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Farm Machinery Use and Agricultural Industries in India

Status, Evolution, Implications and Lessons Learned

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ABSTRACT

Over the last several decades, India has seen a continuous spread of tractor use as well as growth in its domestic tractor manufacturing industry, despite relatively slow wage growth and a slow decline in the employment share of the agricultural sector. By now, arguably as much as 90 percent of the country's farm area may be prepared by tractors. India is now the largest tractor market in the world, purchasing more than 90 percent of the 660,000 tractors it produces per year. The annual value of tractors sold in India is more than US$5 billion per year. This study reviews the evolution of agricultural mechanization, particularly tractors, in India. In doing so, it provides some rough indicators of the extent of mechanization (particularly the spread of tractor use) at different historical phases, emphasizing that India's experiences up to 1990 are as important as the lessons since then. Substantial infrastructure endowments (in terms of roads, for example), which were already high in the 1960s, and investments into rural electrification, as well as knowledge accumulation through the importation of a large number of tractors early on, are likely to have helped the growth of domestic tractor manufacturing. Diverse custom-hiring services for tractors and combine harvesters have emerged to serve areas that are profitable, with relatively little direct support from the government. The private sector has also stepped up to provide facilitating services to connect service providers and farmers. Empirical analyses of the impact of tractor ownership and tractor / combine harvester use confirms many hypotheses about the farm-level impact of mechanization in India. Despite the typically small landholding in India, tractor ownership is led by the motive to expand farm size. Tractors are more bullock saving than labor saving, whereas combine harvesters are more strongly labor saving. Combine harvesters are more yield enhancing than tractors, but land preparation by tractors may indirectly enhance yields through the increased use of chemical fertilizer. All of these patterns provide important lessons for other countries that are still at an early stage of mechanization.

Keywords: Agricultural mechanization, Tractors, Evolution, Village Dynamics in South Asia data, India

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1. INTRODUCTION

Over the last several decades, India has seen a continuous spread of tractor use as well as growth in its domestic tractor manufacturing industry, despite relatively slow wage growth and a slow decline in the employment share of the agricultural sector. By now, arguably as much as 90 percent of the country's farm area may be prepared by tractors (CSAM and UNESCAP 2016). India is now the largest tractor market in the world, purchasing more than 90 percent of the 660,000 tractors it produces per year. The annual market size of tractors sold in India is more than US$5 billion per year (Bhattarai et al. 2017). All of this is despite the fact that India still employs 40 percent or more of its workforce in the agricultural sector, and the average farm size remains low, at only slightly more than 1 ha. Such growth was not anticipated by many of the review studies done in India, and in South Asia in general, until the late 1980s (see Binswanger 1978, 1986; Singh 2015). Information is still relatively scarce on the growth of mechanization, including tractors, such as data disaggregated by different phases in the past, data on the heterogeneity of adoption patterns across regions, and information on policy approaches that were more (or less) likely to have been influential on mechanization growth at different historical phases.

This study reviews the evolution of agricultural mechanization, particularly tractors, in India. In doing so, it provides some rough indicators of the extent of mechanization (particularly the spread of tractor use) at different historical phases, emphasizing that India's experiences up to 1990 are as important as the lessons since then. The paper highlights the growth of diverse patterns of custom-hiring service provision, as well as heterogeneity in the speed of mechanization growth across regions and agroecological zones. It also summarizes the evolution of key related policies in India that are likely to have affected tractor imports, supply, financing, manufacturing, and related inputs such as fuel and electricity.

In addition, this study provides estimates of the farm-level impacts of tractor and combine harvester use on various outcomes, including farm size, labor use, draft animal use, and yield of major crops, using Village Dynamics in South Asia (VDSA) data from the International Crops Research

Institute for the Semi-arid Tropics (ICRISAT). These data come from a long-panel survey of farm households in selected villages in India, covering 2001–2014, with detailed information on plot-level input use, including the hours of labor used. The unique nature of the data allows us to estimate the impact of mechanization by controlling for a farmer's inherent ability and by using more accurate estimates of input use, including labor use, unlike many past studies investigating the potential impact of mechanization.

This paper is structured in the following way. Section 3 presents historical background and the evolution of farm machinery use in India. Section 4 describes the key mechanization patterns. Section 5 describes supply-side issues, Section 6 discusses the impact of mechanization, and Section 7 concludes.

2. HISTORICAL BACKGROUND AND EVOLUTION OF FARM MECHANIZATION IN INDIA

This section takes a historical perspective on the development and evolution of farm machinery use in India, supplemented by numerical data and facts from across the states of India as well as information on changes that have taken place over the years.

Table 2.1 summarizes growth in the use of farm machinery and related agricultural factors, as well as selected agricultural performance metrics, over recent decades. Agricultural land in India has expanded by only 5 percent since 1960, but grain yields have increased by 300 percent, partly due to the growth in land-saving technologies (irrigation and fertilizers). However, the use and density of farm tractors has also increased considerably during this time.

Table 2.1 Change in use of farm machinery and related factors of Indian agriculture, 1960-2012

Item	Unit	1960	1970	1980	1990	2000	2010	2012/ 2013
Agricultural land (net cropped area)	million ha	133	140	140	143	143	142	140
Irrigated area	%	18.32	23.04	28.84	34.03	41.11	44.99	47.62
Cropping intensity	%	115	118	123	130	133	136	139
Grain yield	kg/ha	700	860	1,000	1,300	1,600	1,950	2,130
Nutrient use (N, P, and K)	kg/ha	2.00	13.61	31.95	67.55	90.12	142.35	131.36
No. of irrigation pumps	million	0.4	3.3	6.2	12.9	19.5	28.0	52.8
No. of draft animals	million	80	83	73	71	60	50	48
Agricultural labor	million	131.1	125.7	148.0	185.3	234.1	263.1	—
Total no. of tractors	1,000	37	146	531	1150	2633	5005	5811
Tractors per 1,000 ha of net crop area	no./1,000 ha	0.3	1.0	3.8	8.1	18.6	35.4	41.5
Crop area per tractor	ha	3,594	959	264	124	54	28	24
No. of power tillers	1,000	—	9.6	16.2	32.3	114.7	259.2	312.7
Approximate share of area plowed by tractors[a]	%	—	3	10	20	40	80	90

Source: Singh (2015).
Note: Power tillers are available and used mainly in Kerala, West Bengal, Karnataka, Odisha, and the northeastern hill states. [a] Figures are highly crude estimates based on back-of-the-envelope calculations, as follows. About 90 percent of land preparation in India today is done by four-wheeled tractors, which number about 6 million, and a smaller number of two-wheeled tractors (CSAM and UNESCAP 2016). Therefore, it may be reasonable to assume that, in 2000, with 2.6 million tractors, about 40 percent of the area was prepared by tractors. Figures for earlier years were then estimated proportionally based on the number of tractors in the country. Importantly, these figures may potentially be higher, with some studies, such as that of Ugwuishiwu and Onwualu (2009), suggesting that the share might have been as high as 60 percent in 1994. — = data not available; K = potassium; N = nitrogen; P = phosphorus.

Information is scarce regarding the extent of tractor use, in terms of the share of agricultural area prepared by tractors. However, various sources of information and back-of-the-envelope calculations, detailed in the note accompanying Table 2.1, can offer likely estimates. The share was likely to have been about 10 percent in 1980 and 20 percent in 1990. Therefore, by 1990, India was likely to have exceeded many African countries in its extent of tractor adoption for land preparation. Thus, for African countries today, the experiences in India up to 1990 may be particularly important.

Tractors were first introduced in India in 1914 by the British government for reclaiming land and clearing brush and shrub lands. The tractor industry in India has grown particularly fast in the last 50 years, especially since the early 1990s, when Indian industrial sectors (including the production, import, and export of tractors and their parts) became liberalized.[1]

The historical development of tractor and other farm machinery use in India can be separated into five different phases (Table 2.2). In parallel, there were also major shifts in national and regional policies as well as shifts in macroeconomic policies, which also affected the adoption and use of farm machinery.

Table 2.2 Distinct phases in the development path of farm machinery use in India, 1912-2017

Distinct phase	Major characteristics or events in development of farm machinery production, use, and policies	Remarks
Pre-independent era (before 1947 or until independence of India)	• In 1912, a 30-inch-diameter steam thresher was available for custom hire in Layallpur district. • In 1914, for the first time, tractors were imported into India for reclamation of land and degraded forestland. They were used in government farms or available for custom hire. • In the 1930s, a pump set was imported into India. • Central and state tractor organizations were set up (1947).	• Reclamation of degraded land with high machinery power was another objective of importing high-horsepower tractors and crawlers
Initial period (1947–1967)	• 1 million ha of land reclaimed (through 1959). • 8,500 tractor units used in 1951, 20,000 in 1955, and 52,000 in 1965. • First local production of tractors began in 1961. • Government imposed statutory controls on sales prices of indigenously manufactured tractors in 1967. • Imports of power tillers started in 1961. • Krishi Engines Ltd., Hyderabad, started manufacturing power tillers in 1965.	• Tractor industry as core sector (1951) • Industrial Development and Regulation Act, 1951 • Five major tractor producers: Eicher Motors, Gujarat Tractors, TAFE Ltd., Escorts Tractors Ltd., Mahindra & Mahindra (total of 880 units during 1961)

[1] As described in Section 4, before 1992/1993, a government permit and license were necessary to manufacture, import, or export tractors. After 1992/1993, all of these restrictions were lifted. At present, anybody can set up a tractor factory in India without any license or permit.

Table 2.2 Continued

Distinct phase	Major characteristics or events in development of farm machinery production, use, and policies	Remarks
Green Revolution era of development (1967–1991)	• In 1967, agricultural input corporations were set up in each state to supply fertilizers, seeds, and farm implements. • In 1968, harvesters were introduced in India to address the peak-season labor shortage in Punjab and to increase cropping intensity. • Statutory price controls on tractors withdrawn in October 1974. • Manufacturing of Ford tractors by Escorts began in 1971 with collaboration of Ford UK. • Imports of fully built tractors were banned in 1973, except under specific World Bank projects. • Annual production reached 140,000 in 1990. • Eight new companies started production of power tillers during this period.	• Emphasis on indigenous production of tractors • Government extended full support to establish local manufacturers • India became net exporter of tractors during 1980s • From 1961 to 1974, 12,211 power tillers imported
First wave of reform in national economy (1991/1992–2004/2005)	• Government approval and licensing for manufacturing tractors were abolished in 1992; tractor industry liberalized. • Sonalika International Tractors Ltd. started production in 1998. • Mahindra & Mahindra emerged as the largest tractor producer (68,000 units) in 1997, followed by TAFE and Escorts.	• Escorts started producing the Farmtrac tractor in place of Ford • More than 2 million tractors in use in India by 1997 • Bajaj Tempo Ltd. started production in 1997
Second wave of reform in national policies and economic systems (2005/2006–2015/2016)	• Farmers' cooperative–operated custom hiring service centers were initiated in many parts of Punjab and Karnataka after 2010. • Sub-mission on Agricultural Mechanization was launched in 2014 with huge funding to boost the use of farm machinery (funding > US$23 million/year). • In 2015, the beginning of heavy penalties for straw burning in Punjab provided a huge incentive for conservation agriculture and zero-tillage machinery. • In 2015 Karnataka state set up more than 300 custom-hiring service centers for agricultural mechanization (CHSC-AMs) operated by a third party (tractor company, nongovernmental organization, and so on) through public-private partnerships (PPPs). • Tractor companies set up CHSC-AMs with funding support from the government under PPPs. These centers are using smartphone apps for coordination of services, orders, and payments from farmers. • Many states have started setting up CHSC-AMs, engaging the private sector in running the centers through PPPs.	• In 2016, the government planned to set up 100,000 CHSC-AMs nationally. • Each CHSC-AM would cover 5 or 6 surrounding villages (about 300 ha). • Indian agricultural sector started diversifying from cereal to high-value crops (vegetables, fruits, and flowers).

