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Mitigating Farmland Fragmentation through Land Rental Markets: Evidence from Rural Households in Northeast and Central Thailand

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Abstract

Land fragmentation poses a persistent challenge to rural agricultural sectors, particularly in Thailand, where it hinders productivity and efficient land use. This study explores the role of the land rental market in addressing this issue, using panel data from households in Northeast and Central Thailand. Trends from 2000 to 2017 show a steady decline in the size of land rented per household, while the land fragmentation index exhibits greater variability. Instrumental variable regression results indicate that increased land rental significantly reduces fragmentation, resulting in larger and more efficient farming plots. Larger households tend to rent less land, while older and more educated household heads are associated with lower fragmentation, highlighting the importance of experience and education in land management. Households with higher nonfarm income prioritize land consolidation, further reducing fragmentation, whereas those affected by shocks such as natural disasters experience increased fragmentation as a risk mitigation strategy. Rice farmers, in particular, operate on more fragmented land compared to upland crop farmers. However, an increase in farm activities leads to higher fragmentation, underscoring the need for policies that balance land consolidation with support for farm diversity. Government policy should focus on promoting land rentals by reducing transaction costs, such as revising the adverse possession law, which currently discourages landowners from leasing out their land.

Keywords: land fragmentation; land consolidation; land rental; farm efficiency; instrumental variable regression
JEL Classification: C26; O13; Q12; Q15; R14

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1. Introduction

Agricultural land use in developing countries is influenced by a complex interplay of economic, social, environmental, and policy factors that significantly affect farming practices and rural livelihoods. One of the most persistent challenges within this context is land fragmentation, where agricultural land is divided into smaller, non-contiguous plots, and irregularly sized plots. This fragmentation, often driven by traditional inheritance practices, demographic pressures, and broader economic changes, results in the progressive reduction of land plot sizes across generations. The fragmented structure of landholdings introduces numerous inefficiencies, complicating farm management, increasing production costs, and reducing economies of scale, which are crucial for enhancing productivity (Deininger et al., 2012; Tan et al., 2006).

In Thailand, land fragmentation is particularly pronounced due to the intersection of land tenure systems and demographic factors. The division of land among heirs has led to increasingly smaller and more dispersed plots, posing significant challenges for farmers. These challenges manifest in higher transaction costs, inefficiencies in input application, and difficulties in standardizing farming practices across fragmented plots. Furthermore, the fragmented nature of landholdings hinders the adoption of modern agricultural technologies and practices, thereby constraining productivity and limiting the economic viability of agricultural enterprises (Chankrajang, 2015; Molle & Srijantr, 2003).

The economic implications of land fragmentation are extensive. Fragmentation not only increases the costs of agricultural production, such as labor, transportation, and input utilization, but also complicates the efficient allocation of resources. These inefficiencies are particularly detrimental in regions where agricultural productivity is already limited by other constraints, including restricted access to credit, inadequate infrastructure, and environmental challenges. Moreover, land fragmentation exacerbates the unequal distribution of land resources, deepening socio-economic disparities in rural areas and hindering efforts toward sustainable rural development (Kawasaki, 2010; Van Hung et al., 2007).

Given these challenges, the land rental market has been proposed as a potential mechanism to mitigate the negative effects of land fragmentation. By facilitating the transfer of land use rights, land rental markets can enable the consolidation of fragmented plots into larger, more economically viable units, thereby improving operational efficiency and enhancing agricultural productivity. Land rental provides a flexible means for smallholders to access additional land without the need for substantial capital investment, making it an attractive option for those who lack the resources or land necessary to expand their operations (Holden et al., 2013; Jin & Jayne, 2013). Moreover, land rental markets can serve as an instrument for improving equity in land distribution, allowing land-poor households to gain access to productive land and increase their income-generating potential (Deininger & Jin, 2006; Otsuka, 2007).

The relationship between land fragmentation and the land rental market is complex and highly dependent on the context. While rental markets can facilitate land consolidation by enabling smallholders to rent additional plots and create more contiguous holdings, they can also perpetuate or exacerbate

fragmentation if the rented plots are scattered and irregularly sized, leading to inefficiencies in land management and the use of machinery. The effectiveness of land rental markets in reducing fragmentation hinges on several factors, including the legal and institutional frameworks governing land use, which influence tenure security and contract enforcement, and the socio-economic characteristics of rural households, such as access to capital and risk preferences (Deininger & Jin, 2006; Niroula & Thapa, 2005; Tan et al., 2006). Additionally, broader economic and environmental conditions, such as market volatility and climate change, further complicate this relationship by affecting the desirability and management of rented land (Barrett et al., 2001; Cao et al., 2022). Thus, while rental markets have the potential to mitigate the inefficiencies caused by fragmentation, their success depends on a nuanced interplay of these factors, making it essential to design policies that can optimize their impact on agricultural productivity and sustainability.

