Chapter 9

EVOLUTION OF AGRICULTURAL MECHANIZATION IN NEPAL

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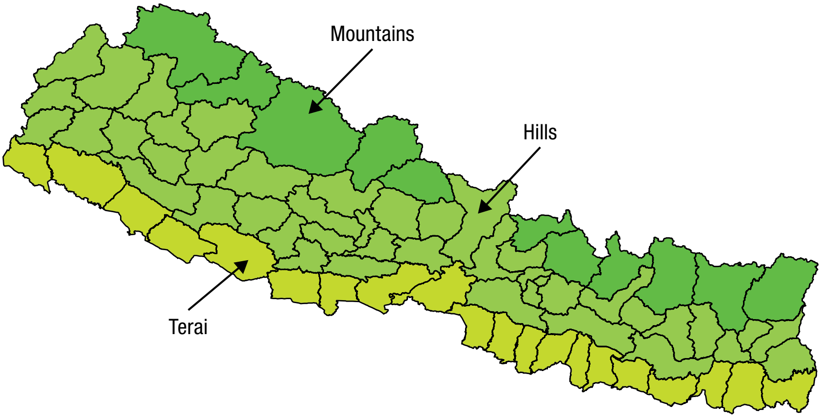
Abstract: Mechanization levels in Nepal, a largely agricultural country, were relatively low until a few decades ago. However, significant mechanization growth, including the adoption of tractors, has occurred since the 1990s, against a backdrop of rising rural wages, particularly for plowing, combined with growing emigration, growth in key staple crop yields, overall broad agricultural production growth, and improved market access and participation. This growth in mechanization has taken place despite the general absence of direct government support or promotion. The growth of tractor use in the plains of the Terai zone has transformed agricultural production rather than inducing labor movement out of agriculture. Thus it has raised overall returns to scale in intensification and enabled the cultivation of greater areas by medium smallholders than by resource-poor smallholders. Tractors have also facilitated the intensification of crop production per unit of land among very small farmers, enabling mechanization growth despite the continued decline in farm size, although these farmers may not have benefited as much as medium smallholders. Potential future research areas with policy relevance include mitigating accessibility constraints on tractor custom hiring services, identifying appropriate regulatory policies for mechanization, and providing complementary support to some smallholders who may not fully benefit from tractor adoption alone.

Historical Background of Mechanization Evolution in Nepal

The mechanization level in Nepal, a largely agricultural country, was relatively low until a few decades ago. Significant mechanization growth, including the adoption of tractors, has occurred since the 1990s. The growth patterns have varied considerably across the country's diverse agroecological environments

This chapter is a shortened version of Takeshima (2017b), which contains more detailed description of the historical evolution of mechanization in the country.

FIGURE 9.1 Agroecological belts in Nepal



Source: Authors.

(Figure 9.1). Table 9.1 summarizes the key mechanization growth trends, as well as the relevant background economic structure of the country in the past several decades. As far as mechanization is concerned, the recent era can be categorized into roughly three periods: (1) pre-1990s, (2) 1990s–2006: takeoff of tractor adoption rates in the Terai, and (3) 2006 and after: widespread growth of tractor adoption throughout the Terai, takeoff of motorized pumps in the Terai, and takeoff of power tillers and mini-tillers in the Hills.

Demand-Side Analysis

Use and/or Ownership of Tractors and Combine Harvesters

Nepal has diverse agroecological environments (Table 9.2) that cut across its five development regions, (from east to west) Eastern, Central, Western, Midwestern, and Far Western. Most notably, whereas the Terai is characterized by more lowland and flatter terrain, the Hills region is characterized by greater endowments of upland and more rugged terrain, as well as more pastures and draft animals.

TRACTORS

Growth in tractor use in Nepal has occurred mostly in the Terai, whereas growth has been slower in the Hills, based on data from the Nepal Living Standards Survey, or NLSS (Nepal, CBS 1996, 2004, 2011); however, there

TABLE 9.1 Evolution of different scales of mechanization in Nepal, 1970–2016

Variable	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999	2000–2004	2005–2009	2010–2016
Percentage of farm power availability from different sources									
Mechanical	—	—	8	—	15	—	32	—	—
Animal	—	—	43	—	39	—	28	—	—
Labor	—	—	49	—	46	—	40	—	—
Approximate number of tractors estimated from various sources									
All tractors	—	2,000	—	5,000	8,500	16,300	25,000	30,000	47,000
4-wheel tractors	—	1,700	—	4,000	7,200	—	—	—	30,000
2-wheel tractors	—	300	750	1,000	1,300	—	—	—	12,000
Mini-tillers	—	—	—	—	—	—	—	500	5,000
Farmers adopting tractors (%)									
Nepal	—	—	—	—	1	5	16	—	23
Terai zone	—	—	—	—	—	8	29	—	46
Rice and wheat areas harvested by combine harvesters (%)									
Western Terai (Kapilbastu, Rupendhai, and Nawalparasi)	—	—	—	—	—	—	1	2	10
GDP share (%)									
Agriculture	68	66	61	51	46	41	38	34	35
Industry	10	10	12	16	19	22	19	17	16
Service	22	24	27	33	35	37	43	49	49
Labor force in agricultural sector (%)	—	—	—	—	83 (1991)	76 (1999)	—	74 (2008)	67 (2013)
Male (%)	—	—	—	—	75	67	—	62	—
Female (%)	—	—	—	—	91	85	—	84	—

Source: Takeshima (2017b).
Note: — = data not available; GDP = gross domestic product.

are some indications that use has been growing faster since 2010 (the most recent round of the NLSS), particularly in the Central development region, thanks to growth in the use of power tillers and mini-tillers. Within the Terai, the Central and Western development regions led the diffusion of tractor use, but the Eastern, Midwestern, and Far Western development regions have caught up (Table 9.3).

Although NLSS data do not report which crops tractors are actually used for, the correlation of crops grown by the households and their tractor use offers certain insights. Table 9.4 summarizes the share (percentage) of farmers

TABLE 9.2 Land-to-labor ratio, terrain ruggedness, and draft animal holdings, Nepal, 2010

Development region	Agricultural area per capita (cropped area + pasture) (ha)		Average owned farm size (lowland) (ha)		Average owned farm size (upland) (ha)		Terrain ruggedness index		Draft animals per farm household (bullocks/cows/ buffalo)	
	Terai	Hills	Terai	Hills	Terai	Hills	Terai	Hills	Terai	Hills
All	0.12	0.22	0.59	0.19	0.09	0.39	43	478	2.2	3.0
Eastern	0.13	0.25	0.59	0.26	0.09	0.54	38	463	2.4	3.5
Central	0.09	0.16	0.60	0.21	0.10	0.28	22	405	1.7	2.4
Western	0.13	0.19	0.69	0.17	0.03	0.35	36	489	2.0	2.6
Midwestern and Far Western	0.12	0.29	0.48	0.13	0.11	0.43	90	554	2.7	3.8

Source: Takeshima, Adhikari, et al. (2015).

TABLE 9.3 Share (percentage) of farm households using tractors, by year and agroecological belt, Nepal, 1995–2010

Development region	Terai			Hills			Mountains		
	1995	2003	2010	1995	2003	2010	1995	2003	2010
All	8	29	46	3	5	8	1	0	2
Eastern	2	13	33	0	0	2	1	0	0
Central	11	39	56	5	9	20	0	0	5
Western	15	56	72	1	4	5	0	0	0
Midwestern and Far Western	5	15	29	1	0	1	1	0	0

Source: Takeshima, Adhikari, et al. (2015).

growing each of the major crops, differentiated by their tractor use status, in the Nepal Terai and Hills in 2010.

One of the dominant staple-crop production systems in the Nepal Terai is the well-known rice-wheat systems that are common in the Indo-Gangetic Plain, in which rice is grown during the rainy season and wheat is produced during the dry season. In 2010, 70 percent and 50 percent of tractor-using farm households and nonusing farm households, respectively, practiced this system in the Nepal Terai (Table 9.4). Although other crops such as maize, lentils, potatoes, and vegetables are also commonly grown, tractors are most commonly used for tillage for rice and wheat (Ladha et al. 2003). In this system, water leveling and wet tillage (puddling) are common forms of tillage for rice, and intensive deep tillage is practiced for wheat at the beginning of the dry season to reduce the soil compaction developed from rainy-season rice

TABLE 9.4 Mechanization and cropping patterns (percentage of farmers growing each crop), Nepal, 2010

	Terai						Hills					
	2010 season		2010 rainy season		2010 dry season		2010 season		2010 rainy season		2010 dry season	
Crop	Tractor users	Non-users	Tractor users	Non-users	Tractor users	Non-users	Tractor users	Non-users	Tractor users	Non-users	Tractor users	Non-users
Rice	95	74	93	72	2	2	90	64	89	63	17	3
Wheat	69	50	0	0	69	50	47	49	0	0	47	48
Maize	38	44	22	34	15	11	73	95	67	91	17	9
Winter maize	16	10	1	0	15	11	17	9	0	1	17	9
Summer maize	21	36	22	34	0	0	67	90	67	90	0	0
Lentils	58	41	0	0	57	41	5	15	0	0	5	15
Winter potatoes	57	53	0	0	52	47	57	46	0	0	57	46
Mustard	48	35	0	1	46	33	31	38	1	1	30	36
Onions	37	37	1	1	27	29	20	24	2	1	18	23
Garlic	42	40	1	1	28	30	27	28	0	2	27	26
Winter vegetables	60	67	1	1	49	59	56	67	2	1	54	66
Summer vegetables	51	57	38	51	1	0	48	66	46	65	2	1

Source: Authors' calculations based on data from the Nepal Living Standards Survey for 2010 (Nepal, CBS 2011).

production. Four-wheel tractors rather than two-wheel tractors have traditionally been more commonly used, because the soil is dry when deep tillage for wheat is practiced and requires fairly strong machine power. Relatedly, wet tillage for rice is often practiced by relying on monsoon rains (Sharma, Ladha, and Bhushan 2003) rather than thoroughly flooding by irrigation, for which four-wheel tractors can be used.