Source: Authors.

At present, even small and medium-size farmers with 2–3 ha of landholdings have started to own tractors on an individual basis. These owners hire out their tractors to fellow farmers and others in their villages for both farm and nonfarm uses, making their tractor purchasing decision more of an entrepreneurial move, based on a prospectus of its benefits from rental services, than a simple investment in plowing their own lands. This phenomenon has led to an extraordinary growth in tractor use in India during the last 40 years. Further discussions on the growth pattern of the tractor market, factors associated with the growth of tractor use in India, and the entry of new tractor manufacturers since 1961 can be found in Bhattarai and others (2017) and in Singh (2015).

3. DEMAND FOR MECHANIZATION IN INDIA

Trends in Machinery Use/Ownership by Farm Size

Table 3.1 shows the change in average landholding size of five types of farmers from 1983 to 2010/2011, as well as a snapshot of tractor ownership among medium to large farmers in 2009. Over time, the farm size distribution has shifted toward small and marginal (in terms of both average size and share of farmers), whereas, as shown above, adoption of tractors has continued rising during the same period. This pattern roughly suggests that tractor use for land preparation has spread in India without a significant increase in farm size.

Table 3.1 Trends of farm holding changes in India, 1983 to 2010/2011

	No. of holdings (million)				Tractor penetration (2009)	Total area (million ha)			
Category of holdings	**1983**	**2000/ 2001**	**2005/ 2006**	**2010/ 2011**		**1983**	**2000/ 2001**	**2005/ 2006**	**2010/ 2011**
Marginal (< 1 ha)	44.5	75.4	83.7	92.4	—	17.5	29.8	32.0	35.4
Small (1–2 ha)	14.7	22.7	23.9	24.7	—	20.9	32.1	33.1	35.1
Semi-medium (2–4 ha)	11.6	14.0	14.1	13.8	18%	32.4	38.2	37.9	37.5
Medium (4–10 ha)	8.2	6.6	6.4	5.9		49.6	38.2	36.6	33.7
Large (> 10 ha)	2.4	1.2	1.1	1	38%	42.9	21.1	18.7	17.4
All holdings	81.4	119.9	129.2	137.8	—	163.3	159.4	158.3	159.1
(hectares/holding)	n.a.	n.a.	n.a.	n.a.	—	2.01	1.33	1.23	1.15
Share of marginal and small farmers (%)	72.6	81.8	83.3	85.0	—	23.5	38.8	41.1	44.3

Source: Shah and Kanodia (2015); Goel and Kumar (2013).
Note: n.a. = not applicable.

In 2009, tractor ownership was still concentrated among medium to large farms, with 38 percent of large farmers (those with more than 10 ha) owning tractors, 18 percent of medium-size farmers (with 2–10 ha), and less than 1 percent of smallholding and marginal farmers (those with less than 2 ha of land). The large and medium-size farmers with tractors have been providing hiring services to enable tractor use among smallholders.

Tractor usage varies spatially across India as well. Table 3.2 shows the distribution of tractor availability across the states of India in 1982 versus 2012. In 1982, almost 60 percent of the tractors in

India were concentrated in three northern states: Uttar Pradesh (27 percent), Punjab (21 percent), and Haryana (12 percent). This share had shrunk to less than 40 percent by 2012. However, the concentration is still high in these three states because they accounted for only 18 percent of the cropped area in India in 2010.

Table 3.2 Distribution of tractors across selected states in India, 1982 and 2012

State	1982		2012	
	Number (1,000)	% of India	Number (1,000)	% of India
Uttar Pradesh	141.4	27.16	1,106.1	19.03
Rajasthan	54.3	10.43	699.9	12.04
Madhya Pradesh	24.5	4.71	660.6	11.37
Punjab	106.7	20.50	517.7	8.91
Haryana	61.5	11.81	516.6	8.89
Gujarat	27.8	5.34	495.1	8.52
Maharashtra	21.5	4.13	419.2	7.21
Karnataka	20.4	3.92	363.9	6.26
Andhra Pradesh	20.9	4.01	342.4	5.89
Bihar	14.2	2.73	266.6	4.59
Tamil Nadu	14.2	2.73	186.7	3.21
Odisha	1.2	0.23	83.1	1.43
West Bengal	1.6	0.31	35.5	0.61
Kerala	1.3	0.25	11.6	0.20
All India	520.6	100.00	5811.1	100.00

Source: Data from India Ministry of Road Transport and Highways (personal communication March 2, 2018).

In many respects, the development path of farm machinery use in India is unique, with growth in the use of other farm machinery mirroring that of tractors. India is one of the largest markets for four-wheeled tractors (4WTs) in the world (both in volume of annual production and in sales). Likewise, the pace of growth in the use of combine harvesters, mechanical threshers, and other farm machinery in the country has also expanded at a massive scale during recent years. Table 3.3 summarizes the annual sales (or market size) of tractors and related farm machinery in India in recent years.

Table 3.3 Major farm machinery used and annual market size of farm machinery in India, 2014/2015

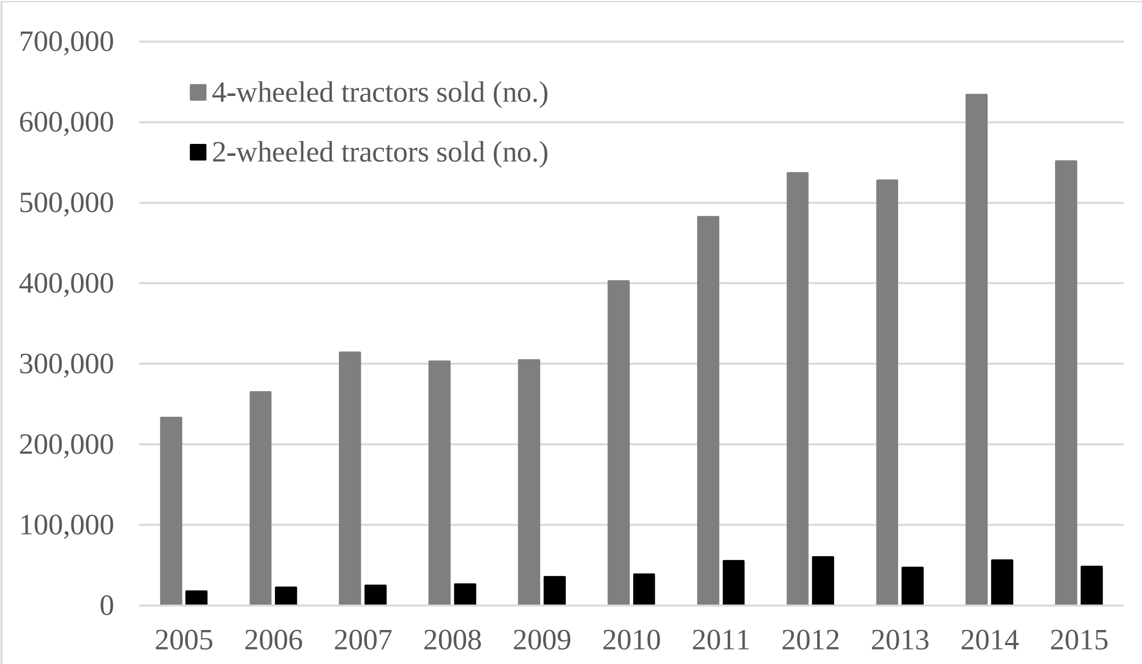
Machinery	Market size annually (units)	Average per-unit cost in US dollars	Average per-unit cost in Indian rupees	Annual industry size in billion rupees
Tractor	600,000	7,000–12,000	570,000	342.00
Power tiller	56,000	2,100	126,000	7.06
Combine harvester	4,000–5,000	22,000–35,000	1,710,000	7.70
Thresher	100,000	1,600–2,500	123,000	12.30
Rotavator	60,000–80,000	1,300–2,000	99,000	6.93
Rice transplanter	1,500–1,600	1,500– 2,500	150,000	0.62
Walking type	—	2,500–4,200	201,000	—
Riding type	—	3,300–16,600	597,000	—
Self-propelled reaper	4,000–5,000	1,300–2,000	99,000	0.45
Zero-till seed drill	25,000–30,000	750–850	48,000	1.32
Multicrop planter	1,000–2,000	850–1,000	55,500	0.08
Laser land leveler	3,000–4,000	5,800–6,500	369,000	1.29
Power weeder	25,000	8,500	510,000	12.75

Source: CSAM (2014); Shah and Kanodia (2015); Singh (2015).
Note: US$1 = 65 Indian rupees in 2014/2015. — = data not available.

Types of Tractors

Most tractors purchased in India are 4WTs, and the share of two-wheeled tractors (2WTs) remained low from 2005 from 2015, while sales of 4WTs more than doubled (Figure 3.1). In general, less than 10 percent of total tractor sales are 2WTs, in contrast to many other countries in Southeast Asia, despite the fact that more than 80 percent farmers in India are smallholders with less than 2 ha of landholdings. In fact, the expansion and diffusion of 2WTs has been confined to only a few states, such as Kerala, Odisha, Karnataka, and some states in the northeast.

Figure 3.1 Two-wheeled and four-wheeled tractor sales in India between 2005 and 2015

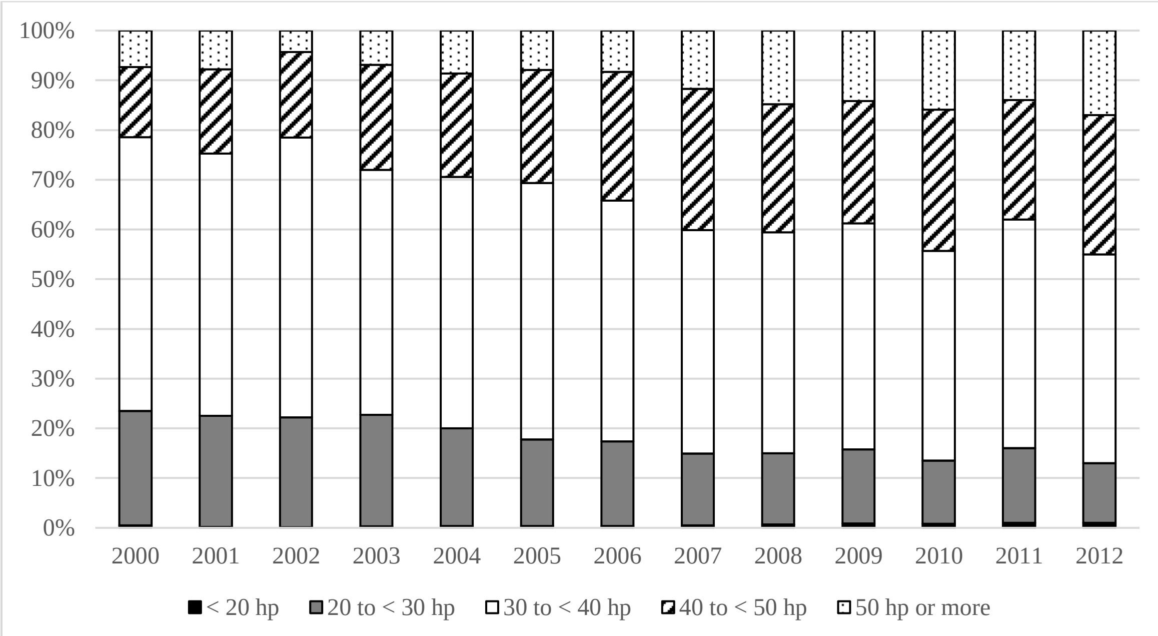


Source: Shah and Kanodia (2015).

