Few studies have directly examined the relationship between land consolidation and investment in farm machinery. Lai et al. (2015) find, using data for China, that on average when farms were consolidated from 2.28 plots to one plot, machinery use increased by 10%. Similarly, in the context of India, Foster and Rosenzweig (2011) show that larger land size and larger plots encourage farmers to increase investment in machinery use, producing higher farm incomes by substituting machinery for labor.

In the case of Vietnam, Hung, MacAulay, and Marsh (2007) find that reducing fragmentation of land holdings raises crop productivity. Land consolidation has been found to improve technical efficiency in rice production (Kompas, 2004; Kompas, 2012). Similarly, Markussen (2013) found that consolidating land holdings facilitated some types of mechanization in farming activities, raising agricultural productivity. They conclude that land consolidation has the potential to increase agricultural output.

The evidence seems clear that land consolidation raises productivity. But the literature is less clear as to whether it promotes or hinders structural transformation of the rural economy. McPherson (1982) and Bentley (1987) argue that in general land fragmentation keeps labor on farms, implying that land consolidation releases labor. Several studies focus on China, but the conclusions are mixed. Tan, Heerink, Kruseman, and Qu (2008) observe that fragmented landholdings cause higher labor costs in Chinese agricultural production and conclude that land consolidation may release more labor for other sectors. Wan and Cheng (2001) reach the same conclusion. These studies thus argue that land consolidation can facilitate both agricultural productivity growth and structural transformation, reducing agricultural surplus labor by facilitating its reallocation to more productive uses. In contrast, Jia and Petrick (2013) draw very different conclusions, also in the context of China. These authors claim that land consolidation increases the use of labor in on-farm production, thereby reducing off-farm use, even though in their empirical results the impact of land-consolidation policies on off-farm labor use is statistically insignificant.

In Vietnam, the effects that land institutional arrangements have on machinery use and labor allocation have not been investigated. Nevertheless, these issues are critical to rural policy in Vietnam. We wish to know whether land consolidation advances the policy objectives of both raising agricultural productivity and promoting rural structural transformation, or whether it achieves the first at the expense of the second. The empirical results presented in this study imply that land consolidation facilitates mechanization and enables farmers to allocate more farm labor to off-farm work. We therefore argue that previous studies of land consolidation in Vietnam, in focusing on the effect on agricultural productivity, may overlook part of the potential value of land consolidation in Vietnam's land reform.

Virtually all previous international studies of land fragmentation rest on the assumption that the degree of land fragmentation is exogenous, due to the imperfect nature of land markets. That is, these studies exclude the possibility that land consolidation is, at least partly, an endogenous response on the part of farming household to rising costs, especially labor costs. In fact, land rental markets in rural Vietnam are active and most households have some capacity to influence their land reallocation (World Bank, 2016). Thus, in estimating its impacts the present study relaxes the

assumption that land consolidation is exogenous. We believe it is the first study to do so.

3. Institutional background for Vietnam

Like many other late-developing East Asian countries, Vietnam is land-poor and labor-abundant. 'Equity-oriented' land reforms were adopted in the late 1980s and early 1990s (Benjamin & Brandt, 2004; Dang, 2006; Marsh et al., 2006; Minot & Goletti, 1998). These land reforms helped to mitigate rural poverty, but they also resulted in small-scale and fragmented farms, contributing to agricultural inefficiency, and slowed structural transformation (Hung et al., 2007; Kompas, 2012). The policy balance between equity and efficiency has been contentious throughout Vietnam's agricultural development. Of all households using paddy land, 85 percent have a farm size of less than 1 ha. Hazell and Rahman (2014) define smallholders as farms operating less than 2 ha of land area, and using this definition, Vietnamese agriculture is dominated by smallholder farming, predominantly using labour-intensive farming methods, particularly in rice production.

In the late 1980s, the Vietnamese government decided to de-collectivize the agricultural system and allocated land to farm households, following a similar decision in China a decade before. Land reallocation was to be based on egalitarian principles (Hung et al., 2007; Ravallion & van de Walle, 2008). Scott (2009) points out that the egalitarian redistribution of land was considered necessary to avoid disputes and to curb the flow of rural migrants to the cities, considered at that time as a threat to stability. Each household was reallocated plots in different areas, based on the different qualities of the field plots, as well as access to water sources and another infrastructure. The land reallocation process reportedly achieved its egalitarian objectives (Ravallion & van de Walle, 2004). In the whole country, there are estimated to be between 75 and 100 million parcels. In 2010, the average number of plots per household was 4.7 (World Bank, 2016).[2] But according to Markussen (2013), the average distance from homes to paddy fields is 4.8 km.

Concern about scattered land holdings emerged in the late 1990s (Ministry of Agriculture and Rural Development, 2002; Research Institute of Agricultural Planning, 2004).[3] In 1998 the government issued a directive intended to encourage plot exchange programs. According to this policy, farm households voluntarily transferred their land-use rights or exchanged their plots. Based on demand, local authorities required farmers to register for land consolidation and issued new land-use right certificates. But progress has been slow, reportedly due to conflicts of interest and high transaction costs (World Bank, 2016).

Land holdings can also be consolidated through plot transactions in land markets, but the impact that land markets have on the process of land consolidation is unclear (Marsh et al., 2006; Hung et al., 2007). In Vietnam, the market for the exchange of land use rights, particularly the land rental market, is active due to recent revisions of the land laws (World Bank, 2016). Nevertheless, the government still controls agricultural land prices, and high transaction costs have restricted transactions within land markets (Le, 2009, 2010; World Bank, 2011).[4] World Bank (2006) concluded that underdeveloped rural land markets pose obstacles for further productivity gains and labor mobility toward higher wage nonfarm employment. Land reform that encourages the development of land markets remains a promising but under-used strategy for reducing land fragmentation.

