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Overview of the Evolution of Agricultural Mechanization in Nepal

A Focus on Tractors and Combine Harvesters

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ABSTRACT

This study was conducted to understand the evolution of agricultural mechanization in Nepal, specifically its determinants on both the demand and supply sides, as well as impacts on agricultural production and associations with broader economic transformation processes, in order to draw lessons that can be conveyed to other less mechanized countries. 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 and growth in key staple crop yields and overall broad agricultural production growth, as well as 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, raising overall returns to scale in intensification and enabling 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 to 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.

Keywords: evolution of agricultural mechanization, tractors, combine harvesters, Nepal

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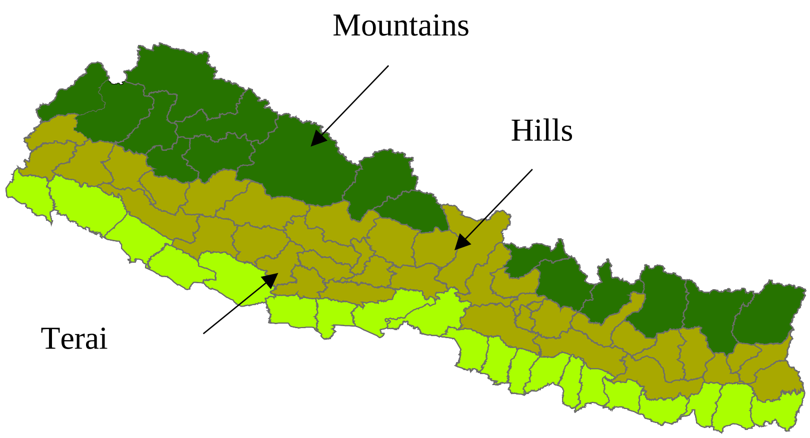
1. HISTORICAL BACKGROUND OF MECHANIZATION EVOLUTION IN NEPAL

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 (see Figure 1.1). Table 1.1 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.

Figure 1.1 Agroecological belts in Nepal



Source: Author.

Table 1.1 Evolution of different scales of mechanization in Nepal

	Periods								
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
% of farmers adopting tractors									
Nepal					1	5	16		23
Terai zone						8	29		46
% of 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: Shrestha (1978); Roumasset and Thapa (1983); Pingali and Hossain (1998); Adhikary (2004); Pullabhotla et al. (2011); Justice and Biggs (2013); CSAM (2014); Biggs and Justice (2015); Takeshima et al. (2015a); Paudel et al. (2015); FAO (2016).

Phase 1: Pre-1990s

Before the early 1990s, Nepal was a largely agricultural society; the agricultural sector employed close to 90 percent of the total workforce, and labor was generally abundant. The agricultural sector remained largely subsistence. In 1995, only half of farm households in Nepal sold surplus crops or livestock products to the market (Takeshima et al. 2015a). When focusing only on those who sold crops, the share dropped to one-third.

Between 1961 and 1995, yields of three major staple crops in Nepal showed little growth; wheat and rice grew only 0.4 and 0.5 percent per year, respectively, and maize yield actually declined by 0.6 percent per year. These rates were much lower than the growth rates realized in Nepal between 1995 and 2014, which were 2.7, 1.8, and 1.9 percent per year, respectively (FAO 2016). These patterns were generally consistent across agroecological zones, but more pronounced in the Hills and Mountains in the case of rice (International Rice Research Institute 2016). While national agricultural research programs for rice and maize were initiated in 1951 and 1965 (Gautam and Shrestha 2012, 54; Ransom, Paudyal, and Adhikari 2003), respectively, adoption of domestically bred varieties was not widespread until the late 1980s (Shrestha, Manandhar, and Regmi 2012). The agricultural transformation had stagnated before the early 1990s, despite investments in irrigation and the considerable expansion of areas equipped for irrigation between the 1960s and early 1990s (FAO 2016; Pingali and Hussain 1998), possibly because manual labor and draft animals were still the dominant source of farm power even in irrigated environments.

While agricultural productivity was low in terms of yield, and half of farm households were subsistence-oriented, the population density was generally high per unit of arable land, and moderate crop-livestock intensification had occurred. While yield growths were slow between the 1960s and early 1990s, the area planted to rice, wheat, and maize increased considerably. The use of draft animals was relatively widespread. In Nepal in 1981, the availability of farm power from animals reached 43 percent, five times the availability of mechanical power (8 percent) (CSAM 2014). By 1991, while mechanical power availability had more than doubled, it was still a fraction of animal power availability (15 percent and 39 percent, respectively). In the late 1970s, the cost per hectare of plowing using animal power was less than half and less than one-third the cost of using power tillers and four-wheel tractors, respectively (Shrestha 1978, 65).

Animals in Nepal often provided both milk and draft power (Lawrence and Pearson 2002). By the 1980s, draft animals were the primary source of power for plowing for various crops; puddling for rice; and planting/sowing for wheat, maize, and sugarcane, as well as some threshing of oilseeds, rice, and wheat (Pariyar and Singh 1995). In 2003, 80–90 percent of farm households owned either a bullock or cow; a buffalo; or a horse, donkey, or mule (Takeshima et al. 2015a). Combined with the data on the share of animal power presented in Table 1.1, this suggests that the use of draft animals was fairly common among Nepali farm households before the 1990s.

However, these conditions did not induce substantial adoption of tractors to substitute these draft animals. Tractors were first introduced in Nepal in the mid-1960s (CSAM 2014). Before the early 1990s, the share of farm households using tractors did not exceed 5 percent for the whole country, and was less than 10 percent even in the Terai (Takeshima et al. 2015a). One study shows that tractor investments and use patterns during this period were economically logical (Roumasset and Thapa 1983), suggesting that low tractor adoption before the early 1990s was generally due to the low profitability of doing so.

Phase 2: 1990s–2006

By the early 1990s, feed deficits for draft animals had become widespread, as the number of livestock kept growing while the major sources of fodder (forest and rangeland, providing 70 percent of fodder) had remained unchanged or continued to decline (Pariyar and Singh 1995). During this period, mechanical power became a more important source of farm power than animals. By 2001, mechanical power availability had increased to 725,000 horsepower (hp), almost equal to the animal power availability of 717,000 hp (CSAM 2014). The period between the 1990s and 2006 saw considerable growth in the adoption of tractors in parts of the Terai. For the Terai as a whole, the share of tractor-using farm households increased from 8 percent in 1995 to 29 percent in 2003 (Takeshima et al. 2015a). In particular, the percentage of farm households renting tractors via custom hiring services increased from 11 percent and 15 percent in 1995 in the Central and the Western regions of the Terai, respectively, to 39 percent and 56 percent in 2003 (Takeshima et al. 2015a). However, it was also the period when various parts of the country (particularly in the Mid-Western and Far-Western regions) experienced civil conflict caused by the insurgency of a Maoist group (Murshed and Gates 2005). The growth of mechanization in these regions, as well as agricultural sector growth in general, remained considerably slower than that in the Central and Western regions (the share of farm households using tractors remained at 4 percent between 1995 and 2003 in the Mid-Western region and at 26 percent in the Far-Western region [Takeshima et al. 2015a]). This is also partly because overall agricultural productivity growth remained low during this period (Devkota and Upadhyay 2013).

