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The Evolution of Tractorization in India's Low-Wage Economy

Key Patterns and Implications

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ABSTRACT

Despite the gloomy prospects for farm tractor use in India and the South Asia region depicted in studies from the 1970s and 1980s, over time the region's farmers have adapted tractor technology innovatively and used it for many purposes. India now constitutes one of the largest tractor market in the world, but the intensity of tractor use varies widely across its states. This study reviews the evolution of tractor use in India in the past few decades, and supplements this with a panel model analysis using factors associated with state-level tractor density growth. Growth in tractor use in India, unlike that in the United States and Japan, has occurred at relatively low wage rates and with a substantial majority of the workforce remaining in the agricultural sector. Considerable growth in domestic manufacturing has contributed to growth in tractor densities. Tractor density across the 14 major states in India between 1982 and 2012 was positively affected by income per capita, cropping intensity, and the average size of farmland holdings. Tractor intensity grew at a fast pace even in low-wage regions of India, indicating that relatively lower labor wages might not have been a binding factor for diffusion of farm machinery and tractors among smallholding farmers in India.

Keywords: Farm tractor, determinants of tractor use, adoption and diffusion of farm machinery technology, panel data analyses, agricultural wage rate, farm machinery policies, India

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The authors would like to dedicate this Discussion Paper in memory of Hans P Binswanger-Mkhize, one of the tallest development economist who extensively studied economics of tractorization extensively in South Asia earlier in 1970s and 1980s, and who passed away last month (August 2017). The authors' associations and intellectual discussions with Hans Binswanger on economics of tractor uses and farm mechanization in India (in 2013 and 2014) have in fact also profoundly influenced development of this paper and the issues covered in this discussion paper. This paper has not gone through IFPRI's standard peer-review process. The authors are solely responsible for all remaining shortcomings and errors in this paper.

1. INTRODUCTION

Agricultural mechanization has been one of the most important processes of agricultural transformation in developing countries, as it often accompanies significant changes in labor productivity, agricultural industrialization (Binswanger 1986; Pingali 2007), and increases in returns to scale in agriculture (Takeshima 2017a). The agricultural sector in some developing regions, including Asia and Latin America, has become increasingly mechanized in the last few decades, particularly in terms of the use of tractors in various farming operations (Pingali 2007). In many Asian countries, for example, the share of area prepared by tractors had increased from small fractions to more than 60 percent (80 percent or more for some countries) by around 2010, in a span of a few decades (Takeshima 2017b; Biggs and Justice, 2015). As we show in a later section, the number of four-wheel tractors across India grew at an average of more than 8 percent per annum during the last 30 years. Four-wheel tractor has four wheels attached in two axels, which makes it different from that of two-wheel tractors, which are usually two wheels attached in single axel. In this study, the term of “tractor use” means use of a common tractor with four wheels drive, unless it is specified otherwise. Likewise, two wheel tractor is commonly also called as power tiller. A power tiller is usually with a lower HP engine (less than 20 HP) than that of the case of Four wheels tractor.

Yet information on how such growth has occurred, and what factors are associated with it, is relatively scarce. This is particularly so in countries like India, where the majority of such growth has been in four-wheel tractors.¹ While the literature has increasingly offered insight into some Asian countries where growth in tractor use has been dominated by smaller, two-wheel tractors (such as Bangladesh and China), information is sparse regarding the process of the diffusion of four-wheel tractors in Asian countries such as India.

This study takes a step toward filling that knowledge gap by assessing certain aspects of tractor ownership and use growth in India. Specifically, the study describes how tractor usage in India has grown even in the presence of relatively low wage levels and while a majority of labor has still

¹Tractor in this means four wheels tractor, unless it is mentioned otherwise. In popular term, two wheel tractor is also commonly referred as power tiller (or walking behind tractor) in many countries in Asia.

been employed in the agricultural sector, in contrast to earlier mechanization growth experiences in developed countries. We then describe how tractor density growth has been heterogeneous across states within India. We complement our analysis with an assessment of factors associated with tractor density growth using state-level panel data between 1982 and 2012 for 14 states, compiled separately from the public domain.