In the Hills, the association between tractors and wheat appears weaker. In addition, although maize (particularly summer maize) is more widely grown in the Hills than elsewhere, the share of maize growers is higher among non-users of tractors. Therefore, in the Hills, tractors may be more strongly associated with rice.

COMBINE HARVESTERS

The extent of combine harvester use in Nepal is not well known, partly because neither the agricultural census nor the NLSS collects such information. Recent studies report that where harvesting services are provided, they are provided by private-sector actors, including large combine owners in India (Biggs, Justice, and Lewis 2011) or within the Terai (Pant 2013). Areas studied by Pant (2013) were populated by farmers with medium-size landholdings (2–3 ha), for whom rice was harvested at a rate of about 0.70 ha per hour and at a cost of about $50[1] per hectare, a price that is approximately 25 percent lower than the cost of manual harvesting. A recent study in the Western development region of the Terai (Kapilvastu, Rupandehi, and Nawalparasi districts) suggests that the number of combine harvesters in these districts has increased from 1 in the year 2000 to 24 in 2010 and 150 in 2014, by which time 21 percent of wheat area and 8 percent of rice area in these districts might have been harvested by combine harvesters (Paudel et al. 2015).

Key Characteristics of Terai Farm Households with Different Mechanization Statuses

Takeshima (2017b, Table 2.4) summarized the key characteristics of Terai and Hills households, differentiated by farming status and further by mechanization status. Farm households generally consume less than nonfarm households do, as measured by real expenditure per capita. Within farm households, tractor-owning households enjoy higher consumption and own more assets than other farm households. In 2010, their expenditures and asset values were about 4 to 6 times higher than the levels of all farm households in the Terai, and more than 10 times higher than those of households in the Hills. Differences between tractor renters and users of only draft animals are smaller than those between tractor owners and users of draft animals. Tractor renters, however, enjoy consumption and assets that are typically 30–50 percent higher than those of draft-animal-only users in the Terai. In the Terai, nonmechanized households' incomes and assets are typically much lower than those of other farm households.

About 40–50 percent of farm households sell their crops, and 60 percent sell either crops or livestock products. These shares are higher among tractor owners, followed by tractor renters and draft-animal-only users. Nonmechanized farm households are primarily engaged in subsistence agriculture. Working-age members of tractor-owning households are better educated, having completed, on average, approximately seven years of schooling, substantially more than the average for other farm households (Takeshima 2017b).

Tractor renters also have generally better market access than draft-animal-only households and other nonmechanized households. This is particularly pronounced in the Hills. In the Terai, between 2003 and 2010, more tractor

1 Dollar figures are US dollars throughout the chapter.

owners emerged in suburban areas or areas where access had improved (closer to various facilities than non-owners, unlike in 2003). Much growth in tractor ownership in the Terai between 2003 and 2010 occurred in relatively suburban areas instead of remote farm areas (Takeshima, Adhikari, et al. 2015).

In the Hills, wages vary more across household types, and tractor renters pay higher wages than do farmers not using tractors. Mechanization status is also positively associated with local land-to-labor ratios (measured in agricultural land endowment per capita, which combines cropped areas and pastures). Intuitively, farm households are in areas with greater agricultural land endowment than are nonfarm households. Among farm households, tractor owners or tractor users are in areas less endowed with agricultural land than are draft animal users, possibly because pastures are important sources of feed for animals.

Mechanization status is closely negatively associated with terrain ruggedness. Specifically, more tractors are used in flatter areas than in rugged areas, and tractor owners are located in especially flat areas. This applies to both the Terai and the Hills, even though the Hills zone has considerably more rugged terrain than the Terai overall.

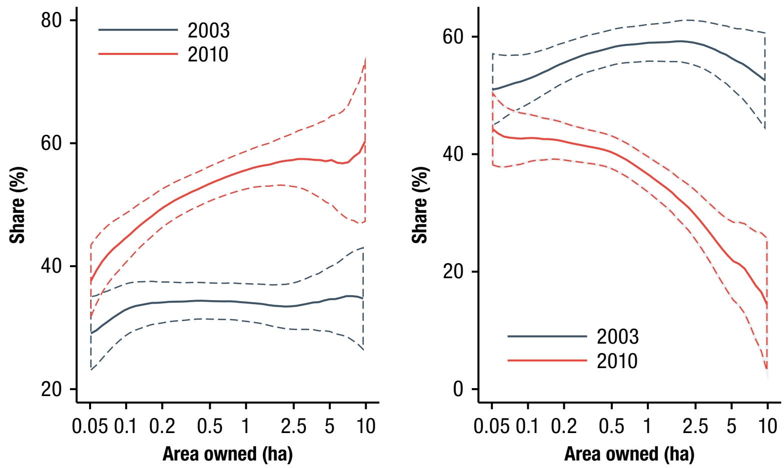
Farm Size Distribution and Tractor Use

In the Nepal Terai, tractor use has grown while average farm size has declined over time due to growth in the absolute number of farm households and also due to land fragmentation (Takeshima, Adhikari, et al. 2015). However, tractor adoption is still positively associated with farm size (Takeshima 2017b, Table 2.4). Tractor-owning households tend to own more farmland than other farm households. Though the patterns are less clear in the Hills, tractor owners own the largest lowland areas (though their cultivated areas are not the largest). However, the extent of substitution of tractors for animal traction in the Terai between 2003 and 2010 was greater among larger farm households (Figure 9.2). Consequently, although in 2003 tractor adoption rates were relatively uncorrelated with farm size, by 2010 they were positively correlated with farm size.

Evolution of Farm Household Characteristics

Although Takeshima (2017b, Table 2.4) compared farm household characteristics across mechanization statuses in 2010, the evolution of overall farm household characteristics up to 2010 also provides a useful indication of the context in which tractor use has grown (Table 9.5).

FIGURE 9.2 Share of Terai farm households renting tractors or using only draft animals, by farm size (left = tractor renters; right = draft animals only), Nepal, 2003 and 2010



Source: Takeshima, Adhikari, et al. (2015).
Note: Dashed lines represent 95% confidence interval.

Between 1995 and 2010, for many farm households in the Terai, access to markets improved considerably, and at a relatively faster rate than in the Hills and Mountains. This access has been associated with increased market participation, which was also slightly higher in the Terai throughout this period. Better market access and adoption of tractors are often positively related because the former often induces more intensive land preparation, for which the substitution of tractor power for animal power has greater returns, and also because tractors may offer an important means of transporting harvests to market. During this period, the operational scale of farm households, in terms of production revenues, increased as well. The operational scale of farm households in the Terai was greater than that of households in the Hills or Mountains and grew relatively faster between 1995 and 2010.

This growth occurred despite the continued decline in average farm size due to fragmentation. The share of those cultivating less than 0.2 ha increased, whereas the share of those cultivating more than 3.0 ha a year decreased. The growth in tractor adoption in the Terai reduced the rate of this decline (this is the positive effect on area cultivated, presented in the later section of this chapter titled “Role of Mechanization in Agricultural Transformation”), but

TABLE 9.5 Farm household characteristics, Nepal, 1995–2010

	Terai			Hills			Mountains		
Variable	1995	2003	2010	1995	2003	2010	1995	2003	2010
Households in farming (%)	76	73	72	88	80	76	97	96	91
Selling crops (%)[a]	52	86	77	38	59	57	41	57	53
Selling crops or livestock products (%)[a]	70	89	85	63	72	73	56	78	68
Area cultivated per year (ha)									
Average (ha)	2.4	2.0	1.4	1.5	1.3	1.0	2.1	1.6	1.3
Distribution (%)									
< 0.2 ha	8	9	15	11	9	12	7	6	5
0.2–3.0 ha	67	72	74	81	83	84	75	84	88
> 3.0 ha	25	19	11	8	8	4	18	11	7
Annual agricultural revenue (crop + livestock) (equivalent to metric tons of cereal)									
Average	3.3	4.5	4.5	2.2	3.2	2.7	2.1	2.8	2.6
Distribution (%)									
< 1.0	22	17	20	30	20	22	30	14	20
1.0–3.0	32	31	33	48	39	46	49	49	52
> 3.0–5.0	21	20	19	15	23	20	14	27	20
> 5.0	25	33	29	7	18	11	7	11	8
Share (%) of agricultural revenue in total Household revenue (among farm households)	79	73	73	82	75	77	87	81	81
Rice, wheat, and maize	57	51	45	42	35	31	42	40	31
Other crops	28	33	36	35	38	43	40	37	47
Livestock products	15	16	19	23	27	26	18	23	22
Time to nearest market center (minutes)	120	60	30	150	180	120	180	180	120

Source: Authors' calculations based on data from the Nepal Living Standards Survey for 1995, 2003, 2010 (Nepal, CBS 1996, 2004, 2011).

Note: a. Figures are weighted by the area cultivated by the household.

it has not caused a substantial turnaround in average farm size. The aforementioned growth in operational scale in terms of production value has therefore been achieved through substantial growth in production value per calculated area.

Importantly, the growth in the production scale in terms of value occurred without substantial changes in household revenue composition; the share of revenues from staple crops (rice, wheat, and maize) remained high and declined relatively slowly, and agricultural revenues remained the majority of overall household revenues. In the Terai, household economic growth was relatively neutral across activities, growing not only for nonagricultural activities but also for agricultural activities, including the production of key staple crops. It was in this context that the adoption of tractors grew rapidly among farm households in the Terai.

Broader Economic Transformation and the Labor Market

Although both agricultural and nonagricultural sectors have grown in Nepal, labor has gradually shifted to more labor-intensive nonagricultural sectors. Combined with the increase in average education levels between 1995 and 2010—from 2.5 to 4.7 years of schooling for those 15 years of age or older (Takeshima, Adhikari, et al. 2015)—this shift in labor has raised farming wages. Takeshima (2017b, Table 2.6) summarized the breakdown of labor activities and the evolution among the working-age population (ages 15–59), which accounts for approximately 55 percent and 58 percent of males and females, respectively, in Nepal. In addition to the aggregate shares of labor force by sector, shown in Table 9.1, Takeshima (2017b, Table 2.6) provided further insights into the breakdown across agroecological belts, more disaggregated types/sectors of activities, and the effects of out-migration on the overall workforce, which are often not taken into account in a standard view of the employment share by sector. Importantly, because Takeshima (2017b, Table 2.6) also allocated shares to emigrants and those who were not working for various reasons, the shares he reported for both the agricultural sector and the nonagricultural sector were lower than the employment shares we report in Table 9.1.