Phase 3: 2006–Present (Democratic System)

In 2006, the civil war caused by the Maoist insurgency ended, and the country transitioned from a monarchy to a republic in 2007 (Dillon, Sharma, and Zhang 2011). Various indicators suggest that agricultural sector growth accelerated after this. The yields of key crops have grown moderately. Rice yield in the whole of Nepal grew from 2.7 tons per hectare in 2006 to 3.4 tons per hectare in 2014 (2.8 percent per year, much faster than the average of 1.1 percent per year between 1961 and 2014). Wheat and maize yields also continued to increase (2.3 percent and 2.4 percent between 2006 and 2014, respectively, as opposed to 1.2 percent and 0.1 percent between 1961 and 2014). The growth in rice yield was associated with the increasing adoption of new domestically bred varieties (Shrestha, Manandhar, and Regmi 2012), as the country began to reap the benefits of growing support for domestic rice research and development and particularly the breeding that had intensified since the 1980s.

At the same time, labor force scarcity in the farming sector likely accelerated during this period. As is shown below, the share of the working-age male population emigrating increased, from 10 percent and 12 percent in 2003 in the Terai and Hills, respectively, to 16 percent and 21 percent in 2010. By 2011, remittances accounted for 16 percent of gross domestic product (GDP), and by 2016, 20 percent of Nepalese households had migrants abroad (Hatlebakk 2016). The share of the working-age population engaged in agriculture declined considerably between 2003 and 2010, relative to the decline between 1995 and 2003, with an increasing share engaged in nonagricultural enterprises or wage work.

Compared to pre-2006, when the growth in tractor use was concentrated in the Central and Western regions of the Terai, significant growth in tractor use was also observed across the regions within the Terai. While the shares of farm households using tractors continued to increase in the Central and Western zones, to 56 percent and 72 percent by 2010, respectively, the shares in the Eastern, Mid-Western, and Far-Western zones also increased, to 33 percent, 24 percent, and 34 percent, respectively.

The Terai also witnessed growth in the adoption of pumps (motorized or manual) during this period. The share of Terai farm households using pumps increased from 4 percent in 2003 to 14 percent in 2010, with the growth equally distributed across regions (Takeshima and Bhattarai 2017). The price distribution for these pumps suggests that roughly half are likely to be motorized pumps, while the remaining half are treadle pumps.

The Hills also began to see growth in tractor use, albeit more slowly than in the Terai. The share of farm households using tractors increased from 9 percent in 2003 to 20 percent in 2010 in the Central region. The use of mini-tillers, imported from China, increased during this period, and their number is estimated to have reached 1,000 by 2010 (personal communication with local importers), supplied by 10 importers (Biggs and Justice 2015). While these numbers are still small, considering the total farming population in Nepal, adoption of these small tillers may accelerate rapidly, given their much greater affordability compared to larger tractors.

2. DEMAND-SIDE ANALYSIS

Use and/or Ownership of Tractors and Combine Harvesters

Nepal has diverse agroecological environments (Table 2.1). Most notably, while 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.

Table 2.1 Land-to-labor ratio, terrain ruggedness, and draft animal holdings (2010)

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 (bullock / cow / 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
Mid-Western / Far-Western	0.12	0.29	0.48	0.13	0.11	0.43	90	554	2.7	3.8

Source: Takeshima et al. (2015a).

Tractors

Growth in tractor use in Nepal has occurred mostly in the Terai, while growth has been slower in the Hills (based on the Nepal Living Standards Survey, NLSS); however, there are some indications that use has been growing faster since 2010 (the last round of NLSS), particularly in the Central zone, thanks to growth in the use of power tillers and mini-tillers. Within the Terai, the Central and Western regions have led the diffusion of tractor uses, while the Eastern, Mid-Western, and Far-Western regions have caught up (Table 2.2).

Table 2.2 Shares (%) of farm households using tractors, by year and agroecological belt

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
Mid-Western / Far-Western	5	15	29	1	0	1	1	0	0

Source: Takeshima et al. (2015a).

While 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 2.3 summarizes the share (percentage) of farmers growing each of the major crops, differentiated by their tractor use status, in Nepal Terai in 2010.

One of the dominant staple-crop production systems in 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 Nepal Terai (Table 2.3). While other crops such as maize, lentils, potatoes, and vegetables are also commonly grown, tractors are mostly 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 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.

Table 2.3 Mechanization and cropping patterns (% of farmers growing each crop)

Crop	Terai						Hills					
	2010 season		2010 rainy season		2010 dry season		2010 season		2010 rainy season		2010 dry season	
	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: Author.

In the Hills, the association between tractors and wheat appears weaker. In addition, while maize (particularly summer maize) is more widely grown in the Hills, the share of maize growers is higher among nonusers 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 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) are populated by farmers with medium-size landholdings (2– 3 hectares), for whom rice is harvested at a rate of about 0.70 hectare per hour and at a cost of about US$50 per hectare, a price that is approximately 25 percent lower than the cost of manual harvesting. A recent study in the Western region of the Terai (Kapilbastu, Rupendhai, and Nawalparasi districts) suggests that the number of combine harvesters in these districts has increased from 1 in 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

Table 2.4 summarizes the key characteristics of Terai and Hills households, differentiated 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 those of households in the Hills. Differences between tractor renters and users of draft animals only 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.

Table 2.4 Household characteristics in the Terai and Hills, by mechanization status in 2010

	Terai							Hills					
		Farm households							Farm households				
Category	(1a)	(1b)	(1c)	(1d)	(1e)	(1f)	(1g)	(2a)	(2b)	(2c)	(2d)	(2e)	(2f)
% of population (households)	19	81	1	1	36	32	13	23	77	0.2	5	65	6
Real expenditure per capita[a,b]	154	95	498	250	104	78	83	166	79	305	155	70	105
Real per capita asset value[b]	154	90	404	436	102	67	79	231	73	1069	318	40	160
Size of owned lowland (ha)	0.1	0.6	3.4	3.3	0.7	0.4	0.3	0.0	0.2	0.3	0.2	0.2	0.1
Size of owned upland (ha)	0.0	0.1	0.3	0.9	0.1	0.1	0.1	0.0	0.4	0.1	0.2	0.4	0.2
Size of cultivated area per ear (ha)	0	1.5	7.6	6.9	1.7	1.2	0.2	0	1.0	0.8	0.7	1.1	0.3
% selling crops	0	50	89	96	64	47	13	0	42	60	54	43	22
% selling crops or livestock products	9	63	89	96	76	64	21	1	58	92	63	61	24
Household size	4.6	5.4	6.8	6.1	5.7	5.4	5.1	3.8	4.8	5.5	4.7	4.9	3.7
Working-age members	2.7	3.0	4.0	3.6	3.2	2.9	2.8	2.7	2.7	3.8	3.2	2.6	2.4
Years of education (working-age)	6.1	4.0	6.7	6.7	4.5	3.4	3.3	8.2	4.1	6.9	6.3	3.8	5.1
Ruggedness index	50	43	7	17	28	61	60	133	478	155	222	511	378
Agricultural land endowment per capita (ha)	.062	.117	.115	.118	.111	.129	.096	.026	.216	.095	.064	.238	.130
Real farm wages (kg of cereals / day)	12	12	12	12	12	12	12	14	10	10	12	10	11
Access to market center (minutes)	25	60	29	38	54	65	58	38	265	43	35	294	185

Source: Takeshima et al. (2015a).

Note: Columns are the following: (1a) = nonfarm households in the Terai; (1b) = all farm households in the Terai; (1c) = tractor owners in the Terai with tractors worth the value of 20,000 kg of rice/wheat or more; (1d) = tractor owners in the Terai with tractors worth less than the value of 20,000 kg of rice/wheat; (1e) = farm households in the Terai using tractors through rentals; (1f) = farm households in the Terai using only draft animals or manual labor; (1g) = farm households in the Terai using only manual labor; (2a) = all farm households in the Hills; (2b) = tractor owners in the Hills; (2c) = farm households in the Hills using tractors through rentals; (2d) farm households in the Hills using only draft animals or manual labor; (2e) = farm households in the Hills using only manual labor. Missing observations are excluded. [a] Figures include subsistence food consumption evaluated at real market values. [b] Figures are index numbers, with national average = 100.