Although formal analyses of the reasons for the dominance of 4WTs among tractors in India have been limited, informal interactions with local experts suggest the following potential reasons. First, in India, 2WTs are well accepted by farmers in paddy-growing states (eastern and southern India), but not in dry regions due to the need for engines with higher horsepower for plowing. Second, in India, registration is not available for 2WTs, so they are not permitted on highways and busy roads, limiting their nonfarm or hauling uses during the off-season. Furthermore, despite the expansion of irrigation, 60 percent of farmland in India is still rainfed (FAO 2018) or under farming systems that rotate rice cultivation with rainfed, nonrice crops (Pingali 2007).

The typical horsepower of a 4WT in India is 30–40 hp (Figure 3.2). Although the share of higher-horsepower tractors has gradually increased since the period 2000–2009, more than 80 percent of 4WTs were still of less than 50 hp in 2012. The average horsepower among tractors in India has therefore been lower than that of the 50–70 hp 4WTs boasted by African governments.

Figure 3.2 Breakdown by horsepower of tractors sold in India between 2000 and 2012



Source: CSAM (2014); Bhattarai et al. (2017).

Agroecological Conditions, Cropping Systems, and the Spread of Farm Machinery

The adoption levels of farm mechanization vary greatly by crop type and operation type. Generally, mechanization is more common for paddy and wheat cultivation than for other crops, except planting for paddy (Table 3.4). Land plowing, and seedbed preparation, and spraying of pesticides for all major crops in India have been more mechanized than other operations.

Table 3.4 Percentage of mechanization by major crop and by operation in India, 2013

Crop	Seedbed preparation	Sowing/planting/ transplanting	Weed and pest control	Harvesting and threshing[a]
Paddy	85–90	5–10	80–90	70–80
Wheat	90–95	80–90	70–80	80–90
Potatoes	90–95	80–90	80–90	70–80
Cotton	90–95	50–60	50–60	0
Maize	90–95	80–90	70–80	50–60
Gram	90–95	50–60	60–70	30–40
Sorghum	80–90	30–50	60–70	20–30
Millet	80–90	30–40	60–70	20–30
Oilseeds	80–90	30–40	60–80	20–30
Vegetables	70–80	5–10	80–90	< 1
Horticultural crops	60–70	30–40	40–50	< 1

Source: FICCI (2015).
Note: [a]The reported harvester use on paddy, wheat, and potatoes seems high, and this may be the case for a few states in the north, but not for the country as a whole.

Compared with paddy and wheat, harvesting of coarse cereals (such as sorghum and pearl millet), pulses, and vegetables is much less mechanized (Table 3.4). If the rate of mechanization does not speed up for several operations on these crops, farmers may lose any comparative advantage in growing them. In fact, the acreage of many of the pulses and coarse cereals (notably sorghum) has already been declining in India in recent years.

The agricultural production pattern in India can be divided into more than 20 distinct agroecological zones, with distinct cropping patterns and cropping intensities in each zone (Figure 3.3). Currently, tractors, combine harvesters, and other farm machinery are used more intensively in Punjab, Haryana, and the western part of Uttar Pradesh (that is, the western part of the Indo-Gangetic Basin), and in central India, the major rice-wheat cultivation belt. Likewise, soybeans are cultivated widely in central India (the states of Madhya Pradesh and Maharashtra), with their crop area expanding partly due to the ready availability of combine harvesters, which allow timely harvesting and land preparation for the following season.

Figure 3.3 Map showing major agroclimatic zones of India

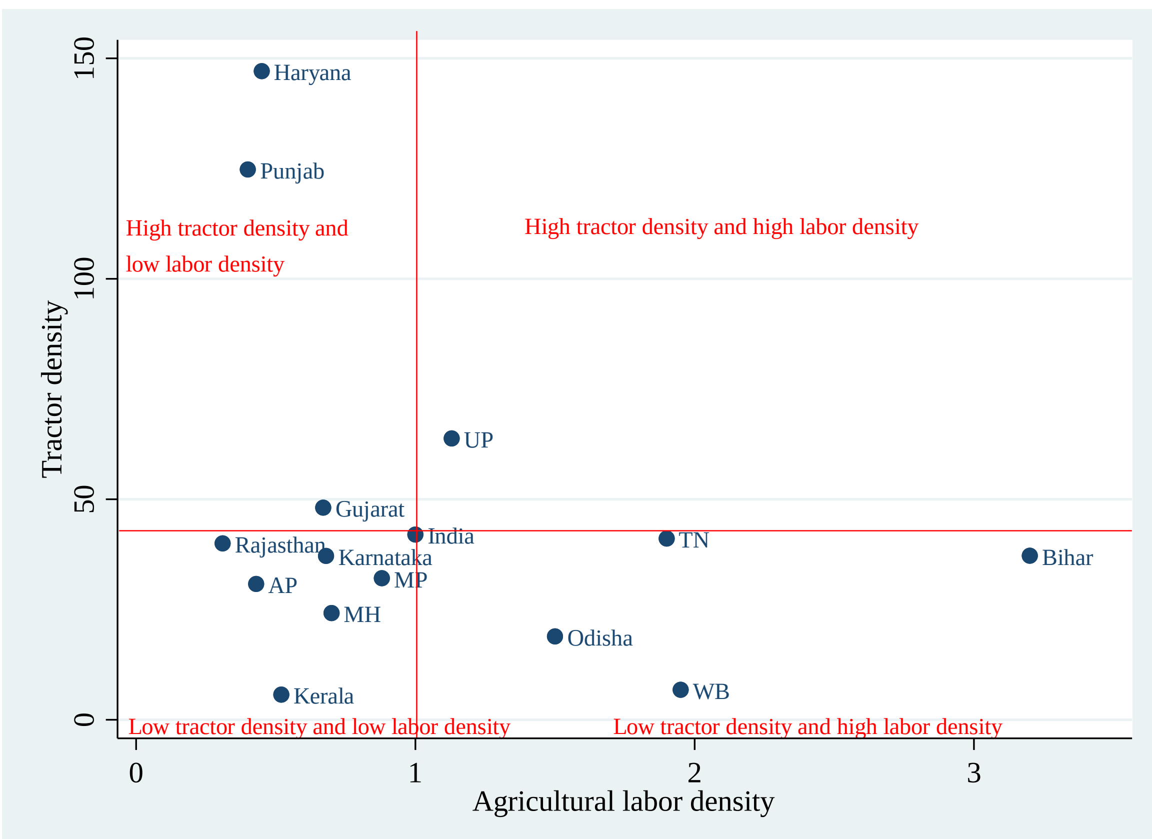
Agroclimatic Zone
1. Western Himalayan
2. Eastern Himalayan
3. Lower Gangetic Plains
4. Middle Gangetic Plains
5. Upper Gangetic Plains
6. Trans-Gangetic Plains
7. Eastern Plateau & Hills
8. Central Plateau & Hills
9. Western Plateau & Hills
10. Southern Plateau & Hills
11. East Coast Plains & Hills
12. West Coast Plains & Hills
13. Gujarat Plains & Hills
14. Western Dry Region
15. Islands

Source: India, MOEIT (2018).

Labor-Land Ratio and Tractor Density

In principle, farm mechanization should grow faster in places with less availability of labor per unit of landholding—that is, where the labor force is scare—due to substitution effects among the factors of production for agricultural commodities. In India, the evidence is mixed, as reflected in Figure 3.4. India itself is a region with one of the highest densities of rural population, where tractors (and power tillers in close neighbor Bangladesh) have spread rapidly in the recent past. Agricultural labor density is also very high in most parts of India, as in the South Asia region as a whole. On the other hand, Haryana and Punjab, two of the states with the highest tractor densities, also have some of the lowest agricultural labor densities in India. Still, several states with agricultural labor densities as low as those of Haryana and Punjab (Rajasthan, Kerala, Gujarat, and Karnataka) have lower tractor densities.

Figure 3.4Tractor density and agricultural labor density across the states of India, 2012



Source: Bhattarai et al. (2017).
Note: AP = Andhra Pradesh; MH = Maharashtra; MP = Madhya Pradesh; TN = Tamil Nadu; UP = Uttar Pradesh; WB = West Bengal.

Table 3.5 shows correlation coefficients between tractor density and selected variables across the states, estimated in 1982 and 2012. The strength of spatial correlation between tractor density and agricultural labor wage declined over this period; it remained the same for agricultural labor density. However, the strength of the correlation has increased for the average operational agricultural landholding, with its correlation coefficient with tractor density having slightly increased in 2012 over that of 1982.

Table 3.5 Correlation coefficients between tractor density and selected factors in India, 1982 and 2012

Factors associated with changes in tractor density	Correlation coefficient (*r*)	
	1982	2012
Real wage rate (Indian rupees/day)	0.60**	0.02
Agricultural labor density (no. of ag. laborers/ha)	-0.38	-0.37
Average operational holding (ha)	0.438	0.639**
Intensity of irrigation (%)	0.714***	0.468*
Cropping intensity (%)	0.794***	0.594**
Scheduled commercial bank credit (Indian rupees/ha)	0.382	0.053

Source: Adapted from Bhattarai et al. (2017, Table 4.3).
Note: Asterisks indicate the statistical significance: *** 1%, ** 5%, * 10%.

Overall, mechanization growth in India has reflected key demand characteristics. First, tractor use in India has grown without significant farm size growth and even with continued land fragmentation. This trend is consistent with the hypothesis that the demand for mechanization was to meet the increasing farm power requirements for land productivity improvement, rather than improving productivity by expanding scale. Second, the speed of growth in tractor use has been heterogeneous across regions and states within India, although the growth curves have gradually converged, with lagging regions starting to catch up. Third, 4WTs are still common, possibly due to the rice-nonrice crop rotation that is still common in India, as well as certain soil characteristics.

4. SUPPLY-SIDE FACTORS

This section describes supply-side factors for growth and expansion in the use of farm machinery such as tractors, harvesters, and other major farm implements, including (1) development and dissemination of farm machinery technologies; (2) support and incentives for effectively engaging the private sector in the adoption and diffusion of farm machinery technology; and (3) the private sector's role in developing machinery technology, markets, and custom-hiring services. In the federal structure of India, issues related to agricultural and farm machinery support fall under state jurisdiction. As a result, each state of India is pursuing its own farm machinery support policies and related other inducements (subsidy programs) to promote farm machinery in its jurisdiction in line with location-specific constraints.

Machinery Purchase, Manufacturing, and Import Policies

In India, importing a diverse set of foreign tractors constituted an important part of technology transfer policies, which helped the country raise its knowledge levels, later inducing the growth of domestic manufacturing. This process was partly led by the premise that an inappropriate foreign technology can be a powerful stimulus to indigenous technology generation (Morehouse 1980). Throughout the 1950s, the Indian government's policy was to permit the import of "conventional" technologies, including tractors, on the condition that these technologies did not exist in the country (Morehouse 1980, 2143). Tractor imports grew throughout the 1960s, from 3,000 tractors per year in 1961 to 16,000 per year in 1970, with a total of about 50,000 tractors imported in 10 years (Patel and Gandhi 1996; Singh, Verma, and Tandon 1984). In 1970, tractors were imported from various countries, including the USSR (3,621), Czechoslovakia (3,247), Poland (3,131), the UK (2,845), and Romania (1,743), among others (Patel and Gandhi 1996). Imports were largely led by the private sector, although there were also often concessional agreements.[2] For example, Escorts Ltd., which started as an importer and domestic agent for Massey Ferguson, built up a dealer network in North India and, after Massey Ferguson moved to South India,

[2] For example, Aurora and Morehouse (1972) mentioned that some of the imported tractor components from Czechoslovakia were subsidized.

formed a joint venture with Ford Motor Company, USA (Morehouse 1980). By 1979, after the Indian government's shift toward technological self-reliance in the 1970s, the Escorts 35 hp tractor (manufactured through a mixture of the original Polish technologies and substantial indigenous modification) became a leader with 21 percent of the market share (Morehouse 1980). The important message here is that the growth of domestic tractor manufacturing in India was preceded by the importation of a large number of tractors, which helped the private sector build its knowledge about tractors and their design, setting the stage for the growth of private-sector research and development (R&D) for further modifications in the 1970s.

