Land Fragmentation and Non-farm Labor SupplyNexus: Evidence from Nepal[1]

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Abstract

In this study we examined the marginal impact of land fragmentation on the off-farm labor supply in Nepal. Utilizing a three-year longitudinal survey data (HRVS) and a separable farm household model with land fragmentation as a form of technical change, we used a Two-way fixed effects (TWFE) panel regression model. We found a negative average effect of land fragmentation on non-farm labor supply, an additional plot reduced non-farm labor supply by 14.06 percentage points. Greater local off-farm opportunities diminished the adverse impact, while no evidence was observed for the moderating impact of machinery on off-farm labor allocation. The effects were significant for the Mountain and Hill regions and were observed only for households with large landholding sizes. Correlation analysis of key production characteristics pointed to reduced labor productivity as an additional potential mechanism. Households appear to respond by increasing farm labor hours, both own and hired, as an adaptation strategy to maintain output levels despite fragmentation. The results were consistent across multiple specifications and robustness tests. The evidence underscores the need for land consolidation and targeted interventions to address reduced labor market imperfections, thereby freeing the surplus labor and accelerating structural transformation in rural Nepal.

Keywords: Land fragmentation, Non-farm labor supply, substitution, Labor productivity, Labor market imperfections, Structural transformation
JEL Classification: J22, Q15, Q12

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1. Introduction

Land fragmentation represents a significant challenge across developing countries (Aslam & Fazal, 2025). Whereas average farm sizes have expanded in upper-middle-income and high-income countries, they have decreased for most low and lower-middle-income countries in the period 1960-2010 (Lowder et al., 2025). In South Asia, the average farm size decreased by 46.2 percent from approximately 2.6 hectares per farm in 1960 to 1.4 hectares in 2010. Notably, the average size of agricultural holding in Nepal decreased to 0.8 hectares by 2000 (Lowder et al., 2016), a figure below the South Asian Average, and this downward trend has continued in subsequent years. In Nepal, land fragmentation has been a serious concern over the years (Ning et al., 2023), with its extent substantially higher in recent decades. Between 1981/82 and 2011/12, the number of parcels increased from about 9.5 million to 12.1 million while the average parcel size decreased further from 0.21 hectares in 2011/12 to 0.19 hectares in 2021/22 (National Statistics Office, 2023).

A systematic review on the impact of land fragmentation, which included 150 studies from 1990 to 2023 (Aslam & Fazal, 2025), found mixed evidence on its effects on agricultural performance and rural livelihoods. Around 70 percent of studies reported a positive impact on different agricultural outcomes, while only 10 percent of studies showed a negative impact. 12 percent reported both positive and negative impacts, and 8 percent exhibited no significant effects. While some studies found that land fragmentation decreased agricultural output, productivity, technical efficiency, and household income (Rahman & Rahman, 2009; Manjunatha et al, 2013; Tran & Vu, 2019) through higher input and transaction costs (Barati et al, 2020, Wang et. al., 2020) and reduced machinery use (Orea et al., 2015; Dyer, 1997). Others observed that fragmentation of landholdings increased crop diversity (Di Falco et al., 2010), increased production diversification (Ciaian et al., 2018), reduced production and weather risks (Nguyen, 2025), mitigated the negative seasonal labour impacts (Blarel et al., 1992), and reduced food insecurity (Knippenberg et al., 2020; Ntihinyurwa et. al., 2019). Similarly, recent studies observed that land fragmentation reduced labor migration for the poor and rural households (Kafle et al., 2026) but increased child education outcomes and women's empowerment (Bui et al., 2020). Thus, land fragmentation (consolidation) has become a contested policy discourse and varies depending on the socio-economic and geographical context.

A rich body of literature exists supporting or challenging the inverse relationship[2] between farm size and productivity (Muyanga & Jayne, 2019). In the Nepalese context, some studies have observed the inverse relationship in Nepal, showing higher productivity on smaller farms. However, small farms have also been found to be inefficient, due to increased labor hours per hectare, and reduced machinery use (Thapa, 2007; Niroula & Thapa, 2007). These higher labor and other input investments are often cited as the reason for greater crop yield and production efficiency in small farms. Nevertheless, greater labor intensity reduces labor productivity, thus creating incentives for rural workers to seek off-farm employment. However, such structural transformation may not occur smoothly in Nepal's rural areas, characterized by significant labor-market imperfections due to factors such as limited off-farm jobs, low education levels, and labor market conditions, similar to what was observed in China (Jia & Petrick, 2014, p.

[2] The inverse relation hypothesis is concerned with farm productivity according to which smaller farms have high productivity. But higher labor hours/cost per hectare as observed in Nepal suggests decreased labor productivity with land fragmentation.

372). Thus, policy measures aimed at land consolidation or addressing fragmentation can play a significant role in managing surplus labor, thereby influencing the trajectory of the structural transformation of agricultural economies like Nepal. A thorough understanding of the dynamics between land fragmentation and the non-farm labor supply is crucial, forming the primary rationale of this study.

The global empirical studies reveal an ambiguous impact of land fragmentation on labor allocation among farm and off-farm sectors. Jia & Petrick (2014) found a modest positive relationship between land fragmentation and non-farm labor supply, mediated through labor productivity. However, the relationship was statistically insignificant due to labor market imperfections such as fixed working hours for off-farm jobs, limited employment opportunities in rural areas, inadequate education and training, nepotism, and fear of loss of land use rights, among others. Similarly, Lu et al. (2019) corroborated that an increased number of plots decreased labor productivity, thus increasing non-farm labor supply.

In contrast, Nguyen & Warr (2020) found opposite results for rural Vietnamese rice production. They observed diminished use of on-farm machinery and decreased farm income as underlying mechanisms. Unlike Jia & Patrick (2014), they treated land consolidation as a labor-augmenting technical change, which reduced off-farm labor due to decreased labor productivity and low elasticity of factor substitution. Other studies broadly support reduced non-farm labor participation due to the greater labor use on fragmented farms, higher labor costs, and reduced machinery use (Tan et al., 2008; Ali & Deininger, 2015; Wangyang et al., 2015).