Since the Doi Moi reforms of 1986 (Timmer, 1993), Vietnam has undergone one of the most rapid structural transformations yet observed in any agrarian economy (Tarp, 2017; Liu et al., 2019). As the nonfarm sectors provided more job opportunities, individuals moved out of farming and agricultural incomes declined as a share of the total incomes of rural households, even though agricultural real wages increased (McCaig & Pavcnik, 2013). That is, off-farm incomes of rural households grew more rapidly than on-farm incomes. Wiggins and Keats (2014) surveyed rural real wages in selected Asian countries (including Vietnam) for 2005–2012, finding an increasing trend in most countries. In Vietnam, average rural wages grew in real terms by 113 per cent.[5] The average household incomes of wage-earners in rural areas increased by 34 per cent in the same period.

Liu et al. (2019) report that land fragmentation (average number of plots per farm) declined between 1992 and 2016, but that the average size of farms did not change significantly. They find (p. 36) "no indication of significant disinvestment of households from farmland." Individuals moved out of farming but households did not. This finding is somewhat unexpected. Vietnamese land-use policy has been more amenable to sales of land-use rights than China's, partly because larger farms were assumed to be more efficient. Moreover, Liu *et al.* show that In Vietnam, the fabled inverse relationship between productivity and farm size has attenuated, seemingly favoring larger farm sizes.[6] But the distribution of farm sizes barely changed in the 24 years covered by their data. As real wages have risen in rural areas, the use of machinery and labor-saving pesticides has increased, starting from a low base. Rising rural wages, described above, apparently explain this trend.[7] The above evidence is consistent with the hypothesis that the development of a robust rental machinery market has made mechanization feasible even though farm sizes remain small and that plot consolidation has facilitated this mechanization process. We test this hypothesis below.

4. Theoretical framework

This section presents a simple theoretical framework for investigating the impact that land consolidation has on labor allocation. It is assumed that the farm household makes decisions about labor allocation between on-farm and off-farm employment based on their respective returns at an exogenously determined off-farm real wage, w. Land consolidation is characterized as an agricultural technical change that involves the rearrangement of plots and farming methods. Its impact on labor allocation is determined by its effect on the marginal product of on-farm labor. The theoretical basis for this proposition can be shown simply, as in Fig. 1.

The total supply of household labor is denoted S and the initial demand for labor on-farm, equivalent to the value of the marginal product of labor in on-farm production at an exogenous price, is denoted D^1. The initial labor allocation equilibrium is that the supply of household labor is LS and the demand for on-farm labor is

[2] According to World Bank (2006) the average number of plots held by rural farm households was 6.5 in the north of the country and 3.4 in the south.

[3] The reduction of land fragmentation 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 noted the slow progress due to rising corruption and cumbersome procedures.

[4] In Vietnam, private land ownership does not exist. Under the Land Law of 2013, local governments issue a certificate of land use right for all plots which households use, showing the number of plots, area, and location of each plot.

[5] Vietnam today is clearly not characterized by surplus rural labor in the sense of Lewis (1954), which would imply infinitely elastic supply of farm labor and hence stationary real wages in agriculture.

[6] Liu et al. (2019) state (p. 35) that this inverse relationship is observed only "when there exist multiple rural market failures".

[7] Some authors have argued, in the context of the Philippines, that agricultural mechanization has been driven not by rising rural wages, which have remained almost stationary, but by distortionary government policies including credit subsidies and over-valuation of the exchange rate, both of which lowered the cost of imported machinery. Rural credit subsidies may also have played some role in Thailand, but in the case of Vietnam rapidly rising real wages seem to be the principal driver.

LD^1. The supply of off-farm labor is $LS - LD^1$. If land consolidation (or any other technical change) raises the marginal product of on-farm labor, the demand for on-farm labor shifts to the right, say to D^2. The on-farm demand for labor expands to LD^2 and the supply of off-farm labor contracts to $LS - LD^2$. Conversely, if the marginal product of on-farm labor contracts, the demand for on-farm labor shifts to the left, say to D^3, on-farm labor use contracts to LD^3, and off-farm labor supply increases to $LS - LD^3$.

But doesn't a productivity-raising event like land consolidation necessarily raise the marginal product of labor? The answer is no. Viewing land consolidation as a form of technical change facilitates application of insights derived from the literature on technical change. A fundamental point is that augmenting a factor of production, by increasing the number of effective units of that factor, is not the same as raising its marginal product. The two must be distinguished from one another and also from the average product of labor. Regrettably, these three distinct notions of factor productivity are routinely confused.

Some formal notation is required. Let the actual input of on-farm labor time applied by farmers be L^f. Now consider a labor-augmentation parameter α_L^f, such that the number of effective units of labor entering the agricultural production function is $\alpha_L^f L^f$. Land fragmentation lowers α_L^f because it wastes farmers' time travelling to and from plots and between plots, along with other unproductive activities caused by difficulties in water management and restricted mechanization (Blarel, 1992; Wan & Cheng, 2001; Hung et al., 2007; Tan et al., 2008). Conversely, land consolidation raises α_L^f because it reduces this time wastage. Now consider the stylized agricultural production function:

$$Y^f = g(\alpha_L^f L^f, X^f) \quad (1)$$

where Y^f is farm output and X^f denotes other on-farm inputs. From Eq. (1), the average product of on-farm labor is $AP_L^f = Y^f / L^f$ and the marginal product of on-farm labor is $MP_L^f = \partial Y^f / \partial L^f$. The term 'labor productivity' is sometimes used alternatively, to mean α_L^f, AP_L^f or MP_L^f, but these are different concepts with sometimes very different properties. In this study, we wish to find the sign of $dL^f / d\alpha_L^f$, where L^f is chosen endogenously by the farm household. The above analysis shows that this sign is the same as the sign of $\partial MP_L^f / \partial \alpha_L^f$.

Hicks (1932) famously showed that if the technical change is factor-neutral (augmenting the productivity of all factors in the same proportion), both the average product and the marginal product of each factor must rise, including the marginal product of labor; but if the technical change is labor-augmenting (augmenting the productivity of labor alone), as with land consolidation, all average products will rise but the outcome on the marginal product of labor depends on a key parameter of the production function – the elasticity of substitution between factors.