Despite the importance of these issues, empirical research directly addressing the relationship between land fragmentation and the land rental market remains scarce. While studies in several countries have explored the inefficiencies associated with land fragmentation (Deininger et al., 2012; Niroula & Thapa, 2005; Rahman & Rahman, 2009) and the potential benefits of land rental markets (Deininger & Jin, 2008; Do & Iyer, 2008; Holden et al., 2013; Jin & Jayne, 2013), there is a notable lack of quantitative research focusing explicitly on their direct relationship. A few studies, such as Tan et al. (2006), have found that off-farm income and land rental markets are associated with lower land fragmentation. Other studies that address this interaction do so as a secondary consideration within broader analyses of agricultural productivity and land use patterns (Blarel et al., 1992; Cao et al., 2022; Ciaian et al., 2018; Niroula & Thapa, 2005; Van Hung et al., 2007). Consequently, the direct dynamics between land fragmentation and rental markets have not been thoroughly explored. Moreover, none have investigated this interaction within the specific context of Thailand's agricultural sector, where unique socio-economic and institutional factors are at play.

This study aims to fill this gap by focusing directly on the impact of participation in the land rental market on the degree of land fragmentation among rural households in Thailand. Additionally, it seeks to identify other key determinants of both land fragmentation and land rental decisions. By providing empirical evidence on the interaction between land rental markets and land fragmentation, this study contributes to a broader understanding of how to optimize land use in rural agricultural settings. The findings will offer valuable insights for policy interventions aimed at enhancing land use efficiency, supporting sustainable rural development, and improving the economic viability of smallholder farms in Thailand.

2. Literature Review

2.1 The Role of Land Rental Markets in Enhancing Agricultural Productivity and Equity

The land rental market is often posited as a crucial mechanism for enhancing agricultural productivity and promoting equity, particularly in developing countries where land ownership is concentrated among a few and where smallholders face significant barriers to land access. Theoretical models, assuming perfect markets for production factors and constant returns to scale, suggest that the amount of land owned does not directly

impact production efficiency or equity. Under such assumptions, the ratio of labor to cultivated area, yield per unit area, and output per unit of labor would be uniform across farms of all sizes, even in the absence of a land rental market (Bardhan, 1973; Feder, 1985). However, empirical evidence indicates that markets for labor and other production factors often operate imperfectly, leading to inefficiencies (Janvry et al., 1991). In such imperfect markets, smallholder farmers often display higher efficiency than larger farms due to their reliance on family labor, which avoids the principal-agent problem associated with hired labor (Binswanger & Rosenzweig, 1986).

The land rental market becomes particularly relevant under these imperfect conditions. Numerous studies have demonstrated that land rental markets serve as a critical tool for economic development in rural areas, especially for small households with limited arable land. These markets facilitate the transfer of land use from less efficient large farms to more efficient smallholders, thus enhancing overall production efficiency (Do & Iyer, 2008; Feder et al., 1988). Moreover, rental markets help reduce inequalities in land ownership by enabling land-poor households to expand their cultivated area, thereby increasing their agricultural output and income. However, the net income gains from land rental markets may be modest, making them insufficient alone to alleviate rural poverty. Smallholders' ability to benefit often depends on their access to capital and the size of their existing landholdings, as imperfect markets for other inputs, like credit, can hinder cultivation expansion. Moreover, the impact of land rental and sale markets on rural development varies by country, influenced by land ownership inequalities, government intervention, weak property rights, and limited non-agricultural employment opportunities (Deininger & Jin, 2008; Jin & Jayne, 2013).

In the context of Thailand, land rental markets have historically played a significant role in rural economic development, though this role has been understudied in recent years. Early land economic studies in Thailand emphasized land ownership rights, land reform, and landholding stability, particularly following the World Bank's support for nationwide land registration efforts in the 1980s (Feder, 1987; Rattanabirabongse et al., 1998). Subsequent research has shown that agricultural households prefer to cultivate land they own, especially in land reform areas, due to fears of repossession if the land is found to be rented out (Giné, 2005). Additionally, factors such as age have been found to influence participation in the rental market, with older farmers more likely to rent out land and thus enhance their net agricultural income. Furthermore, the supply of land in the rental market does not solely come from rural non-farm households, highlighting the significant role of non-farm and urban households as land lessors and the impact of non-agricultural employment, which leads to rural household migration from agriculture (Duangbootsee, 2018).