In the context of Nepal, no empirical research exists that rigorously estimates the impact of land fragmentation on the non-farm labor supply. Nonetheless, several studies provide indirect insights into this relationship. Studies observed higher labor hours per hectare on small farms, indicative of labor-intensive cultivation practices in fragmented lands, thereby reducing non-farm labor hours (Thapa, 2007). Farm labor hours increased despite a substantially higher opportunity cost of labor for small parcels (Niroula & Thapa, 2007) and increased labor costs for landholders (Thapa & Niroula, 2008). In contrast, several studies highlight land fragmentation as one of the potential drivers of farmland abandonment in Nepal (Subedi et al., 2021; Chaudhary et al., 2020). This contrasts with findings from other regions such as Albania, where fragmented land holdings are associated with lower rates of abandonment (Sikor et al., 2009) and indicate that land fragmentation may indirectly contribute to increased non-farm labor hours through the pathway of farmland abandonment.

Overall, the effect of land fragmentation on non-farm labor supply remains inconclusive in global literature. A significant heterogeneity in the observed effect exists across nations and regions, shaped by varying socio-economic and political contexts. Major gaps in existing literature include ambiguous evidence, inconsistencies in both economic theory and empirical methodologies, as discussed above. In the context of Nepal, it is important to note that most studies are qualitative and only suggest possible linkages. The few empirical studies available are limited in scope, typically covering only selected districts, and thus cannot reliably inform national-level inferences about the relationship between land fragmentation and non-farm labor supply.

This research addresses these gaps by generating national-level estimates of the impact of land fragmentation on non-farm labor supply, using a nationally representative panel household survey in Nepal. It overcomes theoretical and empirical challenges found in global literature

and offers direction for future research in this field. Utilizing a Two-way fixed effects (TWFE) panel regression model specified based on a standard separable farm household model with land fragmentation as a technical change, this paper observed a negative impact of land fragmentation on off-farm labor supply. The effect was significant for the Mountain and Hill regions of Nepal, and for only large land holding size. The key mechanisms included low elasticity of substitution between inputs, decreased labor productivity, and local off-farm opportunities. We also observed the decline in the off-farm hours as drivers. a potential household adaptation strategy to maintain output levels in rural Nepal. The effects persisted against a wide range of empirical specifications and sensitivity checks. The evidence indicates that land consolidation and targeted interventions to address reduced labor productivity are vital to free the surplus labor and accelerate structural transformation in rural Nepal.

This paper makes the following three contributions to the literature on the impact of land fragmentation on non-farm labor supply. First, we formalize the separable farm household model with land fragmentation as a technical change, as developed by Nguyen & Warr (2020, p. 10). We also extend the model by including effective non-farm labor participation, moderating the observed effect. Second, we estimate the reduced-form empirical model consistent with our economic framework using rich longitudinal data, allowing for robust methods. Finally, we explore heterogeneous effects and mechanisms driving the effect extremely relevant to low-income contexts like Nepal.

The remainder of the paper is organized as follows. Section 2 introduces a theoretical framework, treating land fragmentation as a technical change with a separable farm household model. Section 3 presents information on the data used, descriptive statistics and graphs. Section 4 outlines the econometric methods used. Section 5 discusses the average and heterogeneous effects, explores potential mechanisms, and presents robustness tests. Finally, Section 6 interprets the results, offers policy implications for rural Nepal, identifies limitations of the study, and concludes the paper.

2. Theoretical model on land fragmentation and labor allocation

Following Singh et. al. (1986), and Huffman and Lange (1989), we consider a separable farm household model to analyze the effects of land fragmentation on labor allocation. Land fragmentation is conceptualized as a labor-augmenting technical change that influences on-farm and off-farm labor supply through changes in marginal productivity (Nguyen and Warr, 2020)[3]. We assume that a representative household allocates total labor time (T) between farm (L_f) and off-farm (L_o) work such that the household faces the following labor constraint:

$$L_f + L_o = T \tag{1}$$

Household's utility is separable in consumption and leisure, and the household derives income from farm production and off-farm wage employment:

$$C = Y + w.L_o, \tag{2}$$

where farm output is given by:

$$Y = A(\varphi) \cdot F(K, L_f) \tag{3}$$

[3] The authors use land consolidation for their purposes. For Mathematical Exposition, see Nguyen & Warr (2020, p. 10)

Land fragmentation (φ) reduces effective labor productivity, represented by a labor-augmenting term A(φ), with A′(φ) < 0, where *K* is capital goods. We assume that the farm production function follows a CES form, where Cobb-Douglas production function is a special case:

$$Y = A(\varphi)\,[\alpha K^{\rho} + (1-\alpha).(L_f)^{\rho}]^{(1/\rho)} \quad (4)$$

where $\sigma = 1 / (1 - \rho)$ is the elasticity of substitution between capital (K) and labor (L_f).

The household maximizes utility $U(C)$ subject to its income constraint. The first-order condition for labor allocation equates the marginal value product of labor to the off-farm wage given by Equation (5):

$$A(\varphi) \cdot \partial F/\partial L_f = w \quad (5)$$

or equivalently, the on-farm marginal return equals the off-farm opportunity cost of time.

Differentiating the first-order condition with respect to land fragmentation (φ) gives the effect of land fragmentation on on-farm labor (L_f):

When σ is high, lower $A(\varphi)$ makes labor relatively expensive, leading to substitution away from on-farm labor ($\partial L_f/\partial\varphi < 0$). When σ is low[4], substitution is difficult, so households increase L_f to offset reduced productivity ($\partial L_f/\partial\varphi > 0$).