The Indian government shifted its focus toward technological self-reliance in the 1970s and set up more regulatory trade policies. These included import duties (30 percent) and an eventual ban on imports in 1973 (Binswanger 1978), an excise duty (about 18 percent), and central and state sales taxes (about 4 percent and 7 percent, respectively), as well as a 40–120 percent import duty and an ad valorem duty on imported tractor components and raw materials in the mid- to late 1970s, among other miscellaneous taxes (Singh 1978). However, it is important to note that these increased duties and taxes were the government's attempt to raise tax revenues, taking advantage of the growing demand for tractors. In addition, a gift program was introduced, allowing citizens residing abroad to buy a tractor in foreign currency and send it free of taxes to friends or relatives in India (Farrington 1986).

Subsidies on Tractors

Since the 1960s, subsidies had been provided for pump sets in India (Singh 1978). The history of subsidies on tractors in India before the 1980s is somewhat sketchy, but they are thought to have had generally more limited effects on tractor purchases than in some other countries, such as Pakistan (Binswanger 1978).[3] By the early 1980s, government subsidies for machinery such as tractors were 25–33 percent (Binswanger and Donovan 1987). It is important to note that the subsidy rates in India have historically been lower than rates in other countries that provided similar subsidies. The subsidies on

[3] For example, Pakistan had been providing 40–50 percent subsidies on tractors since the 1960s (Binswanger 1978).

tractors and other agricultural machines have remained until now, although maximum subsidy rates by machine, type of buyer, and region have changed.[4] On top of the fixed subsidy offered under various central government programs, depending upon local conditions, the state-level agency will often grant a further level of subsidy.

Finance

As in other countries, the Indian government has also provided financial support for the purchase of tractors and other agricultural machines. Although evidence is generally scarce regarding the actual impacts of these supports, it is noteworthy that in India, the share of tractors purchased with bank credit has historically been high. For example, in the early 1980s, 90 percent of tractors in India had been purchased using bank credit (Singh, Verma, and Tandon 1984), and this share has remained high.

In the 1970s, to encourage mechanization, the government directed banks to offer loans of up to 85 percent for farmers to purchase tractors and implements, with a repayment period of 7–10 years and at concessionary rates of 10–14 percent per year (Suri 1978; Singh 1978; Farrington 1986). Similarly, the government encouraged banks to extend equipment manufacturers credit at 10–15 percent interest rates (Singh 1978). After 1975, the National Bank for Agriculture and Rural Development granted US$175 million (at the then-current exchange rate, amounting to perhaps $500–600 million at the 2010 rate) for refinancing tractor loans (Farrington 1986). In the 1980s, the government continued to direct banks to reserve 11 percent of their total credit for tractor purchases by medium-size and large farmers at interest rates of 10–11 percent (Singh, Verma, and Tandon 1984).

The support for financing has continued since then. Recognizing the importance of the agriculture sector in India’s development, the government and the Reserve Bank of India have played a vital role in creating a broad-based institutional framework for meeting the increasing credit requirements of the sector. Agricultural policies in India have been reviewed from time to time to maintain pace with the

[4] For example, the maximum subsidy rates are 25 percent for tractors, 40 percent for power tillers and all other agricultural machines, 50 percent for women farmers and scheduled castes and tribes, and 90 percent for northeastern states.

changing requirements of the agriculture sector, one of the priority sectors for lending among scheduled commercial banks. The government has stipulated a target of 18 percent net bank credit for the sector. Microfinance and the Kisan (Farmer) Credit Card Scheme have emerged as the major policy developments to address the distributional aspects of credit in recent years.

Cooperative banks currently have a major share (51.5 percent) in providing loans to farmers, followed by commercial banks (36.9 percent). About 95 percent of tractor sales in India are on credit. Various institutions provide credit for tractors and machinery—public-sector banks, private-sector banks, publicly funded financial institutions, cooperative banks, and private sector–operated financial institutions (usually subsidiaries of the same tractor companies selling tractors to the farmer).

Import Policies

Once India had reached near-self-sufficiency in tractors in the late 1970s, as mentioned above, the focus of trade policies shifted to imports of tractor components and spare parts.[5] Until the 1980s, the Indian government placed tighter restrictions on imports of tractor components than did other South Asian countries (Farrington 1986).[6] Imports of specialized sophisticated agricultural machines and certain spare parts to the collaborative manufacturers and actual consumers were allowed, but with an import duty of 40 percent and a countervailing duty of 10 percent (Singh, Verma, and Tandon 1984). Nonetheless, tractor manufacturing in India kept growing fast in the 1980s, with annual production growing from around 80,000 in 1980 to about 150,000 in 1991, immediately before liberalization (Singh 1998). Thus, it is important to note that even before the liberalization in the early 1990s, both the demand for and the supply of tractors had already grown considerably in India, and therefore the growth in India up to the 1980s offers important lessons for African countries today. After 1991, licenses and permits were no longer needed to import or manufacture tractors, other farm machinery, or their parts and engines. In

[5] Although Indian tractor exports have also grown, the majority of markets for Indian tractors have been domestic. For example, in 2008, exports accounted for only 14 percent of total tractor sales in India (Sarkar 2013).

[6] Tractor imports dropped to marginal levels after 1978, as India's domestic manufacturing matured (Singh, Verma, and Tandon 1984).

addition, the quota on imports was replaced by a uniform, transparent tax. This liberalization is likely to have helped sustain the momentum of growth that had already occurred in the 1980s (Pray and Nagarajan 2014).

Today, under the government import policy, India levies full duty on the import of spare parts and components for agricultural implements, made up of a customs duty part and an excise duty part. For finished agricultural implements, the countervailing duty, chargeable on assessable value, is nil; the basic customs duty, chargeable on the same, is 7.5 percent; and the additional duty chargeable is 4 percent. These import duties and tariffs are still set by the Central Excise Tariff Act of 1985, which also sets a 0 percent rate of excise duty for these items. However, recently, certain machinery parts and components are being classified by the Central Excise Department under other headings that attract excise duty of about 12 percent even if they are used for agriculture.[7]

Licensing, Regulations, and Registration

As mentioned above, since 1991/1992, no licensing has been needed in India for setting up a new tractor manufacturing plant. Moreover, until 2014, by which time the use of machines such as tractors had already spread widely across the country, only four testing centers offered quality testing and certification of new tractors and implements.[8]

Farmers have to register their tractors with local road and transportation departments even for agricultural and local transport use in the villages. Nowadays, almost all tractor owners register their tractors so that they can drive them on roads and highways for nonfarm-sector uses. Unlike tractors, some other machines, such as power tillers, are not registered, preventing them from moving on the highways and roads outside of villages. This is a major difference between India and other countries in South Asia,

[7] Specifically, they include power take-off shafts and gear boxes (used in agricultural implements such as rotary tillers, rotary slashers, rotary harrows, post-hole diggers, and balers), hooks (used in agricultural implements such as harrows and agricultural trailers), springs (used in agricultural implements such as cultivators, harrows, and rotary tillers), spindles and hubs (used in agricultural implements such as disc plows, disc ridgers, and disc harrows), and others.

[8] Only after 2014 did the government double the number of these testing centers. By assigning the responsibility to competent agricultural engineering divisions of state-level universities all over the country, the government now plans to open more than 30 such machinery quality testing centers in the country within a few years.

where power tillers are often used for hauling farm and nonfarm goods from villages to urban centers and back.

Policies on Fuels

Fuel policies in India, in particular those on diesel, have gradually shifted from taxation before the oil shocks of the 1970s and 1980s to subsidization since then. Before the first oil shock in the early 1970s, high-speed diesel oil was taxed because it was used by road transportation that competed with government-owned railways; gasoline was also taxed because it was assumed to be the fuel of wealthy automobile owners. Central taxes on diesel would usually amount to 300 percent (Desai 1981). In addition, until 1974, a 100 percent import duty was imposed on diesel fuel (Binswanger 1978).

Until the 1980s, the government controlled production and pricing in the energy sectors (Sarkar and Kadekodi 1988). After the second oil shock in 1980 and the consequent price spikes in diesel, the Indian government shifted its emphasis to meeting the energy requirements of the agricultural sector (Moulik 1988). Diesel subsidies expanded gradually throughout the 1980s, and diesel prices were also kept low by relaxing a major portion of the excise duty (Singh, Verma, and Tandon 1984). However, the pace of subsidy expansion was uneven across states. For example, whereas diesel for running a pump was already subsidized as early as 1981 in some states (Srinivasan 1981), in some states in South India, diesel fuel, unlike electricity, was not subsidized even by the late 1980s (Babu and Hallam 1989). By the 1990s, at the national level, India was providing about US$1.3 billion (in 1990s dollars) in subsidies for diesel (Larsen 1994). Fuel subsidies continued until 2015, after which they were gradually removed.

India has also invested substantially in rural electrification. In spite of limited empirical evidence about the effects of rural electrification on the prices of substitutes such as diesel, it is likely that electrification helped diesel prices remain relatively stable and lower than without electrification. Electrification started in the early 1950s, and by 1975/1976, one-third of the approximately 600,000 villages in India had been electrified (Mukherjee 1978); this share increased to 57 percent by 1980 and to almost 90 percent by 1994 (Fan, Hazell, and Thorat 2000). In the 1980s, the rate for electricity used for agriculture was also kept at approximately 50 percent of that charged for industrial and domestic use (Singh, Verma, and Tandon 1984).

Partly due to these factors, the price of diesel at the pump in India has been lower than in other developing countries, at US$0.23 per liter in 1991 as opposed to about US$0.55 per liter among low-income countries, and US$0.91 as opposed to about US$1.10 to about US$1.20 in 2014 (World Bank 2017).

Research and Development

In India, as in other countries, the private sector has led a significant portion of the R&D related to agricultural mechanization. In the late 1970s, most major manufacturers in India had some R&D unit or units associated with the parent mechanical engineering company when a separate joint venture had been created to make tractors with foreign collaboration (Morehouse 1980). This trend continued toward the 1980s. By the mid-1980s, capital investments in R&D facilities and recurring R&D expenditures by Indian manufacturers had reached US$5 million and US$2 million, respectively (Mohan 1986), equivalent to perhaps US$10 million and US$4 million at today’s prices. The agricultural machinery industries almost doubled their R&D spending between the mid-1980s and the mid-1990s (Pray and Nagarajan 2014). By 2008/2009, the industry was spending about US$40 million (in 2005 prices), of which about half was spent by Indian firms and the remainder by multinational companies (Pray and Nagarajan 2014). Throughout the 1990s and the following decade, the agricultural machinery industry devoted about 1.0 percent of the value of its sales to agricultural spending—low from a global standpoint (with a global average of about 2.7 percent) but still substantial (Pray and Nagarajan 2014). Although the private sector has contributed greatly to this R&D, the public sector has also played a complementary role by developing designs for new equipment, educating engineers, and offering extension programs (Singh, Verma, and Tandon 1984).

Policies toward Inclusive Growth of Agricultural Mechanization

As noted in the previous sections, the growth of mechanization, including the use of tractors, has been uneven in India, in terms of regional variations of tractor growth, with the level of mechanization growth lagging especially in the eastern and northeastern regions. Therefore, in 2014, the Indian government initiated a program called the Sub-mission on Agricultural Mechanization (SMAM) in its 12th five-year plan (for 2012–2017) (MOAFW 2015). The sub-mission will primarily help with modernizing mechanization in areas that are lagging or using old technologies, through financial subsidies on acquiring machinery or establishing machinery rental service centers, among other activities (details of this program are provided in the Appendix). The proposed funding outlay for this mission during the period of the 12th plan is 35 billion Indian rupees (Rs), or about US$550 million.[9] It is important to note that addressing inequality in access to mechanization has been challenging even in countries such as India, and the recent approach of the Indian government may suggest that addressing inequality may be more feasible once overall mechanization (in terms of tractor use) has reached a sufficient level that lagged areas and regions can be more easily identified.