2.2 Factors Influencing Land Fragmentation and Its Economic Effects

Land fragmentation, defined as the division of land into smaller, non-contiguous plots, is driven by various economic, social, and legal factors, including inheritance laws that mandate equal land division among heirs, population growth, and specific land reforms (Blarel et al., 1992; Brandt et al., 2004; Niroula & Thapa, 2005). Blarel et al. (1992) identified two main groups of factors affecting land fragmentation: demand factors and supply factors. Supply factors relate to institutional structures or legal stipulations, such as inheritance laws,

which, if requiring equal land division among heirs, lead to increased fragmentation. Factors like population growth (Bentley, 1987; Van Dijk, 2003), specific land reforms distributing state-owned or collectively used land to individual farmers (Swinnen, 1997; Tan et al., 2006), and imperfect land markets, especially in cases where land rental markets fail to facilitate the consolidation of plots, are notable (Blarel et al., 1992; Brandt et al., 2004). Demand factors encompass farmers' production needs, such as farming on multiple scattered plots to mitigate production risks, especially in the absence of agricultural insurance systems. This also includes crop diversification and challenges in the labor market, which make non-agricultural employment difficult to obtain, thereby keeping many engaged in farming on fragmented lands (Ciaian et al., 2018; Manjunatha et al., 2013; Markussen et al., 2016; Xie & Lu, 2017).

While land fragmentation can offer some benefits, such as risk diversification and crop variety, particularly in subsistence farming, its broader economic impacts are generally negative. Fragmentation increases transaction costs, including higher expenses for travel between plots, water management, and weed control, and complicates the uniform application of farming practices, leading to inconsistencies in crop management and yields, which result in significant declines in productivity and technical efficiency (Kawasaki, 2010; Rahman & Rahman, 2009). Additionally, fragmented plots hinder the adoption of modern agricultural technologies and efficient resource allocation, further exacerbating inefficiencies (Deininger et al., 2012; Van Hung et al., 2007). Despite these drawbacks, land fragmentation can drive production diversification among subsistence farming households. For instance, in rural Albania and Vietnam, fragmentation has been found to promote diversification as a risk management strategy, helping spread risk across multiple plots even though it negatively impacts overall productivity (Ciaian et al., 2018; Van Hung et al., 2007). In China, the lack of significant economies of scale in both household-scale and cooperative farming suggests that land consolidation alone may not always enhance efficiency due to technical and infrastructural constraints (Wan & Cheng, 2001). Addressing the challenges of fragmentation requires economic mechanisms such as land tax incentives, credit access support, and the promotion of non-agricultural employment to alleviate land use pressures and mitigate its negative effects (Manjunatha et al., 2013; Xie & Lu, 2017).

3. Methodology

3.1 Land Fragmentation Index

In this study, the Land Fragmentation Index (LFI), based on the Simpson index, is used to quantify the degree of farmland fragmentation. Originally developed in ecology to measure diversity, the Simpson index can be adapted to measure land fragmentation by treating each plot of land as an element of the landholding (Simpson, 1949). In this context, each plot corresponds to a single land title, with no plot comprising more than one deed. The land fragmentation index for household i in year t is computed as follows:

$$LFI_{it} = 1 - \sum_{n=1}^{N} \left(\frac{A_{itn}}{A_{it}}\right)^2$$

where LFI_{it} is the land fragmentation index for household *i* in year *t*

N is the number of plots in the landholding

A_{itn} is the area of the *n-th* plot that household *i* owns in year *t*

A_{it} is the total area of all plots that household *i* owns in year *t*, $A_{it} = \sum_{n=1}^{N} A_{itn}$

In this study, the land fragmentation index measures the distribution of land across plots by size and number, without considering contiguity. The index ranges from 0 to 1, where a value of zero indicates no fragmentation, with land concentrated in a single large plot. Higher values, closer to 1, indicate greater fragmentation, where land is divided into many plots of varying sizes. This fragmentation is more pronounced when there are numerous non-uniform plots. The index captures both the number of plots and their size variation, increasing as the number of plots and the differences in their sizes grow. Lower values, nearer to 0, reflect less fragmentation, where land is concentrated in fewer, more uniformly sized plots, whether large or small (Monchuk et al., 2010). Since the index does not account for the spatial arrangement of the plots, it captures variability in plot sizes but not their geographic proximity.

3.2 Econometric Models

To investigate the effect of land rentals on land fragmentation, the land fragmentation index is regressed on the size of rented land and other variables, which were selected based on previous studies that have examined this issue (Niroula & Thapa, 2005; Tan et al., 2006). However, endogeneity issues, such as omitted variable bias, simultaneity, and selection bias, can lead to biased and inconsistent estimates. Omitted variable bias occurs when a relevant variable that affects both the land fragmentation index and the size of rented land is excluded, resulting in a correlation between the error term and the independent variable. For instance, if land fertility influences both the decision to rent more land and the degree of land fragmentation but is not accounted for, it may cause omitted variable bias. Simultaneity arises when the size of rented land and the land fragmentation index mutually influence each other. For example, farmers may rent more land because their land is highly fragmented, leading to a two-way relationship. Selection bias occurs when the decision to rent land is influenced by unobserved factors that also affect land fragmentation, such as more efficient farmers or those with better access to rental markets being more likely to rent land and exhibiting different fragmentation patterns. Addressing these endogeneity issues is crucial for obtaining reliable estimates of the impact of land rentals on land fragmentation.