In rural economies with imperfect labor markets, off-farm employment opportunities are limited. Let p denote the probability of obtaining an off-farm job. The effective off-farm return becomes $p \cdot w$, modifying the first-order condition:

$$A(\varphi) \cdot \partial F/\partial L_f = p \cdot w \quad (6)$$

Lower p (fewer off-farm jobs or higher barriers such as low skills) weakens the off-farm option, causing households to increase on-farm labor supply even when productivity falls. Cultural preferences, identity, and risk aversion can further reduce p, or increase the utility from farming (Jia and Petrick, 2014).

This model suggests that the direction of land fragmentation's effect on on-farm labor depends on the elasticity of substitution (σ). High σ implies labor substitution (L_f falls); low σ implies complementarity (L_f rises), explaining the divergent findings in empirical literature that we have reviewed. Also, labor-market imperfections (low p) increase on-farm labor responses, as limited off-farm options constrain labor reallocation away from farming.

3. Data

This study uses the Nepal Household Risk and Vulnerability Survey (HRVS), a three-year panel survey data produced by the World Bank (The World Bank, 2020). It provides extensive socio-economic, risk, and vulnerability data of 6000 households in Nepal in 2016, 17, and 18. 15 households were randomly surveyed in each Primary Sampling Unit (PSU), determined from 50 randomly chosen districts in nine analytical strata. Around 94 percent of the 6000 households in wave 1 of the survey participated in all three waves.

[4] Studies report a low elasticity of substitution between inputs for fragmented lands (Wangyang et al., 2015).

The HRVS is particularly well-suited for this study for several reasons. Firstly, its primary focus on rural Nepal aligns with the research objectives. Secondly, the survey provides multiple measures of key variables, which enables a closer examination of the impact mechanism and robustness tests. For instance, for individual labor allocation (dependent variable), the survey provides measures such as involvement in non-farm (yes/no), daily hours spent on different activities, and monthly and seasonal labor allocation. Thirdly, the dataset includes a rich set of individual, household, and plot-level characteristics (Table A1), which serve as valuable controls to mitigate the omitted variable bias. Lastly, the panel structure allows for addressing potential endogeneity and for estimating consistent estimators using empirical strategies such as the First Difference model, as discussed in detail below.

The analytical sample is restricted to individuals in the working age group 15 to 64 residing in rural Nepal (OECD, 2023). The dependent variable, the proportion of non-farm hours (PNFARMHRS), is constructed by dividing the total non-farm hours of the individual by their total labor hours. The average plot size is log-transformed due to its right-skewed distribution. 105 ethnicities are reduced into ten groups as per the classification of CBS (2014a, pp. 3-8), while 75 districts are converted into three ecological belts according to CBS (2014b, pp. 22-25). The final sample is an unbalanced panel with 16650 observations– 4,750 in 2016, 5,767 in 2017, and 6,133 in 2018.

3.1.Descriptive statistics

Table 1 provides summary statistics of key variables along with their definitions[5]. Approximately 27 percent of total individuals were engaged in at least one off-farm activity. On average, individuals spend one out of every five working hours on off-farm activities. The majority of individuals were involved exclusively in either farm activities (79.13%) or non-farm activities (14.88%), resulting in a distribution of PNFARMHRS heavily concentrated at values of 0 and 1.

The average number of plots owned (NPLOTS) was 2, which is 1.4 plots fewer than the national average reported in 2011/12 (CBS, 2013, p. 1). Similarly, the mean log transformed average plot size (LN(ALAND)) is 7.67, equivalent to 0.82 acres or 0.33 hectares- 0.32 hectares below the national average of 2011/12 (CBS, 2013, p. 2). These decreased values observed in the survey years likely reflect the increasing extent of land fragmentation.

Table 1: Definition of key variables with summary statistics

Variables	Definition	Mean	SD	Min	Max
NFARM	1 if engaged in non-farm, else 0	.27	.45	0	1
PNFARMHRS	Proportion of non-farm hours in a day	.18	.37	0	1
NPLOTS	Number of plots owned	2	1.3	1	16
LN (ALAND)	Natural Log of average size of plots (sq. m.)	7.67	.9	0	11.46
LN (LAND)	Natural Log of total size of plots (sq. m.)	8.21	.98	0	11.59
NCROPSW	Number of crops cultivated in wet season	2.31	1.5	0	10
LN (CULTIVATEDW)	Natural Log of average area cultivated in wet season (sq. m.)	8.01	1.74	0	11.59
DEBT	1 if has debt, else 0	.66	.47	0	1
DMARKET	Distance to the nearest market (km)	7.41	10.23	0	85
DMOTOR	Distance to nearest motorable road (km)	3.8	9.69	0	300
EQUIP	1 if the household has at least one equipment	0.69	0.46	0	1
PNFPSU	Proportion of net households in non-farm activity in a PSU	0.53	0.17	0	0.82
AGE	Age of the individual (years)	41.09	12.51	15	64