Takeshima (2017b, Table 2.6) offered key insights. The share of emigrants (measured by the absent population) has grown, particularly among the working-age male population. By 2010, it accounted for approximately 15–20 percent of working-age males in Nepal. The greatest growth is observed in the Hills (from 11 percent in 1995 to 21 percent in 2010), where tractor use growth has been slower than in the Terai. However, some of the migrants from the Hills might have relocated to the Terai, as shown by the faster growth of the working-age population in the Terai than in the Hills. The shares of nonfarm work grew, particularly for males in the Terai (from 9 percent to 17 percent for nonagricultural self-employment, and from 7 percent to 19 percent for nonagricultural wage employment) and for females in the Hills (from 9 percent to 27 percent). Employment growth in the construction sector and the finance and business sector accounted for a substantial share of this growth.

The share of the labor force in agricultural labor needs careful interpretation. The share declined overall between 1995 and 2010, which is consistent with the increase in agricultural wages we will see in the next section. This decline occurred across the agroecological belts, not only in the Terai. Although the share of agricultural wage work declined relatively more sharply in the Terai (from 22 percent to 10 percent for males, and from 21 percent to 14 percent for females), the share also remained higher in the Terai, indicating a greater reliance on hired labor in farming there. As we will see in the section "Role of Mechanization in Agricultural Transformation," tractor use growth has actually had a positive effect on hired labor use for complementary farming operations that have remained unmechanized despite the wage increases. The decline in agricultural wage work is unlikely to have been caused by the growth in tractor use. It is likely to have been caused largely by increasing labor absorption into the nonfarm sector (which would have happened even in the absence of growth in tractor use). This has, however, raised wages, which has induced substitution for labor in certain activities (such as plowing) by tractors.

Table 9.6 shows the changes in real daily wages for various farming operations, measured in terms of how many kilograms of milled rice a day of labor can buy, given the local milled rice price. In absolute terms, the increase in wages for plowing has been relatively greater than the increase in wages for all the other farming operations. Though an investigation of the causes of these differential wage growth rates is beyond the scope of this book, these figures may suggest that agricultural productivity in Nepal has become increasingly dependent on intensive plowing over time. However, although the plowing wage has increased across all agroecological belts, the adoption of tractors in the Hills and Mountains has been slower, due to other geographical features, as described above.

Determinants of Tractor Adoption and Intensity of Use (Expenditures on Rented Tractors)

Applying double-hurdle models to pooled cross-sectional samples of farm households in the NLSS, Takeshima, Adhikari, and Kumar (2016) estimated the determinants of tractor adoption and the intensity of tractor use (total expenditures on hiring services). Generally, both adoption and intensity of use are positively associated with a larger lowland area owned (but not upland area), a higher value of such land, greater holdings of livestock and farm equipment, having electricity as the main source of lighting in the house (which releases family labor), and a larger household—see Takeshima, Adhikari, and

TABLE 9.6 **Daily agricultural wages (in kg of milled rice a day of labor purchases), Nepal, 1995 and 2010**

Activity and year	All—male	Terai	Hills	Mountains	All—female
Plowing—1995	3.6	4.0	3.2	2.7	2.4
Plowing—2010	6.7	7.1	6.3	5.3	7.1
Planting—1995	2.8	3.1	2.4	2.1	2.5
Planting—2010	4.2	4.6	4.0	3.4	4.2
Weeding—1995	2.6	2.9	2.3	2.0	2.5
Weeding—2010	4.9	5.3	4.7	3.9	4.3
Harvesting—1995	2.8	3.1	2.5	2.1	2.5
Harvesting—2010	5.3	5.7	5.0	4.2	4.4

Source: Authors' calculations based on data from the Nepal Living Standards Survey for 1995 and 2010 (Nepal, CBS 1996, 2011).

Note: The milled rice purchase price is the average of the prices of fine, coarse, and beaten/flattened rice, which are appropriately replaced by district, regional, and rural/urban medians when missing.

Kumar (2016) for the interpretations. In addition, adoption of hired tractors is positively associated with flatter terrain, lower elevations, and better access to the nearest market center and a paved road. The intensity of tractor use upon adoption is positively associated with higher real wages and higher chemical fertilizer prices, which are typically substitutes for tractor use.[2] Intensity of use is also positively associated with greater rainfall and less rainfall variability.

Findings in Takeshima, Adhikari, and Kumar (2016) also provide modest evidence that access to custom hiring services may be still limited. A greater share of tractor owners within the village development committee (VDC)[3] is associated with both greater adoption of and greater expenditures on hired tractors in the Hills and Mountains. Even marginal adoption of tractors led to a significant increase in income in the Terai, consistent with the accessibility constraints. This finding is also consistent with the limited spatial mobility of tractors and the geographic coverage of tractor hiring services observed in Nigeria, where four-wheel tractors also provide most tractor services through custom hiring (Takeshima, Edeh, et al. 2015).

2 However, as noted in the section titled "Role of Mechanization in Agricultural Transformation," the use of tractors may lead to an overall increase in some labor or chemical fertilizer use if the income effects or scale effects from using tractors outweigh the substitution effects.

3 VDCs are administrative units below the district level in Nepal. Approximately 3,000 VDCs exist in Nepal, though their numbers change over time.

Summary: Demand for Mechanization

In most of the Terai and the lowland areas of the Hills, demand among smallholders for tractors for land preparation has grown sufficiently, generating large enough markets for custom hiring services. Demand for mechanized harvesting is more difficult to assess due to the lack of information. However, in parts of the Terai, such as the Western development region, the demand is likely to have grown sufficiently, as witnessed by growth in the mechanically harvested shares of wheat and rice. The demand for conventional machines in relatively more rugged areas, particularly in the Hills and Mountains, may remain lower. However, demand for mini-tillers, which are suitable for use in these environments, may be rising to a sufficient scale.

The share of farm households mechanizing harvesting has remained lower than the share of those using tractors (mostly likely for land preparation). These growth patterns, reflecting sequential adoption, are consistent with past theories.

A number of factors seem to affect growth in the demand for tractor use in Nepal. Growth in tractor use in the Terai is correlated particularly with rising wages for plowing, consistent with the hypothesis that tractors substitute for the labor used for plowing. Plowing wages have also increased faster than wages for other farming operations, which may partially explain why overall labor use may not decrease as a result of tractor adoption (see further discussion in “Role of Mechanization in Agricultural Transformation”).

Plowing wages have risen both in the Terai and in the Hills, though they have remained slightly lower in the latter. Geographic factors, however, seem to explain the slower growth in tractor use in the Hills. Slower growth in tractor use is correlated with rugged terrain, general remoteness from the nearest market center, and the relatively lower endowment of lowland in the Hills. Most farm households in the Hills are also located in areas with lower population density with respect to agricultural land, including pastures, conditions that may be more favorable for keeping draft animals.

Supply-Side Analysis

There was no integrated agricultural mechanization policy in Nepal until 2014, when the Agricultural Mechanization Promotion Policy was promulgated (Takeshima et al. 2016). The government of Nepal, however, has implemented various policies relevant to agricultural mechanization.

Machinery Purchase and Import Policies

TRADE AND IMPORT POLICIES (TARIFFS, DIRECT RESTRICTIONS, AND OTHER INTERVENTIONS)

In Nepal, tractor importation was relatively limited until the 1960s (FAO 2016), though between 1965/1966 and 1969/1970, some 794 tractors and 1,280 pump sets were imported by the Land Reform Savings Corporation, the National Trading Corporation, the Agricultural Supply Corporation, Birgunj Sugar Factory, and private dealers (Hjort 1973). A vehicle tax introduced in 1972/1973 applied to all types of vehicles, presumably including tractors (Khadka 1991). In the 1970s, the import tax on farm equipment was reduced to 1 percent of the CIF (cost, insurance, and freight) or FOB (free on board) price of imported equipment (Shrestha 1978).

Throughout the tax reforms in Nepal, tractors were exempted from taxes. In 1990, the Wealth Tax Act exempted agricultural machinery, including tractors, from taxes. Although tractors for other purposes had generally been subject to value-added tax (VAT) (Jenkins and Kuo 2000), the 1996 VAT Act granted tax exemption to selected agricultural products, including agricultural machinery (NARMA Consultancy Pvt. Ltd. 2016). Since then, tractors used for agricultural purposes have been exempt from VAT, but tractors for transporting nonagricultural goods have been subject to VAT (Sharma and Sarker 2015), which was 5 percent as of 2014 (World Bank 2016). There are ad valorem tariffs of 5 percent for nonagricultural tractors as well (World Bank 2016). This differential VAT has, however, not been easily implemented because suppliers of tractors do not always know for which purposes their tractors will be used (Sharma and Sarker 2015).

Generally, 15 percent tariffs have been imposed on general parts that can be used for tractors (World Bank 2016). However, under the India-Nepal Transit Treaty and the bilateral Treaty of Trade, also with India, a preferential tariff applies, which is currently generally 7.25 percent (Sharma 2015; World Bank 2016). Anecdotal evidence suggests that such high tariffs were placed to curb the growing congestion and worsening road conditions across the country.

No concessional loans or other bilateral agreements have been specifically applied to tractor imports to Nepal, though Nepal has various bilateral agreements with India, its largest trade partner and largest foreign aid donor since as early as 1970.[4]

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4 In 1970/1971, India accounted for 45 percent of foreign aid to Nepal, with the United States and China accounting for 22 percent and 17 percent, respectively (Hjort 1973).