To address endogeneity, this study employs an instrumental variable (IV) regression, with the land fragmentation index as the dependent variable and the size of land rented in treated as the endogenous variable. Household adult equivalents and tractor ownership are selected as instruments because they influence land rental decisions without directly affecting land fragmentation. Household adult equivalents represent labor availability, which impacts rental choices but does not alter the physical structure of the land. Similarly, tractor ownership increases the capacity for larger-scale farming, shaping rental decisions but not directly influencing land fragmentation. The estimation process consists of two stages. In the first stage, the

size of land rented in is regressed on the instruments and other exogenous variables, generating predicted values for the size of land rented in. In the second stage, the land fragmentation index is regressed on these predicted values, along with other exogenous variables.

Several tests are conducted to ensure the validity of the instrumental variables. The Durbin-Wu-Hausman test shows a Chi-sq (1) value of 6.444 (p = 0.011), rejecting the null hypothesis and confirming that the size of land rented in is endogenous (Wooldridge, 2010). The under-identification test, using the Kleibergen-Paap rank LM statistic of 8.006 (p = 0.0183), rejects the null hypothesis of under-identification, confirming that the instruments are relevant (Kleibergen & Paap, 2006). The weak identification test, measured by the Cragg-Donald Wald F statistic (18.900), indicates strong instruments, as the F-statistic exceeds the Stock-Yogo critical values for maximal IV bias of 15% and above (Stock & Yogo, 2002). The Hansen J statistic of 0.335 (p = 0.562) does not reject the null hypothesis of over-identification, indicating that the instruments are valid and uncorrelated with the error term (Hansen et al., 1996). Finally, the Hausman test, with a Chi-sq (19) value of 151.64 (p = 0.000), rejects the null hypothesis of no systematic differences in coefficients, supporting the use of the fixed effects model over the random effects model (Hausman, 1978).

The two stages of the regression are specified as follows:

First Stage Regression:

$$\textit{Land rented}_{it} = \gamma_0 + \gamma_1 Tractor_{it} + \gamma_2\, AE_{it} + \boldsymbol{\gamma}_3 x_{it} + \delta_t + \alpha_i + u_{it}$$

Second Stage Regression:

$$\textit{LFI}_{it} = \beta_0 + \beta_1 \widehat{\textit{Land rented}}_{it} + \boldsymbol{\beta_2} x_{\boldsymbol{it}} + \delta_t + \alpha_i + \epsilon_{it}$$

where *i* denotes the *ith* household

t denotes year

$\textit{LFI}_{it}$ is land fragmentation index

$\textit{Land rented}_{it}$ is the size of land rented in

$Tractor_{it}$ is a dummy variable indicating whether the household owns a tractor

AE_{it} is the household adult equivalent

x_{it} represents a vector of other exogenous variables

$\widehat{\textit{Land rented}}_{it}$ is the predicted size of land rented in

u_{it}, ϵ_{it} are the error terms

γ_0, β_0 is the intercept

$\gamma_1, \gamma_2, \boldsymbol{\gamma_3}, \beta_1, \boldsymbol{\beta_2}$ are the coefficients for the respective variables

δ_t represents year fixed effects

α_i represents household fixed effects

Several exogenous variables are included in the model to control for factors that may influence land fragmentation. Age and education of the household head are expected to affect both land rental and

fragmentation decisions, as older and more educated household heads may have greater experience or resources to manage land more efficiently, potentially reducing fragmentation. Total cultivated land reflects the household's farm size, with larger areas often associated with greater fragmentation, as managing a larger farm typically involves working with multiple plots of varying sizes. Total household income, on the other hand, captures financial capacity, where higher incomes may either increase fragmentation through the acquisition of additional plots of different sizes or reduce fragmentation by enabling land consolidation. The number of farm activities and farm-job household members reflect the intensity and diversification of operations, with greater diversification often requiring the use of multiple specialized plots, potentially increasing fragmentation. Female-headed households may face constraints in accessing or consolidating land, leading to higher fragmentation. Past experiences with shocks, such as natural hazards or market fluctuations, may also influence land management strategies, potentially resulting in increased or reduced fragmentation depending on how households adapt. The share of nonfarm income in total household income is included because households with a higher proportion of nonfarm income are less dependent on agricultural land, which may reduce fragmentation by promoting more efficient land use. Specific farming activities like livestock rearing, aquaculture, orchard cultivation, vegetable cultivation, and rice cultivation directly affect how land is utilized and structured. Depending on how these activities are managed, they may either increase or decrease fragmentation, with the impact varying according to the nature of the farming operations. Finally, time dummies are also included in the model to account for temporal variations that could impact land fragmentation. These dummies help control unobserved factors that vary over time but are constant across households, such as changes in agricultural policies, economic conditions, or environmental factors.