The study contributes to the literature on agricultural mechanization in several ways. It complements studies laying out general hypotheses regarding the patterns and roles of agricultural mechanization in agricultural transformation in developing countries (Binswanger 1986; Pingali 2007; Diao, Silver, and Takeshima 2016) by providing deeper insights into India, which has grown to become the largest tractor markets in the world. The study also supplements growing literature on agricultural mechanization in South Asia, including India (Foster and Rosenzweig 2011) and other countries (Takeshima 2017a for Nepal; Mottaleb, Krupnik, and Erenstein 2016 for Bangladesh), by shedding more light on the spread of tractors in 14 Indian states. By evaluating both spatial and temporal variations in tractor spread across India, this study differs from many past studies on the economics of tractor use in India and South Asia, which were largely based on farm household-level economic and financial analysis of tractors at a point in time. Lastly, our analysis of tractor diffusion at the state level in India complements similar analyses of mechanization at aggregate levels, such as provincial-level studies in China (Wang, Yamauchi, and Huang 2016; Zhang, Yang, and Reardon 2015), and offers more insight into associations between key factors at the regional rather than the household level.

In Section 2 we review selected studies dealing with factors affecting tractor usage in India, and in South Asia in general. Section 3 describes our methodology, analytical tools, variables used in the empirical analysis, and data sources. In Section 4 we discuss the results of the empirical analysis and those of the econometric analysis. Section 5 presents our conclusions and some implications of the study.

2. RELEVANT LITERATURE

Agricultural mechanization is defined as a process of improving farm labor productivity through the use of agricultural machinery, implements, and tools (FAO 2013). In this respect, farm mechanization is a continuous process, and it involves the provision and use of all forms of power sources and tools and techniques in agriculture, from simple hand tools to animal draught power to mechanical power technologies to processes of adoption and adaptation of hard and soft machinery technologies. In practice, human power, animal power, and machinery power complement each other in most of the farming systems in the tropics (Pingali 2007). In this process, introduction of both four-wheel tractors and two-wheel tractors in a place is considered a critical component of farm mechanization, and in turn, farm modernization, since in many cases, tractors are in fact a basic element for providing operating power for using other machinery attachments and equipment for various farm operations.

Viability of Tractor Use in South Asia

Early literature on the viability of the use of tractors in South Asia focused on two aspects: the technical aspect of farm mechanization needs and the economic aspect of tractors as a substitute for manual power.

From the technical perspective, earlier literature emphasized the insufficient farm power supplied by labor or animals and the potential for tractors to overcome a farm power bottleneck. Even before Green Revolution technologies had spread to wider areas in India, some scholars were pointing out the tractor's huge potential to help expand cultivated areas and improve cropping intensities by speeding up land preparation compared with the use of animal power (Joppich 1957) and addressing the energy bottleneck in peak periods (Singh and Chancellor 1975; Harrington 1975). Singh and Chancellor (1975) estimated total power need for crop production on a weekly basis in selected villages in North India, taking a yearlong in-depth accounting of energy power needs and energy supply from available human labor and draft animal power in these villages. Then they demonstrated that draft animal power was a serious constraint and a critical bottleneck in most parts of the rice–wheat systems of the Indo-Gangetic Plain of South Asia even in 1971–1972 for doing all farm operations such as irrigation, threshing, and plowing land for sowing wheat in a timely manner while

harvesting and processing paddy at the same time. Similarly, Maggu (1982), surveying more than 900 households in North India, reported that the lack of suitable quality of tractors of proper size needed for different farm operations was a major problem faced by farmers rather than the average landholding or low wage rate in the rural economy. Likewise, Bhattarai and Pandey (1997), using a linear programming model of a typical farm in rice–wheat systems in Nepal, demonstrated that unavailability of tractors was the main constraint for expanding wheat acreage in Nepal’s Terai in the early 1990s.

