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Effects of Agricultural Mechanization on Smallholders and their Self-Selection into Farming

An Insight from the Nepal Terai

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ABSTRACT

This research was undertaken to better assess the role of mechanization in the future of smallholder farmers in Nepal. It addresses the knowledge gap about whether promoting mechanization that is often complementary to land can effectively support smallholders, particularly in the face of a growing nonfarm sector. Rising rural wages in Nepal have increasingly put pressures on smallholder farmers, who tend to operate labor-intensive farming. Agricultural mechanization through custom hiring of tractor services has recently been considered as an option to mitigate the impact of rising labor costs for smallholders. However, the benefit of agricultural mechanization may still be better captured by exploiting the economies of scale of medium to large farmers rather than smallholders. In the meantime, the Nepal agricultural sector still employs a disproportionate share of workers given its share in the economy, potentially depressing agricultural labor productivity. It is therefore an important policy question whether to (1) continue supporting smallholders through custom-hired tractor services or (2) encourage smallholders to rent their farms out to medium-size or larger farmers, while helping smallholders specialize in the nonfarm sector, where their labor productivity may be higher. Using samples from the Terai zone—one of the agroecological belts in Nepal, largely consisting of lowland plains— from the Nepal Living Standards Survey, we assess whether the benefits of hiring in tractor services are greater among medium to large farmers than among smallholders, and how these benefits may depend on smallholders' decision to remain in or leave farming. This study also contributes to the impact evaluation literature by showing that jointly assessing the effects of two treatments (whether to adopt custom-hired tractor services and continue farming, or to search for better options and specialize in off-farm activities) can lead to different implications than assessing them separately. Our analyses suggest that the government should continue to promote custom-hired tractor services not only for medium to large farmers but also for smallholders. If, over time, barriers to specializing in nonfarm activities are lowered and more smallholders start leaving farming, mechanization may no longer benefit the remaining smallholders. Support for mechanization can then be focused more on medium to large farmers, while types of support other than mechanization can be devised for the remaining smallholders.

Keywords: custom-hired tractor services, exit from farming, multinomial-logit, inverse probability weighting, Terai, Nepal

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1. BACKGROUND

Whether smaller farms have advantages over large farms has long been debated globally. Recently, this issue has increasingly gained policy relevance in Asia because many Asian countries have started experiencing rising rural wages and consequent rises in the production costs of smallholder farming systems that rely intensively on labor. Whether to continue supporting smallholder farming systems or to start promoting larger farms is an important question the policy makers in these countries must face in designing appropriate support policies for the agricultural sector.

Agricultural mechanization is one of the key processes that affect the future of smallholder farming systems in Asian countries including Nepal. Historically, mechanization in some parts of the world, such as the United States, led to considerable growth in farm sizes over time. In Japan, while the average farm size has been much smaller than that of the United States, it has nevertheless risen gradually from 1 ha in the 20th century to 2 ha in the 21st century. However, in some parts of Asia, growth in the practice of custom hiring tractors or combine harvesters has actually helped many smallholder farm households to survive through substituting machines for labor without actually owning those machines. In Nepal, earlier studies showed that tractor use grew considerably in the Terai through custom hiring without much change in farm size (Takeshima, Adhikari, et al. 2015).

Several studies have recently assessed the role of mechanization in the comparative advantages of smallholders versus medium to large farmers in Indonesia and Viet Nam (Yamauchi 2016; Liu, Violette, and Barrett 2016). These studies generally have suggested that rising rural wages often induce agricultural mechanization and thus shift the comparative advantage toward larger farmers. However, they have not directly accounted for the process through which some farmers decide to exit farming altogether. Empirically, excluding this process can lead to biased estimates of the comparative advantages across farm sizes and how mechanization affects these comparative advantages.

This paper estimates how the adoption of custom-hired tractor services affects farm households and how the effects differ across farm sizes, by explicitly incorporating the fact that farm households may also choose to exit farming altogether. In doing so, it addresses the endogeneity associated with the two decisions of whether to continue farming or not, and whether to adopt tractors or not. It uses the recently developed multinomial-logit inverse probability weighting (IPW) method, which extends conventional IPW methods into a multinomial treatment framework.

Our analyses use secondary data from the Nepal Living Standards Survey (NLSS), focusing on the Terai zone, where the adoption of custom-hired tractor services grew from about 10 percent in 1995 to 50 percent in 2010, while the average size of farmland owned remained fairly low, at around 0.5 ha. Our analyses find that although medium to large farmers seem to gain more than smallholders from adopting custom-hired tractor services, which is consistent with earlier studies, not accounting for the option to specialize in off-farm activities may underestimate the effect for smallholders. Thus, smallholders' benefits from mechanization may actually be more comparable to the benefits for medium to large farmers than has been previously estimated without controlling for the sample selection problem in which smallholders who are more likely to exit farming are also more likely to benefit from adopting custom-hired tractor services if they were to stay in farming.

2. RECENT AGRICULTURAL MECHANIZATION POLICIES IN NEPAL

Before proceeding to the empirical analyses, this section briefly describes recent developments in the agricultural mechanization policies of Nepal.

Status of Agricultural Mechanization Policy and Policy Gap

The government of Nepal has been implementing national agricultural policies to reduce poverty and spur sustainable economic growth through commercialization and competitiveness in agriculture. The relevant policy documents are the Agriculture Perspective Plan (APP) (Nepal, MoAD 1995), the National Agriculture Policy (NAP) (Nepal, MoAD 2004), the Agribusiness Promotion Policy (AgPP) (Nepal, MoAD 2006), the Agriculture Mechanization Promotion Policy (AMPP) (Nepal, MoAD 2014b), and the Agriculture Development Strategy (ADS) (Nepal, MoAD 2014a). The overwhelming objective of all these policies is to enhance the commercialization and competitiveness of agriculture. Indeed, the policies under the APP, NAP, AgPP, and ADS are more general for agricultural development, while policies in the AMPP are more specifically focused on the mechanization of agriculture.

Government agriculture and livestock farms in Nepal began to import and experiment with modern farm equipment after the country established its Agricultural Engineering Unit under the Ministry of Agricultural Development (MoAD) in 1953. The Agriculture Engineering Division of the Nepal Agricultural Research Council has been testing and developing different agricultural machines and equipment since 1991. In addition, the Directorate of Agricultural Engineering, established in 2004 under the Department of Agriculture in MoAD, has undertaken promotional extension and training programs for agricultural machinery and provided related services (Nepal, MoAD 2014b). Thus, the government's efforts have recently increased, especially from the past decade, to adopt policies to address issues surrounding mechanization, particularly through the APP (1995–2015) and the NAP (2004).

However, the performance of these policies has not been as satisfactory as expected due to the absence of a specific mechanization policy and inadequate budget allocation. Currently, MoAD's annual planning and budgeting provides for an approximate 50 percent subsidy on power trailers and a customs tax exemption for four-wheeled tractors used for agricultural purposes. Custom hiring of tractor services has been growing, but not evenly, across the Terai zone of Nepal. The government has planned to promote custom-hired services to minimize the negative effect of the current labor shortage in agriculture.

Agricultural Mechanization Promotion Policy, 2014

With due consideration of the importance of a separate and specific policy, the government of Nepal promulgated the AMPP in 2014. The goal of this policy is to undertake research, adoption, development, use, expansion, and promotion of agricultural machinery and equipment for increasing productivity in the agricultural sector and for making the sector sustainable and competitive. The policy encourages a cooperation and partnership approach among government, private, and cooperative sectors to optimize the quality of the services adopted by end users. Specifically, the policy has the following objectives: (1) to make agricultural business sustainable, competitive, and commercial by increasing productivity through agricultural mechanization suitable to the economic and geographic conditions of the country; (2) to enhance the access of farmers/entrepreneurs to agricultural machines and equipment by increasing agricultural mechanization–related services and business through collaboration among government, cooperative, and private sectors; (3) to identify and promote women- and environment-friendly agricultural machines and equipment; and (4) to develop an institutional structure for agricultural mechanization as well as to set quality standards for, regulate, monitor, and promote agricultural machines and equipment.

In coordination with the International Food Policy Research Institute, MoAD is formulating an operational strategy consisting of an operational framework, an institutional and regulatory framework, and an implementation plan and budget estimation to materialize the AMPP (Nepal, MoAD 2014b; and IFPRI 2016). The country hopes these steps make the mechanization policy instrumental in increasing the agriculture sector's commercialization and competitiveness, eventually contributing to sustainable economic development in the country.