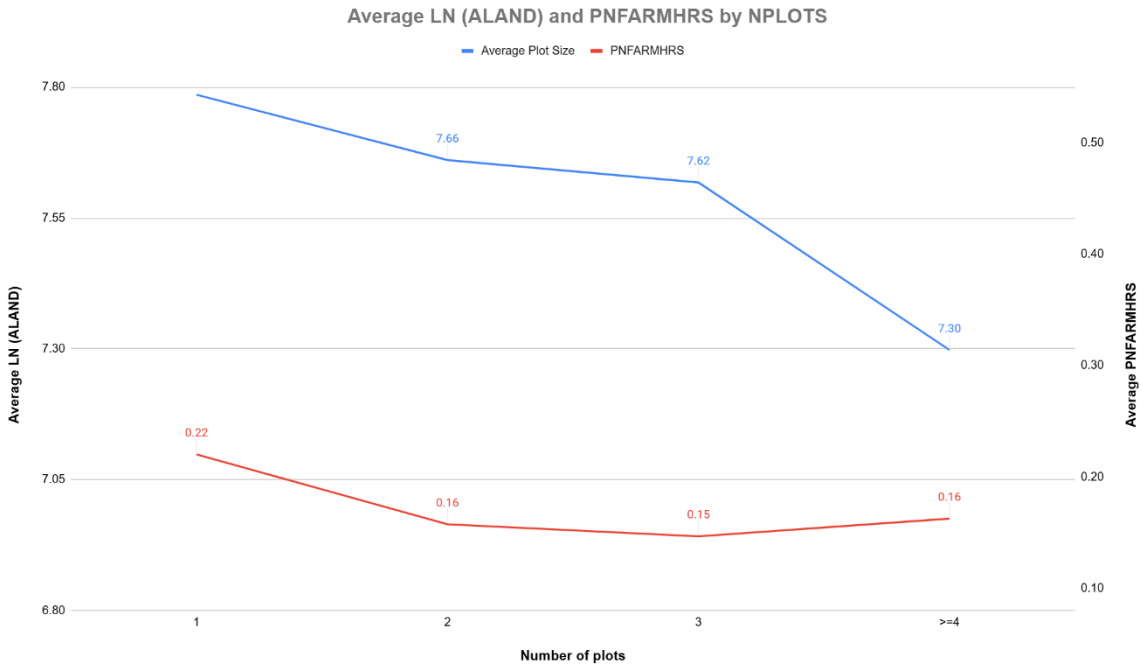
[5] For the summary statistics of all variables, see Table A1.

MARRY	1 if the indiviudal is married, else 0	2.01	.81	0	7
FEMALE	1 if the individual is female, else 0	.53	.5	0	1
YEDU	Years of education	5.58	5.39	0	18

Note: *The full sample includes 16650 individuals in rural households in the working age group 15 to 64.*

A negative association between the average proportion of non-farm hours (PNFARMHRS) and the number of plots owned (NPLOTS) can be observed in Figure 2. Similarly, a positive correlation between PNFARMHRS and LN(ALAND) indicates that households with smaller average parcel sizes tend to allocate a lower share of labor to non-farm activities, and vice versa. These patterns suggest a negative relationship between land fragmentation and non-farm labor allocation.

Fig 2: Average LN (ALAND) and PNFARMHRS by NPLOTS



Note: *The full sample includes 16650 individuals in rural households in the working age group 15 to 64.*

4. Empirical Specification

A reduced-form empirical model consistent with our framework is:

$$PNFARMHRS_{ijk} = \beta_0 + \beta_1 \cdot NPLOTS_{jk} + \beta_2\, NPLOTS_{jk} \times EQUIP_{jk} + \beta_3\, NPLOTS_{jk} \times PNFPSU_{jk} + \boldsymbol{X_{ijk}}'\gamma + \mu_j + \eta_t + \varepsilon_{ijk} \quad (7)$$

Here, i indexes individuals, j indexes households, and k denotes the survey year, and ε_{ijk} represents an independently and identically distributed (IID) error term. $PNFARMHRS_{ijk}$ refers to the proportion of non-farm hours worked by an individual i in household j at time k. PNFARMHRS[6] is used to capture labor allocation across both farm and non-farm sectors

[6] PNFARMHRS is scaled by 100 for convenience in interpretation.

simultaneously, rather than partial-equilibrium variables such as the number of farm or non-farm hours, as commonly used in previous studies.

$NPLOTS_{jk}$ is a measure of land fragmentation which denotes the total number of plots in a household j at time k. $NPLOTS_{jk} \times EQUIP_{jk}$, the interaction between the number of plots and whether the household has equipment captures substitution ease (σ_i) while $NPLOTS_{jk} \times PNFPSU_{jk}$ represents off-farm job access (p_i).

X_{ijk} is a vector of controls for individual i in household j and time k. It includes time variant plot, household, and individual-level controls, respectively, as detailed in Table A1. LN (LAND), which indicates the natural log of total plot size, serves as a primary plot-level control, as households with a larger number of plots may have smaller plots and vice versa. The quadratic term of NPLOTS ($NPLOTS^2$) is also included to capture the non-linear impacts of plot number on the labor market outcomes. These controls help address the potential omitted variable bias that may arise, particularly in labor market allocation studies.

μ_j are the household-level fixed effects, while η_t are the time-fixed effects. The primary coefficient of interest is β_1, which is the average effect of land fragmentation on off-farm labor supply. Its value can be positive or negative, given the inconclusive literature. The coefficients β_2 and β_3 provide the estimates for the elasticity of labor substitution with respect to machinery and the presence of labor market imperfections, respectively.

A TWFE linear regression model is applied for PNFARMHRS. TWFE with clustered standard errors at the district level are used based on several diagnostic tests (Table A2). In particular, Fixed Effects (FE) are preferred over Random Effects (RE) as indicated by the Hausman test. Household-level fixed effects are used to capture unobserved heterogeneity, while Time-fixed effects are included as determined by the F-test. The Modified Wald test rejects Group-wise homoskedasticity, thus standard errors (SE) are clustered at the district level.

To address the potential endogeneity in the selection of individuals into non-farm labor due to unobserved factors, two complementary methods are used. The Heckman Sample Selection Model (H-SSM) is used to address the sample selection bias due to the incidental truncation of the off-farm labor market participation. Similarly, a First Difference (FD) method is utilized to determine causal estimators. These methods are robust empirical strategies and also check the reliability of the baseline estimates.

Model (7) is estimated across different subsamples of ecological regions and total land size to find the disaggregated response of land fragmentation, elasticity of substitution, and labor market imperfections on non-farm labor supply. This approach helps examine if labor market imperfections are driving the observed effect. Finally, the study also explored correlations among production characteristics to confirm the suggestive evidence of potential mechanisms underlying the observed relationships.