The range of possible outcomes is illustrated at an intuitive level by reviewing two hypothetical examples. First, consider the extreme case of a Leontief technology in agricultural production, where factors must be used in fixed proportions, implying that the elasticity of substitution is between factors is zero. A technical change that augments the supply of labor but does not augment the supplies of other factors leads to redundant labor. More output could be produced, using the newly expanded supply of effective labor, only if additional supplies of the other factors of production were also available. When they are not, the additional supply of effective labor cannot be employed, because the newly expanded supply of effective labor cannot be substituted for the fixed supplies of the other factors. The marginal product of labor falls to zero.

On the other hand, suppose the elasticity of substitution is unity (the Cobb-Douglas case). Any technical progress necessarily raises the marginal product of each factor, including labor, regardless of its factor bias (Ferguson, 1969). Between these two values of the elasticity of substitution, zero and unity, lies a critical value at which labor-augmenting technical change has no effect on the marginal product of labor. At elasticities of substitution above this critical value the marginal product of labor rises, and below this critical value the marginal product falls (Benjamin, 1995).[8]

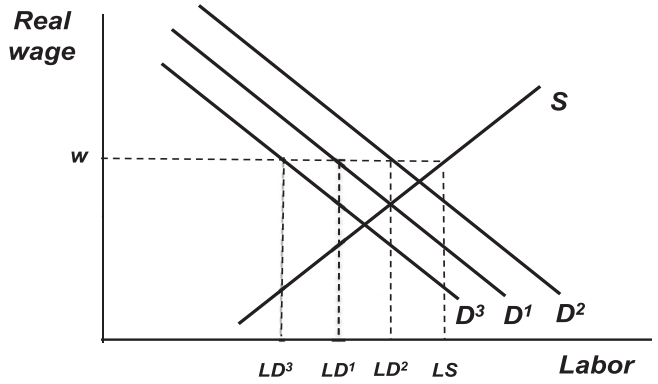

Fig. 1. Technical change and the supply of off-farm labor *Source:* Authors' construction.

In Fig. 1, household preferences between leisure and consumption determine the position and slope of the farm household's labor supply schedule. This, together with the exogenous off-farm wage w, determines the total household labor supply. The allocation of this supply between on-farm work and off-farm work at the wage w, then depends on the position of the on-farm labor demand schedule, reflecting the marginal product of on-farm labor, and *only* that. Events like land consolidation, that change on-farm labor productivity, shift the on-farm demand for labor and this shift drives any changes in the allocation of this predetermined total labor supply between on-farm and off-farm work. The shift in the demand for labor depends on whether the marginal product of labor rises or falls, which in turn depends on the factor bias of the productivity shock and the features of the production function elucidated by Hicks.

Our analysis contradicts the theoretical argument of Jia and Petrick (2013), who claim, based on similar assumptions to those above, including an exogenous off-farm real wage, that the labor allocation effect of land consolidation is "undetermined", depending on household preferences between leisure and consumption (p. 371). It is clear from Fig. 1 that household preferences between leisure and consumption play no role in determining the effect that such changes in productivity have on labor allocation between these two forms of employment. Suppose, for example, that leisure was a superior good and consumption an inferior good, implying that the supply of household labor is backward-bending, as shown in Fig. 2. Provided the off-farm wage is exogenous and the household is initially supplying positive amounts of labor to off-farm employment, the results are unchanged.

Tan et al. (2008) reason that farmers with more fragmented land use more labor to compensate for the fragmentation's negative effects on productivity. In criticizing this argument, Jia and Petrick (2013) state that because land fragmentation 'makes labor less productive', a rational response to it is to use less labor on-farm and more off-farm (pp. 378–9).[9] Both arguments miss the

[8] In the Technical Appendix this critical value is derived for the case of the CES production function.

[9] Jia and Petrick overlook the fact that if this supposed refutation of Tan *et al.* was valid, land consolidation would necessarily increase on-farm use of labor and reduce off-farm use, contradicting their own earlier claim that the effect is "undetermined", depending on household preferences.

key point arising from Hicks' analysis: any given labor-augmenting technical change, including land consolidation, may either raise or lower the marginal product of labor, and thereby raise or lower on-farm use of labor, depending on a key property of the particular production function in which it occurs - the elasticity of substitution between factors. The effect does not depend on household preferences between leisure and consumption, but on technology. It is not possible to say whether, in general, land consolidation increases or reduces on-farm use of labor because the outcome rests not only on the factor bias of land consolidation itself, but also on the elasticity of substitution.

These two conflicting theoretical arguments can be interpreted as resting on different implicit assumptions about the elasticity of substitution. Tan *et al.* implicitly assume a value below Hicks' critical value, as for example in the Leontief case. If a fixed quantity of effective labor is required in production, then by augmenting the supply of effective labor, land consolidation generates effective labor that cannot be substituted for other inputs, meaning that less actual on-farm labor input is required. Costs can be lowered by reducing it. Jia and Petrick implicitly assume a high elasticity of substitution – above Hicks' critical value, as for example in the Cobb-Douglas case. When land consolidation increases the supply of effective labor, a unit of effective labor becomes cheaper. Costs can now be reduced by substituting effective labor for other inputs, sufficiently that actual on-farm labor use increases.

Empirically, either outcome is possible. Although it may seem counter-intuitive, technical change that augments on-farm labor but which reduces labor's marginal product, and hence reduces the on-farm demand for it, seems a genuine possibility. Hicks' great contribution was to clarify the conditions that determine whether this will happen. Treating a reform such as land consolidation as a form of technical change enables these theoretical insights to be exploited. What actually happens in specific circumstances can only be determined empirically.