However, looking at the economic dimension, the early literature was mostly pessimistic about the growth of tractor use in India and other countries in South Asia after the 1980s. Studies carried out in the 1970s and 1980s raised questions about the economic and financial viability of farmers’ investment in tractors for increasing cropping intensity and farm productivity, and raised doubts about the efficacy of public-sector research and development and investment in tractors in South Asia (see Binswanger 1978, 1986; Agarwal 1984; Jayasuriya, Te, and Herdt 1986). These studies reported that “mechanization will contribute very little to growth in countries without a land frontier, and with densely populated farmland in India, Bangladesh, Nepal, since labor scarcity cannot be expected to arise there from non-agricultural growth in the near future as a driving force for mechanization” (Binswanger 1986, p.51). Likewise, Jayasuriya, Te, and Herdt (1986), based on a review of past studies and a field study, reported that power tillers were then not economically viable to use in the Philippines, Bangladesh, India, and other countries in Asia compared with animal draft power. However, the past studies on the economics of farm mechanization in India have generally devoted less attention to the multidimensional uses of tractors, potentially underestimating the economic viability of tractor ownership.

Factors Associated with Tractor Use in India

Most of the socioeconomic studies on tractor use in South Asia were conducted in the 1970s and the early 1980s, during the early stage of the diffusion of Green Revolution technology there. Most studies compared implications of the adoption of tractor use versus draft animal power on crop yield,

cropping intensity, farm intensification, and labor use per unit of land or per farm household (Binswanger 1978, 1986; Agarwal 1981; Jayasuriya, Te, and Herdt 1986).

Binswanger (1978) suggested that use of tractors affected agricultural production and farm operation through two major routes: (1) the net contribution effect on expansion of farm outputs, and (2) the substitution effect, that is, the substitution of capital for labor. A large number of empirical studies carried out in India in the 1970s and 1980s on farm households' use of tractors then focused on the substitution of capital for labor. Earlier, Maggu (1982) had reported that tractorization then led to the replacement of bullock power, not labor power, and that tractorization was then essential for increasing productivity, enhancing innovation in farming, and facilitating the use of high-yield varieties of food crop seeds. Rao (1972) also pointed out that farm mechanization—especially of a land-augmenting type such as tractorization—can substantially raise the potential for overall employment in the rural economy.

Some researchers argue that widespread use of tractors across India over the past three decades has also been facilitated by the co-evolution of a vibrant rental market in services of tractors and farm implements, even in remote villages (Singh 2015). The rental market has made farm tractors accessible to all segments of farmers, including smallholding and marginal farmers, and has improved the economic viability of tractor ownership even by a small or medium landholding farmer with 2 to 3 hectares of farmland. Thus, over time, tractor-owning farmers in India have expanded rental services of tractors to neighboring farms as well as for nonfarm uses both in villages and in nearby urban centers. In 2001 on average about 38 percent of the hours used of the four-wheel tractors at the national level in India was for hiring out services² to other farms and for nonfarm uses (Sarkar 2013; Kishor and Mor 2001).

Tractors' multiple uses in the economy are also important considerations for farmers when deciding whether to own a tractor or just hire one (Zhang, Yang, and Reardon 2015). Recently, the prospect of earning income from renting out one's tractor to others for nonfarm uses has become more

²The National Bank for Agriculture and Rural Development commissioned Kishor and Mor's 2001 study to look at the extent of the use of farm tractors for renting-out activities across the states of India. Since 2001, such a study that covers the business of renting out tractors at the all-India level has not been conducted. However, the agricultural input survey report of India for 2011–2012 reported that about 45 percent of farming households in India then used tractors in their fields at least one time in 2011–2012 (DAC&FW 2016).

important in many smaller town centers in Asia than the use of a tractor for plowing one's own farmland (FAO 2013). Over time, multipurposing of tractors in the rural economy has extended the number of days tractors are used per year, making owning one economically viable to even smallholding farmers, who eventually become a tractor service provider in rural areas.