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.

Tractor renters also have generally better market access than draft-animal-only households and nonmechanized households. This is particularly pronounced in the Hills. In the Terai, between 2003 and 2010, more tractor owners emerged in suburban areas or areas where access had improved (closer to various facilities than nonowners, 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 et al. 2015a).

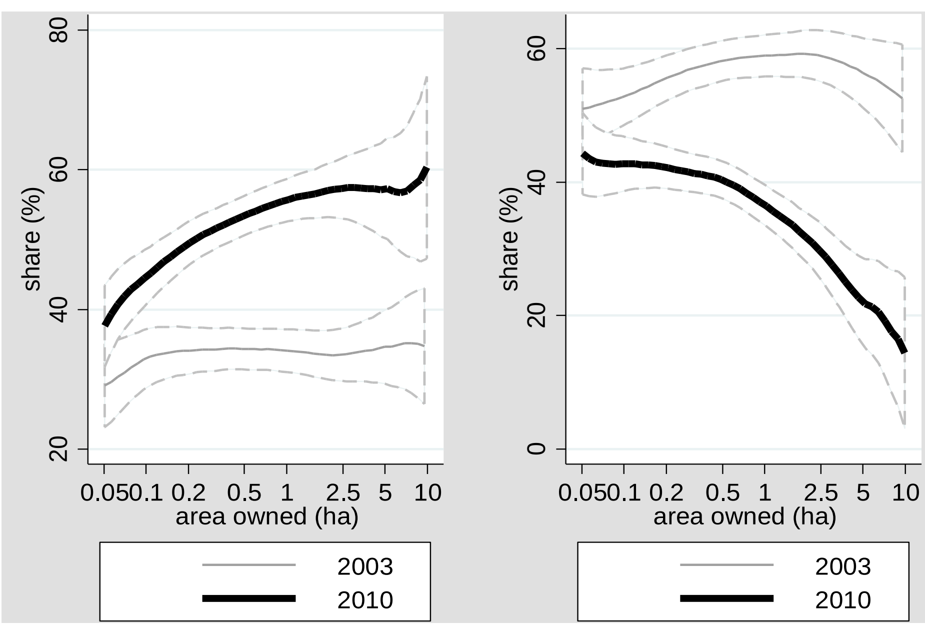
In the Hills, wages vary more across household types, and tractor renters pay higher wages. Mechanization status is also associated with local land-to-labor ratios (measured in agricultural land endowment per capita, which combines cropped areas and pastures). Intuitively, farm households are in areas 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 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 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 land fragmentation (Takeshima et al. 2015a). However, tractor adoption is still positively associated with farm size (Table 2.4). Tractor-owning households tend to own more farmland than other farm households. While 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 animal traction with tractors in the Terai between 2003 and 2010 was greater among larger farm households (Figure 2.1). Consequently, while in 2003 tractor adoption rates were relatively uncorrelated with farm size, by 2010 they were positively correlated with farm size.

Figure 2.1 Share of Terai farm households renting tractors or using only draft animals, by farm size (left = tractor renters; right = draft animal only)



Source: Takeshima et al. (2015a).

Evolution of Farm Household Characteristics

While Table 2.4 compares farm household characteristics across mechanization statuses in 2010, the evolution of overall farm household characteristics up to 2010 provides a useful indication of the context in which tractor use has grown (Table 2.5).

Table 2.5 Farm household characteristics

	Terai			Hills			Mountains		
	1995	**2003**	**2010**	**1995**	**2003**	**2010**	**1995**	**2003**	**2010**
% of 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 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 and not greater than 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: Author’s calculations based on data from the Nepal Living Standards Survey.
Note: [a] Figures are weighted by the area cultivated by the household.

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 animal power with tractor 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 hectare increased, while the share of those cultivating more than 3 hectares 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 section 4), but 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

While 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 et al. 2015a]), this shift in labor has raised farming wages. Table 2.6 summarizes 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. While the aggregate shares of labor force by sector is shown in Table 1.1, Table 2.6 provides further insights into the breakdown across agroecological belts, more disaggregated types/sectors of activities, and the effects of out-migration on an overall workforce, which are often not taken into account in a standard view of the employment share by sector.

Importantly, since Table 2.6 also allocates shares to emigrants and those who are not working for various reasons, the shares for the agricultural sector and the nonagricultural sector are lower than the employment share in Table 1.1.

Table 2.6 offers 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 the working-age population grew faster 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 females in the Hills (from 9 percent to 27 percent). Employment growth in the construction and finance and business sectors accounts for a substantial share of this growth.

The agricultural labor force share needs careful interpretation. The share declined overall, 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. While 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 section 4, 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 of labor in certain activities (such as plowing) by tractors.

Table 2.6 Percentage of workforce engaged in each sector, by hours worked (working-age population ages 15–59), in each agroecological belt in Nepal[a]

Gender	**Male**									**Female**								
Agroecological belt	**Terai**			**Hills**			**Mountains**			**Terai**			**Hills**			**Mountains**		
Year	**1995**	**2003**	**2010**	**1995**	**2003**	**2010**	**1995**	**2003**	**2010**	**1995**	**2003**	**2010**	**1995**	**2003**	**2010**	**1995**	**2003**	**2010**
Working-age population (1995 = 100)	100	126	155	100	121	147	100	116	131	100	126	158	100	119	141	100	115	132
Type of work																		
Agriculture, total	**56**	**47**	**39**	**44**	**41**	**34**	**61**	**58**	**49**	**69**	**69**	**50**	**69**	**66**	**53**	**79**	**87**	**71**
Agriculture, self	34	33	29	38	37	31	50	55	44	48	52	36	59	59	46	66	79	63
Agriculture, wage	22	14	10	6	4	3	11	3	5	21	17	14	10	7	7	13	8	8
Nonagriculture, self	**9**	**11**	**17**	**7**	**11**	**12**	**4**	**8**	**11**	**3**	**5**	**10**	**5**	**6**	**10**	**1**	**1**	**5**
Nonagriculture, wage	**7**	**13**	**19**	**14**	**17**	**22**	**11**	**10**	**17**	**1**	**3**	**10**	**4**	**9**	**17**	**2**	**3**	**12**
Manufacturing	2	4	4	2	3	3	2	1	2	0	1	2	2	4	4	0	0	1
Construction	1	3	6	3	3	7	2	2	8	0	0	4	0	0	3	1	0	3
Finance and business	0	2	2	0	4	4	0	4	4	0	1	1	0	3	4	0	2	3
Trade / retail / restaurant	0	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	1
Transport	1	1	2	1	1	2	1	0	1	0	0	1	0	0	1	0	0	0
Other	3	2	4	7	5	5	5	3	2	1	1	2	2	2	4	1	1	4
Nonworking	**19**	**19**	**9**	**23**	**19**	**10**	**18**	**15**	**8**	**26**	**23**	**27**	**20**	**17**	**16**	**17**	**8**	**10**
Emigration	**9**	**10**	**16**	**11**	**12**	**21**	**6**	**8**	**14**	**1**	**1**	**2**	**2**	**2**	**3**	**2**	**2**	**3**

Source: Author's calculations based on cross-sectional samples from three rounds of the Nepal Living Standards Survey (Nepal CBS 1996, 2004, and 2011a). For migration, refer to the descriptions below.

Note: Bold figures are aggregate figures of each category. The shares of "Agriculture, self," "Agriculture, wage," "Nonagriculture, self," and "Nonagriculture, wage" are based on the weighted averages, across the entire working-age population, of the breakdown of time spent on each of these four types of work in the previous 12 months. The breakdown within "Nonagricultural, wage" is the share (%) of the primary sector of work activities reported. "Nonworking" is the share (%) of the working-age population who did not report any work in the previous 12 months.