Agricultural Machinery Manufacturing Policies

India has seen remarkable growth in its domestic manufacturing sector for agricultural machines, including tractors. It is difficult to point out specific policies that led to this growth because there were no specific policies that promoted it. However, the Indian government did contribute to the creation of an enabling environment. Binswanger and Donovan (1987) listed three areas in which the public sector contributes to the development of the machinery manufacturing industry: (1) providing communication and transportation infrastructure, (2) directly assisting the industry through training and R&D, and (3) establishing the regulatory framework within which the industry operates. The Indian government has generally performed many of these functions.

[9] At the 2011/2012 exchange rate of US$1 = Rs 45.

In terms of infrastructure, both rural electrification (mentioned earlier) and expansion of the road network have been substantial. Although estimates vary, road density in India has generally been higher than in other countries, with estimates of about 388 km of roads per 1,000 km^2 of area at the beginning of the Green Revolution in the 1960s (Bationo et al. 2011), doubling between 1970 and 1990 (Fan, Hazell, and Thorat 2000). These densities are substantially higher than, for example, those of African countries today, which range from 4 km in Ethiopia to 11 km in Kenya to 46 km in Ghana (World Bank 2017).

Regarding training and R&D, as mentioned above, imports of a large number of tractors in the 1960s helped the domestic private sector to study the machines and develop ideas for modifications and adaptions, as well as manufacturing. Furthermore, India had already had a long history of manufacturing tractor parts; its engine manufacturing industry began in the 1930s, and by 1950, 6 companies were manufacturing 20,000 engines (Bell, Dawe, and Douthwaite 1998). These numbers had increased to 32 companies producing 141,000 engines by 1975. With such an accumulation of local expertise, combined with a long history of manufacturing parts such as engines, the protectionism of the 1970s (regulations and banning of tractor imports) helped the domestic manufacturing sector grow by facilitating smooth replacement of imported with domestic tractors in the market, without the substantial negative effects of reduced technology transfer speed that also sometimes result from protectionism (Ito 1986). Unlike in many small developing countries elsewhere, the Indian manufacturing sector also benefited from the country’s large domestic market, in which annual demand for tractors had already reached 10,000 by the early 1970s.

Several international tractor manufacturers (such as Ford and Escorts) entered into Indian tractor markets in the 1970s and 1980s. By 1992, there were more than 15 tractor manufacturers producing tractors in India. Since liberalization in the early 1990s, several mergers among the manufacturers have taken place. Also since then, a few new international (global brand) tractor manufacturing and trading companies have started to produce tractors, combine harvesters, laser land levelers, and other implements in India. The actual market size of each tractor manufacturer varies from year to year (Table 4.1).

Table 4.1 Leading tractor manufacturers, 2009/2010 to 2015/2016

Manufacturer	Percentage share in annual production						
	2009/2010	2010/2011	2011/2012	2012/2013	2013/2014	2014/2015	2015/2016
Mahindra & Mahindra	39.55	39.84	38.60	38.47	40.08	37.72	37.71
TAFE	22.59	20.80	23.51	24.73	24.88	23.96	22.99
Escorts	13.12	12.04	9.78	10.27	10.13	9.55	9.00
Sonalika	8.21	8.58	9.79	10.35	0.83	12.36	11.94
John Deere	8.74	9.77	9.50	7.15	9.63	7.40	8.92
New Holland	4.92	6.00	5.63	6.04	7.42	5.80	5.56
SAME Deutz-Fahr	0.79	1.05	1.08	0.89	5.24	1.36	1.55
VST Tillers Tractors Ltd.	0.87	0.84	1.13	1.37	1.10	1.01	1.37
HMT Tractors	1.07	0.88	0.69	0.44	0.22	0.18	0.13
Force Motors	0.14	0.20	0.29	0.29	0.47	0.66	0.83

Source: Adapted from Singh, Singh, and Singh (2015).

Tractor manufacturers in India are usually not allowed to produce attachments and the like; rather, another entity is encouraged to produce these farm implements. As a result, there is a vibrant farm implement and attachment industry in India, with more than 10,000 small-scale farm implement manufacturers scattered all over the country (Table 4.2).

Table 4.2 Status of farm mechanization industry in India, 2014

Equipment manufacturer	Number of production units in India
Agricultural tractors	22
Power tillers	5
Irrigation pumps	600
Plant protection equipment	300
Combine harvesters	48
Reapers	60
Threshers	6,000
Seed drills and planters	2,500
Diesel oil engines	200
Plows, cultivators, harrows	5,000
Chaff cutters	50
Rural artisans	> 1 million

Source: CSAM (2014).

Ownership and Market Institutions for Mechanization Service Provision

In the early 1970s, public sector–operated custom hiring service centers (CHSCs) were established in many places in India by state-level Agriculture Inputs Corporations to promote farm machinery use along with application of fertilizer and other inputs. But in most states, these public rental service centers could not cover their operating costs. As a result, within a few years of their opening, many were closed down when state governments tightened their budgets. By 1980, most of them had ceased to operate.

Over the years, a variety of forms of custom-hiring service providers have emerged in the leading states and regions of India, each with a different operational modality. The pace of the growth of custom-hiring services for farm machinery has been fast, especially from 2000 onward. The development of vibrant markets for these services in India is one of the reasons for the massive growth of farm machinery use in the last two to three decades. Even marginal and smallholding farmers in India have been effectively using tractors, combine harvesters, and other farm machinery, including the costly laser land leveler, through the development of rental services. The rental market has made the use of these huge and costly machines possible by aggregating services across farmers. Types of ownership and rental services for farm machinery in India can be categorized into the following major groups:

- ***Individual farmers as owners.***

Machinery has become more widespread than ever and is available in every village of India. As individual farmers purchase different pieces of equipment, a farmer-to-farmer system of service provision may develop at the local level. Then, as entrepreneurship develops, the farmer-owners may start working together as local service providers (LSPs), renting out several types of machinery.[10] Eventually, some farmers take on rental services for farm machinery as a major business activity.

[10] Custom hiring services for grain combines are unique because the equipment goes where the work is, starting in the north for a season, going to the south for a season, and then returning to the north again. Custom hiring rates differ from place to place. An elaborate description of custom hiring services for harvesters, their movements across India, and the economics of their use in wheat cultivation are described in Bhattarai and others (2014).

- ***Cooperative and joint ownership among farmers.***

Cooperative ownership of farm machinery has been most successfully adopted in Punjab, where, since 2010/2011, more than 1,250 farmers' cooperatives have been effectively providing rental services through CHSCs. Though other states (Karnataka and others) have recently attempted such initiatives, none have been as successful as Punjab's.

- ***Machinery owned and rented out by rural entrepreneurs (LSPs).***

Several public projects and private businesses are supporting individual rural entrepreneurs to operate as LSPs for rental services. For example, the Cereal Systems Initiative for South Asia supported such LSPs in Haryana, Bihar, eastern Uttar Pradesh, and Odisha.

- ***Big business (corporation)–owned machinery for big farms.***

Rental programs of this type are initiated in intensively cultivated agricultural pockets of southern India. Examples include (1) rentals from Coromandel Agrico Group, (2) Yanmar Coromandel Agrisolutions Service Center in Tamil Nadu, and (3) rental services from sprayer manufacturer UPL Ltd. in North India.

- ***Big private firm–owned farm machinery for organized custom-hiring services.***

In addition to large corporations, individual private firms have also recently started to operate CHSCs with a range of farm machinery at one place, offering services to farmers through various business models. For example, Zamindara Farm Solutions operates a rental program for farm machinery in the state of Punjab.

- ***Government-promoted CHSCs under a public-private partnership model.***

Recently some state governments (Karnataka, Andhra Pradesh, and Madhya Pradesh) have provided encouragement and funding support to private industry or nongovernmental organizations (NGOs) through a public-private partnership mode of operation. CHSCs are set up with 50–75 percent of the cost of farm implements supported by the government, but their ownership, operation, and management is carried out by a private business or NGO. In this model, a large portion of the investment cost is subsidized by the government. Many other state governments are attempting to replicate Karnataka's recent successful CHSC program.

- ***Directly government-implemented rental services, such as the Yantradoot program in Madhya Pradesh.***

Under the Yantradoot Villages Scheme in Madhya Pradesh (in central India), district-level officers of the Department of Agriculture Engineering periodically demonstrate the use of farm implements to farmers in selected villages spread throughout the state and make these implements available for hire to the agricultural community at nominal prices. The designated villages are rotated each year so that all farmers can get the benefit of observing demonstrations of new farm machine technologies within their villages.

There is also an increasing trend toward using smartphone and Web-based technologies to coordinate the demand from the large number of farmers in rural areas with the rental services available to them. CHSCs represent a new business model of rental services for agricultural machinery in India, making machinery and technology accessible to hundreds of smallholding farmers at affordable prices.

Importantly, these service providers have largely emerged informally, with little direct promotion by the government, because support programs have only recently been initiated (including the aforementioned SMAM, launched in 2014).

Custom-hiring service providers have also been emerging for nonconventional machines. Combine harvester service providers have been emerging in Punjab (Singh, Kingra, and Sangeet 2013), where the number of self-propelled and tractor-driven combines has increased from 3,000 and 5,000, respectively, in 2000/2001 to 8,000 and 6,000, respectively, in 2010/2011 (CSAM 2014). Custom-hiring services with tractor-pulled zero-till machines have also been emerging, albeit with 60 percent subsidies on machines that typically cost for Rs 55,000 (or about US$1,000) (Keil, D'Souza, and McDonald 2016). Out of approximately 13 million ha of rice-wheat systems in the Indo-Gangetic Plains, as much as 5 million ha was under zero-till technologies in 2008 (Chauhan et al. 2012). Finally, the number of service providers and contractors for laser land leveling has increased from only about 8 in 2005 to an estimated 2,000–4,000 in India by 2010 (IRRI 2010; CSAM 2014) and has kept growing since then. In Punjab, the area under laser land leveling has increased from about 1,000 ha in 2005 to 600,000 ha in 2010 (CSAM 2014).

5. SELECTED EVIDENCE ON FARM-LEVEL IMPACTS OF AGRICULTURAL MECHANIZATION

This section presents some empirical evidence on the effects of farm machinery use on various outcomes of interest (agricultural performance, crop yield, land size, and so on) in India, using farm household–level panel data from ICRISAT's VDSA project (ICRISAT 2017). For short, we call this the ICRISAT-VDSA dataset or simply VDSA data. The panel form of household data provides us the opportunity to isolate and quantify more meaningfully the net effects of farm machinery use on key agricultural performance metrics (the outcomes of interest).

The ICRISAT-VDSA dataset has been collected through the support of various donors over the years since the 1970s. The data used in this study were collected from 2001 through 2014. Details of the survey are described in Rao and others (2011a, 2011b) for 2001–2008 period and on the VDSA project website[11] for the 2009–2014 period as well as all previous periods. The scope of the ICRISAT-VDSA dataset was to collect detailed information on households' agricultural production activities; economic activities including farming, livestock, and nonfarm activities; household resource use; receipts from welfare programs; and coping mechanisms; among other data. The VDSA data contain details on agronomic production practices gathered through a longitudinal survey of farm households across various locations in the semi-arid regions of India. The data are therefore suitable for estimating the impact of mechanization (particularly tractor and combine harvester use) on different indicators of agricultural performance, including crop yield, labor use in farming, and production practices, as well as farm size dynamics.