PROMOTION POLICIES (SUBSIDIES AND OTHER POLICIES)

The government's efforts to promote agricultural mechanization began in Nepal in the 1960s with the introduction of four-wheel tractors, sometimes through donor-supported policies (Joshi, Conroy, and Witcombe 2012). In 1964, 64 tractors and 30 pump sets were introduced into the country (CSAM 2014). In the 1970s, the Agricultural Development Bank of Nepal provided loans at 14 percent interest per year (Shrestha 1978). Similarly, agricultural credit projects financed by the Asian Development Bank (ADB) started importing tractors and distributing them to farmers, but the initiative was discontinued in the early 1980s (Pariyar and Singh 1995). There were concerns that the demand for mechanization was still too low (Roumasset and Thapa 1983) and that subsidizing it could displace workers. Similarly, over the period 1980–1985, ADB Nepal discouraged financing tractors and other agricultural machines (CSAM 2014).

Since then, subsidies for tractors or other mechanization tools have been rare in Nepal, except for irrigation-related machinery such as pumps (Biggs et al. 2002). Generally, financial support for tractors or power tillers, other than through tax exemptions, as mentioned above, has been discouraged for fear of increased traffic congestion (Joshi, Conroy, and Witcombe 2012).

It is only recently that more direct support for and promotion of machinery such as tractors and power tillers has been expanded. Under the Agriculture Perspective Plan (1995–2015) and National Agriculture Policy 2004, the Directorate of Agricultural Engineering, which was established in 2004 within the Department of Agriculture, has been implementing promotional extension and training programs for agricultural machinery and providing related services (Nepal, MoAD 2014; Takeshima et al. 2017). Sometimes, financial support for machine investments has been provided through poverty reduction programs. For example, in 2004, the Poverty Alleviation Fund in Nepal was prepared to refinance loans for two-wheel tractors and other smaller-scale equipment to poorer rural households (Biggs and Justice 2015). In 2014, the Ministry of Agriculture and Livestock Development approved the Agricultural Mechanization Subsidy Mobilization Directives for distributing subsidies through the Directorate of Agricultural Engineering (NARMA Consultancy Pvt. Ltd. 2016).

LICENSING AND REGULATION

Nepal's regulatory infrastructure related to agricultural machinery is generally underdeveloped. Since 1991, development and testing of agricultural machinery has been conducted at the Agricultural Engineering Division of the Nepal

Agricultural Research Council (Takeshima et al. 2016). However, among the countries studied by the World Bank's Enabling the Business of Agriculture Project, Nepal is one of the countries with the weakest regulatory systems (weaker than those of some of the African countries, including Ethiopia, Ghana, and Tanzania), in terms of "legal requirements with regard to suitability, testing of agricultural tractors, specific licensing required to operate a tractor, as well as warranties and post-sale services that must be provided at the retail level" (World Bank 2016, 88). Although a separate license, issued by the Department of Transport Management under the Ministry of Labour and Transport Management, is required to drive a tractor or power tiller, currently no license is required either to import tractors or to become a tractor dealer.[5]

Imported tractors and combine harvesters are required to be registered with the Zonal Transportation Division and to obtain a Nepal vehicle number plate under the Vehicle and Transport Management Act (1992) and the Vehicle and Transport Management Rule of Nepal (1997) (Paudel et al. 2015; Gyawali 2014). In Nepal, however, the cost to register an imported tractor, when measured as a percentage of per capita income, is higher than that in Ethiopia or Ghana (World Bank 2016), and it is unclear what percentage of tractors or combine harvesters are officially registered. There is also a five-year restriction on change of ownership of two-wheel tractors, the removal of which has been under consideration (ADB 2013).

OWNERSHIP AND MARKET INSTITUTIONS OF MECHANIZATION SERVICE PROVISION

The provision of tractors, power tillers, and mini-tillers has been led by the growing number of private-sector importers and dealers. Indian tractor manufacturers (HMT, Mahindra, and Sonalika), Eicher, and Ford, as well as Bhajuratna Agency, Bhudev Trading Ford Tractor Division, and Bajra Enterprises, operate in Nepal, selling their respective brands of tractors, as well as Chinese power tillers (Adhikary 2004). The number of power tiller importers had reached 6 or 7 by 2002, with each selling about 100 per year without subsidies (Biggs et al. 2002). The number of mini-tiller importers had reached 10 by 2015 (Biggs and Justice 2015).

CUSTOM HIRING SERVICE PROVIDERS

Tractors and combine harvesters are owned by various types of entities—individual owners, cooperatives, and specialized enterprises—for the purpose of providing hiring services. Although information on custom hiring service providers is limited, a recent International Food Policy Research Institute

5 Personal communication with Ministry of Agriculture and Livestock Development staff.

(IFPRI) survey of service providers provides useful insights (IFPRI 2016). Various types of service providers were interviewed (Table 9.7). Because the samples of each type are small, we do not intend to obtain a differential picture of the nature of service provision across different types; rather, we focus on farmer-to-farmer/private service providers and on collective insights for all types combined.

Out of 150 service providers, a majority owned tractors with 35–54 hp. About half of farmer-to-farmer/private service providers had obtained tractors or power tillers at second hand, indicating an active market for secondhand tractors. The providers typically owned a farm of approximately 1.9 ha, with an annual operational size of approximately 3 ha (Table 9.8). Their land was predominantly lowland (irrigated) plots. The farmer-to-farmer/private service providers owned 3.3 ha on average, which is somewhat larger than the landholdings of other types of service providers.

Table 9.9 summarizes the extent of operations (number of days used per year) by different types of tractors and tillers owned, and the breakdown between own-farm use, hiring out in other farms, and nonfarm work. Tractors are generally used approximately 170–200 days per year. Tractors are used more for nonfarm work than for farm work (although we do not have information on total revenues earned from each of these activities). Tractors are typically used 133–190 days a year for nonfarm work, which is far more than the approximately 40 days used for farming. For farming activities, tractors are used predominantly for hiring out; whereas they are typically used for only 2–4 days for farming operations on the owner's farm, they are used about 25–40 days for farming on other farms. It is therefore likely that hiring out is an important source of the benefits derived from tractor ownership. Furthermore, unlike in some African countries, such as Nigeria, the use of tractors for nonfarm work (such as transportation) is much more common in Nepal and can be the primary benefit of tractor ownership. This pattern generally holds true for farmer-to-farmer/private service providers. Importantly, whereas in some countries, such as Bangladesh, higher-horsepower four-wheel tractors are used more in farming and lower-horsepower four-wheel tractors (less than 35 hp) are used more for nonfarm work (such as transportation) (Animaw et al. 2016), patterns of tractor use across farming and nonfarm activities in Nepal do not seem to exhibit differences based on horsepower.

Power tillers and mini-tillers are used less than four-wheel tractors (around 20–40 days per year), especially for nonfarm work, for which a majority are not used at all. Their use for hiring out on other farms is still common. Power tillers are used 15 days for hiring out, as opposed to 5 days on the owner's

TABLE 9.7 Types of hiring service providers interviewed, Nepal, 2016

Type	Sample of interviewed service providers
Farmer-to-farmer/private	39
Nongovernmental organization–led	32
Conventional extension model	28
Cooperative	21
Government-led (Directorate of Agricultural Engineering)	30
Total	**150**

Source: IFPRI (2016).

TABLE 9.8 Size of landholdings by interviewed tractor service providers, Nepal, 2016

Variable	N	Total (ha)	Upland	Lowland (irrigated)	Lowland (nonirrigated)	Grazing/ barren land	Public land
Own four-wheel tractor, 35–54 hp	104	1.9	0.1	1.7	0.1	0.0	0.0
Farmer-to-farmer/private	27	3.3	0.1	3.0	0.2	0.0	0.1
Other types	77	1.5	0.1	1.3	0.0	0.0	0.0
Own power tiller	44	1.8	0.1	1.7	0.0	0.0	0.0

Source: Author's calculations based on data from IFPRI (2016).

farm. Mini-tillers are used about 30 days for hiring out, similar to four-wheel tractors. Hiring out for farming operations is therefore likely to be the primary source of revenue from power tillers and mini-tillers.

SOURCES OF FINANCING

The tractors and power tillers owned by the interviewees were largely financed by personal savings, remittance incomes, and other informal sources, which together accounted for 60–70 percent of the purchasers' total financial requirements (Table 9.10). Although about 30 percent of tractors were also partly financed through loans from commercial banks or agricultural cooperative banks, these loans met only about 20–25 percent of the total financial requirements. The heavy reliance on personal savings and other informal sources to finance tractor purchases is consistent with the findings in other countries (for example, Nigeria).

Table 9.11 summarizes the breakdown of operating costs and depreciation per year per tractor (or power tiller), for farmer-to-farmer/private service providers, and for others. Cost breakdowns are generally similar for both tractors and power tillers and for different types of service providers. Operating costs account for 30–40 percent of expenses for tractors, and close to half for power

TABLE 9.9 Extent of custom hiring service operations, in number of days used per year,[a] Nepal, 2016

Type of tractor/tiller	Sample	Total	Number of days used on own farm	Number of days used on other farms	Number of days used for nonfarm work
Tractor (≥ 55 hp)	10	170 (178)	2 (2)	39 (39)	146 (133)
Tractor (35–54 hp)	98	177 (196)	4 (2)	40 (35)	133 (150)
Tractor (≤ 34 hp)	4	203 (215)	3 (3)	35 (25)	165 (190)
Power tiller	40	32 (20)	5 (4)	15 (13)	12 (0)
Mini-tiller	8	38 (32)	5 (4)	33 (30)	0 (0)
Tractors owned by farmer-to-farmer/private service providers	33	171 (170)	4 (3)	46 (40)	121 (131)

Source: IFPRI (2016).

Note: [a] Figures are sample averages, and figures in parentheses are sample medians.