3.3 Data

This research utilizes panel household data from The Townsend Thai Project, which collected data from households in four provinces of Thailand: Buriram, Sisaket, Lopburi, and Chachoengsao, from the year 1997 to 2017 (Townsend, 2018). The sample includes approximately 1,300 households from 192 villages, selected through a process where 12 sub-districts per province and 4 villages per sub-district were randomly chosen. The study focuses on a balanced-panel data group, which consistently recorded data every year over 17 years, from 2000 to 2017. Data from the years 1997-1999 was not used as data collection was discontinued in some provinces starting in 2000. The researcher chose a balanced-panel sample of 10,472 observations (582 households per year) for econometric estimations. Household incomes and input expenses were adjusted to reflect their real value using the Consumer Price Index (CPI) from the World Bank, with the year 2010 set as the base year. Afterwards, real income was adjusted to real household income per adult equivalent per year to prevent bias in analysis due to varying numbers of household members in different age groups. The researcher assigned an adult equivalent (AE) value of 1 for the household head, 0.5 for other adults, and 0.3 for children, following the definition by the OECD (Hagenaars et al., 1994).

4. Empirical Results

The descriptive statistics in Table 1 reveal an average land fragmentation index of 0.34 with a standard deviation of 0.27. This suggests that while the average level of fragmentation is relatively low, there is substantial variability across households. The index ranges from 0 (no fragmentation) to 0.90 (high fragmentation), reflecting a wide range of landholding patterns, from fully consolidated to highly fragmented plots. This variability indicates that land fragmentation is influenced by various factors leading to deviations from the mean. The size of land rented-in averages 6.5 rai, but it ranges widely from 0 to 173.5 rai, indicating significant variation in rental land access. About 45% of households own a tractor, and the adult equivalent averages 2.32. Household heads are, on average, 56.95 years old with 7.23 years of education. Female-headed households make up 33% of the sample. On average, households have 1.78 members working farm jobs and engage in 1.3 different farm activities. Total cultivated land averages 21.49 rai, and 35% of households experienced shocks in the past two years. Household income averages 280,900 Baht (THB), and non-farm income accounts for 63% of total income. Additionally, 21% of households raise livestock, while smaller shares engage in aquaculture (2%), orchard cultivation (14%), vegetable farming (5%), non-rice crops (18%), and rice farming (62%). These statistics highlight the diversity in household characteristics, land use, and income sources across the sample.

Table 1: Descriptive statistics of key variables

Variable	Unit	Mean	SD	Min	Max
Land fragmentation index	[0,1]	0.34	0.27	0	0.90
Size of land rented-in	Rai [a]	6.50	16.74	0	173.50
Whether HH owns a tractor	Yes=1, zero otherwise	0.45	0.50	0	1
Adult equivalent [b]		2.32	0.73	1	6.40
Age of HH head	Years	56.95	12.59	20	103
Education of HH head	Years	7.23	3.71	0	21
Whether female-headed HH	Female=1, zero otherwise	0.33	0.47	0	1
Number of farm-job HH members	Count	1.78	1.40	0	9
Number of farm activities	Count	1.30	0.93	0	6
Total cultivated land	Rai	21.49	25.16	0.05	280
HH faced shocks in the past two years	Yes=1, zero otherwise	0.35	0.48	0	1
Total income	10,000 THB [c]	28.09	42.36	0	641.20
Share of nonfarm income	[0,1]	0.63	0.32	0	1
Whether HH rears livestock	10,000 baht	0.21	0.41	0	1
Whether HH engages in aquaculture	Yes=1, zero otherwise	0.02	0.14	0	1
Whether HH cultivates an orchard	Yes=1, zero otherwise	0.14	0.35	0	1
Whether HH grows vegetable	Yes=1, zero otherwise	0.05	0.21	0	1
Whether HH grows rice	Yes=1, zero otherwise	0.62	0.48	0	1
Whether HH grows non-rice crops	Yes=1, zero otherwise	0.18	0.39	0	1

[a] 1 hectare = 6.25 rai

[b] OECD Adult Equivalent definition: 1-Head, 0.5-Additional Adults, 0.3-Child

Total observations = 10472, Groups (Households) = 582

[c] THB = Thai Baht, real values computed using the CPI with a base year of 2010

Figure 1 illustrates the trends in the size of agricultural land rented in per household and the land fragmentation index from 2000 to 2017. Both variables exhibit an initial increase, peaking around 2003. Subsequently, the size of agricultural land rented in per household declines consistently, while the land fragmentation index demonstrates a more variable pattern. Although both variables generally decrease after 2003, the fragmentation index shows notable fluctuations between 2011 and 2015 before resuming its downward trend. It is important to interpret these trends with caution, as the visual representation does not imply a causal relationship between the two variables.