The sampling frame of the data consists of a total of six villages in Andhra Pradesh and Maharashtra states, which were covered in the first-generation VDSA study conducted between 1975 and 1985. Based on the census of households in these six villages, households were classified into four groups according to farm size and landownership, from which a predetermined number of households was

[11] http://vdsa.icrisat.ac.in/vdsa-microdoc.aspx.

randomly selected for interviews. A total of 446 farm households were selected for interviews in 2001. All of these households, including any that spun off from the original households, were interviewed again from 2002 to 2008. The same households were interviewed again after 2009, when the VDSA project added coverage in eastern India and Bangladesh. Our analyses use only the samples from Andhra Pradesh and Maharashtra states throughout the period 2001–2014, to maintain consistency.

From these samples, we constructed an unbalanced panel, because some households were not always interviewed every year. We analyzed more than 880 farm households as part of these unbalanced panel data. After missing observations were removed, our final sample is 5,692 households for most specifications, although for some models, such as land dynamics analysis, sample sizes were reduced because certain lagged observations had to be used as independent variables.

The results are summarized by topic under the different subheadings below.

Effects on Farm Size and Farm Size Dynamics

The role of tractor ownership in farm size dynamics is estimated by modifying the specifications provided by Henderson and colleagues (2015) for the dynamic growth patterns of farms in Paraguay. The regression equations and the empirical results of the regression models are provided below.

Specifically, we estimate the equation

$$\begin{aligned}\Delta \ln y_{it} = \alpha + \beta_1 \ln y_{i,t-1} + \beta_2 \left(\ln y_{i,t-1}\right)^2 + \beta_3 \ln(land\ owned)_{i,t-1} + \\ \beta_4 tractor_{i,t-1} + \beta_5 z_{it} + \varepsilon_{it}\end{aligned} \qquad (1)$$

where

- y_{it} = the operational land size of farm household i in year t,
- Δ = the difference in variables between years t and $t-1$,
- $tractor_{i,t-1}$ = the number of tractors owned in $t-1$, and
- z_{it} = the other socioeconomic characteristics of the households.

Other variables include labor endowments (working-age household members), dependency (the number of children and elders), education of the household head, ages, and so on. The other characteristics added are similar to those used by Henderson and others (2015). As in Henderson and others (2015), equation (1) is estimated using the dynamic panel methods developed by Arellano and Bond (1991), Arellano and Bover (1995), and Blundell and Bond (1998), which also address the peculiar endogeneity issues between variables $y_{i,t-1}$ and $tractor_{i,t-1}$.

Specifically, we estimate equation (1) using system generalized method of moments (GMM) methods, which are often considered more efficient than difference GMM methods (Roodman 2009). The models are estimated using the xtabond2 command in Stata. We use lagged values of the differences between $y_{i,t-1}$ and $\left(y_{i,t-1}\right)^2$, and of $tractor_{i,t-1}$, up to a certain period, as the excluded instrumental variables (IVs) to instrument the potentially endogenous variables, together with all the exogenous variables included in the model. The bottom row of Table 5.1 describes the specific lag periods used as IVs. The validity of the instruments is tested by a Hansen test of overidentification, and autocorrelation is also tested, with results of both tests shown near the bottom of Table 5.1. The *p*-values indicate that the model satisfies these conditions.

Table 5.1 Tractor investment and farm size dynamics in semi-arid villages in India

Dependent variable = ln(*cultivated*) (*t*) – ln(*cultivated*) (*t* - 1)	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Endogenous variable					
ln(*cultivated*) (*t* – 1)	-.707***	-.573***	-.707***	-.571***	-.802***
	(.035)	(.053)	(.035)	(.054)	(.074)
ln(*cultivated*)^2 (*t* – 1)					.051**
					(.019)
ln(*land owned*) (*t* – 1)	.417***	.390***	.419***	.392***	.476***
	(.061)	(.056)	(.060)	(.056)	(.043)
Number of tractors owned (*t* – 1)	.313***	.213**			.115†
	(.098)	(.104)			(.069)
Owns tractor (yes = 1) (*t* – 1)			.306***	.199**	
			(.097)	(.093)	
Exogenous variable					
Other household characteristics	Included	Included	Included	Included	Included
Year dummies	Included	Included	Included	Included	Included
0-value dummies	Included	Included	Included	Included	Included

Table 5.1 Continued

Dependent variable = ln(*cultivated*) (*t*) – ln(*cultivated*) (*t* - 1)	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Number of observations	3,839	3,839	3,839	3,839	3,839
Number of panels	625	625	625	625	625
Number of instruments	246	211	246	211	426
p-value					
H_0: Model jointly insignificant	.000	.000	.000	.000	.000
H_0: Overidentified (Hansen test)	.142	.223	.136	.229	.716
H_0: Autocorrelation	.529	.778	.534	.776	.364
Closest lag of endogenous variables used as instrumental variables	1	2	1	2	1

Source: Authors' calculations based on ICRISAT (2017).
Note: Asterisks indicate the statistical significance: *** 1%, ** 5%, * 10%. Other explanatory variables include ln(*household size – working age*), ln(*household size – dependents*), ln(*completed education of household head, years*), ln(*experience of household head*).

Table 5.1 summarizes results on farm size dynamics and the effect of tractor ownership. The dependent variable is the growth rate in area cultivated between the current year and the previous year. The significantly positive coefficients of the number of tractors owned, or the binary indicator of owning a tractor at time t – 1, indicates that these factors significantly increase the growth rate of the operational size between t – 1 and t. For the sample at hand, owning a tractor at t – 1 increases the growth rate of the operational size by about 10–30 percentage points, which is potentially substantial. The positive effects of tractor ownership on the growth of operational size hold even after controlling for the dynamics in operational sizes through the variable ln(*cultivated*) (t – 1) and its squared term, as well as the size of land owned at time t.

Effects on Land Productivity and Adoption of Other Modern Technologies

General Framework of Empirical Analysis

The effects of mechanization (tractor and combine harvester use) on farmers' various behaviors are assessed in the following panel data equation framework:

$$y_{it} = \alpha + c_i + M_{it}\beta + A_{it}\gamma + z_{it}\delta + \varepsilon_{it}, \qquad (2)$$

where y_{it} is the outcome of interest (land productivity and so on), M_{it} is the use of machines (tractors or combine harvesters), A_{it} is the area cultivated, and z_{it} is the vector of other exogenous variables. Variables M_{it} and A_{it} are potentially endogenous, so we also estimate using IV estimation methods. To some extent, a fixed-effects model generally eliminates the endogeneity bias; however, IV methods are preferred in the literature.[12] The various alternative forms of equation (2) are estimated to assess the relationships and implications of farm machinery use (tractors and harvesters) on the adoption of modern varieties, use of other farm technologies, and use of fertilizer and modern inputs. A separate empirical model is estimated for each of the major inputs.

Variable z_{it} includes time-variant household characteristics, such as household size (breaking out working-age members and dependents), completed education of the household head (in years), the farming experience of household head (years), the gender and age of the household head, prices of various inputs or services (chemical fertilizer price, male labor wages, land purchase or rental price, tractor rental price), whether using irrigation or not (yes = 1), the value of agricultural capital, and year-village interaction terms to control for other village-specific shocks in each year.[13]

Effects on Adoption of Other Modern Technologies (Inputs and Others) and Farming Practices

Effects on Labor and Draft Animal Use

Table 5.2 presents the household-level effects of tractor use on the use of human labor and of bullocks for land preparation,[14] estimated through the same panel data specifications as those described above. Similarly, Table 5.3 presents the household-level effects of combine harvester use on the use of labor and bullocks for harvesting and threshing. In both tables, figures for the random-effects Tobit model correspond to responses at a sufficiently high level of labor or bullock use (not at a marginal level).

[12] Generally, the IVs used include the rental fees for the respective machines and the land value per acre. Their natural log transformations are also included to account for potentially nonlinear relations between these price variables and the values for the use of machines or the area cultivated.

[13] Year-village interaction dummies account for various shocks that may affect many households within the village. They may include weather-related shocks, local-level government interventions, or technological shocks such as the diffusion of new varieties in the area, all of which can affect outcomes separately from the effects of tractor or combine harvester use.

[14] Although some rounds of the ICRISAT-VDSA categorize certain activities as "land preparation," the term is not clearly defined for other rounds. We identify all activities such as harrowing, plowing, land clearing, puddling, and any other land-related preparation, aggregating all of them as "land preparation" to calculate the total labor use, bullock use, and tractor use for land preparation.

Table 5.2 Effects of tractor use for land preparation on the use of human labor and animal (bullock) traction for land preparation (per year, all production seasons combined)

Dependent variable	Labor use for land preparation	Labor use for land preparation	Bullock use for land preparation	Bullock use for land preparation
	(hours/year)	(hours/year)	(hours/year)	(hours/year)
Estimation model	**Fixed-effects OLS**	**Random-effects Tobit**	**Fixed-effects OLS**	**Random-effects Tobit**
Tractor used for land preparation (hours)	-.273	-.384***	-.343***	-1.601***
Area cultivated (acres)	4.288***	4.893***	1.457***	4.333***
ln(*bullock rental costs*)	n.a.	n.a.	-3.098	-28.398***
ln(*male labor wage for land preparation*)	-10.018**	-13.764**	n.a.	n.a.
Other household characteristics	Included	Included	Included	Included
Year dummies	Included	Included	Included	Included
Village dummies	Included	Included	Included	Included
Year * village dummies	Included	Included	Included	Included
Intercept	Included	Included	Included	Included
Household fixed effects	**Fixed effects**	**Random effects**	**Fixed effects**	**Random effects**
Number of observations	5,692	5,692	5,692	5,692
Number of panels	1,054	1,054	1,054	1,054
% of uncensored observations		84%		44%
H_0: Variables are exogenous	Yes		Yes	

Source: Authors' calculations based on ICRISAT (2017).
Note: Asterisks indicate the statistical significance: *** 1%, ** 5%, * 10%. n.a. = not applicable; OLS = ordinary least squares.

Table 5.3 Effects of combine harvester use on the use of human labor for harvesting and threshing (per year, all production seasons combined)

Dependent variable	Labor use for harvesting and threshing (hours)	
	(hours/year)	(hours/year)
Estimation model	**Fixed-effects OLS**	**Random-effects Tobit**
Combine harvester use (hours)	-54.448***	-68.287***
Area cultivated (acres)	20.003***	60.753***
ln(*bullock rental costs*)	-2.054	-19.964
ln(*male labor wage for land preparation*)	-158.638***	-365.694***
Used irrigation (yes = 1)		
Other household characteristics	Included	Included
Year dummies	Included	Included
Village dummies	Included	Included
Year * village dummies	Included	Included
Intercept	Included	Included
Household fixed effects	**Fixed effects**	**Random effects**
Number of observations	5,692	5,692
Number of panels	1,054	1,054
Fractions with 0 dependent values (%)		2,857 (62%)
H_0: Variables are exogenous	Yes	

Source: Authors' calculations based on ICRISAT (2017).
Note: Asterisks indicate the statistical significance: *** 1%, ** 5%, * 10%. OLS = ordinary least squares.

Generally, tractor use for land preparation is mostly bullock saving, although it is also somewhat labor saving. In the sample at hand, 1.00 hour of using a tractor for land preparation leads to about a 0.34-hour reduction in the use of bullocks. However, this effect is for all households, including those not using bullocks. Among households actually using bullocks for land preparation, 1.00 hour of tractor use for land preparation substitutes for about 1.60 hours of bullock use for land preparation. The effect on labor use for land preparation is relatively small, at about a 0.40-hour reduction.

These patterns are generally consistent with early mechanization experiences in the United States and Japan, where much of the farm power for land preparation had been provided by animals (horses and so on) and the use of tractors substituted for more animal power than human labor.