5. Data

This study uses the Vietnam Household Living Standards Surveys (VHLSS) for 2004, 2006 and 2008. These surveys, conducted by the General Statistical Office of Vietnam with technical assistance from the Word Bank, are nationally representative and consist of questionnaires at both household and communal levels. To concentrate on labor allocation of rural households in the full sample, we select farm households with at least one member who describes his/her main occupation as farming. In addition, households with no rice crop outputs and/or land were excluded from the analysis. World Bank (2006) and Marsh et al. (2006) show that land fragmentation mainly occurs in rice production in Vietnam. Accordingly, our data focuses on rice farms and includes production of rice and other annual crops. We construct a panel dataset in two rounds, 2004–06, and 2006–08 by removing households with missing data and apparent enumerator errors or households for which observations were available for only a single time period. The VHLSSs of 2004 and 2006 form a panel dataset containing 4028 farm households in both years. Similarly, the VHLSSs of 2006 and 2008 form a panel dataset consisting of 3756 farm households (see Statistical Appendix 1 of the Supplementary data for detailed summary statistics).

A result of Vietnam's egalitarian land distribution, combined with high rural population density, is that farms are small and each farm is commonly fragmented into several separate plots (Markussen, 2013). Table 1 provides statistics of land fragmentation, rental machines, and labor allocation of farm households using the VHLSS 2004, 2006, and 2008. There has been a reduction in the degree of land fragmentation over time, as measured by the number of plots and the Simpson index.[10] The reduction of the Simpson index means that more plots are consolidated. Meanwhile, average farm sizes also increased. Thus, land consolidation and accumulation occurred together. The mean number of plots operated dropped from 6.0 in 2004 to 5.0 in 2008.

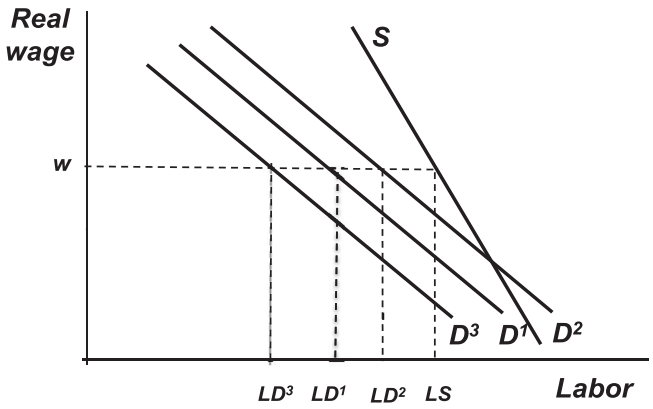

Fig. 2. Technical change and the supply of off-farm labor: leisure as a superior good
Source: Authors' construction.

Table 1 also provides information on the proportion of households renting machines for annual crop production. Using datasets on Vietnam similar to the present paper Liu et al. (2016) find that increasing machine rentals indicates a scale-biased substitution of machinery for labor. Tractor ownership is not reported in Table 1 because it remained almost zero from 2004 to 2008. But as the table shows, 65% of farm households rented machines in 2008, compared with 61% in 2004. Similarly, farm hours worked declined by 4.6% over the same period. Hours devoted to off-farm jobs increased. Thus, land consolidation was associated with increasing machinery rentals, decline in farm hours and increase in off-farm wage hours as described by the datasets. Of course, these associations do not necessarily indicate causality.

Farm income is measured as the annual difference between the total value of annual crops produced (including home consumption) and their variable costs, including fertilizer, seed, insecticide, livestock, storage, hired labor and transportation.[11] This measure is known as restricted income (Lau & Yotopoulos, 1971; Jollife, 2004) because it does not allow for the opportunity cost of land or household labor used in production and does not include income from family members working off-farm. Subsequent references to 'farm income' mean restricted farm income. The measure of rice output is the physical quantity harvested during the previous 12 months. To compare incomes between years, their monetary values were deflated to January 2000 prices using deflators obtained from General Statistics Office of Vietnam (2010). Rice is the most common crop growing in all provinces in Vietnam, representing 65.4% of farm households. The average rice output per rice-producing household increased from 3436 kg in 2004 to 3988 kg in 2008. Rice output of the households in the sample represented more than 75% of the total annual crops in terms of quantity, and over 78% in terms of value. As a proportion of total household agricultural revenue derived from annual crops (including rice), aquaculture, livestock, and agricultural services, revenue from rice declined from an average of 42.3% in

[10] The Simpson index (SI) is defined as (Blarel, 1992) as: $SI = 1 - \sum_{i=1}^{n} a_i^2 / \left(\sum_{i=1}^{n} a_i\right)^2$, where a is the area of each plot, and n is the number of plots. SI lies between zero and one, where a higher value shows more land fragmentation.

[11] We apply the concept of restricted income, also called restricted profit in the literature, which is conditional on the cost of certain inputs. Thus, we do not impute a value of family labor (see Lau & Yotopoulos (1971) and Jolliffe (2004) for more details on the concept of restricted profit). In this paper, the term income means restricted income.

Table 1
Land fragmentation, machinery rental and labor allocation, 2004–2008.

Indicators	2004	2006	2008
Average rice output, tons/ha	4.86	4.89	5.23
Average farm size (ha)	0.45	0.48	0.55
Average size of plots (m^2)	1112.1	1530.7	1721.8
Average number of plots	6.0	5.2	4.98
Simpson index			
0–0.2	10.18	13.70	15.5
0.2–0.4	13.70	13.31	16.16
0.4–0.6	25.67	27.46	25.53
0.6–0.8	34.46	33.57	32.63
0.8–1.0	15.99	11.96	10.18
Machinery renting			
Households renting machines (%)	60.8	62.0	65.4
Real value of rental machines	459.63	603.25	1052.9
Household labor, hours per year			
Farm hours	3,121	3,042	2,978
Off-farm wage hours	1,360	1,408	1,462
Self-employed, off-farm hours	765	747	660

Notes: Real value of rental machines is expressed in 1000 VND, constant 2000 prices.
Source: Authors' calculations, using data from VHLSS 2004, 2006 and 2008.

2004 to 39.3% in 2008, compared with an average of 70% of total household agricultural revenue in the period 1993–1998 (Dang, 2006). Farmers are switching from rice to other annual crops that bring higher returns (Nguyen, 2017).