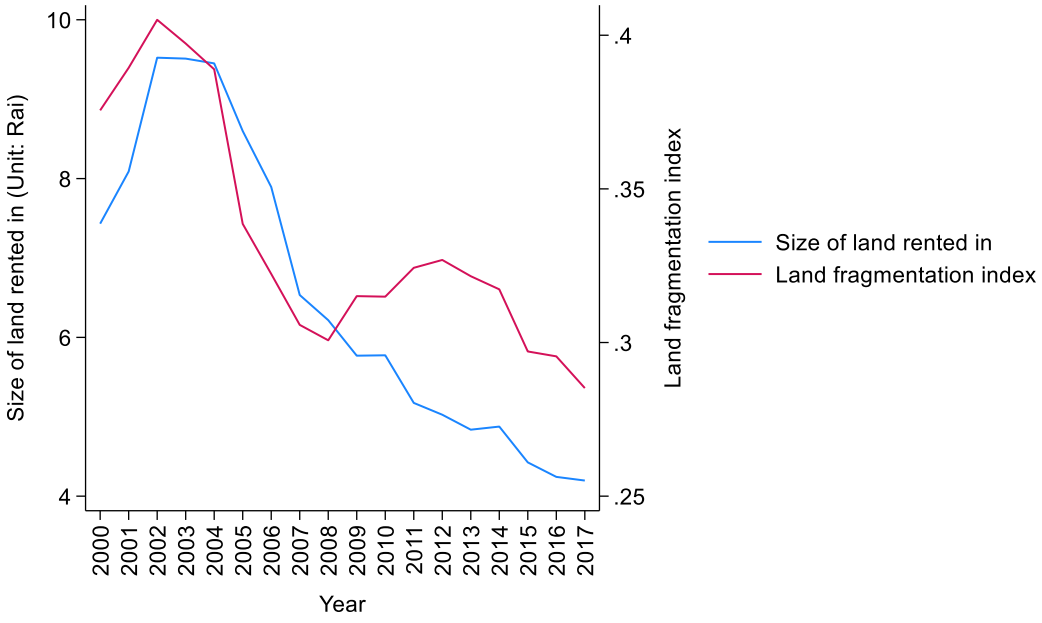

Figure 1: Relationship between land rented-in and land fragmentation index

Table 2 presents the instrumental variable regression results for the land fragmentation model, where the size of land rented in is the endogenous regressor. In the first-stage regression, the results show that household adult equivalents negatively affect the size of land rented in, with a statistically significant coefficient of -1.077 at the 1% level. This suggests that larger households with more adult members are less likely to rent additional land, possibly because more adult members may seek employment outside agriculture, reducing the need to rent extra land for farming. In addition, the number of farm activities also reduces the size of land rented in because households engaged in diverse farming activities might prefer to optimize existing plots to accommodate different crops or farming practices, rather than expanding through rental. Conversely, total

cultivated land has a positive and significant effect, indicating that households with larger initial landholdings tend to rent in more land, likely aiming to increase economies of scale by expanding their operations and consolidating production across more land.

The second-stage results highlight the critical role of the land rental market in rural agriculture. The negative coefficient of the size of land rented suggests that increasing the amount of rented land reduces the land fragmentation index. Specifically, renting one more rai reduces the index by 1.5 percentage points. This reduction occurs because renting more land enables farmers to consolidate their landholdings by acquiring larger plots, reducing the variability in plot sizes. Other factors that reduce land fragmentation include the age and education of the household head, the share of nonfarm income, and the presence of livestock. Older household heads often manage fewer, larger plots, while more educated household heads are better equipped to employ efficient farming practices and make informed decisions, leading to reduced plot size variability and more efficient land use. An increase in the share of nonfarm income also reduces land fragmentation, as households relying less on agriculture can focus on optimizing their existing landholdings rather than expanding through small, fragmented plots. Additionally, households with livestock tend to manage larger plots to meet the needs of grazing or feed production, which helps reduce plot size variability.