[a] The shares of emigrating workers in each agroecological belt are estimated in the following way:

- Nepal CBS (2014, Volume I, Table 9.5) provides the absent population differentiated by their ages at the time they left home, and the years since they left. From this, we estimate the absent population that is currently working age (15–59), for males and females.
- Nepal CBS (2011b, Table 11) provides the absent population in each agroecological belt by gender for all ages, but it does not provide the same figures for the working-age population. Assuming that the breakdown of the absent population across agroecological belts is the same for the working-age population as for the all-age population, we estimate the absent working-age population in each agroecological belt.
- Nepal CBS (2014, Table 7.11) provides the total numbers of the absent population by gender for 1991, 2001, and 2011. From these figures, we interpolate the numbers of the absent population for 1995 and 2003. Further assuming that the same breakdown across belts holds for 1995 and 2003, we estimate the total absent population for each belt in 1995 and 2003.
- Combining these figures with the Nepal population census, we obtained the shares of the absent population in the total population for each agroecological belt, year, and gender. Note that the absent population is excluded from the total population reported in the Nepal census (Nepal CBS 2011b).

Table 2.7 shows the changes in real daily wages of 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. While an investigation of the causes of these differential wage growth rates is beyond the scope of this paper, these figures may suggest that agricultural productivity in Nepal has become increasingly dependent on intensive plowing over time. However, while 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.

Table 2.7 Daily agricultural wages (in kg of milled rice purchased)

Activity – 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: Author's calculations based on data from the Nepal Living Standards Survey.
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.

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 NLSS, Takeshima, Adhikari, and Kumar (2016) estimate 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), 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 Kumar [2016] for the interpretations). In addition, adoption of hired tractors is positively associated with flatter terrain and 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.[1] 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)[2] is associated with both greater adoption 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 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 et al. 2015b).

[1] However, as noted in section 4, 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.

[2] 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 in 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 region, the demand is likely to have grown sufficiently, as witnessed by the 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 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 section 4).

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, which may be more favorable for keeping draft animals.

3. 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/Import Policies

Trade/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, National Trading Corporation, 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 1991b). 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, 2047, 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 2016). Since then, tractors used for agricultural purposes have been exempt from VAT, while 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 Treaty of Trade, which is a bilateral agreement 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.[3]

Petroleum products represent the majority of energy sources in Nepal, unlike in neighboring countries such as Bhutan (Thakur and Kaushik 2004), and certain taxes and tariffs have been applied. For petroleum products, taxes were levied before the 1995 introduction of the VAT. In the 1970s, no special incentives were provided for the purchase of fuel and lubricants for agricultural purposes (Shrestha 1978). A road-bridge tax was introduced in 1982/1983 (Khadka 1991b). When the road-bridge tax began to hinder the free flow of traffic and trade (as it was collected at specified bridges), it was replaced by a specific tax on imports of high-grade diesel and gasoline to be used for vehicles, and the tax was collected at customs points together with customs duties (Khadka 1991b), at the rate of 0.1 rupee per liter (1984/1985) and 0.2 rupee per liter in 1987/1988 (Khadka 1991a). Since the introduction of the VAT, fuel used for agricultural purposes has been exempt from this tax (Acharya 2016), though it is unclear how this policy has been implemented. Tariffs of only about 10 percent on average (6 percent for preferential tariffs, including India) are currently imposed (World Bank 2016). Petroleum products are mostly imported from India (Bassnet and Pandey 2014). For nonagricultural purposes, gasoline and diesel are currently subject to 22 percent and 15 percent VAT, respectively; 22 percent and 2.5 percent customs duty; and road maintenance as well as environmental taxes (Sapkota 2015, Annex II). Over the past several decades, petroleum products in Nepal have been distributed solely by the government-owned

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

Nepal Oil Corporation (Sapkota 2015). Diesel and gasoline prices in Nepal are higher than prices in Bangladesh and Sri Lanka, as well as Nigeria, but similar to or slightly lower than those in India (Table 3.1).

Table 3.1 Prices of gasoline and diesel in 2006, including tariff and tax, in 2006 US cents per gallon

Fuel	Nepal	Bangladesh	India	Pakistan	Sri Lanka	Nigeria	USA
Gasoline	356	299	382	382	333	193	238
Diesel	276	170	284	242	208	250	261

Source: Dahl (2012).

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 subsidizing it could displace workers. Similarly, in 1980–1985, ADB Nepal discouraged financing tractors/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 Agricultural Perspective Plan (APP) (1995–2015) and National Agriculture Policy 2004, the Directorate of Agriculture 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 (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 Agricultural Development approved the Agricultural Mechanization Subsidy Mobilization Directives, 2070, for distributing subsidies through the Department of Agriculture Engineering (NARMA 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 Agriculture Engineering Division of the Nepal Agriculture 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). While a separate license, issued by the Department of Transport Management under the Ministry of Labor and Transport Management, is required to drive a tractor or power tiller, currently no license is required to either import tractors or become a tractor dealer.[4]

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, 2049 (1992) and 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-

[4] Personal communication with the Ministry of Agricultural Development staff.

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, 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. While information on custom hiring service providers is limited, a recent IFPRI survey of service providers provides useful insights. Various types of service providers were interviewed (Table 3.2). Since the samples of each type are small, we do not intend to obtain a differential picture of the nature of service provisions across different types; rather, we focus on farmer-to-farmer/private service providers and on collective insights for all types combined.

Table 3.2 Types of hiring service providers interviewed

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

Source: IFPRI (2016).

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

Table 3.3 Size of landholdings by interviewed tractor service providers

Variable	N	Total (ha)	Upland	Lowland (irrigated)	Lowland (non-irrigated)	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).

Table 3.4 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 for 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; while 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 like 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, while 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.

Table 3.4 Extent of custom hiring service operations, in number of days used per year[a]

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, while figures in parentheses are sample medians.

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 farm. Mini-tillers are used about 30 days for hiring out, similar to four-wheel tractors. Hiring out for farming operation 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 3.5). While 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 3.5 Sources of financing for tractors and power tillers

Source	% share of finance			% of service providers using each source to partly finance each machine		
	Four-wheel tractors		Power tillers	Four-wheel tractors		Power tillers
	Farmer-to-farmer/private	Other (government, extension, cooperatives, NGOs)		Farmer-to-farmer/private	Other (government, extension, cooperatives, NGOs)	
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
Loan (other informal sources)	2	6	5	3	12	7
Loan (commercial bank)	16	18	4	25	29	4
Loan (agricultural cooperative bank)	4	5	9	6	9	9
Loan (government scheme)	0	0	0	0	0	0
Other sources	0	6	6	0	11	6

Source: IFPRI (2016).

Table 3.6 summarizes the breakdown of operating costs and depreciation per year per tractor or per power tiller, for farmer-to-farmer/private service providers and 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 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 and may be incurring lower costs than the other types of service providers (spending on average US$3,000 per tractor, as opposed to the US$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.

Table 3.6 Breakdown of key cost components for four-wheel tractors and power tiller operations (US dollars per year per machine), excluding costs for attachments

	Four-wheel tractors		Power tillers
	Farmer-to-farmer/private	Other (government, extension, cooperatives, NGOs)	
Sample size	32	76	46
Operators (self-assessed if operating by themselves)	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, while figures in parentheses are sample medians. [b] Calculated by dividing the expected service life of tractors by the original (unsubsidized) values of the tractors, deflated by the consumer price index (World Bank 2016).

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 NLSS provide hiring-out services. While 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 3.7).