6. Empirical strategy

6.1. Econometric models of farm outcomes

To estimate the effect that land consolidation has on annual crop production, machinery use and labor allocation, we need a measure of land consolidation and also to account for its possible correlation with unmeasured attributes of farm households. The basic set of four equations for farm outcomes that we seek to estimate is:

$$Y^f_{it} = \lambda_0 + \lambda_1 S_{it} + \gamma' X_{it} + \varepsilon_{it}, \quad (2)$$

where: i denotes the household; t indexes the survey year (years 1 and 2); Y^f_{it} denotes a column vector of four farm outcomes (rice output; farm labor supply; farm income; and machinery use in farming activities); S_{it} is a measure of land consolidation of operating plots for household i at time t, for which we use two empirical indices - the log of number of plots and the Simpson index;[12] X_{it} is a column vector of regional dummy variables,[13] variables related to communal characteristics (dummies including transport, electricity, post office employment, eductional programs and the number of business units, and disasters in the commune), variables involved in household characteristics (the land size, number of household members from 15 to 60 years old, dependency ratio, mean education of working age men and women, asset value, age of the household head, dummies indicating family members in state, private economic sector and the household's own business); γ' is a row vector of coefficient estimates corresponding to the variables in X_{it}; and ε_{it} is a column vector of the error terms corresponding to each of the four equations.

The dependent variables are estimated by using the same set of independent variables, which control incentives and constraints affecting the participation in farm and off-farm activities (Reardon et al., 1992). The OLS estimation of Eq. (2) is not likely to provide consistent estimates of the impacts of land consolidation due to omitted variables and reverse causality problems. For instance, farm households who are unobservably profitable can finance plot purchase and rental through active land markets, resulting in a spurious effect on farm outcomes. Taking the first difference of Eq. (2), the change in farm outcomes across survey years is given by $\Delta Y^f_{it} = Y^f_{it} - Y^f_{it-1}$:

$$\Delta Y^f_{it} = \lambda_1 \Delta S_{it} + \gamma' \Delta X_{it} + \Delta \varepsilon_{it}. \quad (3)$$

Given the possible correlation of X_{it} with changes in land consolidation, a vector of initial values X_{it-1} from the survey for the first of the two years is introduced as a control to reduce the potential for biased estimates arising from this source, to give:

$$\Delta Y^f_{it} = \lambda_1 \Delta S_{it} + \gamma' \Delta X_{it} + \delta' X_{it-1} + u_{it}. \quad (4)$$

Even after controlling for the correlation between land fragmentation and unobservable time-invariant variables, a further problem may arise in estimating Eq. (4). Land rental markets may be sufficiently fluid that at least some households are able to influence their level of land fragmentation, meaning that this variable becomes at least partly endogenous. All prior studies assume independence between land fragmentation and unobserved time-varying variables due to the imperfect nature of land markets in developing countries like China and Vietnam. For example, in the case of China, Jia and Petrick (2013) assume land fragmentation to be exogenous and justify this treatment with the claim that it is very unlikely for farm households to reduce land fragmentation systematically through the land rental market.

In rural Vietnam, despite the absence of private land ownership, land rental and sales markets for land use-right certificates are active (Deininger & Songqing, 2003; World Bank, 2016). To obtain consistent estimates of λ_1, it is therefore appropriate to relax the assumption of exogenous land consolidation by employing an instrumental variables strategy. We experimented with a range of instrumental variables like the number of land use right certificates transferred in the commune, communal population density, and the area of annual crop land titled by certificates of land-use right in the commune.[14] However, in each case, the estimated coefficient of the experimented instrument variable was not significant.

A good instrumental variable should be linked to land governance or the perception of households of the benefits of land consolidation. However, these variables are not surveyed in the VHLSS. To address this issue, we adapt the method applied by Foster and Rosenzweig (2011) in studying the relationship between farm size, agricultural productivity and mechanization in rural India. This approach uses inherited land as an instrument for operating land. While land fragmentation of farming plots may be reduced by unobserved heterogeneity such as shocks from land markets and given level of agricultural ability (Deininger & Songqing, 2003), we argue that initially inherited land plots can serve as an instrument because it is exogenously driven through demographical changes, and the land reallocation to farmers during the decollectivization process of the late 1980s (Scott, 2009; Marsh et al., 2006). We use this instrument to predict the change in operating plots of a farm between each two different survey years. Thus, we address the concern of endogenous land consolidation by instrumenting the operating plots with the lagged plots inherited prior to the survey at the village level ($S^*_{v,t-1}$), where v denotes the village. In addition, a vector of initial values, X_{t-1} from the first survey is also introduced. The first-stage of Eq. (3) is, writing β for a

[12] Log of plots is an alternative measure of land fragmentation, as used in Wan and Cheng (2001); Hung et al. (2007); Jia and Petrick (2013).
[13] Regional dummies are: Red River Delta, North East, North West, South Central Coast, Central Highlands, South East, Mekong River Delta.
[14] The communal surveys cover agriculture and land types, but do not provide information related to land consolidation programs.

column vector of estimated coefficients corresponding to the components of X_{it} :

$$\Delta S_{it} = \alpha_1 S^*_{v,t-1} + \beta' X_{it} + \epsilon_{it} \quad (5)$$

The expected positive sign for α_1 is yielded by Eq. (5). In addition, Eq. (4) is estimated by with 2SLS using two different datasets, first for the survey periods of 2004 and 2006, and second for the periods 2006 and 2008. Instruments are used from the previous survey period[15].

6.2. Econometric models of off-farm outcomes

In the case of off-farm outcomes, sample selection bias may occur due to the incidental truncation of the off-farm labor participation (Cunguara, Langintuo, & Darnhofer, 2011). To reduce the censoring problem, we aggregate two types of off-farm labor supply, including off-farm wage and off-farm self-employed jobs. From Eq. (1), we can have a similar approach for off-farm outcomes, Y^{of}_{it}:

$$Y^{of}_{it} = \eta_0 + \eta_1 S_{it} + \theta' X_{it} + \omega_{it} \quad (6)$$

where Y^{of}_{it} is a column vector of two off-farm outcomes: off-farm labor supply; and off-farm income. Other variables are defined similarly to Eq. (2).