5. Results

5.1. Average Effect

Table 2 presents five model specifications used to estimate the average effect of land fragmentation on non-farm labor supply. The first model regresses the proportion of non-farm hours (PNFARMHRS) on the proxy of land fragmentation- the number of plots (NPLOTS), and its quadratic term (NPLOTS2). The model also includes baseline fixed effects (HH FE and Year FE) and several exogenous controls. The exogenous controls include FEMALE, HHSIZE,

HHSIZE2, HHEAD, AGE, and AGE2, as it is unlikely for an individual to have complete control over these socio-demographic characteristics. In Model 2, plot-level (PT) controls are added. Finally, we also add the interactions of land fragmentation with household ownership of equipment and the proportion of net off-farm labor supply at a PSU level in Model 3 with Household level (HH) and Individual level (IN) controls. We use clustered standard errors at the district level in Model 4.

In Model 5, we test the robustness of our findings using an alternative measure of land fragmentation (LN(ALAND)), the natural logarithm of average plot size.

Table 2: Regression Results of Land Fragmentation on Non-farm Labor Supply

VARIABLES	(1) PNFARMHRS	(2) PNFARMHRS	(3) PNFARMHRS	(4) PNFARMHRS	(5) PNFARMHRS
NPLOTS	-6.59***	-9.23***	-14.06***	-14.06***	
	(2.37)	(2.45)	(4.09)	(3.62)	
NPLOTS2	0.53**	0.66***	0.67***	0.67***	
	(0.21)	(0.21)	(0.21)	(0.09)	
LN(ALAND)					3.62**
					(1.71)
NPLOTS*EQUIP			-0.21	-0.21	
			(0.38)	(0.37)	
NPLOTS*PNFPSU			11.99*	11.99**	
			(6.32)	(5.96)	
Observations	16,639	16,634	16,287	16,287	16,287
R-squared	0.14	0.15	0.17	0.17	0.17
Number of HHs	2,683	2,683	2,677	2677	2677
Exogenous controls	Yes	Yes	Yes	Yes	Yes
Plot level controls	No	Yes	Yes	Yes	Yes
HH level controls	No	No	Yes	Yes	Yes
Individual controls	No	No	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
HH FE	Yes	Yes	Yes	Yes	Yes
Clustered SE	No	No	No	Yes	Yes

Note: *The total number of individuals between 17 and 65 in the sample (N) is 16650. The total number of HHs is 2683. Standard errors (SE) are in parentheses and clustered at District level. *** p<0.01, ** p<0.05, * p<0.1*

The effect of land fragmentation on non-farm labor supply in Nepal is negative across all models presented in Tables 2. The effect remains statistically significant, even after accounting for rich controls and fixed effects. This justifies the robustness of the direction of impact. Lastly, the increasing R-squared in Table 2 across the specifications from 0.14 in Model 1 to 0.17 in Model 4 and 5 demonstrates a substantial enhancement in the explanatory power of the econometric models.

The magnitude of the effect of NPLOTS on PNFARMHRS is -14.06. This indicates a decline in the reduction of non-farm working hours by 14.06 percentage points. Furthermore, a positive and statistically significant effect of the logarithm of average plot size (LN(ALAND)) on non-farm labor supply corroborates these findings, suggesting that greater land fragmentation, whether measured by the number of plots or smaller average plot size, reduces non-farm labor participation.

We also found a significant quadratic relationship between NPLOTS and PNFARMHRS. As the second derivative of the estimated model with respect to NPLOTS is positive, a concave-

up representation with a minimum when NPLOTS is equal to 4.8 is found[7]. This suggests that non-farm work hours initially decline with more plots, reach a minimum at 5.1 plots, and then begin to increase, highlighting a threshold effect in landholding dynamics[8].

The elasticity of substitution between labor and machinery, as indicated by the coefficient of NPLOTS*EQUIP, is very low (statistically equal to zero) and does not moderate the effect of land fragmentation on off-farm labor supply. However, low labor market imperfections were found to increase the probability of off-farm employment despite land fragmentation. In particular, with a 0.01 increase in the proportion of non-farm labor activity in a given PSU, the negative effect of an increase in plots decreases by 0.12 percentage points.

Table 2: Results of Additional Model Specifications

	(1)	(2)	(3)
VARIABLES	OLS	H-SSM	FD
NPLOTS	-14.06***	-3.40***	-16.96***
	(3.62)	(1.07)	(4.30)
NPLOTS2	0.67***	0.15	0.79***
	(0.09)	(0.12)	(0.21)
NPLOTS*EQUIP	-0.21		0.47
	(0.37)		(0.36)
NPLOTS*PNFPSU	11.99**		13.85**
	(5.96)		(6.40)
Observations	16,287	16,296	8,581

Note: *Standard errors in parentheses. Variables in (3) are in first difference. All models have all the controls from Model 4 in Table 2.*
**** p<0.01, ** p<0.05, * p<0.1*

Table 3 presents the estimated effect of land fragmentation on off-farm labor supply across multiple model specifications. The direction of the impact remains consistently negative, though the magnitude varies. The reduction in the proportion of non-farm working hours (PNFARMHRS) per additional plot ranges from -3.40 percentage points in the heckman sample selection model to -16.96 percentage points in the first difference model.

5.2.Heterogeneous effects

A significant heterogeneity is detected when the effect of land fragmentation on non-farm labor supply is analyzed across Nepal's ecological regions (REGION) and by terciles of total landholding size (ln (LAND)) (Table A3 and A4).

Specifically, we found a significant negative impact of land fragmentation on off-farm labor supply in the mountain and hill regions. The negative effect is reduced with greater off-farm employment activity in the region, which suggests that local off-farm opportunities can offset the observed effect. For terai, land fragmentation has no impact on the off-farm labor supply. Furthermore, the effect becomes statistically significant only for households in top tercile which highlights that the negative impact is pronounced among larger landholders. Thus,

[7] Model 2 results were used to find the point of inflection.
[8] A similar pattern in Figure 2 supports the findings.

regional context and farm size are crucial in understanding the impact of fragmentation on rural labor allocation.