Factors that increase land fragmentation include the number of household members with farm jobs, the number of farm activities, total cultivated land, experience with shocks negatively impacting livelihoods, orchard farming, and rice farming. As more household members engage in farming, land may be divided into smaller plots to accommodate the various activities of each member, increasing the variability in plot sizes. Additionally, crop diversity often requires specialized growing conditions, pest management, and resource allocation, resulting in the division of land into smaller plots tailored to these needs, thereby increasing fragmentation in terms of plot size. Holding the size of land rented and other factors constant, increasing total cultivated land raises fragmentation because expanding through non-rental methods, such as using owned or family land, often results in smaller, non-uniform plots. This increases plot size variability, reflected in the land fragmentation index. Experience with past shocks, such as natural hazards or market fluctuations, prompts households to acquire scattered plots to mitigate risk and ensure agricultural productivity. Rice farmers often operate on more fragmented land compared to those cultivating upland crops like sugarcane, maize, or cassava. This is primarily due to the nature of rice as a lowland crop, which requires effective water management across smaller, dispersed plots, making fragmentation more prevalent (Pingali, 2007; Zhou et al., 2024). In contrast, upland crops typically occupy larger, contiguous plots that are less dependent on water management, thus benefiting from consolidation (Ntihinyurwa & de Vries, 2021; Tittonell & Giller, 2013). Farmland fragmentation in rice cultivation is sometimes a strategic choice by farmers to manage risks and optimize resource use, whereas larger land holdings are more common in upland crop farming due to different environmental and cultivation needs.

Table 2: IV Regression results for land fragmentation model

	First-stage		Second-stage	
	Land rented-in		Land fragmentation	
Adult equivalent	-1.077	***		
	(0.374)			
Whether HH owns a tractor	0.385			
	(0.762)			
Size of land rented-in			-0.015	**
			(0.007)	
Age of HH head	-0.035	*	-0.001	**
	(0.019)		(0.001)	
Education of HH head	-0.070		-0.005	**
	(0.094)		(0.002)	
Whether female-headed HH	-0.016		0.005	
	(0.582)		(0.014)	
Number of farm-job HH members	0.050		0.003	
	(0.163)		(0.004)	
Number of farm activities	-1.431	***	0.052	***
	(0.525)		(0.014)	
Total cultivated land	0.507	***	0.010	***
	(0.038)		(0.003)	
Whether HH faced shocks in the past two years	0.071		0.013	***
	(0.200)		(0.005)	
Total income	0.014	*	0.0002	*
	(0.008)		(0.000)	
Share of non-farm income	-0.213		-0.056	***
	(0.957)		(0.020)	
Whether HH rears livestock	0.906	*	-0.053	***
	(0.469)		(0.013)	
Whether HH engages in aquaculture	3.849	**	0.052	
	(1.791)		(0.042)	
Whether HH cultivates an orchard	0.159		0.033	**
	(0.690)		(0.013)	
Whether HH grows vegetable	-0.754		-0.019	
	(0.716)		(0.021)	
Whether HH grows rice	0.338		0.042	***
	(0.691)		(0.016)	
Intercept	1.056			
	(1.902)			
Number of observations	10472		10472	

	First-stage	Second-stage
	Land rented-in	Land fragmentation
Number of groups	582	582
Adjusted R-squared	0.44	
Standard errors in parentheses		
Time dummies for 2001–2017 are included but not reported, with 2000 as the base year		
*** p<.01, ** p<.05, * p<.1		

5. Discussion

5.1 Role of the Land Rental Market

The findings from the econometric model of land fragmentation highlight the critical role of the land rental market in reducing land fragmentation, which can significantly complement the Thai government's efforts to consolidate land for more efficient input use and economies of scale. This enables farmers to integrate fragmented owned plots with contiguous and uniform large, rented plots, enhancing operational efficiency and productivity. Consistent with Tan et al. (2006), which found that land rental markets are associated with lower land fragmentation, the results suggest that improving the functionality of the land rental market could further benefit agricultural efficiency. To enhance the functionality of the land rental market, the Thai government could implement policies to secure and simplify land rental agreements. This might include legal reforms to protect both landlords and tenants, financial incentives to encourage landowners to rent out underutilized land, and mechanisms to ensure transparency and accessibility in the land rental market. A key area of reform could involve revising the adverse possession law, which allows tenants to claim ownership of land after occupying it for a certain period. This law currently discourages landowners from leasing out their land due to concerns over potential loss of ownership. Addressing this issue would help alleviate landowners' fears and make it easier for farmers to access and utilize contiguous plots, thereby supporting large-scale farming.

5.2 Role of Nonfarm Income

The study finds that nonfarm income has no significant effect on the size of land rented in but does help reduce land fragmentation. This result is consistent with Tan et al. (2006), who found that off-farm income is associated with lower land fragmentation. Additionally, Jin and Jayne (2013) suggest that the impact of off-farm income on land rental markets can vary depending on rural economic contexts. Higher nonfarm income allows households to focus on land consolidation rather than expanding agricultural activities, providing financial stability that contributes to reduced fragmentation. The policy implication is that promoting nonfarm income opportunities can reduce fragmentation by encouraging more efficient land use. By diversifying rural income through non-agricultural sectors, policymakers can help decrease land pressure and foster a more consolidated and productive agricultural sector.