To solve the problem of sample selection in Eq. (6), the estimating procedure requires exclusion restrictions related to the models of off-farm outcomes. However, the exclusion restriction is not easy to accept on *a priori* grounds. van de Walle and Cratty (2004) argue that given the imperfect land markets in rural Vietnam such an exclusion restriction seems far-fetched. Therefore, the present study applies a method that does not require imposing exclusion restrictions. The two-step double hurdle model (DHM) developed initially by Cragg (1971) is chosen in this case to estimate censored dependent variables. The approach has been widely adopted in studying the drivers of farmers' participation in the off-farm economy.[16]

The DHM is more flexible than the Tobit model b hbecause it takes into account of the possibility that the factors affecting the participation in farm activities and factors affecting the level of farm labor supply and profits may be different (Matshe & Young, 2004). In hurdle 1, farm households decide whether or not to participate into farm activities, and if household members agree to take part, then hurdle 2 takes into consideration the number of hours to work off-farm and income earned by households, Y^{of}_{it}. 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. Time periods are pooled together and the data set is treated as a cross section. The pooling of all panel observations is a shortcoming of this approach, but it is the only option for the DHM.

In addition, to allow dependence between the unobserved random effects and time-variant explanatory variables by using the DHM, an approach proposed by Mundlak (1978) is applied. This method allows unobserved heterogeneity to be correlated with independent variables. The means of time-varying independent variables in Eq. (6) are denoted $\overline{X}_i$ and i indexes the household. Using the approach of Mundlak (1978), let unobserved heterogeneity $\omega_{it} = \overline{X}_i\gamma + \mu_{it}$, where γ is a vector of coefficients capturing possible correlation between ω_{it} and household characteristics and μ_{it} is an error term that is not correlated with $\overline{X}_i$. We substitute $\omega_{it} = \overline{X}_i\gamma + \mu_{it}$ into hurdle 1 (off-farm participation equation) and hurdle 2 (off-farm labor supply or off-farm income) to yield the Mundlak specifications.

We also use the estimating procedure introduced by Wooldridge (1995) to validate the findings. To solve the problem of sample selection Wooldridge developed a level equation to obtain consistent estimations using a pooled method by parameterizing the conditional expectations. The model first obtains the inverse Mills ratio from a reduced form selection probit equation. Next, time periods are pooled together and the data set is treated as a cross section. The model includes the inverse Mills ratio, computed from the participation equation, as an additional variable to control sample selection bias.

7. Empirical results

7.1. The effect of land fragmentation on farm outcomes

To estimate Eq. (4), we regress farm income, farm labor, number of individuals in farming activities, rice output, and machinery use on household characteristics, land use of different annual crops, measures of land fragmentation, location factors and regional characteristics. Eq. (4) is estimated using both first differences (FD) and first differences with the instrumental variable method (FD-IV). The main explanatory variable of interest is the measure of land fragmentation. We use two such measures: the Simpson index and the log of plots.

Tables 2 and 3 provide the estimated results for the panel datasets, 2004–2006, and 2006–2008, respectively. In each case, Panel A uses the log of plots, and Panel B uses the Simpson index. All five dependent variables are estimated on the same set of explanatory variables using the panel data method to control for the fixed unobserved heterogeneity and shocks. Because of the survey design, error terms are correlated within the sampling units. Thus, we apply the *cluster* option in STATA 12 to compute robust standard errors.

In Tables 2 and 3, Panel A (using log of plots) shows that, using the first difference method, a 10% reduction of plots (land consolidation) resulted in a reduction in farm labor supply by 3.4%, and 0.81% over a two-year period in 2006 and 2008, respectively. In Panel B, the alternative measure of land consolidation, the Simpson index, provides a similar picture. Farmers with more fragmented land holdings switch to more labor-intensive farming. Based on the first difference method, in Panel A, if land fragmentation is reduced by 10%, farm income per hectare and farm output per hectare increase by 1% and 0.4% in the period 2004–2006 and 1.57% and 1.15% for the panel period of 2006–2008, respectively. The impacts are larger in the later dataset. A similar pattern can be seen by using the Simpson index in Panel B. As a result, the reduction of land fragmentation results in a decline in farm labor intensity in rice production. This finding is consistent with previous studies in China such as Wan and Cheng (2001) and Tan et al. (2008). For example, Tan et al. (2008) find that in China, incomes from off-farm employment are associated with lower land fragmentation.

Using the FD-IV estimation for farm outcomes, the effects of land consolidation on farm labor supply are larger: 4.6%, and 3.2% in the period of 2004–2006 and 2006–2008, respectively. Similarly, the estimates of FD-IV for farm income in both Panel A and B are also larger. In particular, a 10% reduction in the number of plots results in a decline in 2.05% and 4.26% in 2006 and 2008, respectively. In addition, the evidence of land consolidation on improving rice output is also consistent with the finding in the literature. By using the first difference model, in Panel A, a 10%

[15] Statistical Appendix 2 of the Supplementary data provides the results of the first-stage regression.

[16] See Hitayezu, Okello, and Obel-Gor (2014) and Matshe and Young (2004) for the details of the double hurdle model in off-farm studies.

Table 2
The effect of land consolidation on farm outcomes using the VHLSS 2004–2006.

	Dependent variables (2004–2006)				
	Farm labor supply	Farm income per ha.	Rice output per ha.	No of individuals in farming activities	Machinery use in farming
Alternative measures of land consolidation					
i) Panel A using log of plots					
First difference (FD)					
Log of plots	0.335*** (0.13)	−0.100*** (0.03)	−0.040*** (0.007)	0.041 (0.042)	−0.122*** (0.036)
First difference-IV (FD-IV)					
Log of plots	0.460** (0.193)	−0.205*** (0.04)	−0.034*** (0.011)	0.089 (0.062)	−0.125** (0.052)
ii) Panel B using the Simpson index					
First difference					
Simpson index	0.543* (0.314)	−0.072 (0.077)	−0.075*** (0.018)	0.194** (0.096)	−0.132** (0.066)
First difference-IV (FD-IV)					
Simpson index	0.868 (0.542)	−0.393*** (0.121)	−0.078** (0.031)	0.392** (0.170)	−0.242* (0.129)
No of observations	2014	2014	2014	2014	2014

Notes: IV: instrument includes plots inherited from VHLSS 2004; Standard errors (SE) are robust through the *cluster* option and appear in parentheses. All dependent variables are expressed as logs, except number of individuals in farming activities; *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively.
See Statistical Appendices 2, 3, 4, 5, 10, and 11 of the Supplementary data for full regression results.
Source: Authors' calculations, using data from VHLSS 2004 and 2006.