In contrast, the combine harvester is strictly labor saving (Table 5.3).[15] On average, 1 hour of combine harvester use reduces the labor for harvesting and threshing by approximately 54 hours when the sample includes households that are not using labor for harvesting and threshing, and approximately 68 hours among only households that are actually using labor for these activities. The use of labor is also highly responsive to wages, unlike the case for land preparation, shown in Table 5.2. This result is consistent with the generalization in Binswanger (1986) that mechanization of harvesting is profitable only when the wages are sufficiently high and rising, whereas mechanization of land preparation can be profitable even at low wages.

The use of tractors substitutes for animal and human power only in specific operations, rather than for their aggregate use over the whole farming operation. This point becomes clearer if we assess the effects of overall tractor use (including activities other than land preparation) on the overall use of draft animals or human labor for farming. Table 5.4 presents these results: 1.0 hour of tractor use reduces the overall use of bullocks by 0.2 hours, which is considerably smaller than the effect of tractors on bullock use for land preparation. For human labor, the effects are even weaker and generally insignificant. Thus,

[15] The use of bullocks for harvesting or threshing was minimal in the samples.

the effects of tractor use on animal and labor use vary across farming operations, and are more pronounced for land preparation than for other operations.[16]

Table 5.4 Effects of tractor use on overall labor and animal use at the household level

Variable	Bullock use/hour	Labor use/hour
	Random-effects Tobit	Fixed-effects OLS panel
Tractor use (hours)	-.217***	3.011
Tractor use (hours), squared		
Area cultivated (acres)	8.145***	107.199***
ln(*bullock rental costs*)	-51.113***	n.a.
ln(*male labor wage for land preparation*)	n.a.	76.847
Other household characteristics	Included	Included
Year dummies	Included	Included
Village dummies	Included	Included
Year * village dummies	Included	Included
Fixed effects	Included	Included
Intercept	Included	Included
Number of observations	5,692	5,692
Number of panels	1,054	1,054
R-squared	.272	.346

Source: Authors' calculations based on ICRISAT (2017).
Note: Asterisks indicate the statistical significance: *** 1%, ** 5%, * 10%. n.a. = not applicable. OLS = ordinary least squares.

These findings are consistent with other recent findings that the adoption of tractors does not simply substitute for human labor or animal traction, but changes the overall returns on scale in production, and the use of labor or animals is also affected more profoundly by such transformations of overall production technologies than by piecemeal adoption for a single process (Takeshima 2017).

Effects on Chemical Fertilizer Use Intensity

Table 5.5 presents the estimated effects of tractor use for land preparation on chemical fertilizer use intensity. Generally, 1 hour per acre of tractor use for land preparation (approximately a 50 percent increase) is associated with increased chemical fertilizer use by about 2–3 kg/acre, or approximately 5

[16] Evidence on gendered labor use in India is scarce, except for one study. Carranza (2014) showed that in contemporary India, plow technology is more likely to be adopted for deep, loamy soils than for shallow, clayey soils, and that tractors are associated with less participation of women in agriculture because in India, deep tillage reduces the use of human labor for subsequent activities (transplanting, fertilizing, weeding, and the like), particularly reducing female labor demand.

percent. Therefore, although the effects are significantly positive, they are modest. This result is consistent with the conventional view that tractor use leads to yield-enhancing operations only modestly or not at all. However, a recent study in the Terai zone of Nepal, adjacent to Bihar state in India, suggests that the mechanization may raise the returns to chemical fertilizer uses at intensive margins (Takeshima et al. 2017). Future studies in India should investigate whether similar effects hold in India.

Table 5.5 Effects of tractor use for land preparation on the use of chemical fertilizer per acre (per year, all production seasons combined)

Dependent variable	**Chemical fertilizer use**		
	(kg per acre/ year)	**ln(*kg per acre/ year*)**	**(kg per acre/ year)**
Estimation model	**Fixed-effects OLS**	**Fixed-effects OLS**	**Random-effects Tobit**
Tractor use for land preparation (hours per acre)	1.973	.054***	2.800***
ln(*male labor wage for land preparation*)	3.064	-.017	7.780
ln(*fertilizer price*)	-13.632**	-.370***	-16.656***
Used irrigation (yes = 1)	16.037***	.151***	34.992***
Other household characteristics	Included	Included	Included
Year dummies	Included	Included	Included
Village dummies	Included	Included	Included
Year * village dummies	Included	Included	Included
Household fixed effects	Included	Included	Included
Intercept	Included	Included	Included
Number of observations	5,692	4,636	5,692
Number of panels	1,054	996	1,054
% of observations censored at 0			19
p-value			
H_0: model jointly insignificant	.000	.000	.000
H_0: variables are exogenous	Yes		

Source: Authors' calculations based on ICRISAT (2017).
Note: Asterisks indicate the statistical significance: *** 1%, ** 5%, * 10%. OLS = ordinary least squares.

Effects of Tractor and Combine Harvester Use on Yields of Key Crops

We next consider how tractor and combine harvester use affects the yields of key crops. Given the prevalence of various crops in the areas covered by the VDSA, we select rice and cotton in kharif season, wheat in rabi season, and sugarcane (an annual) to investigate. Utilizing detailed information from the VDSA, we estimate effects on yields, controlling for fixed effects of plot, season, and variety.

Specifically, we estimate

$$y_{ijt} = \alpha + c_{ij} + M_{ijt}\beta + P_{ijt} + z_{it}\delta + \varepsilon_{it}, \tag{3}$$

in which y_{ijt} is the natural log of the yield of the crop grown by household i in year t. Here, notation j is added to indicate that the model controls for plot, season, and variety. The set of variables is similar to those for equation (2), except that here we drop area, A_{it}, which is part of the dependent variable, and add P_{ijt}, the price of the crop, which is specific to variety, plot, and season.

Table 5.6 summarizes the estimated yield effects. Generally, the use of tractors does not seem to affect yield. Only for cotton does tractor use appear to exhibit weakly significant effects on yield (statistical significance at the 15 percent level). This result may be partly because of significant adoption of Bt cotton varieties in India observed lately in areas including those covered by VDSA data. Bt cotton may be more suitable for production on large farms than on smaller ones because its resistance to major pests can reduce the labor cost for pest control, particularly on large farms (Deininger and Byerlee 2012). Although the exact mechanisms need to be investigated in future studies, the results suggest potential interactions between tractors and certain improved varieties.

Table 5.6 Yield effects of tractor and combine harvester use on key crops

Dependent variable	**Growth rate of yield (1 = 100% increase)**			
Crop and season	**Rice (kharif season)**	**Cotton (kharif season)**	**Wheat (rabi season)**	**Sugarcane (annual)**
Whether using tractor or not (yes = 1, no = 0)	.042	.275	-.062	.052
Whether using combine harvester or not (yes = 1, no = 0)	.228**	n.v.	-.031	n.v.
Price of crop (natural log)	.006**	.111	-.057	.097
Other household characteristics	Included	Included	Included	Included
Year dummies	Included	Included	Included	Included
Village dummies	Included	Included	Included	Included
Year * village dummies	Included	Included	Included	Included
Household fixed effects	Included	Included	Included	Included
Intercept	Included	Included	Included	Included
Number of observations	423	522	475	479

Source: Authors' calculations based on ICRISAT (2017).
Note: Asterisks indicate the statistical significance: *** 1%, ** 5%, * 10%. n.v. = variables are dropped because there is no variation among the samples.

The adoption of combine harvesters seems to have mixed effects. Although yield effects on wheat are insignificant, those for rice in kharif season are significant, with the adoption of combine harvesters leading to about a 22.8 percent increase in yield, given the prevailing yield levels in the sample. This finding is consistent with the hypothesis that adopting combine harvesters can raise rice yield through reduced harvest loss associated with improved harvesting and threshing precision enabled by machines, among other things. The insubstantial effects for wheat indicate that the yield effects of combine harvester use could vary by crop.

Effects on Seasonal Wage Variability

To analyze seasonal wage variability, we use monthly microlevel VDSA data on seasonal wage rates in a particular Andhra Pradesh village, Aurapally. We analyze the seasonal and monthly variations in agricultural wages by taking the average rate in the village for each of four types of labor in each month of 2011 (Table 5.7).

Table 5.7 Wage rates for agricultural labor, bullocks, and tractors in a typical dryland village in Andhra Pradesh, India, 2011

Month	Bullock pair + driver wage	Female labor wage	Male labor wage	Tractor + driver
Unit	**Rupees per day**	**Rupees per day**	**Rupees per day**	**Rupees per hour**
Jan.	600	118	200	600
Feb.	610	88	190	465
Mar.	610	93	200	430
Apr.	570	84	200	550
May	650	93	210	510
Jun.	775	138	200	585
Jul.	580	141	194	568
Aug.	610	127	210	570
Sep.	640	135	205	520
Oct.	610	124	200	600
Nov.	610	126	200	520
Dec.	570	104	200	550
Average	623	118	201	540
Standard deviation	55	21	6	53
Coefficient of variation	9	18	3	10

Source: Authors' calculations based on ICRISAT (2017).

Interestingly, the seasonal fluctuation (coefficient of variation) in the wage rate for female agricultural labor is six times higher than that of male labor. This result suggests that employment is more stable for men than women, who are hired largely for peak-season work; indeed, we see more fluctuation in demand for female labor than for male labor across the sampled 18 villages. Furthermore, the wage rate for women in India is almost 50 percent lower than that for men, except in the peak season of farm operation, June to November. The rate for a bullock pair and male operator for a day in 2011 was substantially higher than the rate for either a male or female worker, and almost as much as hiring a tractor and driver for a mere hour. A typical tractor of 40 hp can plow almost 50 percent more area in an hour than a pair of animals can plow in a day. These findings illustrate the field-level economics behind the astonishing increase in tractor rentals among Indian farmers.

6. CONCLUSIONS AND IMPLICATIONS

Historical review of the evolution of mechanization growth in India reveals important lessons about the drivers and impacts of mechanization. The spread of tractors despite the continuous decline in average farm size indicates that mechanization can grow even in a smallholder-dominated society through extensive custom-hiring services, at least in the medium term, before the comparative advantage starts shifting toward larger farms as mechanization deepens. The speed of mechanization growth can vary considerably across regions, depending on agroecological conditions and farming and cropping systems. Although 4WTs are more common than power tillers, due possibly to the prevalence of rice-nonrice rotation and other soil-related constraints, a popular horsepower for 4WTs has been 30–50 hp.

Substantial infrastructure endowments (in terms of roads, for example), which were already high in the 1960s, as well as investments into rural electrification, were likely to have been important for the growth in domestic manufacturing of tractors. The promotion of importing tractors in the early days was likely to have helped farmers and technicians in India accumulate knowledge about tractors and parts. This knowledge, again, may have contributed to the growth of the domestic tractor manufacturing sector even as import restrictions in the 1970s were negatively affecting the continuous transfer of foreign tractor technologies. Over time, diverse models of providing custom-hiring services for tractors and combine harvesters have begun to serve areas where such services are profitable, with relatively little direct support from the government. The government's direct support has instead concentrated on recent efforts to achieve inclusive growth by providing services to those left behind. With some subsidies, service providers for zero-till technologies and laser land leveling have also emerged. The private sector has also stepped up to provide facilitating services that connect service providers and farmers.

Empirical analyses of the impact of tractor ownership and tractor / combine harvester use confirm many of our hypotheses. Despite the typically small landholding in India, tractor ownership is led by the motive to expand farm size. Tractors are more bullock saving than labor saving, whereas combine harvesters are more strongly labor saving. This finding is consistent with the hypothesis that power requirements in Indian farming are much greater than can be met by human labor only, so that the returns on substituting with tractors are substantial. These returns are an important precondition for custom-hiring service providers to earn enough profit to provide services. Combine harvesters are more yield enhancing than tractors because the former are likely to directly reduce harvesting losses. Tractor adoption for land preparation, however, induces greater chemical fertilizer use, which may then lead to yield increases.