Provision of Agricultural Mechanization in the Agricultural Development Strategy (2015–2035)

Currently, the ADS is the main guiding policy document for the development of the agricultural sector in Nepal. Mechanization (with tractors, plowing machines, pumps, combine harvesters, and processing machinery) has been considered one of the important inputs to improve productivity and address reduced labor availability in rural areas due to outmigration. Moreover, ADS has been provisioned to support mechanization through creating awareness and stimulating demand. It also offers a concessionary financing arrangement and works to build the technical capacity of the dealer network, particularly for dealers of two-wheeled power tillers and mini-tillers throughout the country. Dealers also benefit from some modifications in taxation. This strategy calls for a lot of coordination with private-sector equipment providers and the commercial banking sector. The approach emphasizes (1) power tillers with multifunctional tilling options in the Terai zone; (2) a gradual increase in the number of mini two-wheelers (with some optional attachments) in the Hills zone; and (3) labor-saving, low-energy implements and mechanized irrigation in the Mountain zone.

More specifically, ADS covers various policies and plans for the promotion of agricultural mechanization in Nepal, including the following areas of focus: promoting private-sector development of agricultural mechanization, disseminating information, improving customer access to financing, building the capacity of service and maintenance providers, enabling the business environment for leasing agricultural equipment, revising regulations and taxes to support mechanization, establishing agricultural mechanization centers, and piloting a voucher program for agricultural mechanization.

3. FARM SIZE, TRACTOR ADOPTION, AND EXIT FROM FARMING IN THE NEPAL TERAI: DESCRIPTIVE ANALYSIS

This section provides various descriptive figures regarding the farmland market, mechanization, and their linkages with farm size in the Nepal Terai between 1995 and 2010. This study uses three rounds of the NLSS—1995, 2003, and 2010 (Nepal, CBS 1996, 2004, and 2011, respectively). Some of the descriptive statistics presented in this section pertain to specific subsamples of the NLSS, which are described in the notes for the respective tables. In certain tables, only cross-section samples are used even when panel samples are available, because our interest is in obtaining nationally representative figures and, in NLSS, cross-section samples are representative while panel samples are not. However, when the interest is in the dynamics among specific households, we focus on the panel sample.

Table 3.1 summarizes the types of Terai households studied in terms of landownership and cultivation status. About 70 percent of households owned farms, among which 7 percent (= 5/[66 + 5]) did not cultivate at all, mostly sharecropping out their farm plots to other households. About 6 and 8 percent of households, respectively, cultivated others' farms as tenants and worked on others' farms as agricultural workers in 2010.

Table 3.1 Breakdown (percentage) of Terai households by farmland ownership and cultivation status

Status	1995	2003	2010
Own farm and cultivate	68	64	66
Own farm and do not cultivate	4	6	5
Rent out farm (typically sharecropped out)	4	6	5
Do not own farm, cultivate as tenant	7	8	6
Do not own farm, do not cultivate as tenant, but work in agriculture	16	14	8
Do not own farm, do not cultivate as tenant nor as agriculture worker	5	7	15

Source: Authors' calculations based on Nepal Living Standards Survey (NLSS) 1995, 2003, and 2010 (Nepal, CBS 1996, 2004, 2011).
Notes: Samples for this table are all farm households in the Terai among cross-section samples of each round of the NLSS.

Table 3.2 summarizes the transitions in landownership and cultivation between 2003 and 2010 of different types of households in the Terai (owner-cultivators, tenants, landless agricultural workers, nonagricultural workers), tracked as panel samples in the 2003 and 2010 rounds of the NLSS. For example, it shows that 71 percent of panel households in 2010 were owner-cultivators in both 2003 and 2010, while 4 percent of households in 2010 were tenants in 2003 but had become owner-cultivators by 2010. Of the owner-cultivator households in 2003 (first column), approximately 7 percent (= [2+ 1 + 2]/[71 + 2 + 1 + 2]) had become landless (becoming either tenants, landless agricultural workers, or nonagricultural workers) by 2010.

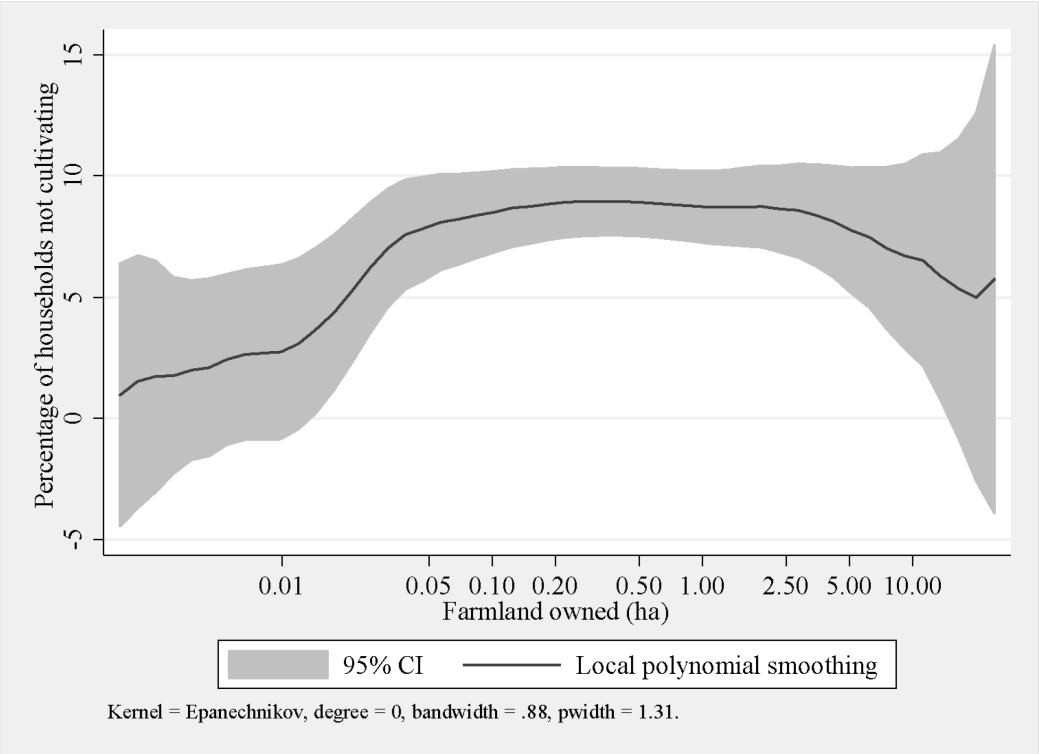
Table 3.2 Exit from / entry into farming among smallholders: Percentage share among the panel sample (all panel farm households in Terai in 2010; N = 396)

Year	Type of farm household	2003			
		Owner-cultivator	Tenant	Landless agricultural worker	Only nonagricultural worker
2010	Owner-cultivator	71	4	3	1
2010	Tenant	2	2	2	0
2010	Landless ag. worker	1	1	4	0
2010	Only nonag. worker	2	0	4	2

Source: Nepal Living Standards Survey (Nepal, CBS 2004, 2011).
Notes: Samples for this table are farm households in the Terai from panel samples in NLSS 2010, for whom information for 2003 are also available. Assuming the same sample weights for 2010 as in 2003.

Figure 3.1 illustrates the relationship between the size of farmland owned (in ha) and the share of farm-owning households not cultivating their plots by themselves, among cross-section samples in 2010. As shown, approximately 8 percent of the farm-owning households in the Terai did not cultivate their land by themselves in 2010. For the range of farmland owned between 0.05 ha and 5.00 ha, this share is fairly constant regardless of the amount of farmland owned. Only for those owning less than 0.01 ha do the shares seem to drop significantly compared with other households, but the households in this category are likely to be few.