Table 3
The effect of land consolidation on farm outcomes using the VHLSS 2006–2008.

	Dependent variables (2006–2008)				
	Farm labor supply	Farm income per ha.	Rice output per ha.	No of individuals in farming activities	Machinery use in farming
Alternative measures of land consolidation					
i) Panel A using log of plots					
First difference (FD)					
Log of plots	0.081* (0.048)	−0.157*** (0.039)	−0.115*** (0.034)	−0.01 (0.063)	−0.179*** (0.058)
First difference IV (FD-IV)					
Log of plots	0.318*** (0.112)	−0.426*** (0.079)	−0.269*** (0.062)	0.075 (0.112)	−0.323*** (0.113)
ii) Panel B using the Simpson index					
First difference (FD)					
Simpson index	0.086 (0.109)	−0.187 (0.129)	−0.178** (0.073)	−0.064 (0.125)	−0.307*** (0.119)
First difference IV (FD-IV)					
Simpson index	0.514* (0.278)	−0.444* (0.257)	−0.611*** (0.143)	0.059 (0.245)	−0.474** (0.230)
No of observations	1878	1878	1878	1878	1878

Notes: IV: instrument includes plots inherited from VHLSS 2004; Standard errors (SE) are robust through the *cluster* option and appear in parentheses. All dependent variables are expressed as logs, except number of individuals in farming activities; *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively.
See Statistical Appendices 6, 7, 8, 9, 10, and 11 of the Supplementary data for full regression results.
Source: Authors' calculations, using data from VHLSS 2006 and 2008.

increase in land consolidation increased rice output per hectare by 0.4% and 1.15% in 2006 and 2008, respectively. The impact on rice output for FD-IV model is larger, at 2.69%, in the later dataset.

Regarding the impact of land consolidation on machinery use, Tables 2 and 3 present the estimates with different specifications. In the FD model, Panel A shows that a 10% increase in land consolidation (reduction in the number of plots) increases machinery use by 1.22% and 1.79% for over the two period of 2006 and 2008, respectively. Similarly, in Panel B (Simpson index), a one unit increase in land consolidation results in an expansion of mechinization by 13.2% in the period of 2004–2006 and 30.7% in 2006–2008. Meanwhile, the results after instrumenting operating plots by inherited plots have similar effects for both datasets. Compared with the FD, the results are larger. These findings are consistent with arguments by Bentley (1987) and McPherson (1982) that land fragmentation induces extra farm labor use and difficulty in accommodating machinery use due to higher transaction costs. Therefore, the decline in land fragmentation improves farm productivity and reduces labor intensity in agriculture. The advantage of land consolidation is to save labor time. These empirical results support the characterization of the expansion of land consolidation as a non-Hicks-neutral technical change, consistent with the hypothesis of non-neutral effects argued by Wan and Cheng (2001).

7.2. The effect of land consolidation on off-farm outcomes

Do exogenous shocks to agricultural productivity lead to economic diversity into off-farm activities? Table 4 indicates the effect of land fragmentation on off-farm outcomes using the double hurdle model. All estimated coefficients have negative signs, meaning that the reduction of land fragmentation results in an increase in off-farm labor supply and off-farm income. Using the FD estimation in panel A, a 10% increase in the number of plots increases off-farm income by 1.47% and 1.07% in 2006 and 2008, respectively. Similarly, panel B indicates that a one unit increase in the Simpson index (more land fragmentation) reduced the off-farm labor supply by 10.7% in 2006.

For robustness, the likelihood ratio test is carried out to determine whether the double hurdle model fits the model of factors affecting off-farm labor supply and income better than the Tobit estimation. As in Matshe and Young (2004), all the Tobit models can be rejected in favor of the double hurdle model at the 5% significance level. We provide the estimates with the specification of the Mundlak (1978) approach and test the Mundlak fixed effects for off-farm supply and income. The double hurdle model is estimated by correlated random effects, which control for Mundlak fixed effects. The test results for off-farm labor supply reported in Table 4 do not show evidence of endogeneity bias after controlling for fixed effects.

Table 4
The effect of land consolidation on off-farm outcomes using the double hurdle model.

	2004–2006	2006–2008		
	Dependent variables			
	Off-farm labor supply	Off-farm income	Off-farm labor supply	Off-farm income
Alternative measures of land consolidation				
Panel A				
i) Double Hurdle Model				
Log of plots	−0.024	−0.147***	−0.037	−0.107**
Mundlak fixed effect test *p*-value	12.51 [0.186]	64.64 [0.000]	9.31 [0.317]	16.95 [0.031]
ii) Wooldridge (1995)				
Log of plots	−0.023	−0.143***	−0.041	−0.141**
Mundlak fixed effect test, *p*-value	1.28 [0.2434]	2.79 [0.003]	22.64 [0.004]	12.36 [0.136]
Sample selection bias test, F(2,1956), *p*-value	0.57 [0.564]	4.67 [0.0094]	2.69 [0.260]	17.31 [0.000]
Panel B				
i) Double Hurdle Model				
Simpson index	−0.107*	−0.261***	−0.07	−0.111
Mundlak fixed effect test, *p*-value	12.58 [0.1697]	65.87 [0.000]	9.46 [0.305]	16.68 [0.034]
ii) Wooldridge (1995)				
Simpson index	−0.122*	−0.297***	−0.143*	−0.156
Mundlak fixed effect test, F(9,1956), *p*-value	1.31 [0.2282]	2.96 [0.0017]	25.12 [0.002]	17.61 [0.024]
Sample selection bias test, F(2,1956), *p*-value	0.60 [0.548]	4.44 [0.012]	2.58 [0.276]	23.19 [0.000]
Number of observations	2,008	2,008	2,036	2,036

Notes: Standard errors (SE) are robust through the cluster option.
DHM standard errors are bootstrapped with 500 replications.
All dependent variables are expressed in logs.
*, **, *** indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively.
See Statistical Appendices 12 and 13 of the Supplementary data for full regression results.
Source: Authors' calculations, using data from VHLSS 2004, 2006 and 2008.