Lastly, the literature is fairly thin on the factors associated with tractor use or ownership growth at regional levels, such as at the state level. At the state level, observed conditions of various variables reflect equilibria determined by both supply- and demand-side factors. Agricultural mechanization, including that through tractor use, can have important economywide effects in (as well as feedback effects from) the labor sector, farm size changes, overall economic growth, and so forth. Insufficient attention to the economywide benefits and multiple uses of tractors by farmers could be a reason for the anomalies in socioeconomic analyses of tractor use in Asia implied in the past studies, as noted earlier.

3. KEY ASPECTS OF THE GROWTH IN TRACTOR USE IN INDIA

More than six million tractors were estimated to be in the fields in India in 2015 (Singh 2015), and annual tractor sales in India have grown by double digits during the last 20 years. However, there is a huge variation in the intensity of tractor use across the states of India. For example, there were seven tractors per 1,000 hectares of net sown area (NSA) in West Bengal state in 2012, whereas there were 145 tractors per 1,000 hectares of NSA in Haryana state in the same year. Hence, in this paper we analyze the different patterns of tractor use and the major determinants of variation in tractor use across 14 major states of India from 1982 to 2012. These 14 states are responsible for more than 90 percent of the agrarian economy of India.

Annual sales of four-wheel tractors in India increased from 63,000 pieces in 1982 to 634,150 pieces in 2014—a tenfold increase in sales volume in 30 years (Table 3.1). Over that period, the power tiller spread massively in Bangladesh and Sri Lanka, Thailand, Vietnam, and other countries in Asia, whereas the tractor spread astonishingly in India, where annual power tiller sales remained less than 10 percent of the total number of annual tractor sales. In fact, use of the power tiller in India is confined largely to a few states where wetland paddy is cultivated predominantly (such as Kerala, Odisha, and West Bengal) or to hilly states of the northeast region, where the terrain is not suitable for movement of four-wheel tractors.

Table 3.1 Tractor and power tiller sales in India, 1982 to 2015

Financial year	Four-wheel tractors		Power tillers (two-wheel tractors)	
	Annual sales (in numbers)	Annual growth (%)	Annual sales (in numbers)	Annual growth (%)
1982	63,000	-	2,220	-
2005	232,906	-	17,481	-
2006	264,790	13.69	22,303	27.58
2007	313,941	18.56	24,791	11.16
2008	302,948	-3.50	26,135	5.42
2009	304,622	0.55	35,294	35.04
2010	402,586	32.16	38,794	9.92
2011	482,286	19.80	55,100	42.03
2012	536,891	11.32	60,000	8.89
2013	527,768	-1.70	47,000	-21.67
2014	634,151	20.16	56,000	19.15
2015	551,463	-13.04	48,000	-14.29

Source: ICICI (2015); Singh (2009); original data sources: India, Ministry of Agriculture.

Even with a conservative estimate, the annual market value of tractor sales in India was about US\$5 billion³ in 2014–2015 (Grant Thornton India 2015). Despite the remarkable progress in tractor sales in India at aggregate national-level statistics, a huge disparity exists in tractor usage across the states. Historically, large numbers of tractors have been concentrated only in selected states in northwest India, namely, Punjab, Haryana, and the western part of Uttar Pradesh (Table 3.2). In 2012, tractor density at the all-India level was about 42 tractors per 1,000 hectares of NSA; this varied from 148 in Haryana⁴ to 125 in Punjab to 64 in Uttar Pradesh to 40 in Bihar to 7 in West Bengal. In 2012, whereas the two states of Punjab and Haryana accounted for about 18 percent of the total cumulative number of tractors at the national level, those two states accounted for only less than 5 percent of the NSA in India. In early 1980, the situation was even worse, as nearly half of the total number of tractors in use in India in 1982 were confined to only the two states of Punjab and Haryana.