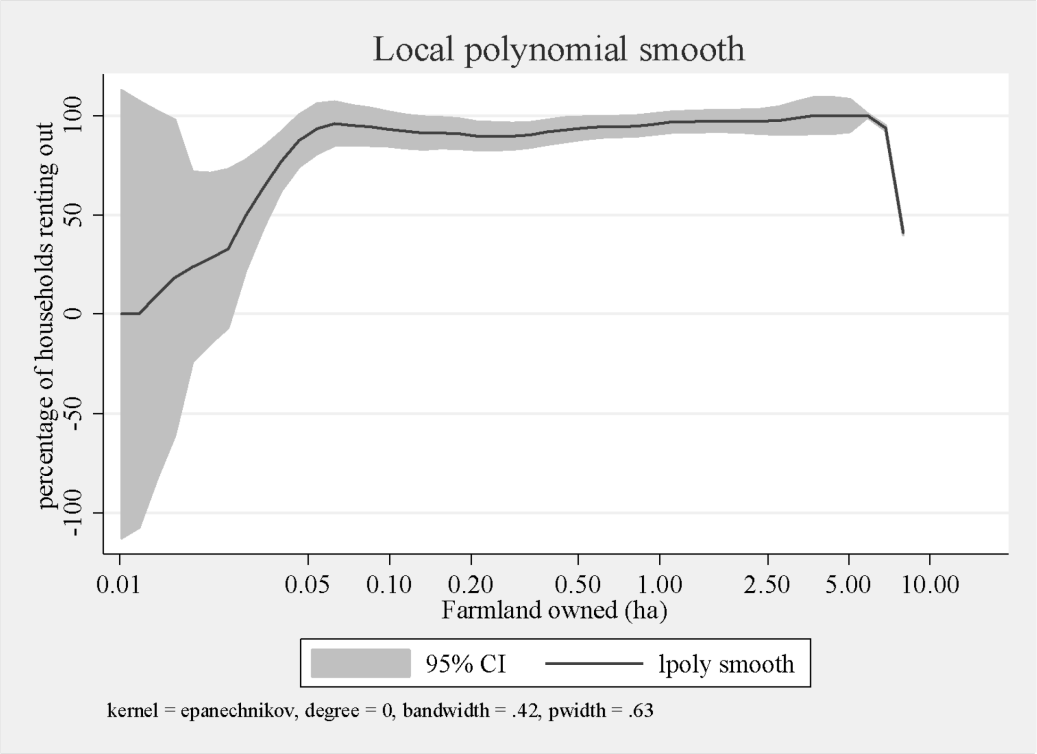
Figure 3.1 Share of households owning farmland but not cultivating it, by size of farmland owned



Source: Authors.
Notes: Sample is all farm households in the Terai from cross-section samples of the Nepal Living Standards Survey 2010. CI = confidence interval.

Do these landowning but not cultivating households always sharecrop / rent out their land to other farmers? Among the cross-section sample from the Terai in 2010, that is the case. Figure 3.2 illustrates the share (percentage) of such households, differentiated by the size of farmland owned. For households owning 0.05 ha or more, the share is around 90–100 percent. The shares are lower among those owning less than 0.05 ha, but these households are relatively few.

Figure 3.2 Percentage of noncultivating landowning households sharecropping/renting out their land, differentiated by size of farmland owned

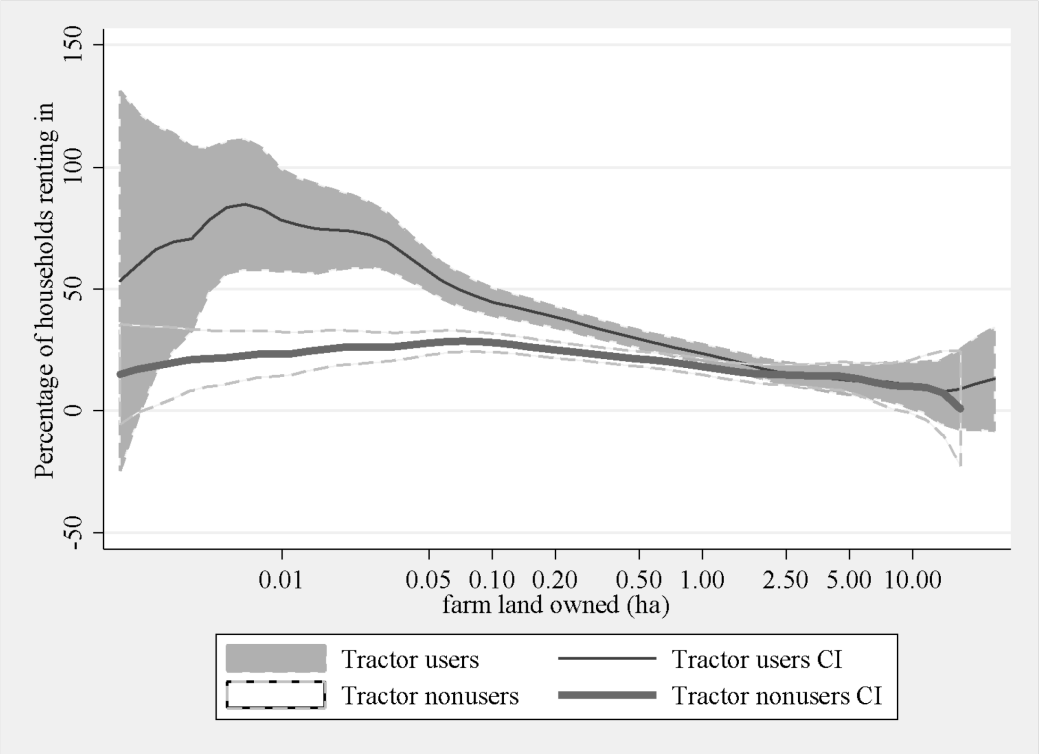


Source: Authors.
Notes: Sample is all farm households in the Terai from cross-section samples of the Nepal Living Standards Survey 2010. CI = confidence interval.

Directions of Land Rental and Relationship with Mechanization Status

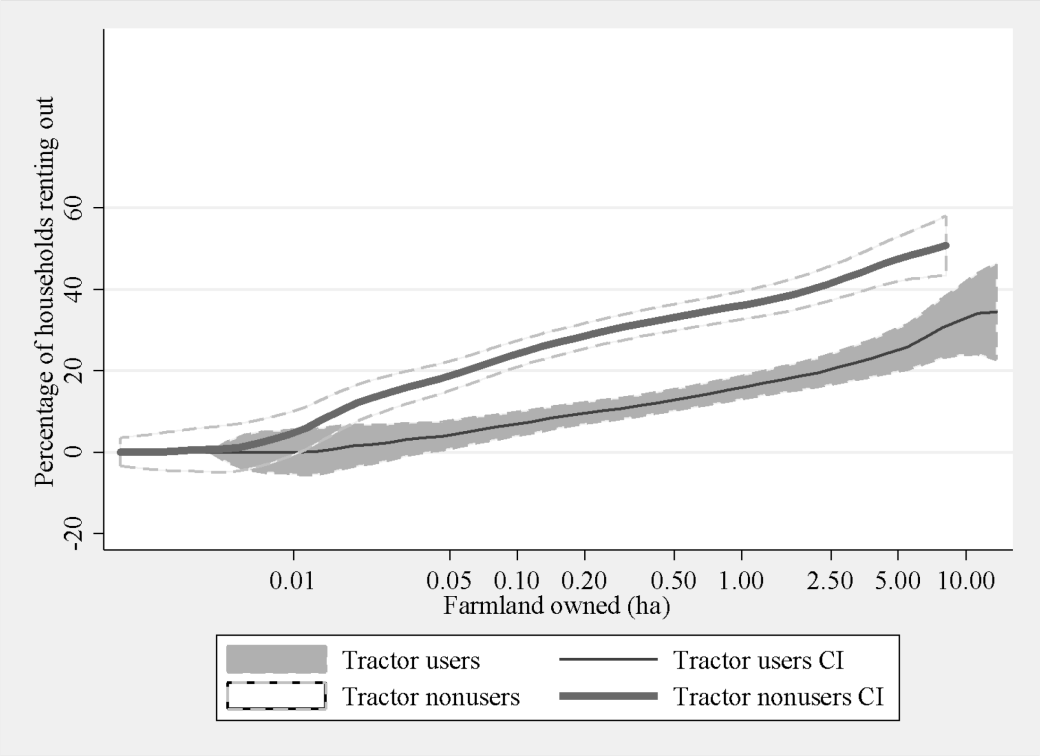
Figure 3.3 illustrates the share of farm households sharecropping/renting in, and how they vary across size of farmland owned and tractor use status. Similarly, Figure 3.4 illustrates the shares of farm households sharecropping/renting out. Overall, land rental/sharecropping appears to be in the direction of large to small (larger farms sharecropping/renting out more land and smaller farms sharecropping/renting in more land).

Figure 3.3 Percentage of farm households sharecropping/renting in land, differentiated by size of farmland owned and tractor use status



Source: Authors.
Notes: Sample is all farm households in the Terai from cross-section samples of the Nepal Living Standards Survey 2010. CI = confidence interval.

Figure 3.4 Percentage of farm households sharecropping/renting out part of their owned land, differentiated by size of farmland owned



Source: Authors.
Notes: Sample is all farm households in the Terai from cross-section samples of the Nepal Living Standards Survey 2010. CI = confidence interval.