APPENDIX

1. An Overview of the Sub-mission on Agricultural Mechanization[17]

Consolidating several independent national rural development schemes with farm mechanization supports to farmers as a component of the schemes, the central government of India in 2014 launched an integrated national Sub-mission on Agricultural Mechanization (SMAM). Its main aim is to catalyze an accelerated pace but inclusive growth of agricultural mechanization in India. The mission also allows for continuation of the 1 ongoing farm mechanization–related schemes of 11th plan intervention, as listed below:

(1) Promotion and strengthening of agricultural mechanization through training, testing, and demonstration

(2) Postharvest technology and management

(3) Financial assistance or procurement subsidy for agricultural machinery and equipment

Further, it is proposed that SMAM include the following additional interventions in India:

(1) Establishment of farm machinery banks for custom hiring

(2) Establishing high-tech, high-productivity equipment centers

(3) Enhancing farm productivity at the village level by introducing appropriate farm mechanization in selected villages

(4) Creating ownership of appropriate farm equipment among small and marginal farmers in the eastern and northeastern regions

The proposed funding outlay for this mission during the 12th plan is Rs 35 billion (US$550 million).[18]

Farm power use has grown unevenly across the states of India, and a very low level of farm power is available in large parts of the country. For instance, availability of farm power is much lower in the eastern and northeastern regions than in northern India. Therefore, the promotion of farm

[17] Material in this section is taken from the brochures and policy documents of Ministry of Agriculture and Farmers' Welfare.

[18] Using the 2011/2012 exchange rate of US$1 = Rs 45.

mechanization must be a special mission. Thus, the SMAM scheme is to be implemented in all the states to promote the use of farm mechanization and increase the ratio of farm power to cultivable unit area up to 2 kW/ha throughout India. The mission of SMAM comes under the ambit of the National Mission on Agricultural Extension and Technology.

1.1 Objectives

The mission endeavors to fulfill the following objectives:

(1) Increasing the reach of farm mechanization to small and marginal farmers and to the regions where availability of farm power is low, especially the eastern and northeastern regions

(2) Offsetting adverse economies of scale and the higher cost of ownership of high-value farm equipment by promoting custom-hiring centers (CHCs) for agricultural machinery

(3) Passing on the benefit of high-tech, high-value, and high-productivity agricultural machinery to farmers through creating hubs for such farm equipment

(4) Promoting farm mechanization by creating awareness among stakeholders through demonstrations and capacity-building activities

(5) Ensuring quality control through evaluating the performance of newly developed agricultural machinery and equipment and certifying them at designated testing centers located all over the country

1.2 Approach of SMAM

The objectives of SMAM are to be achieved through multipronged approaches such as the following:

(1) Conducting performance testing on various farm machinery and equipment at the four farm machinery training and testing institutes, designated state agricultural universities (SAUs), and institutions of the Indian Council of Agricultural Research

(2) Promoting farm mechanization among stakeholders by way of on-field and off-field training and demonstrations

(3) Providing financial assistance to farmers for procurement of farm machinery and implements

(4) Establishing CHCs for location- and crop-specific farm machinery and implements

(5) Providing financial assistance to small and marginal farmers for hiring machinery and implements in less mechanized regions

1.2.3 Major Components of the interventions under SMAM

The mission of SMAM has the following eight components of work:

(1) Promotion and strengthening of agricultural mechanization through training, testing, and demonstration. This component aims to ensure performance testing of agricultural machinery and equipment, capacity building of farmers and end users, and promotion of farm mechanization through demonstrations.

(2) Demonstration, training, and distribution of postharvest technology and management (PHTM). This part aims at popularizing technology for primary processing; value addition; low-cost, scientific storage and transport; and crop by-product management through demonstrations and capacity building of farmers and end users. Provides financial assistance for establishing PHTM units.

(3) Financial assistance for procurement of agriculture machinery and equipment. This would promote ownership of various agricultural machinery and equipment as per norms of assistance.

(4) Establishment of farm machinery banks for custom hiring. This would provide suitable financial assistance to establish farm machinery banks for custom hiring for appropriate locations and crops.

(5) Establishment of a high-tech, highly productive equipment hub for custom hiring. This would provide financial assistance to set up high-tech machinery hubs for high-value crops such as sugarcane, cotton, and so on.

(6) Promotion of farm mechanization in selected villages. This component provides financial assistance to promote appropriate technologies and to set up farm machinery banks in identified villages in less mechanized states.

(7) Financial assistance for promotion of mechanized operations carried out through CHCs. This function aims to provide financial assistance on a per-hectare basis to the beneficiaries hiring machinery/equipment from CHCs in less mechanized areas.

(8) Promotion of farm machinery and equipment in the northeastern region. This work extends financial assistance to beneficiaries in high-potential but less mechanized states of the northeast.

1.2.4 Coverage

Although this mission will be operational throughout the country, some components will have location-specific approaches for creating more inclusiveness. The component providing adequate financial assistance to individuals, groups of farmers, cooperatives, and self-help groups for creating ownership of appropriate low-cost, lightweight, but multi-utility farm machinery and implements will be implemented in those potential villages where the level of mechanization is poor but the potential can be harnessed for higher production, multicropping, or both. Similarly, the nucleus for a CHC can be a cluster of villages or blocks having a catchment area of 5,000–10,000 ha. On the other hand, a hi-tech, high-productivity agricultural machinery hub that needs minimum infrastructure and service support for operation and maintenance will be established at the subdivision/district level. This high-tech hub, primarily handling self-propelled equipment, will be able to cover a greater catchment area. The advice of SAUs, Krishi Vigyan Kendras, the Agricultural Technology Management Agency, and reputable NGOs may be taken in identifying the appropriate equipment for implementation and also the source of supplies (Table A.1).

Table A.1 Financial assistance to establish farm machinery banks for custom hiring

Item	Maximum permissible project cost	Pattern of assistance
Procurement subsidy for establishment of custom hiring center up to Rs 1.0 million	Project-based Rs 0.4 million	40%
Procurement subsidy for establishment of custom hiring center up to Rs 2.5 million	Project-based Rs 1.0 million	40%
Procurement subsidy for establishment of custom hiring center up to Rs 4.0 million	Project-based Rs 1.6 million	40%
Procurement subsidy for establishment of custom hiring center up to Rs 6.0 million	Project-based Rs 2.4 million	40%

Source: India, MOAFW (2015).
Note: In 2015/2016, the central government allocated Rs 1,497 (about US$23.03 million) to be spent under the Sub-mission on Agricultural Mechanization for activities across the country. Rs = Indian rupees.

2. Various Financial Supports and Subsidy Schemes for Purchasing Farm Machinery Types from Central Government Funds

The information is summarized below by activity type or machinery type (Tables A.2 ~ A.6).

Table A.2 Promotion policies for agricultural mechanization

Component	Pattern of assistance
Demonstration (at farmer's field)	100% assistance @ Rs 4,000/ha up to 100 ha per season
Training (farmers / users / other stakeholders) by institution identified by ICAR / state govt.	Rs 4,000/trainee per week Maximum permissible outlay is Rs 2.5 million per state
Testing (by SAUs / ICAR / state govt.)	Maximum permissible outlay is Rs 15 million per center One-time grant of up to Rs 15 million

Source: India, MOAFW (2015).
Note: ICAR = Indian Council of Agricultural Research; Rs = Indian rupees; SAU = state agricultural university.

Table A.3 Financial assistance for promoting ownership of various agricultural machinery and equipment by farmers (Sub-mission on Agricultural Mechanization guidelines)

Type of agricultural machinery	For SCs, STs, small and marginal farmers, women, and NE states beneficiaries		For other beneficiaries	
	Maximum permissible subsidy per machine /equipment/beneficiary	Pattern of assistance	Maximum permissible subsidy per machine /equipment/beneficiary	Pattern of assistance
Tractors				
Tractor (08–20 PTO HP)	Rs 100,000	35%	Rs 70,000	25%
Tractor (20–70 PTO HP)	Rs 125,000	35%	Rs 100,000	25%
Power Tillers				
Power tiller (less than 8 BHP)	Rs 50,000	50%	Rs 40,000	40%
Power tiller (8 BHP and greater)	Rs 75,000	50%	Rs 60,000	40%

Table A.3 Continued

Type of agricultural machinery	For SCs, STs, small and marginal farmers, women, and NE states beneficiaries		For other beneficiaries	
	Maximum permissible subsidy per machine /equipment/beneficiary	Pattern of assistance	Maximum permissible subsidy per machine /equipment/beneficiary	Pattern of assistance
Rice transplanters (self-propelled rice transplanters)				
Up to 4 rows	Rs 94,000	50%	Rs 75,000	40%
More than 4–16 rows	Rs 200,000	40%	Rs 200,000	40%
Self-propelled machinery				
Reaper cum binder	Rs 125,000	50%	Rs 100,000	40%
Specialized self-propelled machinery	Rs 63,000	50%	Rs 50,000	40%
Self-propelled horticultural machinery	Rs 125,000	50%	Rs 100,000	40%
Tractors / power tillers, driven / animal drawn / manual equipment				
Land development, tillage, and seed bed preparation equipment	Rs 8,000–63,000	50%	Rs 6,000–50,000	40%
Sowing, planting, reaping, and digging equipment	Rs 10,000–63,000	50%	Rs 8,000–50,000	40%
Intercultivation Equipment	Rs 600–63,000	50%	Rs 500–50,000	40%
Equipment for residue management / hay and forage equipment	Rs 15,000–63,000	50%	Rs 12,000–50,000	40%
Harvesting and threshing equipment	Rs 5,000–63,000	50%	Rs 4,000–50,000	40%

Source: India, MOAFW (2015).
Note: BHP = brake horsepower; NE = northeastern; PTO HP = power take-off horsepower; Rs = Indian rupees; SC = scheduled castes; ST = scheduled tribes.

Table A.4 Financial assistance to establish farm machinery banks for custom hiring purposes

Item	Maximum permissible project cost	Pattern of assistance
Procurement subsidy for establishment of custom hiring center up to 1.0 million	Project-based Rs 0.4 million	40%
Procurement subsidy for establishment of custom hiring center up to 2.5 million	Project-based Rs 1.0 million	40%
Procurement subsidy for establishment of custom hiring center up to 4.0 million	Project-based Rs 1.6 million	40%
Procurement subsidy for establishment of custom hiring center up to 6.0 million	Project-based Rs 2.4 million	40%

Source: India, MOAFW (2015).
Note: Rs = Indian rupees.

Table A.5 Promotion of farm mechanization in selected villages

Item	Maximum permissible project cost	Pattern of assistance
Financial assistance for farm machinery banks with minimum of eight farmers per bank	Up to Rs 1 million per farm machinery bank	80% of the cost of farm machinery bank

Source: India, MOAFW (2015).
Note: Rs = Indian rupees.

Table A.6 Promotion of farm machinery and equipment in northeastern states

<table>
<tr><th>Item</th><th>Maximum permissible project cost</th><th>Pattern of assistance</th><th>Norms of intervention</th></tr>
<tr><td>Financial assistance for procurement of machinery/implements</td><td>Up to Rs 0.125 million per beneficiary</td><td>100% of cost of machinery/implements</td><td rowspan="2">Eight northeastern states to participate on a project basis with a minimum of 8–10 farmers and a maximum of 150 farmers in a group</td></tr>
<tr><td>Financial assistance for farm machinery banks for groups of farmers</td><td>Up to Rs 1.000 million per farm machinery bank</td><td>95% of cost of farm machinery bank</td></tr>
</table>

Source: India, MOAFW (2015).
Note: These eight northeastern states are also the places in India with the lowest level of farm mechanization at this time. Rs = Indian rupees.

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