³Tractor prices vary widely by size and brand. Hence, the figure is derived by using the average price of a 40-horsepower tractor in 2015 and the number of tractors sold annually in 2015.

⁴The sharp increases in tractor density in Haryana state in recent days is also due to many ongoing infrastructure projects in and around suburban Delhi metro city areas. This has provided an increased opportunity to earn additional income and employment from nonfarm uses of tractors by farmers in Haryana. Likewise, sharply increasing land values in Haryana during the last 10 to 12 years have produced a wealth effect among farmers and provided farmers an incentive to buy tractors and reduce some of the drudgery of farm work. The increasing land values and income effect are also reflected in easier access to institutional credit from banks and financial institutes in Haryana now compared to other states. A farmer in Haryana must mortgage only a third of an acre of land to take a bank loan to buy a tractor, but in bordering Uttar Pradesh a farmer needs to mortgage more than an acre, as is the case in other states of India. Hence, a complex set of factors affects tractor use in India.

Table 3.2 Tractor density across Indian states in decadal time from 1962 to 2012 (unit: number of tractors per 1,000 hectares of net sown area)

State	1962	1972	1982	1992	2002	2012	Rank (in 2012)
Haryana	0.7	5.4	17.0	49.3	103.1	147.1	1
Punjab	2.4	10.9	25.4	66.6	105.3	124.8	2
Uttar Pradesh	0.5	1.6	8.2	20.4	40.7	63.8	3
Gujarat	0.3	1.3	2.9	8.3	26.9	48.1	4
Tamil Nadu	0.4	0.8	2.6	7.2	15.3	41.1	5
Rajasthan	0.3	0.7	3.5	7.4	34.6	40.0	6
Bihar	0.2	0.6	1.8	7.3	15.7	37.2	7
Karnataka	0.2	0.5	2.0	4.2	11.4	37.16	8
Madhya Pradesh	0.1	0.3	1.3	4.8	16.0	32.1	9
Andhra Pradesh	0.2	0.5	1.9	5.9	6.1	30.8	10
Maharashtra	0.1	0.3	1.2	3.3	10.6	24.2	11
Odisha	0.1	0.3	0.2	0.7	4.9	18.9	12
West Bengal	0.2	0.1	0.3	1.6	3.8	6.8	13
Kerala	0.2	0.4	0.6	2.1	3.9	5.7	14
All-India average	0.3	1.7	8.7	10.0	24	42	-

Source: Compiled by authors by referring to several publications of the Indian government.

The number of four-wheel tractors used in India has increased by an average of more than 8 percent per annum during the last 30 years, but, again, this measure varies greatly across the states. For example, usage increased by an average of more than 16 percent per annum in Odisha in the last 30 years, but by only 5 percent in Punjab (Table 3.3). Odisha's higher growth rate can be attributed to a lower base level of tractors compared with other states such as Punjab,⁵ Haryana, and Uttar Pradesh. In absolute terms, during the last 30 years, a greater number of tractors were added in these three states than in all the other states together.

⁵The percentage increase in tractors in use in Punjab, Haryana, and Uttar Pradesh during the last 30 years is slightly lower than the case in other states of India, since there were already a high number of tractors in these three states in 1982.

Table 3.3 Cumulative annual growth rate of the number of four-wheel tractors across states of India, 1982–2012

SN	State	1982–1991	1992–2001	2002–2012	Overall (1982–2012)
1	Andhra Pradesh	10.65	-3.44	23.55	7.24
2	Bihar	15.77	7.83	8.23	9.75
3	Gujarat	10.41	13.39	6.83	10.10
4	Haryana	10.62	5.05	4.07	7.18
5	Karnataka	7.76	10.26	12.55	9.27
6	Kerala	14.12	6.65	3.22	6.64
7	Madhya Pradesh	14.48	13.56	7.21	11.94
8	Maharashtra	10.06	13.33	8.53	10.44
9	Odisha	12.68	20.25	11.99	16.07
10	Punjab	9.67	4.81	1.57	5.06
11	Rajasthan	8.33	12.35	6.61	9.43
12	Tamil Nadu	11.21	5.26	9.42	8.27
13	Uttar Pradesh	9.26	9.46	4.47	7.21
14	West Bengal	20.45	7.41	3.73	10.48
15	All India	10.32	8.36	6.46	8.13