Within this overall framework, the use of tractors generally induces more sharecropping/renting in and discourages sharecropping/renting out. Figure 3.3 illustrates that adopting tractors and renting/sharecropping in land seems one of the strong, albeit minor, options available for smallholder farmers. Combined with the overall trend that land is rented/sharecropped in from larger farms, tractor use may have the potential to enable smallholders to expand, shifting the land from larger farms.

Trends in the Shares of Sharecropping Out among Landowning but Noncultivating Households

While sharecropping out has remained the dominant use of farmland owned by households not cultivating their farm, its share has been gradually declining. As shown in Table 3.3, the share of these households only sharecropping out their farm has declined from 76 percent in 2003 to 68 percent in 2010, although the statistical significance of this decline is weak due to small sample sizes. In addition, the share of those renting out has also gradually increased, from 15 percent in 1995 to 24 percent in 2010. Because sharecropping, in contrast to fixed-rate leasing, is often employed to share production risks among landowners and tenants (Singh 1989), this trend suggests that renting out their farmland may be becoming relatively risk-free for these landowning but noncultivating households.

Table 3.3 Different land transaction types among Terai households owning farmland but not cultivating it (regime = 2)

Land transaction type	Year			Total
	1995	2003	2010	
Total sample	**44**	**136**	**150**	**330**
Sharecropping out only (%)	85	76	68	75
Renting / mortgaging out (%)	15	21	24	21
Not renting out (%)	0	3	8	4

Source: Authors.
Note: The samples for this table are households in the Terai who own farmland but do not cultivate it, among cross-section samples from each round of the Nepal Living Standards Survey.

Under the sharecropping arrangements in Nepal in 2010, typically 40 percent of outputs are given to landlords (Table 3.4), although there are some variations in the shares across households. These average figures are generally similar regardless of tractor-use status (shares among tractor users are sometimes slightly lower, but without statistical significance). The average figures are also generally constant regardless of the size of sharecropped area.

Table 3.4 Typical shares in sharecropping: Percentage of outputs given to the landlord, in values (mean)

Types of plot	Terai	Hills	Total
	2010	2010	2010
Rice plot	42 (22)	46 (21)	44 (22)
Wheat plot	43 (30)	34 (34)	39 (32)
All (share in production value)	39 (23)	38 (21)	38 (23)

Source: Authors' calculation based on Nepal Living Standards Survey 2010 (Nepal, CBS 2011).
Notes: The figures are exclusively from farm households who cultivated only through sharecropping. This is because sharecropping households report only the total amount of each crop given to the landlord rather than the specific amount from sharecropped plots, and thus the harvested amount (including the amount reported for home-produced foods in the consumption module) does not distinguish crops grown on sharecropped plots from those grown on other plots. Mean and median values are always found to be very similar. Standard deviations are in parentheses.

4. CONCEPTUAL FRAMEWORK

This study categorizes farm households into three regimes: $R = (0, 1, 2)$. $R = 0$ if a farm household cultivates the plots it owns but without tractors (nontractor cultivators); $R = 1$ if it cultivates the plots it owns with tractors (tractor cultivators); $R = 2$ if a farm household does not cultivate the plot it owns (it either sharecrops/rents the plot out or simply leaves it unused) (noncultivators).[1] While sharecropping/renting out is observed among all three types, this study focuses on the difference in terms of whether the household itself cultivates or not, because that has important implications on "exit from farming."

A farm household chooses one of the regimes, R, and maximizes its income, π, in this particular regime, so that

$$\max_{I_0, I_1, I_2} \pi,$$

subject to

$$\pi = I_0^* \pi_0^* + I_1^* \pi_1^* + I_2^* \pi_2^*.$$

I_R is a binary indicator that takes the value of 1 if regime R is chosen by the household, and 0 otherwise. π_R is the highest value of the outcomes of interest (profit, food consumption, and so on) achievable in regime R given the factors, Z_R, that affect π in each regime:

$$\pi_0 = f(Z_0),$$

$$\pi_1 = f(Z_1), \textit{ and}$$

$$\pi_2 = f(Z_2).$$

However, because of transaction costs (explained below) that are associated with switching regimes, the adjusted π_R^* also depends on the transaction costs to enter the regime:

$$\pi_0^* = f(Z_0, \eta_0),$$

$$\pi_1^* = f(Z_1, \eta_1), \textit{ and}$$

$$\pi_2^* = f(Z_2, \eta_2),$$

in which η_R is the fixed transaction cost to enter into each regime (η_0 may be $= 0$). For those in regime i, η_i may or may not be 0.

Thus,

$$I_R^* = 1 \textit{ and } I_{-R}^* = 0 \textit{ if } \pi_R^* = max(\pi_R^*, \pi_{-R}^*),$$

where "$-R$" denotes all regimes other than R.

An implication is that households select regime R even when $\pi_R < \pi_{-R}$, if the transactions costs are so high that $\pi_R^* > \pi_{-R}^*$.

[1] We use this trichotomous representation because of our particular interests in farmers' mechanization behavior and movement into / out of agriculture. Although farmers engage in diverse land transactions, we focus only on the distinction between whether landowning households cultivate their farms at all or not. In other words, households are categorized into $R = 0$ or $R = 1$ regardless of whether they rent in or out part of their farms or do not engage in rental at all, as long as they cultivate part of their own farms. Future studies should assess whether further breaking down the cultivating households into subgroups would affect the implications of our results.

Effects of Farm Endowments on π_R^*

When the complementarity between tractor use and farm size is strong due to the economies of scale associated with tractors, then $\frac{\partial(\pi_1-\pi_0)}{\partial A} > 0$ (meaning that the benefit of tractor adoption is greater if the farm endowment is greater). In addition, the inverse productivity relationship may be more pronounced in a nonmechanized farm because of greater reliance on labor for farming, a situation in which the supervision costs that account for a significant share of labor costs tend to be more positively correlated with farm size. This condition further strengthens $\frac{\partial(\pi_1-\pi_0)}{\partial A} > 0$.

However, if a tractor simply substitutes for labor and does not help the farmer realize additional gains through economies of scale, and if either there is no inverse productivity relationship or tractor use does not significantly mitigate the inverse productivity relationship, then $\frac{\partial(\pi_1-\pi_0)}{\partial A} = 0$ (meaning that the benefit of tractor adoption is independent of the farm endowment). It is also possible to have $\frac{\partial(\pi_1-\pi_0)}{\partial A} < 0$ if households with larger farms are less constrained than those with smaller farms prior to tractor adoption, and if tractor adoption helps to mitigate the constraints for the latter households. For example, while households with larger farms may have better credit access, those with smaller farms may be cash constrained. If tractor use saves labor costs and helps these smallholders overcome cash constraints, they may benefit not only from savings on labor costs but also from the ability to make more optimal production decisions (a benefit arising from switching to unconstrained optimization).

Similarly, $\frac{\partial(\pi_2-\pi_0)}{\partial A}$ or $\frac{\partial(\pi_2-\pi_1)}{\partial A}$ may depend on various conditions. Conceptually, if small farm sizes limit the returns on family labor from farming compared with a larger farm size, smallholders may gain relatively more from reallocating all family labor into the nonfarm sector while sharecropping/renting out the farm to other farmers. In this case, $\frac{\partial(\pi_2-\pi_0)}{\partial A} > 0$. If this situation holds even with the use of tractors, $\frac{\partial(\pi_2-\pi_1)}{\partial A} > 0$. However, the reverse is also possible if, for example, large farms attract a higher rental rate per area than smaller farms because renters can access large plots of land at lower transaction costs.

All of these factors suggest that the relationship of the relative benefits of the three regimes with farm size can be in either a positive or negative direction. This consideration motivates our empirical investigations.

5. EMPIRICAL METHODS

From the conceptual framework in the previous section, general empirical specifications are now

$$(I_0, I_1, I_2) = I(Z_0, Z_1, Z_2, \eta_0, \eta_1, \eta_2)$$

and

$$(E(\Delta\pi_{01}), E(\Delta\pi_{02})) = g(\hat{\pi}_R, Pr(I_R^* = 1)) = h(Z_0, Z_1, Z_2, \eta_0, \eta_1, \eta_2),$$

where $\hat{\pi}_R$ is observed outcomes and $\Pr(I_R^* = 1)$ is the probability of belonging to each regime.