5.3.Labor productivity

Table 4 presents a correlation matrix of key production characteristics to explore potential mechanisms and household adaptation strategies in response to land fragmentation. First, a positive correlation between NPLOTS and NCROPSW (a proxy for crop diversity) suggests that households with more fragmented land tend to diversify their cropping patterns. Second, a positive correlation between NPLOTS and LN(CULTIVATEDW) suggests that households with larger number of plots cultivate larger areas on average. We observe similar positive associations with LN(OUTPUTW), LN(OWNLABORW), and LN(LABORCOSTW), which indicate that households may compensate for potential productivity loss due to land fragmentation by using more labor input in the form of own as well as hired labor[9] thereby producing similar levels or more output by cultivating in a larger area[10].

Third, a positive correlation between NPLOTS and NDEBT suggests that households with larger number of plots have a higher amount of debt possibly to support their labor-intensive farming practices. Finally, a negative association of land fragmentation variables with LN(CAPITALW) may reflect constraints in machinery use, consistent with findings, by Wangyang et al. (2015). This also may ask for labor-intensive farming to maintain the same level of output. However, it is important to note that these are correlational findings and should not be interpreted cause and effect.

Table 3: Correlation matrix of key production characteristics

VARIABLES	NPLOTS	LN(ALAND)
NCROPSW	0.35***	-0.06***
LN(CULTIVATEDW)	0.21***	0.35***
LN(DEBT)	0.06***	-0.04***
LN(OUTPUTW)	0.01	0.35***
LN(ENTINC)	-0.05***	0.12***
LN(OWNLABORW)	0.13***	0.13***
LN(LABORCOSTW)	0.08***	0.23***
LN(CAPITALW)	-0.03**	0.19***

Note: *The sample includes information from 6109 rural households.*

[9] For similar findings look: Tan et al. (2008), Ali & Deininger (2015), Thapa & Niroula (2008), and Niroula & Thapa (2007)

[10] Sikor et al. (2009) has made similar inferences while Subedi et al. (2021) makes the opposite claim.

5.4.Robustness Checks

We use three different strategies to check the robustness of our results. First, we consider NPLOTS as a categorial variable with four levels (1, 2, 3, and >=4) as shown in Model 1 of Table 4. This also allows precise estimation of non-linear effects. Second, an alternative measure of off-farm labor supply is used: PNFARMDAYS, which captures the fraction of total working days an individual is engaged in off-farm activities. Third, the same model is estimated separately for both wet and dry seasons, as presented in Models 2 and 3, respectively.

On average, households with 2, 3, and >=4 plots exhibit a lower proportion of non-farm working hours than when NPLOTS is equal to one. The magnitude of the effect increases with increased number of plots. Similar results hold for both Model 2 and 3, regardless of the measure of the dependent variable and the season of interest, thus providing further validity of our result.

Table 5: Robustness Checks

VARIABLES	(1) PNFARMHRS	(2) PNFARMDAYSW	(3) PNFARMDAYSD
NPLOTS		-14.13***	-13.94***
		(3.63)	(4.23)
2	-11.79***		
	(3.96)		
3	-19.51***		
	(6.81)		
>= 4	-35.87***		
	(9.96)		
NPLOTS2	0.12	0.71***	0.71***
	(0.11)	(0.09)	(0.22)
NPLOTS*EQUIP	-0.24	-0.07	-0.13
	(0.37)	(0.36)	(0.39)
NPLOTS*PNFPSU	10.58*	12.17**	12.09*
	(6.03)	(5.90)	(6.53)
Observations	16,287	16,249	16,076
R-squared	0.17	0.16	0.16

Note: *Standard errors in parentheses. All models have all the controls and fixed effects from Model 4 in Table 2. *** p<0.01, ** p<0.05, * p<0.1*

6. Discussion and Conclusion

Structural transformation within economies has historically been facilitated through the release of surplus labor from agriculture to off-farm sectors, influenced by a combination of pull and push mechanisms (Alvarez-Cuadrado & Poschke, 2011). Advances in manufacturing technology often act as a major pull factor, driving labor out of farming. At the same time, increased agricultural productivity serves as a critical push factor for structural change in economies after the 1960s. Among the major determinants of off-farm employment decisions (Zheng et al., 2023, p. 4), the degree of land fragmentation or consolidation plays a significant

role in the labor allocation decisions outside agriculture, thus shaping the trajectory of an economy's structural transformation, which forms the basis for this research. The existing body of literature offers mixed findings on land fragmentation's effect on non-farm labor supply, with notable inconsistencies in theoretical approaches and ambiguous empirical evidence. Thus, this study is timely and pertinent to inform broader global discussions on economic transformation.

To the best of current knowledge, this study is the first to empirically estimate the effect of land fragmentation on off-farm labor supply in Nepal based on a separable household economic model. This study contributes to existing literature by estimating the marginal response of land fragmentation on off-farm labor supply, utilizing a Two-Way fixed effects (TWFE) panel model using a three-year longitudinal survey data (HRVS). We identify labor productivity and labor market imperfections as potential channels of effect. We also examined the heterogeneous estimates for ecological regions and total land size.

This study uncovered three principal findings. First, we found an average negative impact of land fragmentation on off-farm labor supply. Local off-farm opportunities reduced the impact, while we did not find evidence for the moderating impact of machinery. The observed impact has significant methodological and policy relevance. From a methodological standpoint, these results suggest a low elasticity of factor substitution in the specified economic framework. Despite a potential decrease in labor productivity, limited factor substitution justifies the persistence of the negative impacts. An insignificant effect of the interaction between NPLOTS and EQUIP provides evidence of the low elasticity of factor substitution. Previous research in Nepal (Thapa, 2007; Thapa & Niroula, 2008) corroborates these findings, indicating that fragmented parcels are associated with labor-intensive farming practices. This relationship justifies a low elasticity of factor substitution as a primary determinant of the observed impact in the Nepalese context.