Table 3.7 Median owned and annually cultivated farm size (ha) of tractor owners, differentiated by hiring-out status, Terai

Type of tractor owner	Owned land		Annually cultivated land	
	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: Author's calculations based on data from the Nepal Living Standards Survey.

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 et al. (2015), based on a survey of 150 service providers in the three districts in Western

Terai (Kapilbastu, Rupendhai, 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 hectares per year on average, though this rate has declined from about 500 hectares 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 et al. 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.

4. 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 matching method (detailed technical issues are discussed in Appendix). 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. While most farmers in Nepal are smallholders, we differentiate resource-poor smallholders (owning low-land farm not more than 1 acre) and medium smallholders (owning low-land farm greater than 1 acre) in the Terai where appropriate, to highlight the differential effects of tractor adoption on their outcomes.

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. 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 nine tractor owners in the panel sample saw increases in farmland owned or cultivated before the next round of NLSS (Table 4.1).

Table 4.1 Change in owned farm size and operational size, by tractor owners and nonowners (panel samples)

		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
Nonowners (N = 1,400)	Mean	1.0	-0.2	1.9	-0.4
	Median	0.6	-0.0	1.2	-0.1

Source: Author.

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 17.5 percent increase in agricultural income and an 11.9 percent increase in per capita household income for medium smallholders (Table 4.2), indicating improvement in the overall profitability of their production systems. In contrast, the effects for small 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 is therefore likely to help larger farm households in the Terai to survive in farming more than it helps smaller farm households in the Terai or those in the Hills. These results are consistent with the hypothesis that tractors are complementary to land and flatter topography.

Table 4.2 Effects of adopting tractors on household income (total income and agricultural income)[a]

Outcomes	Small	Medium	Hills
Real per capita household income (kg of cereals)	-8.393 (254.253)	527.443** (260.674)	-307.716 (465.889)
Growth rate of real per capita household income (natural log)	.090 (.072)	.119* (.072)	-.053 (.087)
Per capita agricultural income (kg of cereals)	90.997 (110.625)	63.36 (84.025)	192.850** (78.291)
Growth rate of per capita agricultural income (natural log)	.154 (.135)	.175* (.104)	.278* (.151)

Source: Author. Results for the Hills are from Takeshima and Bhattarai (2017).

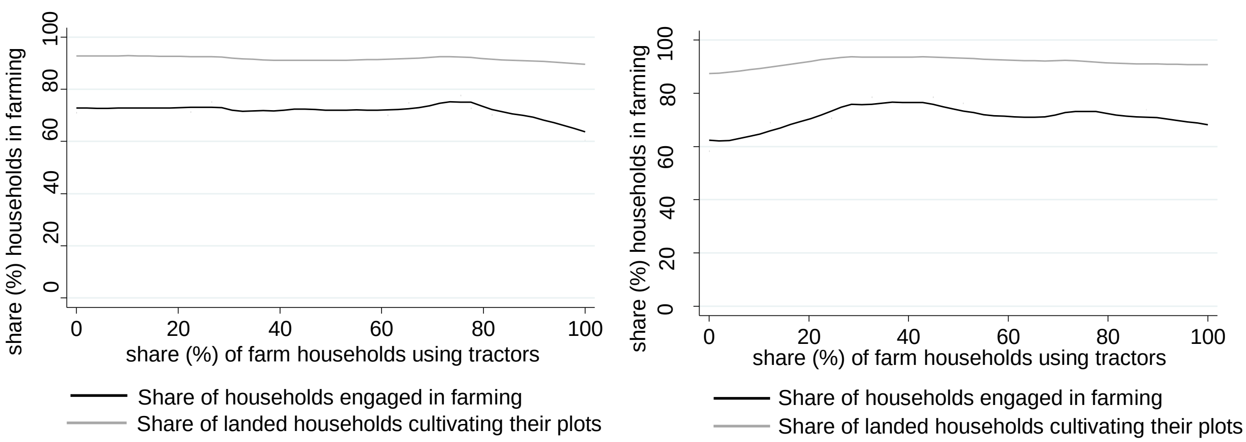
Note: [a] Figures are estimated effects. Figures in parentheses are standard errors of the estimated effects. Asterisks indicate the statistical significance: ** 5%, * 10%

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 4.1 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 4.1. 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 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.[5]

Figure 4.1 Correlation between village development committee level share (%) of tractor-using farm households and share of households engaged in farming

All years combined; 2010 only



Source: Author's calculations based on data from the Nepal Living Standards Survey.

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 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 4.3). While using tractors often leads to reduced land rental revenues, these effects are clearer among resource-poor smallholders (while the changes in land rental revenues are greater for medium smallholders, they are not precisely estimated). Similarly, tractor adoption also lowers off-farm income more among resource-poor smallholders. Off-farm income decreases for resource-poor smallholders due

[5] 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.

to tractor adoption, partly as a result of the reduced time spent by adult female household members in off-farm activities (Table 4.4). These conditions suggest that tractor adoption does not induce farm exit, and resource-poor smallholders may actually shift more resources to farming (however, as shown above, the overall effect of tractors on household incomes is less clear among resource-poor smallholders).

Table 4.3 Effects of tractor use on livestock revenue, land rental revenue, and off-farm income

	Terai		Hills
	Small	Medium	
Real per capita livestock revenue (kg of cereal)	137.745 (84.989)	115.390*** (35.303) [1.45]	73.712* (43.491) [1.10]
Real per capita land rental revenue (kg of cereal)	-6.606* (3.958) [2.90]	-42.798 (30.736)	-15.608 (12.320)
Real per capita land rental revenue (kg of cereal) – rainy season	-6.424** (2.718) [3.85]	-24.810 (21.996)	-12.749 (7.892)
Real per capita land rental revenue (kg of cereal) – dry season	-.182 (1.872)	-17.987 (13.906)	-2.858 (6.491)
Real per capita land rental payment (kg of cereal)	-.155 (.377)	.152 (.233)	.307 (.264)
Real per capita off-farm income (kg of cereal)	-499.111* (291.659) [1.70]	287.116 (303.348)	-840.236*** (310.450) [1.90]

Source: Author's calculations based on data from the Nepal Living Standards Survey.
Note: Asterisks indicate the statistical significance: *** 1%; ** 5%; * 10%.

Table 4.4 Effects of tractor use on off-farm income-earning activities (person-hours within 12 months)

	Terai		Hills
	Small	Medium	
Male family member (hours per year)	-51.889 (223.171)	-92.201 (165.596)	104.119 (197.617)
Male family member per capita (hours per year)	4.873 (110.682)	-126.329 (97.913)	35.556 (131.761)
Female family member (hours per year)	-93.737 (85.214)	-111.337 (84.043)	99.064 (123.199)
Female family member per capita (hours per year)	-104.287† (67.999) [1.70]	-6.965 (50.424)	22.284 (72.021)

Source: Author's calculations based on data from the Nepal Living Standards Survey.
Note: Asterisks indicate the statistical significance: † 15%.

Recent studies in Nepal also suggest that resource-poor smallholders may experience an increase in household income by exiting farming, while medium smallholders do not experience such increases (Takeshima et al. 2016). This is part of the reason why resource-poor smallholders may not experience a significant increase in income from tractor adoption, if it involves reducing off-farm income-earning activities.

Effects on Land Productivity and on the Adoption of Other Modern Technologies

Tractor adoption has different effects on the farming practices of resource-poor smallholders and medium smallholders in the Terai and of those in the Hills (Table 4.5). For resource-poor smallholders in the Terai, tractor adoption generally has land-productivity-enhancing effects through more intensive uses of nonland inputs, such as chemical fertilizer and irrigation. In contrast, for medium smallholders in the Terai, tractor adoption generally induces expansion of the cultivated area.