The empirical condition stated is important. For example, it suggests that $E(\Delta\pi_{01}) = h(\hat{\pi}_0, \hat{\pi}_1, \Pr(I_1^* = 1), \Pr(I_2^* = 1))$, meaning that $\Pr(I_2^* = 1)$ can affect the estimation of $E(\Delta\pi_{01})$ because it affects both $\Pr(I_1^* = 1)$ and $\Pr(I_0^* = 1)$. In other words, $E(\Delta\pi_{01}) = h(\hat{\pi}_0, \hat{\pi}_1, \Pr(I_1^* = 1))$, as in the "two-regime" case in the conventional literature, only if $h(\hat{\pi}_0, \hat{\pi}_1, \Pr(I_1^* = 1), \Pr(I_2^* = 1)) = h(\hat{\pi}_0, \hat{\pi}_1, \Pr(I_1^* = 1))$, meaning that $\Pr(I_2^* = 1)$ is uncorrelated with the true $\Delta\pi_{01}$. However, it is often likely that they are correlated. Our empirical approach incorporates this potential correlation and shows that ignoring it may lead to biased inferences. Importantly, as described later on, if the focus is on the average treatment effect on the treated (ATT) rather than the average treatment effect (ATE), the unconfoundedness assumption does not require independence between $\Pr(I_2^* = 1)$ and $\Delta\pi_{01}$.

Multinomial-Logit Inverse Probability Weighting

The model[2] consists of a set of equations that are estimated by an exactly identified generalized method of moments (GMM):

Equation 1: Score function corresponding to quasi-maximum likelihood estimate of multinomial logit:

$$g(z_i, \hat{\gamma}) = \begin{cases} \{1 - p(z_i, k, \hat{\gamma})\} z_i' & t_i = k \\ -p(z_i, k, \hat{\gamma}) z_i' & \text{otherwise} \end{cases}, \tag{1}$$

where $p(\cdot)$ is the multinomial logit specification,

$$p(z_i, k, \hat{\gamma}) = \frac{exp(z\gamma_t)}{1 + \sum_{k=1}^{q} exp(z\gamma_k)}.$$

Equation 2: Weighted ordinary least squares with dummy variables for each treatment regime:

$$f(w_i, \hat{\beta}) = w_i(y_i - T_i\hat{\beta})T_i'. \tag{2}$$

T is the ith row of the matrix, consisting of dummy variables indicating the treatment status of each regime, with the control group indicator variable replaced by a constant term (at a value of 1 for all observations). $\hat{\beta}$ is the vector of the parameter estimating the ATE or ATT of each regime relative to the control regime. In the case of ATT, w_i is the normalized adjusted inverse probability,

$$w_i = \frac{N_t \delta_i(t)}{\sum_i^N \delta_i(t)}, \tag{3}$$

where

$$\delta_i(t) = \frac{p_1(z_i, k, \hat{\gamma})}{p(z_i, k, \hat{\gamma})}, \tag{4}$$

[2] Other studies have dealt with similar cases in which more than two treatment statuses were considered. Lechner (2002) suggested a series of binomial models, but this method can be computationally costly. Lechner and Miquel (2010) focused more explicitly on the sequence of treatments, and thus this method may not be easily applicable to our case. Hong (2013) developed two-variate propensity score matching, but this method is not applicable to our case.

with $p_1(\cdot)$ being the probability for each i of belonging to regime 1, and $p(\cdot)$ being the probability of belonging to the actual observed regime.

The moment conditions suggest that optimal $\hat{\gamma}$ and $\hat{\beta}$ are solved through GMM using the facts that with $\hat{\gamma}$, $E[g(z_i, \hat{\gamma})] = 0$ (a property of score functions), and with $\hat{\beta}$, $E\left[f\left(w_i, \hat{\beta}\right)\right] = 0$. As shown, $\hat{\gamma}$ affects $\hat{\beta}$ through w_i.

Note that the weights w_i (called ATT weights hereafter) differ from standard weights under the ATE (ATE weights), which use $\delta_i(t) = 1/p(z_i, k, \hat{\gamma})$. In estimations using propensity scores, ATT weights are typically constructed by multiplying the ATE weights for all individuals by p_1 (Pan and Bai 2015). In other words, weights for all treatment samples are 1, and weights for control samples are $p1/p0$ instead of $p0$. Modifying the weights in this way affects the solution of the weighted GMM given above, often leading to a difference between ATT and ATE.

This study focuses on ATT instead of ATE because ATT requires a weaker assumption. Specifically, in the case of two treatments, while ATE requires that $Y^1 \perp t \mid X$ for all treatment groups and $0 < p(\text{regime} = 1) < 1$, ATT requires only $Y^0 \perp t \mid \text{X}$ and $p(\text{regime} = 1 \mid X) < 1$ (Caliendo and Hujer 2006). Although, to the authors' knowledge, literature is thin regarding extending these properties of ATT to multiple-treatment cases, ATT rather than ATE is likely to be more robust in multiple-treatment cases, given the aforementioned implications of a single-treatment case.[3]

Importance of Jointly Estimating Three Regimes

Unlike standard IPW or propensity score matching (PSM) models, which consider only two regimes, our methods jointly consider three regimes through multinomial logit. This issue broadly relates to the issues of unidimensionality of standard IPW or PSM with only two states. While the virtue of the propensity score is the "dimension reduction" for matching (Hahn 1998), this is sometimes considered restrictive.

In a multinomial logit model, the probability of a household's belonging to regime 2 (p_2) affects both p_0 and p_1, even though p_1/p_0 may remain unchanged (in particular under the independence of irrelevant alternatives principle, which holds in models like multinomial logit). Since the IPW estimator depends on the absolute value of p_0, p_1, and p_2, if a particular household i has high p_2 given its characteristics, both p_0 and p_1 are low (and their inverses are high), and therefore IPW places greater weight on this household when estimating average incomes from regime 0 or regime 1. The opposite also applies: if the effects of switching from regime 0 to regime 1 are particularly high for this household, then the estimated average effects of switching from regime 0 to regime 1 are also raised.

Importantly, if we focus only on regimes 0 and 1 but ignore regime 2, the weights p_0 and p_1 will be greater, and less weight will be placed on this household for estimating the effect of switching from regime 0 to regime 1. In other words, if the impact of switching from regime 0 to regime 1 is not independent of p_2 across i, ignoring regime 2 can lead to biased estimates of the average of this impact. A later section demonstrates an example of this effect in our results.

Key Determinants of the Decision Either to Cultivate with Tractors, Cultivate without Tractors, or Not Cultivate (Rent Out or Leave Land Uncultivated)

The same set of variables, X, is used for both the multinomial IPW and parametric methods. The mechanisms of IPW in our case are the same as those of any other impact evaluation using IPW. However, the difference is that in our case, each regime is not really an option for the observed households because moving to a different basin is not an easy decision. Therefore, our multinomial logit is not interpreted in the standard way.

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3 This is also suggested by the formula of ATT weights, in which all ATE weights are multiplied by p_1. In this case, the value of p_1, close to 0, does not inflate the weights as it does for ATE weights, and thus we avoid the "identified-at-infinity" problem raised by Khan and Tamer (2010) by requiring only $p(\text{regime} = 1 \mid X) < 1$ but not $p(\text{regime} = 1 \mid X) > 0$.

In a typical multinomial logit model, results are interpreted as the probability that a household *I* (with characteristics *X*) chooses option *m*. In our multinomial logit model, results are interpreted as the probability that a household *I* (with characteristics *X*) appears in regime *m* in the data at hand. Because of this difference, the estimated results in our case have no causal interpretation (while in the typical impact evaluation case, it is possible to interpret from multinomial logit that *X affects* the choice of *m*). However, our approach works exactly in the same way as in typical impact evaluation studies, by constructing suitable counterfactuals for observed outcomes through the use of probability weights.

The set of variables *X* is therefore selected in the same way as in a typical impact evaluation case. As shown in Table 5.1, these variables consist largely of (1) agroecological conditions; (2) access to complementary inputs and technologies; (3) household demographics; (4) household assets/wealth; (5) land market activity; (6) tractor market development; (7) access; and (8) time, administrative, and other multiple factors. As pointed out, we include not only factors that may directly affect tractor adoption but also factors that more broadly affect agricultural productivity, because the latter often affect tractor adoption indirectly.