TABLE 9.10 Sources of financing for tractors and power tillers

	% share of finance			% of service providers using each source to partly finance each machine		
	Four-wheel tractors			Four-wheel tractors		
Source	Farmer-to-farmer/ private	Other (government, extension, cooperatives, NGOs)	Power tillers	Farmer-to-farmer/ private	Other (government, extension, cooperatives, NGOs)	Power tillers
Personal savings	61	53	60	88	76	63
Remittance income	13	5	1	19	8	2
Other family members	1	1	2	3	1	2
Loan						
Money lender	3	2	2	6	7	2
Other informal sources	2	6	5	3	12	7
Commercial bank	16	18	4	25	29	4
Agricultural cooperative bank	4	5	9	6	9	9
Government scheme	0	0	0	0	0	0
Other sources	0	6	6	0	11	6

Source: IFPRI (2016).

Note: NGO = nongovernmental organization.

TABLE 9.11 **Breakdown of key cost components for four-wheel tractors and power tiller operations (US dollars[a] per year per machine), excluding costs for attachments, Nepal, 2016**

Component	Four-wheel tractors: Farmer-to-farmer/ private	Four-wheel tractors: Other (government, extension, cooperatives, NGOs)	Power tillers
Sample size	32	76	46
Operators (self-assessed if owner-operated)	1,060 (1,200)	1,270 (1,420)	635 (400)
Fuels/lubricants	240 (225)	263 (250)	127 (35)
Repair/maintenance	431 (300)	420 (360)	199 (95)
Spare parts	347 (235)	302 (200)	139 (55)
Labor	72 (50)	83 (50)	37 (18)
Depreciation[b]	865 (870)	997 (947)	350 (234)
Total costs related to tractors/power tillers, excluding costs related to attachments	**3,016 (3,013)**	**3,337 (3,215)**	**1,472 (878)**

Source: IFPRI (2016).

Note: [a] Figures are calculated using the exchange rate of US$1 = 100 Nepalese rupees. Figures are sample averages, and figures in parentheses are sample medians. [b] Calculated by dividing the expected service life of machine by the original (unsubsidized) value of the machine, deflated by the consumer price index (World Bank 2016). NGO = nongovernmental organization.

tillers; maintenance, repairs, and spare parts account for 25–35 percent; fuels and lubricants account for less than 10 percent; and depreciation costs account for the remaining 25–30 percent.

Importantly, farmer-to-farmer/private service providers who are receiving relatively less support (such as subsidies) appear at least as efficient as and may be incurring lower costs than the other types of service providers (spending on average $3,000 per tractor, as opposed to the $3,337 spent by other service providers). These figures suggest that continued research is important in better understanding the nature of service provision by such private-sector farmer-to-farmer service providers.

Medium-Scale Farms as Major Suppliers of Hiring Services

In some countries, evidence suggests that farmer-to-farmer service providers tend to be owners of medium-scale farms rather than large farms (Houssou et al. 2015). In Nepal, approximately half of tractor owners participating in the NLSS said they provide hiring-out services. Although statistically significant differences cannot be detected due to the extremely small sample size of tractor owners in NLSS data, the median size of the owned and annually cultivated farm is consistent with the hypothesis that medium-scale farms rather than large-scale farms are the major suppliers of tractor renting-out services (Table 9.12).

TABLE 9.12 Median owned and annually cultivated farm size (ha) of tractor owners, differentiated by hiring-out status, Nepal Terai, 2003 and 2010

	Owned land		Annually cultivated land	
Type of tractor owner	2003	2010	2003	2010
Those with hiring-out revenue	1.2	1.7	3.0	3.2
Those without hiring-out revenue	2.0	2.7	4.0	4.3

Source: Authors' calculations based on data from the Nepal Living Standards Survey for 2003 and 2010 (Nepal, CBS 2004, 2011).

COMBINE HARVESTER SERVICE PROVIDERS

The number of farmer-to-farmer combine harvester service providers has also been growing. The IFPRI (2016) survey did not interview a sufficiently large number of combine harvester service providers. However, Paudel and colleagues (2015), based on a survey of 150 service providers in the three districts in Western Terai (Kapilavastu, Rupandehi, and Nawalparasi), found that the share of area harvested by combine harvesters increased from 1 percent in 2000 to 8 percent and 20 percent for rice and wheat, respectively, in 2014. The 150 combine harvester owners operate approximately 200 ha per year on average, though this rate has declined from about 500 ha in the early 2000s. It appears most operate within their home districts.

The emergence in Nepal of private-sector providers of tractors, power tillers, and combine harvesters for hire has likely contributed to the recent growth in the use of these mechanization technologies. In addition, as is mentioned in the next section, in the neighboring Bihar state of India, private-sector service providers of zero-till machines have also been emerging (Keil, D'Souza, and McDonald 2016), and some may operate in the Terai zone of Nepal. Many of these private service providers have grown with essentially no government support, acquiring machines and financing from the private sector and achieving a cost-efficiency that is comparable to or even better than that of other service providers. As is shown in the next section, however, there remain some signs that farmers are constrained by the lack of access to these services at competitive market prices, and continued research is needed to identify how the government can support these service providers to address unmet demands.

Role of Mechanization in Agricultural Transformation

This section provides empirical evidence of various effects of the adoption of tractors on agricultural productivity, intensification, and farm household welfare, using NLSS data. These effects are estimated using the propensity score–based inverse probability weighting (IPW) method (more detailed descriptions of model specifications are provided in Appendix 9A). Specifically, the section highlights the (1) effects on farm size dynamics and exit from agriculture; (2) effects on land productivity; (3) effects on other aspects such as gender, feminization, and the environment. Although most farmers in Nepal are smallholders, we differentiate resource-poor smallholders (owning a lowland farm of not more than 1 acre) and medium smallholders (owning a lowland farm larger than 1 acre), in the Terai where appropriate, to highlight the differential effects of tractor adoption on their outcomes. Because these outcomes are potentially correlated with each other, IPW is estimated using IPW-SUR (seemingly unrelated regressions) methods.

Effects on Farm Size and Farm Size Dynamics

The effects of tractor ownership on farm size dynamics are more difficult to assess due to the small number of tractor owners in the data. However, available evidence suggests that tractor ownership may not have strong effects on farm size dynamics in the short term. All nine tractor owners in the NLSS panel sample decreased the size of their owned farm and operational scale, by typically around 20–30 percent, and only two out of the nine tractor owners in the panel sample saw increases in farmland cultivated before the next round of the NLSS (Table 9.13).

Can Mechanization Help Smallholders Survive and Become More Productive?

Tractor adoption seems to have helped some smallholders survive in the agricultural sector and become more productive. For example, tractor adoption has led to an approximately 14 percent increase in agricultural income and a 12.5 percent increase in per capita household income for resource-poor smallholders (Table 9.14), indicating improvement in the overall profitability of their production systems. In contrast, the effects for medium smallholders are weaker and statistically insignificant. Similarly, in the Hills, the effects are positive on agricultural income but insignificant on overall household income. Tractor adoption may help smallholders in the Terai to survive in farming more than it helps those in the Hills. These results are consistent with the hypothesis that tractors are complementary to flatter topography.

TABLE 9.13 Change in owned farm size and operational size, by tractor owners and non-owners (panel samples), Nepal, 1995, 2003, 2010

Tractor ownership		Initial size of farmland owned (ha)	Change in farmland owned between rounds of NLSS (ha)	Initial size of farmland cultivated per year (ha)	Change in farmland cultivated per year between rounds of NLSS (ha)
Tractor owners (*N* = 9)	Mean	3.1	−0.9	6.7	−2.5
	Median	3.3	−0.9	8.1	−1.7
Non-owners (*N* = 1,400)	Mean	1.0	−0.2	1.9	−0.4
	Median	0.6	−0.0	1.2	−0.1

Source: Authors' calculations based on data from the Nepal Living Standards Survey for 1995, 2003, 2010 (Nepal, CBS 1996, 2004, 2011).

TABLE 9.14 Effects of adopting tractors on household income (total income and agricultural income), Nepal, 1995, 2003, 2010

Outcome	Small	Medium	Hills
Real per capita household income (kg of cereals)	77.399 (166.531)	112.244 (210.136)	106.011(351.600)
Growth rate of real per capita household income (natural log)	.125*** (.050)	.039 (.054)	.085 (.062)
Per capita agricultural income (kg of cereals)	101.161* (59.332)	117.965** (50.870)	196.137*** (58.900)
Growth rate of per capita agricultural income (natural log)	.140* (.084)	.070 (.068)	.326*** (.106)

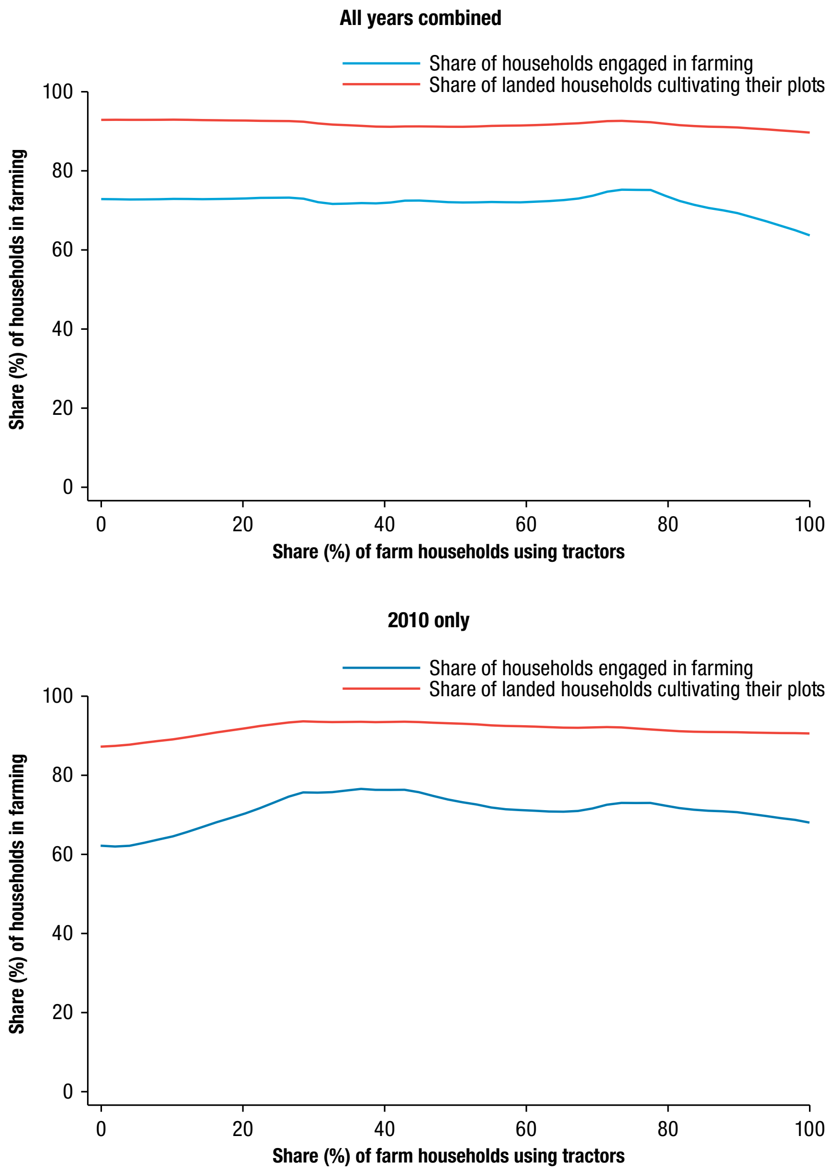
Source: Authors' calculations based on data from the Nepal Living Standards Survey for 1995, 2003, 2010 (Nepal, CBS 1996, 2004, 2011); results for Hills are from Takeshima and Bhattarai (2019).