To control for sample selection bias, we estimate equations using the method of Wooldridge (1995) with pooled data**.** The tests for sample selection bias and fixed effects use an *F*-test. The results reveal that off-farm labor supply does not suffer from sample selection bias at the 5% significance level. Thus, the approach of controlling sample selection bias is only demanding for the estimation of off-farm income. More land consolidation may release more labor to off-farm sectors. All the coefficients of the Simpson index and log of plots are significant and have the same sign. The increase in agricultural productivity resulting from land consolidation leads to an increase in farm households' income. This, combined with non-homothetic preferences, will generate a demand for non-agricultural goods and services. Consequently, this process will pull farm labor to off-farm sectors.

8. Conclusions

This paper challenges the common assumption that agricultural productivity growth arises from factor-neutral technical change. The literature on technical change predicts that if productivity growth was factor-neutral an increase in agricultural productivity would slow the pace of rural structural transformation. Conversely, if the technical change is labor-augmenting and the elasticity of substitution is low enough – below a critical value, which lies between zero and one – it can reduce farm labor supply and release more farm labor for off-farm uses. This paper shows that by treating land consolidation as a form of technical change, the above insights can be used fruitfully to understand its impacts.

An empirical analysis is developed for the effect of land consolidation on farm and off-farm outcomes in rural Vietnam. The findings are that, in the context of Vietnamese rice production, land consolidation reduces on-farm labor use, reduces on-farm labor intensity, increases on-farm machinery use, raises farm income, releases more farm labor to off-farm sectors, and increases off-farm income. Viewing land consolidation as a form of factor-biased technical change helps in understanding these findings. If the productivity-raising effect of land consolidation was factor-neutral, our findings would be impossible.

Previous studies of land consolidation have assumed that the rate at which consolidation occurs is exogenous to farmers' decisions. Nevertheless, there is reason to believe that Vietnam farmers have some capacity to influence the rate of land consolidation in response to changing economic circumstances, violating the exogeneity assumption. The present paper relaxes this assumption using instrumental variable methods and is apparently the first attempt in the literature to do so. The analysis could be improved using information on the history of household splits and the inheritance of plots that most often occur at the death of the household head. The survey data used in the study do not include this information. The results of the estimated models, using instrumental variables, must therefore be interpreted with caution. Our data consist of a sample of continuously existing farms, operated either full-time or part-time, which contains no farm exits. Better functioning land markets may facilitate sufficient consolidation of farm land that some marginal farmers exit farming, reinforcing the stimulation of the off-farm rural economy that we have described. Despite these qualifications, the findings are fully consistent, with and without the instrumental variable.

According to our findings, productivity improvement in the farm sector, at least that derived from land consolidation, will promote the development of the off-farm economy and the economic diversification of rural households, thus promoting announced government policy objectives. The upgrading of institutions related to land consolidation and the development of land markets, such as land ownership rights and the promotion of land rental markets, will be key factors in the next phase of reforms if Vietnam is to accelerate the land consolidation process.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Technical Appendix

Effect of labor-augmenting technical change on the marginal product of labor - the CES production function

Consider the standard two-factor CES production function:

$$Y = \alpha_1\left[\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}} + (1-\gamma)(\alpha_3 A)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} = \alpha_1[\omega]^{\frac{\sigma}{\sigma-1}}, \quad \text{(A1)}$$

with $\omega = \left[\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}} + (1-\gamma)(\alpha_3 A)^{\frac{\sigma-1}{\sigma}}\right] > 0$, where Y denotes agricultural output and the input factors are labor (L) and land (A). There are five parameters: the share parameter, $0 < \gamma < 1$, the elasticity of substitution between factors, $\sigma \geq 0$, and the factor efficiency parameters α_1 α_2 and α_3 (each strictly positive). As σ approaches one, $(\sigma-1)/\sigma$approaches zero, and Eq. (A1) approaches the Cobb-Douglas form. Technical progress is captured by increases in the three efficiency parameters, corresponding to Hicks-neutral, labor-augmenting and land-augmenting technical progress, respectively.

The marginal product of labor (MPL) is obtained by differentiating (A1) with respect to L:

$$MPL = \partial Y/\partial L = \alpha_1[\omega]^{\frac{\sigma}{\sigma-1}-1}\gamma L^{\frac{\sigma}{\sigma-1}-1}\alpha_2^{\frac{\sigma-1}{\sigma}} > 0 \quad \text{(A2)}$$

The impact of labor-augmenting technical change on the marginal product of labor is now obtained by differentiating (A2) with respect to α_2:

$$\partial MPL/\partial\alpha_2 = \alpha_1\omega^{\frac{1}{\sigma-1}}\gamma L^{\frac{-1}{\sigma}}\alpha_2^{\frac{-1}{\sigma}}\frac{\sigma-1}{\sigma}\left[1+\frac{1}{\sigma-1}\omega^{-1}\gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}}\right] \quad \text{(A3)}$$

$$\begin{matrix} > \\ = 0 \text{ as } \sigma = \gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}}/\omega. \\ < \end{matrix} \quad \text{(A4)}$$

In summary, at values of the elasticity of substitution above the critical value $\sigma^* = \gamma(\alpha_2 L)^{\frac{\sigma-1}{\sigma}}/\omega$, where $0 < \sigma^* < 1$, labor-augmenting technical progress raises the marginal product of labor; at values below σ^*, the marginal product of labor declines.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.worlddev.2019.104750.

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