Table 5.1 Variables

Group	Variable
Agroecological condition	Distance to nearest major river
	Soil type (similarity with soils at nearby agricultural research stations)
	Rainfall (historical average)
	Rainfall uncertainty (historical standard deviation)
	Terrain ruggedness
	Agricultural land per population
Access to complementary inputs and technologies	Size of lowland farm plots owned
	Distance to agricultural research station
	Wages
	Chemical fertilizer price
	Farm manure endowments
	Share of households using canal irrigation in VDC area
	Share of households using natural surface water irrigation in VDC area
	Agricultural capital owned
Household demographics	Age, gender
	Number of members (adults, children, genders)
	Years of education
Household assets/wealth	Value of assets other than farm, owned house, and owned nonfarm land
	Whether household has enterprise business assets
	Whether household receives remittances
Land market activity	Sold farmland in the previous year
	Sample share (%) of landless agricultural households in VDC area
Tractor market development	Share of farm households renting out tractors in VDC area and district
Access	Access to nearest market center
	Access to nearest agricultural center
	Access to nearest paved road
	Access to nearest bank
Time	Year dummies
Political/administrative factor	Development region dummies
Other multiple factors	Distance to Indian border

Source: Authors.
Notes: VDC = village development committee.

Distance to the nearest major river and average rainfall indicate the general accessibility to water, while soil type (the similarity of the farm's soil to that of the area where the nearest agricultural research station, or ARS, is located) captures the suitability of improved varieties and cropping systems, often developed by an ARS. Note that this variable is different from the distance to the nearest ARS, which rather affects the diffusion of improved technologies. Rainfall uncertainty can capture rainfall risks that affect the returns on farm power use, as well as onset risks that affect the timing of plowing (Takeshima 2015). Terrain ruggedness can affect the suitability of using tractors as opposed to animals. Finally, agricultural land per population captures spatial variations in the land-to-labor ratio.

The size of lowland farm plots owned is included because tractors may be used more intensively on lowland than upland plots, and in the Nepal Terai, lowland plots vary more substantially across households than upland plots. Wages, chemical fertilizer prices, farm manure endowments, share of households using irrigation of different types, and agricultural capital owned all capture the cost and accessibility of other inputs that are complementary to tractors.

Age, gender, and education level of the household head capture various demographics on tractor adoption. The number of household members disaggregated by adults, children, and gender captures family labor endowments for farming as well as the dependency ratio, which affects opportunity costs.

Household assets/wealth generally captures the ability to pay for tractor services as well as other complementary inputs. Its evaluation excludes the farm, owned houses, owned nonfarm land, and enterprise business assets, which are often difficult to liquidate quickly. As described below, households owing houses and nonfarm land are excluded from the analyses to improve the balancing properties of the sample. Whether the household receives remittances can affect the additional income that can be used to pay for renting tractors.

Land market activity is intended to capture the transaction costs of selling farmland. The share of landless agricultural households in the village development committee area (VDC) intends to capture the potential demand for farmland rental.

Tractor market development, measured as the share of farm households renting out tractors in the VDC and district, is intended to capture the accessibility of tractor services. This indicator is used because tractor service provision is often limited to a certain locality, given the indivisibility and low mobility of machines in many developing countries (Takeshima, Edeh, et al. 2015).[4]

Access to various types of infrastructure or key institutions is measured by the time it takes to reach the nearest market center, agricultural center, paved road, and bank. Agricultural center is different from the ARS mentioned above and provides more general services, such as inputs distribution and extension, while an ARS focuses more on technology development.

Both time-specific effects and administrative zone–specific factors are captured by their dummy variables. Finally, distance to the nearest Indian border is included to control for other miscellaneous multiple factors, particularly those associated with access to the information, goods, and technologies supplied in India.

[4] Note that we use the share of farm households "renting out" tractors, rather than the share of those "renting in" tractors. This is because the latter variable would be contaminated by various mechanization demand factors, which are controlled for by the many other VDC-level variables and household characteristic variables already included. In contrast, the former variable captures important variations across VDCs in the density of tractor service providers, which is often affected by the presence of households that invest in considerably expensive capital goods like tractors, and relatively independent of other VDC-level variables and household characteristic variables already included.

6. DESCRIPTIVE STATISTICS

Samples of Focus

As discussed above, we need to construct samples that are comparable across regimes (farming without tractors, farming with tractors, and not farming) in order to identify the effect of switching regimes. While the IPW method can facilitate the construction of such samples, it still requires that we start out with fairly comparable samples. Therefore, this study limits our samples to the following:

1. Households in the Terai zone
2. Farm households owning farmland (excluding landless agricultural households)
3. Districts with at least one sample in regime 1
4. Districts with at least one sample in regime 2
5. Households owning any type of agricultural equipment
6. Households that purchased farmland in the year prior to survey (very few; does not affect the results, but affects the balancing properties)
7. Households with heads with more than 12 years of education
8. Households that own their houses
9. Households without nonfarm land (aside from the residence)

Households that satisfy these criteria are relatively comparable across three types of regimes. Households that do not satisfy these criteria are typically found only among particular regimes, making it difficult to compare similar households across regimes. Limiting the sample as above improves the internal validity of the analysis but limits its external validity. Therefore, findings among households that satisfy these criteria should be generalized to other households with caution.

Key Descriptive Statistics across Types of Households

Table 6.1 summarizes the sample means of covariates across different regimes among the samples selected based on the above criteria. We show both unweighted and inverse probability–weighted statistics (the results of the multinomial logit model from which the inverse probability weights are calculated are presented in the next section). Similarly, Table 6.2 summarizes the same statistics for medium-size farmers. Since the weights are ATT weights with treatment = regime 1, unweighted and inverse probability–weighted statistics are the same for regime 1 samples.

Table 6.1 Descriptive statistics of smaller farm households (unweighted, weighted)

Variable	Unweighted				IP weighted			
Regime	0	1	2		0	1	2	
Sample size	320	259	48		320	259	48	
Euclidean distance to nearest major river (geographical minutes)	.015	.015	.017		.015	.015	.013	
Agricultural capital owned (natural log)	6.85	6.61	5.54	***	6.77	6.61	6.15	
Manure endowments (natural log)	2.96	2.70	1.89	***	2.85	2.70	2.47	
Size of lowland farm plots owned (ha, natural log)	-1.82	-1.64	-1.78	**	-1.61	-1.64	-1.96	
Soil type (similarity to agricultural research station soil)	.69	.83	.92	***	.87	.83	.63	
Average of historical annual rainfall (mm)	1,337	1,447	1,357	***	1,400	1,447	1,518	
Standard deviation of historical annual rainfall (mm)	564	628	587	***	601	628	609	
Terrain ruggedness index	48.7	36.4	25.9	**	39.8	36.4	39.5	
Age of household head	44.4	46.0	45.2		45.9	46.0	48.1	
Gender of household head (1 = male)	.775	.753	.646		.756	.753	.794	
Years of completed education of household head	2.40	2.86	4.67	***	2.60	2.86	1.36	*
Male adult household members (> 20 yrs)	1.17	1.21	.92	**	1.31	1.21	1.27	
Female adult household members (> 20 yrs)	1.37	1.44	1.25		1.51	1.44	1.84	
Child household members (< 20 yrs)	2.73	2.70	2.04	***	2.88	2.70	2.76	
Household assets value (excluding houses, enterprise-related assets)	1.59	1.96	2.40	**	1.95	1.96	3.21	
% owning any business enterprise–related assets	27	19	31	**	17	19	39	
Euclidean distance to Indian border (geographical minutes)	.090	.092	.083		.080	.092	.122	
Euclidean distance to nearest plant breeding center (geographical minutes)	.341	.248	.284	***	.276	.248	.362	
Distance to nearest market center (geographical minutes)	3.71	3.67	3.43		3.73	3.67	3.53	
Distance to nearest agricultural center (geographical minutes)	3.70	3.62	3.37	**	3.66	3.62	3.77	
Distance to nearest paved road (geographical minutes)	3.58	3.24	3.22	***	3.36	3.24	3.27	
Distance to nearest bank (geographical minutes)	3.98	3.75	3.43	***	3.84	3.75	3.78	
% receiving remittances	34	40	38		39	40	28	
Sample share (%) of landless agricultural households in VDC	18	17	16		16	17	23	
Real agricultural wages (daily wage in kg of cereals, natural log)	2.43	2.47	2.42	***	2.47	2.47	2.40	
Real fertilizer price per kg (in kg of cereals, natural log)	.54	.51	.58	*	.54	.51	.61	
% who sold farmland in the previous year	2.2	3.9	10.4		6.6	3.9	3.9	
Agricultural land per capita in VDC (natural log)	118	100	81	***	105	100	111	
% of sample households in VDC using canal irrigation	34.8	34.4	32.3		33.2	34.4	40.1	
% of sample households in VDC using natural water irrigation	5.4	5.6	5.9		5.9	5.6	6.7	
% of sample households in VDC renting out tractors (yes = 1)	6.9	11.2	12.5		12.5	11.2	17.8	
% of sample households in district renting out tractors (yes = 1)	52.8	54.1	56.3		56.7	54.1	35.3	
Year dummy—2010	55.6	63.7	56.3		60.7	63.7	52.9	
Region dummy (Central)	26.3	53.3	39.6	***	47.7	53.3	44.4	
Region dummy (Western)	10.0	23.9	8.3	***	25.8	23.9	6.9	**
Region dummy (Mid-Western)	14.4	5.4	12.5	***	6.3	5.4	3.1	
Region dummy (Far-Western)	13.8	3.5	18.8	***	3.8	3.5	6.5	

Source: Authors.