This issue warrants serious attention, given the prevailing pattern of land fragmentation in Nepal. The extent of land fragmentation may be construed as a negative technical change, significantly absorbing labor resources, and thereby impeding the structural transformation and overall economic development (Alvarez-Cuadrado & Poschke, 2011). Thus, land consolidation emerges as a significant policy instrument to release the surplus labor, so as to accelerate the structural change in the Nepalese Economy, as observed in other contexts, notably in Vietnam (Nguyen & Warr, 2020).

Despite the introduction of numerous land use and reform policies by the Nepalese government to address burgeoning land fragmentation (Nepal et al., 2020; Upreti, 2021), these measures have large found to be ineffective (Paudel et al., 2013). Among them, the Land Use Policy 2015 stands out for its inclusion of policy measures such as land ceilings, establishment of Special Land Use Zones (SLUZs), land consolidation, and the provisions of subsidies/taxes (MoLRM, 2015, p. 8). Furthermore, various legal provisions exist to prevent land fragmentation. One of the significant laws includes the mandate to offer any subdivided plots to adjacent landowners before sale (Niroula & Thapa, 2005, p. 367). In the case of non-compliance, contiguous plot owners retain the legal right to pursue a legal claim within seven months of sale. These frameworks indicate that the challenge has not been a lack of policy initiatives but their transparent and effective implementation.

Secondly, the study reveals substantial evidence in favor of labor market imperfections shaping the observed relationship between land fragmentation and off-farm labor supply. This is

particularly evident in the significant positive effect of the interaction between the number of plots and the proportion of net local off-farm activity. This underscores the likelihood of labor market frictions, which may constrain individuals from selecting into higher wage non-farm employment despite the increased opportunity cost of farm work and reduced labor productivity. Under such conditions, individuals may adapt by increasing farm hours or hiring additional labor, shifting to labor-intensive farming as observed in the Results section and indicated in the literature. This asks for policy interventions aimed at addressing the labor market imperfections in Nepal's rural sector.

Thirdly, we found a heterogeneous impact of land fragmentation on off-farm labor activity in different ecological regions of Nepal and also based on total landholding size. We found that the effect persists only in the Mountain and Hill region and only for the households with relatively larger farm size (in tercile 3). This suggests that the constraints imposed by fragmentation on off-farm activity are evident for larger landholders and only in specific geographic contexts. This asks for targeted policy responses to address these region and size-specific challenges.

The consistency of results across multiple specifications and robustness tests offers greater validity for the inferences and implications. Utilizing panel data enabled the application of methods addressing endogeneity, including H-SSM and FD models alongside TWFE. Throughout these varied analytical approaches, evidence persistently demonstrates an average negative effect of land fragmentation on off-farm labor supply.

Nonetheless, this study demands further robustness tests using longitudinal data over extended periods, as land fragmentation is a gradual and long-run phenomenon. Additional cross-country analysis would further strengthen the external validity of the findings. From a research perspective, examination of the impact using a natural experiment focused on land fragmentation or consolidation would offer substantial value, enabling causal interpretation of underlying effects and mechanisms.

In summary, this study finds that land fragmentation leads to a reduction in the off-farm participation in Nepal. As the transition into off-farm activities is pivotal for the structural transformation of a rural agrarian economy, targeted policies aimed at addressing land fragmentation, coupled with measures to address labor market imperfections, are essential.

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Competing Interests

The authors declare no conflicts of interest. Grammarly was used to improve sentence structures and grammar usage.

Ethics statement

The authors declare none. No human participants, animals, or sensitive data were involved that would require formal ethical approval.

Data availability statement

The data supporting the results is available publicly from the World Bank portal, and the authors do not have rights to re-share.

Appendix

Table A1: Descriptive statistics with all variables with definitions

	Variables	*Definition*	*Mean*	*SD*	*Min*	*Max*
	NFARM	1 if engaged in non-farm, else 0	.27	.45	0	1
	PNFARMHRS	Proportion of non-farm hours in a day	.18	.37	0	1
	PNFARMDAYSW	Proportion of average non-farm days in a wet month	.18	.37	0	1
Dependent	PNFARMDAYSD	Proportion of average non-farm days in a dry month	.19	.38	0	1
	NPLOTS	Number of plots owned	2	1.3	1	16
Explanatory Variable	LN (ALAND)	Natural Log of average size of plots (sq. m.)	7.67	.9	0	11.46
	LN (LAND)	Natural Log of total size of plots (sq. m.)	8.21	.98	0	11.59
	NCROPSW	Number of crops cultivated in wet season	2.31	1.5	0	10
	NCROPSD	Number of crops cultivated in dry season	1.91	1.62	0	10
	LN (CULTIVATEDW)	Natural Log of average area cultivated in wet season (sq. m.)	8.01	1.74	0	11.59
	LN (CULTIVATEDD)	Natural Log of average area cultivated in dry season (sq. m.)	6.54	3.05	0	11.55
	TLAND	**Type of land owned**				
	TLAND1	All owned plots are lowland	.31	.46	0	1
	TLAND2	Some plots are lowland while some are upland	.31	.46	0	1
	TLAND3	All are upland	.38	.48	0	1
	IMODEW	**Irrigation mode in the wet season**				
	IMODEW1	1 if all plots are rainfed, else 0	.59	.49	0	1
	IMODEW2	1 if plots are either rainfed or non-rainfed	.23	.42	0	1
	IMODEW3	1 if all plots are non-rainfed, else 0	.18	.38	0	1
	IMODED	**Irrigation mode in the dry season**				
	IMODED1	1 if all plots are rainfed, else 0	.7	.46	0	1
	IMODED2	1 if plots are either rainfed or non-rainfed	.19	.39	0	1
	IMODED3	1 if all plots are non-rainfed, else 0	.11	.31	0	1
	ITYPEW	**Irrigation type in the wet season**				
	ITYPEW1	1 if all plots have seasonal irrigation, else 0	.74	.44	0	1
	ITYPEW2	1 if plots have either seaonal or year-round irrigation, else 0	.16	.37	0	1
	ITYPEW3	1 if all plots have year-round irrigation, else 0	.1	.31	0	1
	ITYPED	**Irrigation type in the dry season**				
	ITYPED1	1 if all plots have seasonal irrigation, else 0	.76	.43	0	1