Source: India, Ministry of Road, Transport, and Highway. Various years of publication reports. See Table 4.1 for the data sources of each of the variables.

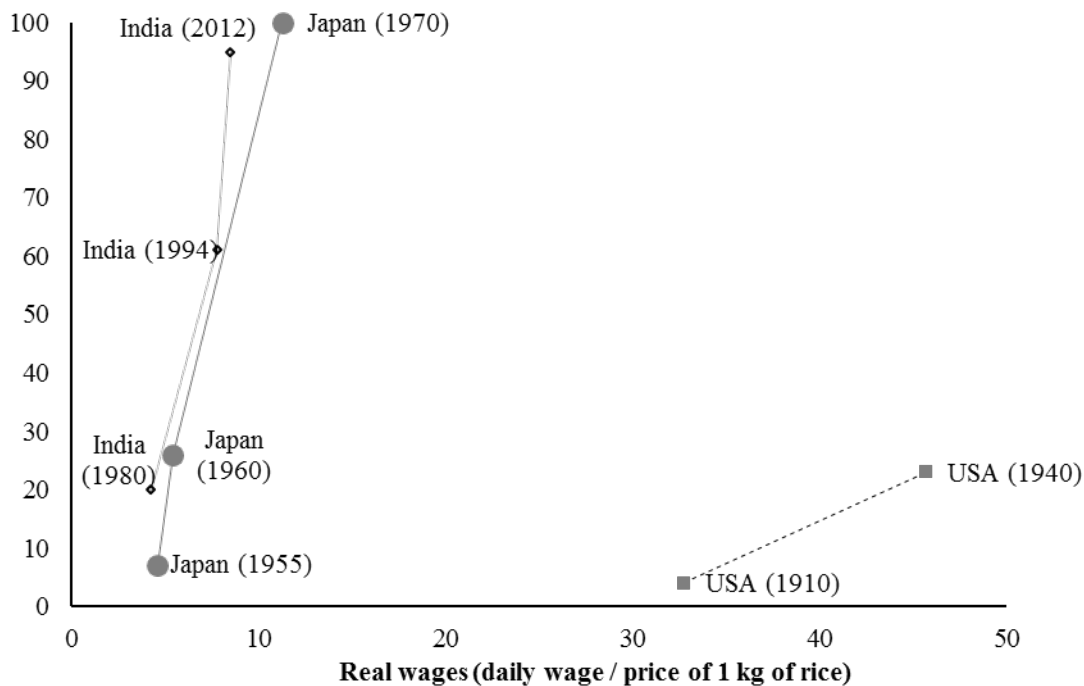
Unique Aspects of Tractor Use Growth in India

The pattern of growth in tractor use in India has differed from earlier patterns in various developed countries. Specifically, tractor use has grown while real farm wages have remained at relatively low levels and the share of employment in the agricultural sector has remained at relatively high levels. Figure 3.1 supports the former point, while Figure 3.2 supports the latter point. Figure 3.1 illustrates the trajectories of the share (percentage) of cultivated area plowed by tractors and real daily wages (measured in how many kilograms of rice can be bought by one day of farm labor earnings) in the United States, Japan, and India at different points in time. First, it can be seen that the tractor use growth in the United States did not begin until real wages were considerably high. In Japan, tractor use began to grow in the presence of much lower wage levels than in the United States. The trajectory

in India indicates that tractor use grew in India in the presence of even lower real wages than those of Japan.