Notes: IP = inverse probability; VDC = village development committee area. Asterisks indicate the statistical significance of joint differences of means across regimes, based on F-test or adjusted Wald test: *** 1%; ** 5%; * 10%.

Table 6.2 Descriptive statistics of medium-size farm households (unweighted, weighted)

Variable	Unweighted				IP weighted		
Regime	0	1	2		0	1	2
Sample size	321	302	50		321	302	50
Euclidean distance to nearest major river (geographical minutes)	.014	.016	.015	***	.016	.016	.014
Agricultural capital owned (natural log)	7.52	7.33	5.73	***	7.24	7.33	6.67
Manure endowments (natural log)	3.46	3.24	1.89	***	3.16	3.24	2.76
Size of lowland farm plots owned (natural log)	-.400	-.395	-.487		-.383	-.395	-.360
Soil type (similarity to agricultural research station soil)	.72	.81	.80	**	.84	.81	.85
Average of historical annual rainfall (mm)	1,349	1,419	1,384	***	1,401	1,419	1,366
Standard deviation of historical annual rainfall (mm)	568	607	573	***	598	607	584
Terrain ruggedness index	46.8	34.8	26.1	**	32.3	34.8	56.2
Age of household head	49.2	49.8	47.3		49.9	49.8	50.4
Gender of household head (1 = male)	.82	.82	.60	***	.83	.82	.81
Years of completed education of household head	2.85	3.51	3.62		3.46	3.51	2.47
Male adult household members (> 20 yrs)	1.52	1.49	.98	***	1.45	1.49	1.32
Female adult household members (> 20 yrs)	1.70	1.72	1.48		1.69	1.72	1.67
Child household members (< 20 yrs)	3.20	2.93	2.38	**	2.86	2.93	2.47
Household assets value (excluding houses, enterprise-related assets)	2.07	2.11	2.61		1.98	2.11	3.18
% owning any enterprise-related assets	23	23	16		21	23	11
Euclidean distance to Indian border (geographical minutes)	.094	.093	.089		.084	.094	.099
Euclidean distance to nearest plant breeding center (geographical minutes)	.36	.28	.25	***	.27	.28	.25
Distance to nearest market center (geographical minutes)	3.71	3.64	3.16	***	3.61	3.64	3.76
Distance to nearest agricultural center (geographical minutes)	3.72	3.61	3.43	*	3.56	3.61	3.79
Distance to nearest paved road (geographical minutes)	3.57	3.32	3.01	***	3.35	3.32	3.60
Distance to nearest bank (geographical minutes)	4.01	3.79	3.37	***	3.84	3.79	3.93
% receiving remittances	25	38	30	***	34	38	37
Sample share (%) of landless agricultural households in VDC	19	17	17		17	17	12
Real agricultural wages (daily wage in kg of cereals, natural log)	2.41	2.46	2.41	***	2.45	2.46	2.46
Real fertilizer price per kg (in kg of cereals, natural log)	.59	.50	.58	***	.51	.50	.57
% sold farmland in the previous year	3.4	4.3	2.0		4.9	4.3	13.7
Agricultural land per capita in VDC (natural log)	120	113	81	***	109	113	116
Sample share (%) of households in VDC using canal irrigation	36.2	33.7	33.5	*	33.3	33.7	35.6
Sample share (%) of households in VDC using natural surface water irrigation	5.7	5.3	4.6		5.2	5.3	5.1
% of sample households in VDC renting out tractors (yes = 1)	7.2	10.6	4.0		9.3	10.6	6.6
% of sample households in district renting out tractors (yes = 1)	48.0	54.3	58.0		57.5	54.3	42.1
Year dummy—2010	43.9	61.6	40.0	***	60.6	61.6	59.9
Region dummy (Central)	22.7	40.7	30.0	***	39.0	40.7	30.8
Region dummy (Western)	12.5	24.5	14.0	***	23.8	24.5	28.0
Region dummy (Mid-Western)	17.4	3.6	14.0	***	4.0	3.6	15.6
Region dummy (Far-Western)	12.1	6.0	10.0	**	6.9	6.0	6.7

Source: Authors.

Notes: IP = inverse probability; VDC = village development committee area. Asterisks indicate the statistical significance of joint differences of means across regimes, based on F-test or adjusted Wald test: *** 1%; ** 5%; * 10%.

It is clear that inverse probability–weighted samples are more comparable across regimes than unweighted samples, with very few variables exhibiting statistically significant differences in means across regimes. Therefore, IPW procedures have successfully generated the matched samples, so that any significant differences in outcome variables across regimes can be attributed to the change in regimes rather than any observed covariates. Importantly, IPW generally improves balancing properties by making the means of regimes 0 and 1 closer, while the difference between the mean of regime 2 and other means occasionally becomes wider for some variables, although in general the difference seems narrower. This is because sample sizes in regimes 0 and 1 are larger than that in regime 2, and the similarity of the first two regimes is more important for the overall balancing properties of the sample.

7. RESULTS

Table 7.1 presents the effects of switching regimes, estimated by multinomial IPW (results of the multinomial logit are presented in Appendix Table A.1). Our primary results are from joint estimations (in which the effects of switching from regime 0 to regime 1 and the effects of switching from regime 0 to regime 2 are jointly estimated through multinomial IPW). For comparison, we also show the results from pairwise estimation (in which the former effects and latter effects are estimated separately, through conventional logit).

Table 7.1 Growth rate of real per capita household income from switching mechanization and farming status, estimated from multinomial-logit inverse probability weighting (average treatment effect on the treated)

Farm household group	Compared regimes	Estimation method	
		Joint	Pairwise
Smallholders (owning less than 0.45 ha of lowland plots)	Renting in tractors instead of cultivating manually (regime 1 versus regime 0)	.135* (.076)	.118 (.079)
	Exiting farming instead of cultivating manually (regime 2 versus regime 0)	.306* (.175)	
Medium (owning approx. 0.30–2.50 ha of lowland plots)	Renting in tractors instead of cultivating manually (regime 1 versus regime 0)	.136** (.056)	.136** (.056)
	Exiting farming instead of cultivating manually (regime 2 versus regime 0)	.154 (.216)	

Source: Authors.
Note: *** significance at 1% level; ** at 5% level; * at 10% level. Numbers in parentheses are standard errors based on Huber-White robust sandwich estimators, which provide consistent estimates for the class of inverse probability weighting models.

In most cases, switching from regime 0 to regime 1 (that is, renting in tractors instead of cultivating manually) increases per capita household income for those households who are currently in regime 1. Smallholders (owning less than 0.45 ha of lowland plots) who were renting in tractors instead of cultivating manually at the time of the survey had increased their per capita income by 13.5 percent. This is quite close to the 13.6 percent increase found among medium-size farmers (owning about 0.30–2.50 ha of lowland plots).

The effect of leaving farming and specializing in nonfarm activities, however, differs between these two groups based on farm size. Smallholders who were currently renting in tractors (regime 1) might have increased per capita income by 30.6 percent if they had left farming and specialized in nonfarm activities, compared with farming manually. The same effect among medium-size farmers is much more ambiguous and statistically insignificant. The results weakly indicate that smallholders may have greater incentives to leave farming and specialize in nonfarm activities than medium-size farmers.

Importantly, when the effect of switching from regime 0 to regime 1 is estimated in a pairwise fashion (ignoring the option of regime 2), the estimated effect is 11.8 percent, which is statistically insignificant at the 10 percent level. A possible explanation for this is that those with a greater ATT_{10} (regime 1 versus 0) are also more likely to be in regime 2.[5] Because of such self-selection, when we limit our analysis to those who remained in farming, we tend to underestimate the effect of renting in tractors. This condition is likely to arise if a large number of farmers who would potentially gain more by switching from regime 0 to regime 1 (from manual cultivation to tractor user) are also leaving farming to specialize in off-farm activities. The results point to an important improvement attained by using joint estimates over conventional pairwise estimates, which are typically used in impact evaluation literature.