5.3 Role of Age and Education of Household Head

The age and education level of the household head significantly reduce land fragmentation. Older household heads tend to manage fewer, larger plots due to their experience and preference for less labor-intensive farming. More educated household heads implement better farming practices and make informed decisions, leading to efficient land use and larger-scale farming. These findings are consistent with those of Deininger et al. (2012) and Manjunatha et al. (2013), who emphasized the importance of experience and education in land management. Educational programs and training can enhance these effects, suggesting that government policies should focus on improving access to education and extension services for farmers. Encouraging older and more experienced farmers to share their knowledge with younger generations can also promote better land management practices.

5.4 Impact of Past Shocks on Land Fragmentation

Households that have faced shocks in the past two years tend to experience higher land fragmentation. Such shocks, which affect the social and economic well-being of a household member, can force households to adopt risk-averse strategies. In response, they may acquire scattered plots in different locations to diversify risk and ensure agricultural productivity and income stability. This strategy, while mitigating short-term risks, leads to increased land fragmentation. This finding aligns with the research by (Rahman & Rahman, 2009), who suggested that risk-averse strategies lead to increased fragmentation as households diversify their plots to mitigate risks. To address this, the government could develop policies that provide better risk management tools and social safety nets to reduce the need for such fragmentation. Financial products like crop insurance, disaster relief funds, and support for health crises can help households manage shocks without resorting to acquiring fragmented plots.

5.5 Balancing Land Consolidation and Farm Diversity

While land consolidation is important for achieving economies of scale, increasing farm activities is also crucial for diversifying risk. The results from this study indicate that an increase in farm activities leads to higher land fragmentation. This underscores the need for the government to balance efforts between promoting land consolidation and supporting farm or crop diversity. Integrated farming systems could help achieve this balance by allowing farmers to consolidate land while maintaining diverse crop production. These systems can facilitate efficient land use by integrating various crops and practices on the same plots, reducing the negative effects of fragmentation. Additionally, they can enhance productivity and resilience by diversifying income sources and minimizing risk exposure. Providing technical support, training, and financial products for these systems could further help achieve this balance, ensuring both efficient land use and risk diversification.

5.6 Specific Concerns for Rice Farmers

The findings also reveal that rice farmers generally manage more fragmented land compared to those cultivating upland crops such as sugarcane, cassava, or maize. This fragmentation is primarily attributed to the specific agronomic requirements of rice, which necessitate precise water management across numerous small plots in lowland areas. In contrast, upland crops are typically grown on larger, contiguous plots, which are less

dependent on intricate water control and thus more conducive to consolidation. The fragmentation observed in rice cultivation often results from historical land distribution patterns and the adaptation to local water availability, which complicates efforts to consolidate land. To mitigate these inefficiencies, it would be prudent to promote cooperative farming models, which can facilitate resource pooling and management of larger plots, and invest in infrastructure enhancements, such as advanced irrigation systems, to improve water management and support land consolidation. This perspective aligns with Kawasaki (2010), which highlights the elevated costs and inefficiencies associated with fragmented rice farming compared to more consolidated land holdings.

6. Conclusions

This study underscores the critical role of the land rental market in mitigating land fragmentation. Historically, Thai land policy has viewed land rent as a potential contributor to land ownership issues. However, the findings of this study challenge that perspective, demonstrating that increasing the amount of rented land significantly reduces land fragmentation and enables farmers to consolidate their holdings, thereby optimizing their farming operations. Therefore, government policy should focus on promoting land rentals by reducing transaction costs, such as revising the adverse possession law, which currently discourages landowners from leasing out their land.

Households with more adult members tend to rent less land, as these members often seek employment outside of agriculture. This dynamic suggests that understanding household composition can strategically influence land rental practices and land use efficiency. Additionally, the study highlights that older and more educated household heads are more effective in reducing land fragmentation due to their experience and improved decision-making capabilities. Policies aimed at enhancing educational opportunities and leveraging the experience of older farmers could further promote efficient land management.

Households with higher nonfarm income rely less on farming and focus more on land consolidation, thereby improving efficiency. Promoting nonfarm income opportunities can reduce land fragmentation by decreasing land pressure and fostering more productive, consolidated agricultural practices. The study also emphasizes the impact of past shocks on households, which can lead to increased land fragmentation, highlighting the need for robust risk management tools and social safety nets. Providing financial products such as crop insurance and disaster relief funds can help households manage shocks without resorting to fragmented land use.

Balancing land consolidation with farm diversity is crucial, as increased farm activities can lead to higher fragmentation. The government should promote integrated farming systems that maintain crop diversity while minimizing land fragmentation. Providing technical support, training, and financial products can help mitigate risks associated with farming practices that are not sufficiently diversified, contributing to this balance. Specific interventions are needed for rice farmers, who tend to operate on more fragmented land. Promoting cooperative farming models and investing in infrastructure improvements, such as irrigation systems, can help

create larger, more uniform plots, enhancing the efficiency of rice farming, which is vital for Thai rural households.

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