Note: Figures are estimated effects. Figures in parentheses are standard errors of the estimated effects. Asterisks indicate the statistical significance: *** 1%, ** 5%, * 10%.

POSSIBLE CAUSAL EFFECTS ON SMALLHOLDER EXIT FROM FARMING

Will mechanization allow some smallholders to scale up while allowing others to exit farming, with the development of other nonfarm economic opportunities? The available data do not allow a thorough assessment of the causal effects of tractor diffusion on smallholders' exit from farming. However, a rough diagnosis suggests that the linkages are relatively weak. Figure 9.3 illustrates how, at the VDC level, the share of households engaged in farming is associated with the share of farm households using tractors. If tractor diffusion induces a significant rate of exit from farming by smallholders, we would expect negatively sloping lines in Figure 9.3. However, the share of households engaged in farming among all households in the VDC is generally unrelated to the level of diffusion of tractor use in the VDC. This also holds if we limit

FIGURE 9.3 Correlation between village development committee–level share (percentage) of tractor-using farm households and share of households engaged in farming, Nepal, 1995–2010



Source: Authors' calculations based on data from the Nepal Living Standards Survey for 1995, 2003, and 2010 (Nepal, CBS 1996, 2004, 2011).

our sample to households that own farmland (landed households) and to figures at the district level. Therefore, the evidence is generally weak for tractor-induced exit from farming by smallholders.[6]

Similarly, tractor rentals in 2003 did not seem to have a significant effect on farming exit. This is based on a separate propensity score matching method using the panel samples that constitute a fraction of the NLSS, in which we assessed the effect of tractor use in 2003 on whether the same households were still farming in 2010. Results are not shown due to the small sample size, but they at least suggest that the linkage between the use of tractors and future exit from farming is generally weak.

These effects also differ between resource-poor smallholders and medium smallholders (Table 9.15). Although using tractors often leads to reduced land rental revenues, these effects are clearer among medium smallholders. Similarly, tractor adoption also lowers off-farm income more among resource-poor smallholders than among medium smallholders. Off-farm income decreases for resource-poor smallholders due to tractor adoption, partly as a result of the reduced time spent by adult female household members in off-farm activities (Table 9.16). These conditions suggest that tractor adoption does not induce farm exit, and resource-poor smallholders may actually shift more resources to farming when they use tractors.

EFFECTS ON LAND PRODUCTIVITY AND ADOPTION OF OTHER MODERN TECHNOLOGIES

Tractor adoption has different effects on the farming practices of resource-poor smallholders and medium smallholders in the Terai, versus those in the Hills (Table 9.17). For resource-poor smallholders in the Terai, tractor adoption generally has greater land productivity–enhancing effects through more intensive use of nonland inputs, such as chemical fertilizer and irrigation, as well as expansion of the cultivated area. These effects are somewhat weaker among medium smallholders in the Terai and farmers in the Hills.

Importantly, tractor adoption often increases rather than decreases the overall use of labor, particularly labor by adult female household members and/or hired labor (only child labor use by resource-poor smallholders in the Terai is reduced). This is possibly because in the Nepal Terai, although tractor use has been increasingly adopted for certain activities, other farming operations (planting, fertilizer application, weeding, bird scaring, harvesting)

6 Of course, we cannot extract from these figures longer-term trends or more general equilibrium patterns at more aggregated regional levels, or the effects of more advanced mechanization patterns beyond tractor use. The evidence here, however, at least suggests that growth in tractor use has largely preserved smallholders in Nepal instead of inducing their exit from farming.

TABLE 9.15 **Effects of tractor use on livestock revenue, land rental revenue, and off-farm income, Nepal Terai and Hills, 1995, 2003, 2010**

	Terai		
Variable	Small	Medium	Hills
Real per capita livestock revenue (kg of cereal)	72.672 (48.643)	54.930** (25.985)	110.625** (42.427)
Real per capita land rental revenue (kg of cereal)	–9.363 (7.845)	–48.225** (20.274)	–9.467 (7.568)
Real per capita land rental revenue (kg of cereal)—rainy season	–8.433 (7.118)	–27.833* (16.046)	–11.986** (4.915)
Real per capita land rental revenue (kg of cereal)—dry season	–.905 (1.193)	–16.685* (8.561)	.461 (4.438)
Real per capita land rental payment (kg of cereal)	–.155 (.220)	–.457 (.291)	.045 (.087)
Real per capita off-farm income (kg of cereal)	–323.972* (173.072)	–111.731 (266.625)	–626.314*** (210.504)

Source: Authors' calculations based on data from the Nepal Living Standards Survey for 1995, 2003, 2010 (Nepal, CBS 1996, 2004, and 2011).

Note: Figures in parentheses are standard errors of the estimated effects. Asterisks indicate the statistical significance: *** 1%; ** 5%; * 10%.

TABLE 9.16 **Effects of tractor use on off-farm income-earning activities (person-hours within 12 months), Nepal Terai and Hills, 1995, 2003, 2010**

	Terai		
Variable	Small	Medium	Hills
Male family member (hours per year)	–181.506 (119.734)	–253.592** (116.907)	140.680 (135.114)
Male family member per capita (hours per year)	–127.228* (70.311)	–189.902*** (66.515)	105.653 (87.294)
Female family member (hours per year)	–164.931*** (53.729)	–96.195 (57.381)	74.070 (86.619)
Female family member per capita (hours per year)	–118.865*** (41.493)	–11.061 (34.994)	78.202 (55.237)

Source: Authors' calculations based on data from the Nepal Living Standards Survey for 1995, 2003, 2010 (Nepal, CBS 1996, 2004, and 2011).

Note: Figures in parentheses are standard errors of the estimated effects. Asterisks indicate the statistical significance: *** 1%; ** 5%; * 10%.

TABLE 9.17 Effects of mechanization on agricultural input use (land, fertilizer, labor), Nepal Terai and Hills, 1995, 2003, 2010

	Terai		
Outcome	Resource-poor smallholders	Medium smallholders	Hills
Area cultivated per year (ha)	.257*** (.078)	.151 (.129)	–.005 (.080)
Own area cultivated in dry season (ha)	.041** (.021)	.090 (.058)	.021 (.038)
Own area cultivated in rainy season (ha)	.048** (.023)	.138** (.057)	.029 (.040)
Net area sharecropped in (ha)	.080** (.033)	.213*** (.063)	.038 (.028)
Net area rented in (ha)	.005 (.012)	–.014 (.029)	–.016 (.012)
Chemical fertilizer use per ha (kg of nutrients/ha)	11.016*** (3.645)	–2.435 (4.612)	–9.372 (10.659)
Irrigation in dry season (%)	9.056*** (3.447)	2.940 (3.163)	11.634*** (3.855)
Irrigation in wet season (%)	10.989*** (3.426)	6.303** (3.117)	21.068*** (3.561)
Family labor use—male (hours per year)	69.703 (71.019)	14.961 (101.170)	–90.606 (71.869)
Family labor use—male per capita (hours per year)	32.341 (43.945)	49.657 (56.864)	–32.305 (49.755)
Family labor use—female (hours per year)	233.178*** (67.669)	176.655* (106.665)	99.382 (87.648)
Family labor use—female per capita (hours per year)	181.401*** (41.420)	109.870** (51.484)	156.866** (62.623)
Family labor use—child (hours per year)	–179.180*** (49.150)	1.946 (69.557)	–72.732* (42.401)
Hired labor male (days per year)	.391 (.554)	7.506*** (2.038)	.832 (1.075)
Hired labor female (days per year)	2.854*** (1.120)	7.645** (3.679)	5.074*** (1.805)

Source: Authors' calculations based on data from the Nepal Living Standards Survey for 1995, 2003, 2010 (Nepal, CBS 1996, 2004, 2011). Results for Hills are from Takeshima and Bhattarai (2019).

Note: Figures in parentheses are standard errors of the estimated effects. Asterisks indicate the statistical significance: *** 1%; ** 5%; * 10%.

remain largely unmechanized. Although tractor adoption substitutes for labor in land preparation, the resulting intensification, expansion of operational size, and growth in harvest may raise the demand for labor, leading to net increases in labor use. Effects on labor source differ as well; for resource-poor smallholders, adult female family members' labor accounts for much of the increase in overall labor use, whereas for medium smallholders, hired labor accounts for an important share of labor use increases. These differences in the effects on labor type may relate to the aforementioned differences between land productivity–enhancing behaviors and land-expansion behaviors.[7]

The patterns in the Hills are slightly different from those in the Terai. Whereas the effects of mechanization on labor use by farmers in the Hills are similar to those on labor use by resource-poor smallholders in the Terai, the effects on use of certain inputs, such as chemical fertilizer, are relatively small. This is partly because of the potentially lower returns on use of chemical fertilizer in the hilly environment than in the flatter Terai zone (Takeshima et al. 2017).