[5] Their p_1 (if in regime 1) or p_0 (if in regime 0) is lower in the joint estimate than in the pairwise estimate, so that they both receive greater weights in joint estimates than in pairwise estimates; in other words, their ATT_{12} or ATT_{02} is more informative, and the model adjusts the estimates of ATT_{10} appropriately by placing greater weight on ATT_{12} and ATT_{02} (from which ATT_{10} is derived) than on direct estimates of ATT_{10}.

Overlap Properties

As discussed above, the overlap condition required for the ATT estimation is that the propensity score for belonging to regime 1 be strictly lower than 1. Table 7.2 reports the upper tails of the propensity scores of samples in each regime. It shows that the highest propensity score is 0.976, and most scores are less than 0.900. While the literature provides no criteria for how much lower than 1 the propensity score must be, there is no clear evidence that propensity scores are massed around 1, and therefore this test serves as weak evidence that the overlap condition is satisfied.

Table 7.2 Upper-tail distribution of propensity scores for belonging to regime 1

		Percentile of samples			
Farm household group	**Sample**	**90th percentile**	**95th percentile**	**99th percentile**	**Maximum**
Smallholders	Regime 0	.642	.694	.793	.889
	Regime 1	.829	.848	.893	.934
	Regime 2	.679	.770	.806	.806
Medium-size farmers	Regime 0	.621	.674	.821	.903
	Regime 1	.902	.943	.966	.976
	Regime 2	.679	.748	.959	.959

Source: Authors.

For IPW methods, an additional requirement is that the propensity score of belonging to regime 1 be strictly greater than 0 for the regime 1 sample. Thus, weighting by the inverse of probability (which is close to 0) amounts to weighting by infinity, leading to the "identified at infinity" problem discussed by Khan and Tamer (2010). Table 7.3 shows the lower-tail distribution of estimated propensity scores for the regime 1 sample. It shows that all propensity scores are different enough from 0 and therefore are unlikely to affect the identification problem.

Table 7.3 Lower-tail distribution of propensity scores for belonging to regime 1

		Percentile of sample			
Farm household group	**Sample**	**Minimum**	**1st percentile**	**5th percentile**	**10th percentile**
Smallholders	Regime 1	.060	.096	.152	.230
Medium-size farmers	Regime 1	.039	.124	.179	.249

Source: Authors.

Balancing Properties

Although Cattaneo (2010) and Busso, DiNardo, and McCrary (2014) focused only on the overlap conditions and did not explicitly discuss the balancing properties of covariates, it is common practice in the IPW literature to check whether the weighted mean of the covariates does not differ statistically significantly across groups of different treatment status (Cavatassi et al. 2011; Takeshima 2017).

Because our analysis deals with three treatment statuses using the IPW method (manual farming, mechanized farming, and exit from farming), we conduct an F-test to see if the weighted means of the covariates differ significantly across the three regimes. As discussed earlier in relation to Tables 6.1 and 6.2, fewer than 10 percent of inverse probability–weighted variables have means that are statistically significantly different across regimes at 10 percent significance, supporting the hypothesis that inverse probability–weighted samples are balanced across regimes.[6]

[6] We also checked the balancing properties following the procedure used by Austin (2009). While its balancing property diagnostics may not readily apply to a small-sample case like ours (balancing is often a large-sample property, as indicated by Austin 2009), IPW generally improved the similarity of both means and variances of the sample distributions of each covariate across regimes.

8. CONCLUSIONS

As in many parts of Asia, Nepal has been increasingly facing the challenge of rising costs of rural labor, which many farmers rely on. Of course, rising wages are welcomed by substantial shares of the population in Nepal because they reflect a growing income-earning opportunity in the nonfarm sector within and outside of Nepal. However, the trend also affects the competitiveness of smallholder farming and thus requires the government to rethink its overall agricultural sector support strategies.

This paper shows that among the samples of Terai farm households for whom suitable counterfactuals can be found, smallholder farmers owning less than 0.45 ha of lowland plots are likely to benefit more (in terms of per capita household consumption) from the adoption of tractors through custom hiring services, but they may also have incentives to exit farming and specialize in nonfarm income-earning activities. Farm households owning approximately 0.30–2.50 ha of lowland plots, on the other hand, are likely to benefit more from continuing mechanization with tractors. Importantly, not accounting for the possibility that some smallholders may exit farming may lead to underestimating the benefit for smallholders of adopting tractors, because of the sample selection problems whereby those who are likely to benefit more from mechanized farming may be also more likely to leave farming and specialize in nonfarm activities.

The results of this study have an important implication. Significantly, the benefits of mechanization identified suggest that smallholders face barriers to both adopting tractors and specializing in off-farm activities, potentially due to various imperfections in custom-hired tractor markets, land markets, and so forth, which can be alleviated by appropriate government interventions. The role of mechanization in smallholder farming is affected by smallholder farmers' decisions to exit farming and specialize in nonfarm income-earning activities. The results suggest that if such a transition is difficult and many smallholder farmers are forced to remain in farming, mechanization with tractors can benefit these smallholders, not just medium to large farmers. Given our findings, custom-hired tractor services should continue to be promoted not only for medium to large farmers but also for smallholders. If, over time, barriers to specializing in nonfarm activities become lower and more smallholders start leaving farming, mechanization may no longer benefit the remaining smallholders. Support for mechanization can then be focused more on medium to large farmers, while different types of support other than mechanization can be sought for the remaining smallholders.

APPENDIX: MULTINOMIAL LOGIT RESULTS

Table A.1 Results of multinomial logit model

	Smallholders		Medium-size farmers	
Dependent variable	**Regime 1**	**Regime 2**	**Regime 1**	**Regime 2**
% of households renting out tractor in VDC in the sample (yes = 1)	.317	.594	-.027	-.782
% of households renting out tractor in district outside the VDC in the sample (yes = 1)	.199	.585	-.367	-.133
Euclidean distance to nearest major river (geographical minutes)	-20.620	17.308	16.850	19.691
Agricultural capital owned (natural log)	-.376*	-.753**	-.173	-.687**
Manure endowments (natural log)	.284	.368	.059	-.139
Size of lowland farm plots owned (natural log)	.398***	.202	.299	.258
Soil type (similarity to agricultural research station soil)	.714**	2.029***	.261	.394
Average of historical annual rainfall (mm)	-.008	.028	-.003	.024
Standard deviation of historical annual rainfall (mm)	.100***	-.033	.060***	-.075
Terrain ruggedness index	-.001	-.006	-.000	-.003
Age of household head	.001	.040**	-.006	.015
Gender of household head (1 = male)	-.351	-1.283**	.041	.194
Years of completed education of household head	.009	.190***	.016	.036
Male adult household members (> 20 yrs)	.046	-.306	-.089	-.998***
Female adult household members (> 20 yrs)	.132	-.563	.045	.063
Child household members (> 20 yrs)	-.001	-.185	-.026	-.027
Household assets value (excluding houses, enterprise related assets)	.104**	.177*	.044	.130
% owning any enterprise-related assets	-.278	.369	-.005	-.353
Euclidean distance to Indian border (geographical minutes)	2.643	8.511**	1.141	-1.051
Euclidean distance to nearest plant breeding center (geographical minutes)	.745	-1.824	-1.482**	-4.463***
Distance to nearest market center (geographical minutes)	.140	.467	-.061	-.369
Distance to nearest agricultural center (geographical minutes)	.057	.157	-.034	1.092***
Distance to nearest paved road (geographical minutes)	-.247	.026	.030	-.131
Distance to nearest bank (geographical minutes)	-.138	-.852*	-.125	-.992
% receiving remittances	-.096	-.151	.086	.984
Sample share (%) of landless agricultural households in VDC	.312	.597	-.517	.133
Real agricultural wages (daily wage in kg of cereals, natural log)	1.492	-4.346**	1.158	-1.869
Real fertilizer price per kg (in kg of cereals, natural log)	.306	.986	-.801	.490
% sold farmland in the previous year	.000	.013	.000	.000
Agricultural land per capita in VDC (natural log)	-.103	-.838**	.088	-.617*
Sample share (%) of households in VDC using canal irrigation	.002	-.023	-.005	.007
Sample share (%) of households in VDC using natural surface water irrigation	.026	.040	-.018	-.097**
Year dummy—2010	.901**	.211	.642*	-.974
Region dummy (Central)	Include	Include	Include	Include
Sample size	627		673	
p-value (H_0: variables jointly insignificant)	.000		.000	
Pseudo-R^2	.280		.236	

Source: Authors.
Notes: VDC = village development committee area. *** significance at 1% level; ** at 5% level; * at 10% level.

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