Figure 3.1 Mechanization of land preparation and real agricultural wages

Share (%) of area plowed by tractors



Source: Various, as follows:

Japan: Tractor use—Economic Planning Agency (1962) for 1955 and 1960. Barker, Herdt, and Rose (1985, Fig. 8.1) suggest that by 1970, the adoption rate had reached almost 100 percent. Wages for 1955 and 1960, as well as rice prices for 1955 and 1960—Japan, Ministry of Agriculture, Forestry, and Fisheries. Barker, Herdt, and Rose (1985) for real wage in 1970.

USA: Figures of the share of tractor-owning farm households (Olmstead and Rhode 2001) are used to approximate the share of area prepared by tractors. Figures for 1920 are used for 1910, assuming fairly small changes in the share between 1910 and 1920. Wages—assessed from Statistical Abstract of the United States (1936, 595) for 1910; Hayami and Ruttan (1985) for 1940. Rice price—University of Arkansas (2013).

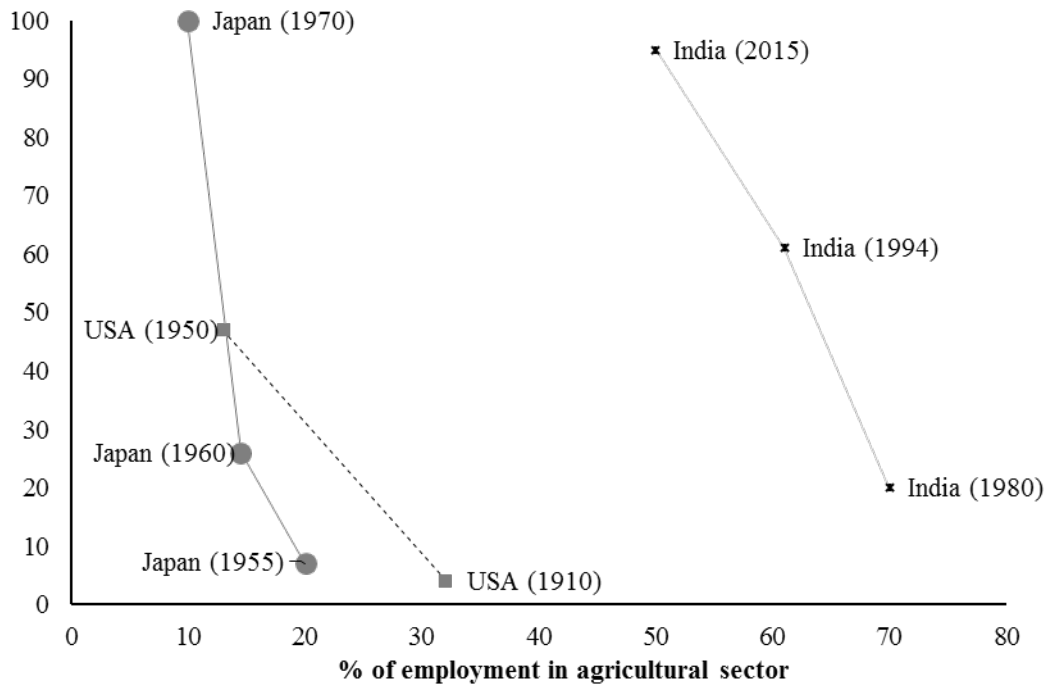
India: Tractor use—Ugwuishiwi and Onwualu (2009) for 1994, assessed from figures for 2014 in Grant Thornton India (2015). Figures for 1980 were assessed proportionally using the number of tractors reported by FAO (2017) in 1980 and 1994. Real wages for 1980—Barker, Herdt, and Rose (1985); Wages—Wiggins and Keats (2015) for 2012. For 1994, interpolated using figures from Barker, Herdt, and Rose (1985) in 1980 and Wiggins and Keats (2015) for 2001, which leads to approximately US\$1.6/day (constant 2010 USD). Rice price—FAO (2017) and deflated by Consumer Price Index deflator of US dollar from Bureau of Labor Statistics, United States Department of Labor.