Importantly, tractor adoption often increases rather than decreases the overall use of labor, particularly labor by adult female household members and/or hired labor. This is possibly because in Nepal Terai, while tractor use has been increasingly adopted, other farming operations (planting, fertilizer applications, weeding, bird scaring, harvesting) remain largely unmechanized. While tractor adoption substitutes labor in land preparation, the resulting expansion of operational size, intensification, and harvest growth may raise the demand for labor, leading to net increases in labor use. Effects on labor use differ as well; for resource-poor smallholders, adult female family members' labor accounts for much of the increase in overall labor use, while for medium smallholders, hired labor accounts for an important share of labor use increases. These differences in the effects on labor type are consistent with the aforementioned differences between land-productivity-enhancing behaviors and land-expansion behaviors.[6]

[6] In Asian countries, more hired labor is typically used for activities for which efforts are easily visible (such as transplanted areas, harvested quantities), while 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 4.5 Effects of mechanization on agricultural input use (land, fertilizer, labor)

Outcomes	Terai		Hills
	Resource-poor smallholders	Medium smallholders	
Area cultivated per year (ha)	.135 (.119)	.313* (.162) [1.05]	.080 (.103)
Own area cultivated in dry season (ha)	-.009 (.028)	.140* (.075) [1.30]	.035 (.046)
Own area cultivated in rainy season (ha)	.008 (.030)	.192*** (.076) [1.10]	.045 (.050)
Net area sharecropped in (ha)	.088* (.053) [1.00]	.210** (.105) [1.80]	.065 (.044)
Net area rented in (ha)	.001 (.019)	.033 (.037)	.010 (.014)
Chemical fertilizer use per ha (kg of nutrients / ha)	14.915*** (4.659) [1.35]	-3.877 (6.721)	1.844 (15.995)
Irrigation in dry season (%)	9.892* (5.061) [1.35]	2.810 (4.445)	15.737*** (5.018) [1.80]
Irrigation in wet season (%)	12.620** (5.050) [1.40]	5.452 (4.403)	18.205*** (4.887) [1.90]
Family labor use – male (hours per year)	145.131 (109.979)	-15.914 (135.682)	14.578 (11.612)
Family labor use – male per capita (hours per year)	78.101 (68.431)	9.468 (85.979)	131.431* (72.287) [1.25]
Family labor use – female (hours per year)	274.168*** (99.441) [1.15]	91.735 (126.881)	23.001 (14.775)
Family labor use – female per capita (hours per year)	146.840** (62.590) [1.25]	146.081** (72.615) [1.15]	120.382 (75.529)
Family labor use – child (hours per year)	-70.952 (66.744)	6.115 (96.363)	3.355 (62.204)
Hired labor male (days per year)	.121 (.899)	9.554*** (2.528) [1.25]	2.964* (1.533) [1.05]
Hired labor female (days per year)	1.933 (1.740)	9.011** (4.204) [1.30]	6.942*** (2.431) [1.30]

Source: Author. Results for the Hills are from Takeshima and Bhattarai (2017).
Note: Asterisks indicate the statistical significance: *** 1%; ** 5%; * 10%.

The patterns in the Hills are slightly different. While 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 like chemical fertilizer are relatively small. This is partly because of the potentially lower returns to use of chemical fertilizer in the hilly environment than in the flatter Terai zone (Takeshima et al. 2017).

The patterns for medium smallholders in the Terai are generally commonly observed, in which the often-cited complementary relationship between mechanization and farm size dominates the effects of tractor adoption on farming practices. The land-productivity-enhancing patterns for resource-poor smallholders and those in the Hills are somewhat unique. While detailed agronomic information is not available in NLSS, these patterns 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).

Consistent with Table 4.5, tractor adoption has significant effects on land productivity, an indicator of yield (Table 4.6). For resource-poor smallholders in the Terai, real crop revenue per hectare of cultivated area increases by 12 percent. The effects are generally insignificant for medium smallholders in the Terai and for smallholders in the Hills.

Table 4.6 Effects of mechanization on real revenue per hectare

	Terai		Hills
	Small	Medium	
Growth rate of real crop revenue per ha of cultivated area	.121† (.086) [1.40]	-.133 (.101)	.115 (.098)

Source: Author.
Note: Asterisks indicate the statistical significance: † 15%.

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 hire services affects the shape of the production function itself by increasing the returns to scale in agricultural production, including livestock (Takeshima 2017) (Table 4.7). 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 adoption and use of other inputs) through an inverse probability weighted generalized method of moments estimator (see Takeshima 2017 for detail). In addition, it shows that this transformational effect is realized through tractor custom hire services instead of tractor ownership. While the external validity of the evidence requires further research, it shows that in certain areas in Nepal, tractors are not simply complementing or substituting other inputs but also substantially transforming production technology.

Table 4.7 Effects of tractor custom hire service on agricultural returns to scale in Nepal Terai

	Estimated Cobb-Douglas production function coefficients with and without hired tractors	
	Tractor custom hire 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 (2017).
Note: Asterisks indicate the statistical significance: *** 1%; ** 5%; * 10%.

Effects on Gender and Feminization of Farming

The adoption of tractors in 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 fertility, which is often interpreted as the result of labor substitution. For example, Bhandari and Ghimire (2013) show that tractor adoption reduces the subsequent fertility of women in the Western Chitwan Valley of Nepal. While Bhandari and Ghimire (2013) associate the findings with the reduced demand for children as a result of substitution of labor by tractors, 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.[7]

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

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 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), in which tractors are commonly used in Nepal Terai (section 2), 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 cause waterlogging, poor soil aeration, restricted root growth, and decreased availability of soil nutrients in wheat (Sharma, Ladha, and Bhushan 2003). Soil compaction is one of the key outcomes, which causes the development of subsurface hardpans (often to a depth of 10–45 centimeters below the puddled layer). While subsurface hardpans develop due to various factors, including animal and human processes during tillage, transplanting, weeding, and other processes, and 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 raising further 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 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 hectares of rice-wheat systems spreading over the Indo-Gangetic Plain (Chauhan et al. 2012), some 5 million hectares 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 hectares of this rice-wheat system (Chauhan et al. 2012). In the state of Bihar, situated adjacent to Nepal Terai, private-sector-led zero-tillage custom hiring service providers have emerged over time, where 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 Nepal Terai if there is demand. Although information is currently scarce, some zero-till service providers may actually be located inside Nepal Terai.

5. CONCLUDING REMARKS

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 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 areas 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 the 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 to eventually develop their own mechanization systems in the future. The recent growth (albeit from a low base) of Chinese mini-tillers on sloped upland plots in the Hills may be an example of such a system.

There are several key policy issues to consider. While 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. Identifying whether and how government support can mitigate such constraints remains an important policy area for the Nepalese government.

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. Given that adoption has reached sufficient scale, designing and implementing appropriate regulatory policies has also likely become more relevant to the sector. These policies should, however, be designed to avoid unnecessarily suppressing growth in the supply of mechanization services that have emerged.

Lastly, while tractor use has grown among smallholders generally, evidence suggests that larger farmers (medium smallholders as opposed to resource-poor smallholders) benefit relatively more overall, and that tractor adoption alone does not seem to be one of the factors that raises the household incomes of resource-poor smallholders. Broader agricultural strategies, in which mechanization is one element rather than the primary tool, must be identified to assist these resource-poor smallholders.

APPENDIX: ESTIMATION OF THE IMPACTS OF TRACTOR ADOPTION

We focus our analyses on specific regions with relatively favorable environments for intensifying tractor adoption. As was seen in section 2, the extent and depth of the adoption of tractors vary considerably across agroecological belts (the Terai and Hills), as well as within the Terai zone. Comparing adopters and nonadopters of tractors in very different environments often biases the estimates of tractor adoption.