	ITYPED2	1 if plots have either seaonal or year-round irrigation, else 0	.15	.36	0	1
	ITYPED3	1 if all plots have year-round irrigation, else 0	.09	.29	0	1
	USEW	**Use of land in the wet season**				
	USEW1	1 if all plots are cropped by oneself, else 0	.91	.29	0	1
	USEW2	1 if all plots are left fallow, else 0	.03	.17	0	1
	USEW3	1 if all plots sharecropped out/ fixed rent out/ mortaged out/other, else 0	.06	.24	0	1
	USED	**Use of land in the dry season**				
	USED1	1 if all plots are cropped by oneself, else 0	.74	.44	0	1
	USED2	1 if all plots are left fallow, else 0	.09	.28	0	1
	USED3	1 if all plots sharecropped out/ fixed rent out/ mortaged out/other, else 0	.17	.38	0	1
	HHSIZE	Household size	5.68	2.26	1	22
	HOME	1 if owns a home, else 0	1.01	.09	1	2
	DEBT	1 if the household has debt	.66	.47	0	1
	NLIVESTOCK	Number of livestock	14.84	119.27	0	8014
	DMARKET	Distance to the nearest market (km)	7.41	10.23	0	85
	DMOTOR	Distance to nearest motorable road (km)	3.8	9.69	0	300
	EQUIP	1 if the household has at least one equipment	0.69	0.46	0	1
	PNFPSU	Proportion of net households in non-farm activity in a PSU	0.53	0.17	0	0.82
	REGION	**Region of the household**				
	Mountain	1 if household is locatied in mountain region	.16	.37	0	1
	Hill	2 if household is locatied in hill region	.54	.5	0	1
HH level controls	Terai	3 if household is locatied in terai region	.3	.46	0	1
	AGE	Age of the individual	41.09	12.51	15	64
	MARRY	1 if the indiviudal is married, else 0	2.01	.81	0	7
	FEMALE	1 if the individual is female, else 0	.53	.5	0	1
	YEDU	Years of education	5.58	5.39	0	18
	ETHNICITY	**Ethnicity of individual**				
	ETHNICITY1	1 if Hill groups, else 0	.32	.47	0	1
	ETHNICITY2	1 if Hill Adibasi/Janajati groups, else 0	.36	.48	0	1
	ETHNICITY3	1 if Hill Low caste or dalits, else 0	.1	.29	0	1
	ETHNICITY4	1 if Madhesi caste (Level 1), else 0	0	.06	0	1
Individual level controls	ETHNICITY5	1 if Madhesi caste (Level 2), else 0	.09	.29	0	1

ETHNICITY6	1 if Madhesi low caste groups (Level 3), else 0	.02	.14	0	1
ETHNICITY7	1 if Madhesi Adibasi/ Janajati groups, else 0	.07	.26	0	1
ETHNICITY8	1 if Musalman or Muslim, esle 0	.01	.11	0	1
ETHNICITY9	1 if Unidentified, esle 0	.02	.13	0	1

Number of observations= 16650

Note: *The full sample includes 16650 individuals in rural households in the working age group 15 to 64.*

Table A2: Diagnostic tests for the TWFE model

Tests	Null Hypothesis	(1) p-value
Hausman test	Random effects should be used	0.00
F-test (wave2=wave3=0)	Time fixed effects are not needed	0.00
Modified Wald test	Group-wise heteroskedasticity is not present	0.00

Note: *The full sample includes 16650 individuals in rural households in the working age group 15 to 64.*

Table A3: Disaggregated regression results by REGION

VARIABLES	(1) MOUNTAIN	(2) HILL	(3) TERAI
NPLOTS	-45.64*	-11.81***	-16.08
	(23.87)	(4.16)	(22.86)
NPLOTS2	0.54	0.58***	3.10
	(1.67)	(0.21)	(5.14)
NPLOTS*EQUIP	0.14	-0.39	-0.36
	(0.77)	(0.51)	(0.83)
NPLOTS*PNFPSU	65.23*	11.25*	-6.07
	(37.94)	(6.46)	(35.21)
Observations	2,682	8,789	4,816
R-squared	0.16	0.15	0.23
Controls	Yes	Yes	Yes
FE	Yes	Yes	Yes

Note: *Standard errors in parentheses. All models have all the controls and fixed effects from Model 4 in Table 2. *** p<0.01, ** p<0.05, * p<0.1*

Table A4: Disaggregated regression results by TERCILE OF TOTAL LAND AREA

VARIABLES	(1) TERCILE1	(2) TERCILE2	(3) TERCILE3
NPLOTS	10.02	17.81	-15.81***
	(18.42)	(20.26)	(5.31)
NPLOTS2	-3.91	-4.40	0.64***
	(3.95)	(3.59)	(0.24)

NPLOTS*EQUIP	-1.40	-0.75	0.50
	(0.96)	(0.67)	(0.53)
NPLOTS*PNFPSU	7.95	-5.26	18.48**
	(27.55)	(14.11)	(7.89)
Observations	5,617	5,272	5,398
R-squared	0.21	0.16	0.16
Controls	Yes	Yes	Yes
FE	Yes	Yes	Yes

Note: *Standard errors in parentheses. All models have all the controls and fixed effects from Model 4 in Table 2. *** p<0.01, ** p<0.05, * p<0.1*