Although detailed agronomic information is not available in the NLSS, the patterns among resource-poor farmers in the Terai are consistent with the hypothesis that in land-constrained environments, tractor use can allow deeper tillage that may improve the soil quality and raise fertilizer absorption efficiency or irrigation efficiency (through improved drainage, for example).

These differences are also reflected in the effects on real crop revenue per hectare, an indicator of yield (Table 9.18). Although the effects of tractor adoption on real crop revenue per hectare are significantly negative for medium smallholders in the Terai, they are relatively insignificant for resource-poor smallholders in the Terai and those in the Hills.

TRACTOR ADOPTION AND RETURNS TO SCALE IN FARMING

Not only is input use affected by tractor adoption, but a recent study also suggests that renting in tractors through custom hiring services affects the shape of the production function itself by increasing the returns to scale in agricultural production, including livestock (Takeshima 2017a) (Table 9.19). The study shows a direct causal effect of tractor use on returns to scale, unlike earlier studies that only assume the association between mechanization and returns to scale. The study addresses the two sources of endogeneity (tractor

7 In Asian countries, more hired labor is typically used for activities for which efforts are easily visible (such as transplanted areas, harvested quantities), whereas family labor is used for watering, pest control, fertilizer application, seedbed preparation—tasks that require care and judgment without immediately visible outcomes (Kikuchi and Hayami 1999).

TABLE 9.18 Effects of mechanization on real revenue per hectare, Nepal Terai and Hills, 1995, 2003, 2010

	Terai		
Variable	Small	Medium	Hills
Growth rate of real crop revenue per ha of cultivated area	−.012 (.056)	−.150** (.065)	.085 (.073)

Source: Authors' calculations based on data from the Nepal Living Standards Survey for 1995, 2003, 2010 (Nepal, CBS 1996, 2004, 2011).

Note: Figures in parentheses are standard errors of the estimated effects. Asterisks indicate the statistical significance: ** 5%.

TABLE 9.19 Effects of tractor custom hiring service on agricultural returns to scale in Nepal Terai, 2010

	Estimated Cobb-Douglas production function coefficients with and without hired tractors	
Variable	Tractor custom hiring service hirers	Nonhirers
Fertilizer nutrients	.002 (.027)	−.016 (.016)
Adult male family labor	−.003 (.005)	.003 (.009)
Adult female family labor	−.015 (.013)	.060*** (.007)
Child family labor	.019*** (.006)	.019*** (.006)
Hired labor	−.010 (.009)	−.015* (.009)
Area cultivated	.529*** (.058)	.397*** (.061)
Irrigation	.009 (.008)	.016 (.012)
Agricultural capital	.291*** (.055)	.161** (.064)
Other cash expenditures	.092 (.064)	.084*** (.024)
Returns to scale	.914*** (.056)	.709*** (.061)

Source: Takeshima (2017a).

Note: Figures in parentheses are standard errors of the estimated effects. Asterisks indicate the statistical significance: *** 1%; ** 5%; * 10%.

adoption and use of other inputs) through an IPW generalized method of moments estimator (see Takeshima 2017a for detail). In addition, it shows that this transformational effect is realized through tractor custom hiring services instead of tractor ownership. Although the external validity of the evidence requires further research, it shows that in certain areas in Nepal, tractors are not simply complementing or substituting for other inputs but also substantially transforming production technology.

EFFECTS ON GENDER AND FEMINIZATION OF FARMING

The adoption of tractors in the Nepal Terai seems to lead to a slight feminization of farming, but through increased overall use of female labor rather than a substantial decrease in male labor. This effect may be different from the feminization that occurs after more comprehensive mechanization, in which a further decrease in male labor use becomes more pronounced.

Increased use of female labor as a result of tractor adoption can also explain the recent findings on the effect of tractor use on women's fertility, which is often interpreted as the result of labor substitution. For example, Bhandari and Ghimire (2013) showed that tractor adoption reduces the subsequent fertility of women in the Western Chitwan Valley of Nepal. Although Bhandari and Ghimire (2013) associated the findings with the reduced demand for children as a result of substitution of tractors for labor, it is also possible that this decline is actually a result of increased demand for female labor in farming for activities that are not easily mechanized even after a tractor is introduced (such as planting, weeding, and harvesting), which is consistent with the findings above.[8]

KEY ENVIRONMENTAL EFFECTS

Various studies have suggested that tractor use in Nepal, which is part of the Indo-Gangetic Plain, will have certain environmental effects, though their extent has not been identified based on representative data from the Nepal Terai. Some of the effects with global implications are increased emissions of carbon dioxide to the atmosphere as a result of biological decomposition of soil organic matter, and increased emissions through machinery fuel usage (Grace et al. 2003). However, one of the key effects with more direct local implications is the impact on the physical characteristics of soils and on the productivity of the dominant production system in the region, the rice-wheat system. In particular, wet tillage (puddling), for which tractors are commonly used in the Nepal Terai (see "Demand-Side Analysis," above), often has negative effects on post-rice wheat production during the dry season (Sharma, Ladha, and Bhushan 2003). These effects are caused by loss of soil organic matter, destruction of soil structure that leads to higher bulk density, higher soil penetration resistance, enhanced surface cracking, low porosity, and low water permeability. These conditions cause waterlogging, poor soil aeration, restricted root growth, and decreased availability of soil nutrients to the wheat plants (Sharma, Ladha, and Bhushan 2003). Soil compaction is one of the key outcomes, causing the development of subsurface hardpan (often to a depth of 10–45 cm below the puddled layer). Though subsurface hardpan develops due to various

8 See Do, Levchenko, and Raddatz (2016) for the negative effect of increased female labor demand on fertility.

factors—including animal and human processes during tillage, transplanting, weeding, and other activities, as well as chemical precipitation of certain minerals in the subsoil layers—it is also caused by the use of heavy machinery such as tractors (Sharma, Ladha, and Bhushan 2003). Soil compaction is partly caused on purpose, because moderate soil compaction is ideal for rice cultivation. However, it necessitates intensive tillage during the land preparation for dry-season wheat production, often further raising demand for intensive tillage for wheat under the conventional tillage system (Ladha et al. 2003).

In the rice-wheat systems in regions like the Indo-Gangetic Plain across India, Pakistan, and the Nepal Terai, where tillage intensity per hectare has reached quite a high level, the demand for an alternative farming system that reduces tillage intensity is gradually on the rise as a solution to reduce the aforementioned effects on the soil, including soil compaction, and raise overall productivity. Out of 13 million ha of rice-wheat systems spreading over the Indo-Gangetic Plain (Chauhan et al. 2012), some 5 million ha are under production systems involving no tillage for dry-season wheat, although the adoption of no tillage for rainy-season rice is still minimal (Hobbs, Sayre, and Gupta 2008). Nepal accounts for 600,000 ha of this rice-wheat system (Chauhan et al. 2012). In the Indian state of Bihar, situated adjacent to the Nepal Terai, private sector–led zero-till custom hiring service providers have emerged over time, whereby tractors continue to be used but with zero-till implements (Keil, D'Souza, and McDonald 2016). This procedure has been adopted for land preparation for wheat after rice is harvested. Some of these service providers may travel to the Nepal Terai if there is demand. Although information is currently scarce, some zero-till service providers may actually be located inside the Nepal Terai.

Conclusions

Given the country's small average landholdings and heavy reliance on agriculture, the recent growth of tractor use in Nepal has been impressive, particularly in the Terai. The growth has occurred against a background of rising rural wages, particularly for plowing, combined with growing emigration, increases in the yields of key staple crops, and overall broad agricultural production growth, as well as improved market access and participation—factors that have all potentially raised the demand for machine power, including tractors.

In the Terai zone, increasing tractor use has played a role in agricultural transformation mostly through the effect on agricultural production, rather than by inducing smallholder farm households to exit agriculture or laborers to shift out of agriculture. Tractors have helped resource-poor smallholders intensify crop production per unit of land while also helping medium smallholders expand their cultivated area. This has enabled growth in tractor use despite the continued decline in average farm sizes caused primarily by fragmentation, and despite the continuing high share of households engaged in farming. Tractor adoption has also transformed overall agricultural production technologies by directly causing the shift from diminishing returns to scale to constant returns to scale in the production function, which has been an important process experienced by agricultural sectors in developed countries.

This growing demand for tractors has been met by various types of custom hiring service providers, including private-sector farmer-to-farmer service providers who have emerged with essentially no direct government support, acquiring machines and financial resources from the market and informal sources. The growth in combine harvester service providers also suggests the potential of the private sector to meet the demand by smallholders.

In the Hills and Mountains regions of Nepal, the contrast with the Terai zone offers useful insights that could be relevant to future growth in mechanization in similarly hilly or mountainous regions in Africa. Certain factors in the Hills are similar to those in the Terai; for example, the labor market in the Hills has seen increases in wages, caused in part by rising education levels, the growth of the nonfarm sector, and extensive emigration from the area by working-age males. The unique agroecological characteristics of the Hills, such as the rugged terrain and relative scarcity of lowland, however, seem to have remained key obstacles to the growth in tractor use there, despite its substantial growth in the neighboring Terai zone. However, even in the Hills and Mountains regions, induced innovations often enable improvements in land quality (Templeton and Scherr 1999). These areas too are expected eventually to develop their own mechanization systems in the future. The recent growth (albeit from a low base) in the use of Chinese-made mini-tillers on sloped upland plots in the Hills may be an example of such a system.