Specifically, we focus on farm households in the Terai zone and in the village development committees in which at least one tractor adopter and nonadopters are included in the samples in each round of NLSS. Furthermore, we separately assess the impacts for small-farm households (owning less than 0.4 hectare of lowland farmland) and medium-farm households (owning 0.4–5 hectares of lowland farmland). The application of propensity score matching shows that selected samples and estimated propensity scores satisfy sufficient balancing properties (Table A.1).

Table A.1 Balancing properties of propensity score matching

	Resource-poor smallholders (owning less than 0.4 ha of lowland farmland)	Medium smallholders (owning 0.4–5 ha of lowland farmland)
Rubin’s B	0.358	0.392
Rubin’s R	1.13	1.23
% of variables with statistically significant differences in means at 10%	0	0
Sample		
Control	538	357
Treated	319	383
Treated – on support	278	350
Total	816	707

Source: Author.

Note: In a well-balanced sample, Rubin’s B should be less than 0.4, Rubin’s R should be between 0.5 and 2 (Cochran and Rubin 1973; Rubin 2001), and few variables should have statistically significant differences in means between adopter and nonadopter samples.

REFERENCES

Acharya, S. 2016. "Reforming Value Added Tax System in Developing World: The Case of Nepal." *Business and Management Studies* 2 (2): 44–63.

ADB (Asian Development Bank). 2013. *ADB 7762-NEP Final Report*. Technical Assistance for the Preparation of the Agricultural Development Strategy. Manila, the Philippines: ADB.

Adhikary, S. K. 2004. *Nepal Country Paper*. Paper presented at the Technical Advisory Committee (TAC) and Governing Board Meeting of Asia and the Pacific Centre for Agricultural Engineering and Machinery (APCAEM) in Hanoi, Vietnam, December 13–16.

Animaw, A. T., J. A. M. Nkanya, J. M. Nyakiba, T. H. Woldemariam, and H. Takeshima. 2016. *Agricultural Mechanization and South-South Knowledge Exchange: What Can Ethiopian and Kenyan Policymakers Learn from Bangladesh's Experience?* ESSP Policy Note 47. Washington, DC: International Food Policy Research Institute.

Basnett, Y., and P. R. Pandey. 2014. *Industrialization and Global Value Chain Participation: An Examination of Constraints Faced by the Private Sector in Nepal*. Asian Development Bank Economics Working Paper Series 410. Manila, the Philippines: Asian Development Bank.

Bhandari, P., and D. Ghimire. 2013. "Rural Agricultural Change and Fertility Transition in Nepal." *Rural Sociology* 78 (2): 229–252.

Biggs, S., and S. Justice. 2015. *Rural and Agricultural Mechanization: A History of the Spread of Small Engines in Selected Asian Countries.* IFPRI Discussion Paper 01443. Washington, DC: International Food Policy Research Institute.

Biggs, S., S. Justice, C. Gurung, J. Tripathi, and G. Sah. 2002. "The Changing Power Tiller Innovation System in Nepal: An Actor-Oriented Analysis." Paper presented at the workshop Agricultural and Rural Mechanization, Bangladesh Agricultural University, Mymensingh, Bangladesh, November 2.

Biggs, S., S. Justice, and D. Lewis. 2011. "Patterns of Rural Mechanisation, Energy and Employment in South Asia: Reopening the Debate." *Economic and Political Weekly* 46 (9): 78–82.

Chauhan, B. S., G. Mahajan, V. Sardana, J. Timsina, and M. L. Jat. 2012. "Productivity and Sustainability of the Rice-Wheat Cropping System in the Indo-Gangetic Plains of the Indian Subcontinent: Problems, Opportunities, and Strategies." *Advances in Agronomy* 117 (1): 315–369.

Cochran, W. G., and D. B. Rubin. 1973. "Controlling Bias in Observational Studies: A Review." *Sankhyā: The Indian Journal of Statistics, Series A* 35 (4): 417–446.

CSAM (Center for Sustainable Agricultural Mechanization). 2014. "Country Pages." Accessed July 2. http://un-csam.org/cp_index.htm.

Dahl, C. A. 2012. "Measuring Global Gasoline and Diesel Price and Income Elasticities." *Energy Policy* 41: 2–13.

Devkota, S., and M. Upadhyay. 2013. "Agricultural Productivity and Poverty Reduction in Nepal." *Review of Development Economics* 17 (4): 732–746.

Dillon, A., M. Sharma, and X. Zhang. 2011. "Estimating the Impact of Rural Investments in Nepal." *Food Policy* 36 (2): 250–258.

Do, Q. T., A. A. Levchenko, and C. Raddatz. 2016. "Comparative Advantage, International Trade, and Fertility." *Journal of Development Economics* 119: 48–66.

FAO (Food and Agriculture Organization of the United Nations). 2016. FAOSTAT database. Accessed December 1, 2016.

Gautam, A. K., and N. P. Shrestha. 2012. "Temperate Rice in Nepal*.*" In *Advances in Temperate Rice Research*. Los Baños, the Philippines: International Rice Research Institute.

Grace, P. R., L. Harrington, M. C. Jain, and G. P. Robertson. 2003. "Long-Term Sustainability of the Tropical and Subtropical Rice-Wheat System: An Environmental Perspective." In *Improving the Productivity and*

Sustainability of Rice-Wheat Systems: Issues and Impacts, edited by J. K. Ladha, J. E. Hill, J. M. Duxbury, R. K. Gupta, and R. J. Buresh. Madison, WI, US: American Society of Agronomy.

Gyawali, P. K. 2014. “A Final Year Project Report on Vehicle Over Speed Detection and Recognition.” Doctoral dissertation, Tribhuvan University, Kirtipur, Nepal.

Hatlebakk, M. 2016. “Inter-generational Determinants of Migration Decisions: The Case of International Labour Migration from Nepal.” *Oxford Development Studies* 44 (1): 93–112.

Hjort, H. W. 1973. *Assisting Agricultural Development in Nepal.* Washington, DC: Foreign Development Division, Economic Research Service, US Department of Agriculture, cooperating with United States Agency for International Development.

Hobbs, P. R., K. Sayre, and R. Gupta. 2008. “The Role of Conservation Agriculture in Sustainable Agriculture.” *Philosophical Transactions of the Royal Society B: Biological Sciences* 363 (1491): 543–555.

Houssou, N., C. Asante-Addo, X. Diao, and S. Kolavalli. 2015. *Big Tractors, but Small Farms: Tractor Hiring Services as a Farmer-Owner’s Response to an Under-developed Agricultural Machinery Market.* IFPRI GSSP Working Paper 39. Washington, DC: International Food Policy Research Institute.

International Rice Research Institute. 2016. *World Rice Statistics*. Los Baños, Philippines; IRRI.

International Food Policy Research Institute. 2016. *Custom Hiring Services of Agricultural Machinery Survey*. Kathmandu, Nepal.

Jenkins, G. P., and C. Y. Kuo. 2000. “A VAT Revenue Simulation Model for Tax Reform in Developing Countries.” *World Development* 28 (4): 763–774.

Joshi, K. D., C. Conroy, and J. R. Witcombe. 2012. *Agriculture, Seed, and Innovation in Nepal: Industry and Policy Issues for the Future*, 1–60. Washington, DC: International Food Policy Research Institute.

Justice, S., and S. Biggs. 2013. “Rural and Agricultural Mechanization in Bangladesh and Nepal: Status, Processes and Outcomes.” In *Mechanization for Rural Development: A Review of Patterns and Progress from around the World*, edited by J. Kienzle, J. E. Ashburner, and B. G. Sims. Rome: Food and Agriculture Organization of the United Nations.