Nepalese experiences offer various useful policy recommendations for African countries. First, whereas tractor use has grown considerably in the Terai, access to custom hiring services may still be somewhat constraining. This is similar to the situation in some of the African countries, where the majority of tractors are four-wheel tractors, for which indivisibility of technologies is still relevant because of limited mobility and seasonal fluctuations in demand. These experiences suggest that in locations where conditions indicate that four-wheel tractors are more suitable and common, the overall spread of tractor use requires market developments that support a substantial increase in tractor populations as well as efficiency improvements in custom hiring service markets.

Second, tractor use has grown in the Terai even though the area has one of the weakest regulatory policies for tractors in terms of machine quality controls. Once adoption has reached a sufficient scale, designing and implementing appropriate regulatory policies becomes more relevant to the sector. African countries can also first focus on liberalizing machine imports to allow the inflow of various types of tractors and machines, and then start investing in regulatory capacity once adoption reaches certain levels.

Third, recent evidence suggests that the investments in complementary technologies, such as high-yielding improved varieties, have also been partly responsible for increased tractor use among smallholders (though these effects dissipate as farms get larger) (Takeshima and Liu 2018). Such patterns suggest that similar investments in complementary technologies are likely to be important to raise the uptake of mechanization in Africa, especially among smallholders who would otherwise not benefit from mechanization due to the lack of scale economy.

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Appendix 9A: Estimation of the Impacts of Tractor Adoption (Tables 9.14–9.19)

Tables 9.14–9.18

We focus our analyses on specific regions with relatively favorable environments for intensifying tractor adoption. As was seen in the section titled "Demand-Side Analysis," the extent and depth of the adoption of tractors vary considerably across agroecological belts (the Terai and the Hills), as well as within the Terai zone. Comparing adopters and non-adopters of tractors in very different environments often biases the estimates of tractor adoption.

Specifically, in Tables 9.15 through 9.18, we focus on farm households in the Terai zone and in the VDCs in which at least one tractor adopter and one or more non-adopters are included in the samples in each round of the NLSS. Furthermore, we separately assess the impacts for small-farm households (those owning less than 0.4 ha of lowland farmland) and medium-farm households (those owning 0.4–5.0 ha of lowland farmland). Table 9A.1 summarizes the set of variables used for estimating the probability of adopting tractors for each subgroup of samples, which are then used to construct the inverse of the weights in an IPW regression. These variables are selected to capture diverse aspects of household characteristics that are likely to be directly or indirectly associated with tractor adoption decisions, including agroecological conditions, household demographics, access to infrastructure and institutions, human capital and other wealth, and market conditions for complementary inputs. As is shown, when considering the IPW-adjusted results, no variable exhibits statistically different means between tractor adopters and non-adopters. Furthermore, Figure 9A.1 shows that the estimated probability, using the variables above, shows sufficient balancing properties. Using these diverse sets of variables to construct the probability weights minimizes the risk that we might incorrectly attribute the observed differences in outcomes to tractor adoption, when in fact the differences are due to differences in other household characteristics.

Table 9.19

Table 9.19 is based on similar IPW regressions, but with extensions through a combination of regression adjustments and instrumental variable regressions (detailed descriptions are available in Takeshima 2017a). In short, the effect of tractor adoption on returns to scale is estimated by simultaneously addressing the endogeneity of input variables in standard Cobb-Douglas production functions using instrumental variables (typically price variables of these inputs) and addressing the endogeneity of tractor adoption variables through IPW. As is shown in Takeshima (2017a), the model satisfies various properties, including the validity of instrumental variables used and the balancing properties of IPW.

TABLE 9A.1 Significance (p-values) of differences in averages between tractor adopters and non-adopters for each variable used in inverse probability–weighted regression

Variable	Sample					
	Terai (small)		Terai (medium)		Hills	
	Raw sample	IPW sample	Raw sample	IPW sample	Raw sample	IPW sample
Obtained credit in the previous year (yes = 1)	.161	.611	.206	.898	.351	.734
Obtained formal-sector credit in the previous year (yes = 1)	.072	.757	.725	.960	.503	.778
Land area owned (lowland)	.000	.547	.008	.826	.239	.767
Land area owned (upland)	.694	.268	.498	.582	.007	.512
Gender of household head (male = 1; female = 0)	.815	.902	.738	.782	.651	.719
Real household asset value—excluding farmland, livestock, equipment	.087	.865	.985	.876	.888	.801
Real household asset value—livestock	.149	.424	.142	.579	.041	.839
Real household asset value—equipment	.121	.935	.378	.655	.078	.957
Literacy of household head (literate = 1)	.000	.907	.005	.788	.006	.044
Whether owning nonproductive land (yes = 1)	.009	.970	.000	.330	.164	.562
Whether owning enterprise asset (yes = 1)	.038	.796	.815	.516	.237	.597
Average education levels of working-age household members	.000	.805	.003	.888	.009	.477
Number of plots owned	.199	.876	.000	.790	.219	.905
Ownership of draft animals (yes = 1)	.638	.233	.698	.938	.696	.894
Age of household head	.062	.920	.780	.814	.653	.643
Rainfall (average)	.000	.970	.000	.900	.000	.800
Rainfall (standard deviation)	.000	.992	.000	.654	.004	.639
Solar radiation index	.374	.727	.002	.568	.001	.667
Piped water as drinking water source (1 = yes)	.720	.677	.188	.654	.165	.921
Electricity the main source of light (1 = yes)	.000	.872	.000	.888	.000	.825
Wood the main source of cooking fuel (yes = 1)	.056	.782	.000	.673	.000	.453

(continued)

TABLE 9A.1 Continued

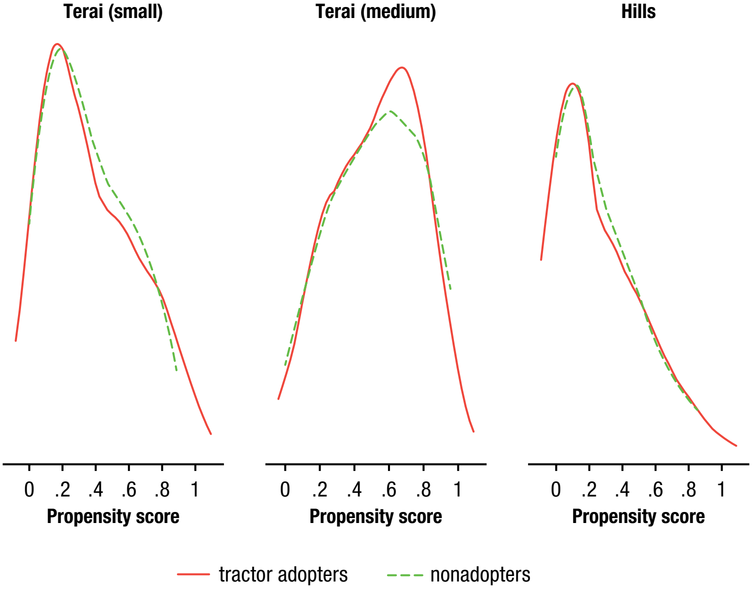
	Sample					
	Terai (small)		Terai (medium)		Hills	
Variable	Raw sample	IPW sample	Raw sample	IPW sample	Raw sample	IPW sample
Whether the community has garbage disposal service (yes = 1)	.201	.862	.926	.891	.777	.774
Use garbage for fertilizer (yes = 1)	.364	.538	.203	.327	.086	.997
Household size (adult males)	.615	.908	.619	.629	.423	.962
Household size (adult females)	.059	.838	.492	.696	.205	.532
Household size (children)	.406	.799	.091	.992	.013	.148
VDC sample share of irrigators	.314	.511	.672	.688	.726	.383
Per capita agricultural area	.006	.923	.410	.678	.002	.850
Terrain ruggedness index	.044	.979	.000	.607	.000	.773
Elevation	.002	.779	.000	.981	.001	.939
Share of samples with advanced caste in VDC	.000	.627	.000	.571	.000	.591
Share of nonindigenous population in VDC	.828	.899	.008	.563	.604	.895
Price of chemical fertilizer (urea)	.790	.661	.022	.862	.973	.855
Price of chemical fertilizer (DAP)	.217	.769	.000	.903	.587	.771
Farm wage	.001	.714	.003	.811	.000	.913
Tractor rental service price	.717	.526	.506	.826	.000	.519
Distance to the nearest major river	.667	.361	.004	.989	.000	.465
Distance to the nearest agricultural R&D institute	.000	.888	.000	.966	.000	.391
Distance to Indian border	.116	.788	.001	.925	.006	.640
Time of travel to the nearest bank	.007	.444	.336	.927	.000	.761
Time of travel to the nearest bus	.001	.326	.617	.391	.000	.757
Time of travel to the nearest cooperative	.485	.890	.046	.560	.000	.781
Time of travel to the nearest market center	.076	.369	.003	.962	.000	.769
Time of travel to the nearest shop	.312	.792	.909	.954	.001	.764
Year dummy (2010)	.382	.563	.000	.745	.006	.608
Year dummy (2003)	.382	.563	.000	.752	.077	.996
Urban area dummy	.235	.770	.588	.965	.970	.822
Region dummy (Central)	.000	.895	.002	.869	.000	.654
Region dummy (Western)	.000	.965	.000	.680	.124	.288

	Sample					
	Terai (small)		Terai (medium)		Hills	
Variable	Raw sample	IPW sample	Raw sample	IPW sample	Raw sample	IPW sample
Region dummy (Midwestern)	.002	.734	.000	.966	.000	.593
Region dummy (Far Western)	.000	.700	.000	.978	.003	.734
VDC sample share renting out tractors	.161	.861	.356	.850	.351	.910
Number of observations	**852**		**731**		**644**	

Source: Authors' calculations based on data from the Nepal Living Standards Survey for 1995, 2003, 2010 (Nepal, CBS 1996, 2004, 2011).

Note: DAP = diammonium phosphate; IPW = inverse probability–weighted; R&D = research and development; VDC = village development committee.

FIGURE 9A.1 Balancing properties of inverse probability–weighted regressions



Source: Authors based on Nepal Living Standards Survey for 1995, 2003, 2010 (Nepal, CBS 1996, 2004, 2011).