Keil, A., A. D’Souza, and A. McDonald. 2016. “Growing the Service Economy for Sustainable Wheat Intensification in the Eastern Indo-Gangetic Plains: Lessons from Custom Hiring Services for Zero-Tillage.” *Food Security* 8 (5): 1011–1028.

Khadka, R. B. 1991a. *An Outline of Nepalese Taxes.* Tokyo: Seijo University.

———. 1991b. *Evolution, Current Problems, and Possibilities for Reform of the Nepalese Tax System (I).* Tokyo: Seijo University.

Kikuchi, M., and Y. Hayami. 1999. “Technology, Market, and Community in Contract Choice: Rice Harvesting in the Philippines.” *Economic Development and Cultural Change* 47 (2): 371–386.

Ladha, J. K., J. E. Hill, J. M. Duxbury, R. K. Gupta, and R. J. Buresh. 2003. *Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts*. Madison, WI, US: American Society of Agronomy.

Lawrence, P. R., and R. A. Pearson. 2002. “Use of Draught Animal Power on Small Mixed Farms in Asia.” *Agricultural Systems* 71 (1): 99–110.

Murshed, S. M., and S. Gates. 2005. “Spatial-Horizontal Inequality and the Maoist Insurgency in Nepal.” *Review of Development Economics* 9 (1): 121–134.

NARMA Consultancy Private Limited. 2016. *Agri-mechanization Promotion Strategy Implementation Plan and Budgeting*. Report prepared for the Government of Nepal. Kathmandu, Nepal: Ministry of Agricultural Development.

Nepal CBS (Central Bureau of Statistics). 1996. Nepal Living Standards Survey Report 1996: Main Findings. Vol. 1. Kathmandu, Nepal: Nepal CBS.

———. 2004. Nepal Living Standards Survey II (2003/04): Survey Design and Implementation. Kathmandu, Nepal: Nepal CBS.

———. 2011a. Nepal Living Standards Survey 2010/11: Statistical Report. Vol. 1. Kathmandu, Nepal: Nepal CBS.

———. 2011b. Population and Housing Census 2011. Kathmandu, Nepal: Nepal CBS.

———. 2014. *Population Monograph of Nepal. Volume I (Population Dynamics).* Kathmandu, Nepal: Nepal CBS.

Nepal, MoAD (Ministry of Agricultural Development). 2014. *Agriculture Mechanization Promotion Policy*. Kathmandu.

Pant, K. P. 2013. *Monetary Incentives to Reduce Open-Field Rice-Straw Burning in the Plains of Nepal.* South Asian Network for Development and Environmental Economics (SANDEE) Working Paper 81. Kathmandu, Nepal: SANDEE.

Pariyar, M. P., and G. Singh. 1995. "Farm Mechanization in Nepal." *Agricultural Mechanization in Asia, Africa and Latin America* 26: 55–61.

Paudel, G., A. McDonald, S. Justice, S. Adhikari, M. Devkota, and D. Sherchan. 2015. "Conservation Agriculture: A Resilient Way to Exterminate Trade-offs in Combine Harvesters Use and Residue Burning in Rice-Wheat Systems of Nepal." Paper presented at the International Conference on Open Burning of Agricultural Residue in the Himalayas Region, Kathmandu, Nepal, February 20–21.

Pingali, P., and M. Hossain. 1998. *Impact of Rice Research*. Los Baños, the Philippines: International Rice Research Institute.

Pullabhotla, H., G. Shreedhar, A. G. Kumar, and A. Gulati. 2011. *A Review of Input and Output Policies for Cereal Production in Nepal.* Report prepared for the Cereals System Initiative for South Asia (CSISA). Discussion Paper 1114. Washington, DC: International Food Policy Research Institute.

Ransom, J. K., K. Paudyal, and K. Adhikari. 2003. "Adoption of Improved Maize Varieties in the Hills of Nepal." *Agricultural Economics* 29 (3): 299–305.

Roumasset, J., and G. Thapa. 1983. "Explaining Tractorization in Nepal: An Alternative to the 'Consequences Approach.'" *Journal of Development Economics* 12 (3): 377–395.

Rubin, D. B. 2001. "Using Propensity Scores to Help Design Observational Studies: Application to the Tobacco Litigation." *Health Services and Outcomes Research Methodology* 2 (3–4): 169–188.

Sapkota, S. 2015. *Trade Study Series: A Look at Petroleum and Fertilizer Supply in Nepal.* Kathmandu, Nepal: Samriddhi, The Prosperity Foundation.

Sharma, K. 2015. "Trade Policymaking in a Land-locked Developing Country: The WTO Review of Nepal." *World Economy* 38 (9): 1335–1349.

Sharma, K., J. Ladha, and L. Bhushan. 2003. "Soil Physical Effects of Puddling in Rice-Wheat Cropping Systems." In *Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts*, edited by J. K. Ladha, J. E. Hill, J. M. Duxbury, R. K. Gupta, and R. J. Buresh. Madison, WI, US: American Society of Agronomy.

Sharma, D. R., and T. Sarker. 2015. *Weaknesses of VAT in Nepal.* Amsterdam, the Netherlands: International Bureau of Fiscal Documentation.

Shrestha, B. K. 1978. "Status of Agricultural Mechanization in Nepal." In *Proceedings of the International Agricultural Machinery Workshop.* Los Baños, the Philippines: International Rice Research Institute.

Shrestha, H. K., H. K. Manandhar, and P. P. Regmi. 2012. "Variety Development Cost versus Variety Adoption in Major Cereals in Nepal." *Nepal Journal of Science and Technology* 13 (1): 7–15.

Takeshima, H. 2017. "Custom-Hired Tractor Services and Returns to Scale in Smallholder Agriculture: A Production Function Approach." *Agricultural Economics* 48 (3): 363–372.

Takeshima, H., R. Adhikari, and A. Kumar. 2016. *Is Access to Tractor Service a Binding Constraint for Nepali Terai Farmers?* IFPRI Discussion Paper 01508. Washington, DC: International Food Policy Research Institute.

Takeshima, H., R. Adhikari, M. N. Poudel, and A. Kumar. 2015a. *Farm Household Typologies and Mechanization Patterns in Nepal Terai*. IFPRI Discussion Paper 01488. Washington, DC: International Food Policy Research Institute.

Takeshima H, E Edeh, A Lawal & M Isiaka. (2015b). Characteristics of private-sector tractor service provisions: Insights from Nigeria. *Developing Economies 53*(3), 188-217.

Takeshima, H., R. Adhikari, S. Shivakoti, B. D. Kaphle, and A. Kumar. 2017. "Heterogeneous Returns to Chemical Fertilizer at the Intensive Margins: Insights from Nepal." *Food Policy* 69: 97–109.

Takeshima, H., and M. Bhattarai. 2017. "Agricultural Mechanization in Nepal: Patterns, Impacts and Enabling Strategies for Promotion." In *Agricultural Development in Nepal*, edited by G. Thapa, P. K. Joshi, and A. Kumar. Draft.

Takeshima, H., R. B. Shrestha, B. D. Kaphle, M. Karkee, S. Pokhrel, and A. Kumar. 2016. *Effects of Agricultural Mechanization on Smallholders and Their Self-Selection into Farming: An Insight from the Nepal Terai.* IFPRI Discussion Paper 01583. Washington, DC: International Food Policy Research Institute.

Templeton, S. R., and S. J. Scherr. 1999. "Effects of Demographic and Related Microeconomic Change on Land Quality in Hills and Mountains of Developing Countries." *World Development* 27 (6): 903–918.

Thakur, T., and S. Kaushik. 2004. "Regional Power Market for Energy Development in South Asia: Some Issues." *South Asia Economic Journal* 5 (2): 301–310.

World Bank. 2016. *World Integrated Trade Solution*. Washington, DC: World Bank.

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