Figure 3.2 shows the trajectories of tractor use growth and the employment share of the agricultural sector in India and selected developed countries. In most developed countries, tractor use has grown only after a majority of workers have left the agricultural sector for the industrial or service sectors. In contrast, tractor use in India has grown even as a majority of workers have remained in the

agricultural sector. Figures 3.1 and 3.2 suggest, then, that tractor use growth in India in terms of its relationship with labor has constituted a different experience than the earlier experiences in many developed countries. Such uniqueness in the Indian experience motivates our study.

Figure 3.2 Mechanization of land preparation and employment share in agriculture

Share (%) of area plowed by tractors



Source: Various, as follows:

Japan: Sources for tractor figures as in Figure 3.1. Employment shares are from Japan, Ministry of Agriculture, Forestry, and Fisheries (2017).

USA: Sources for tractor figures as in Figure 3.1. Employment shares are from Steckel and White (2012, 8) for 1910; Kjeldsen-Kragh (2007, Table 3.2) for 1950.

India: Sources for tractor figures as in Figure 3.1. Employment shares for 1980 are assessed from figures in Nagaraj (2003). Figures for other years from World Bank (2017).

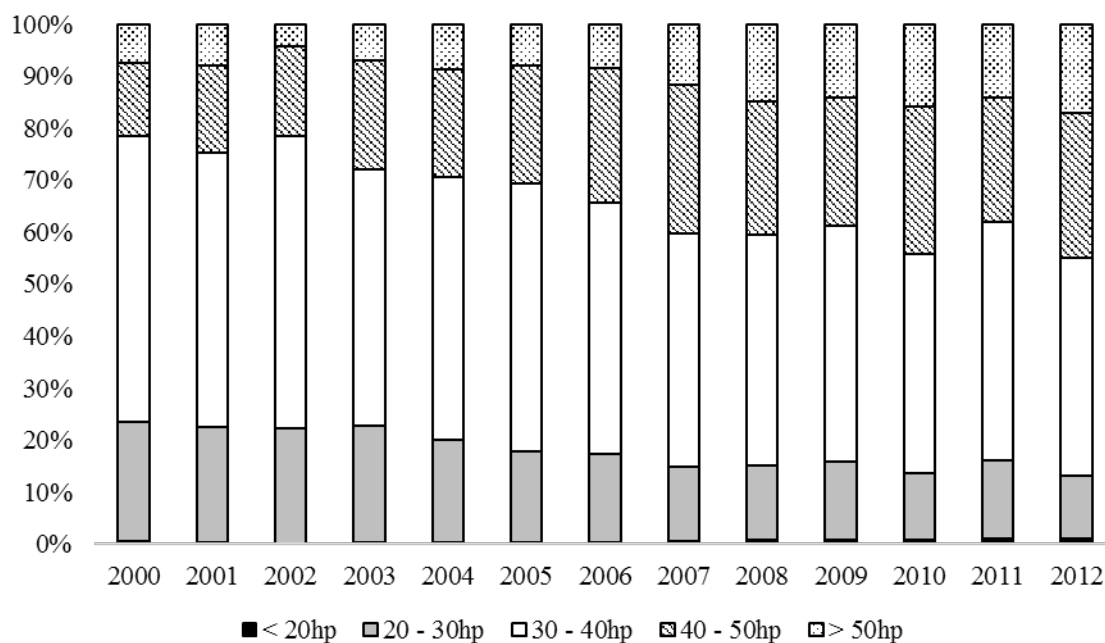
The evolution of tractor density may not accurately capture the changes in overall tractor power capacities if the average horsepower of tractors has changed substantially during the corresponding period; however, that is not a major concern for the case of India. Tractor horsepower in India has remained relatively stable since the 1980s up to 2012. In the early 1980s, the typical horsepower of tractors in India was below 50 horses, with the most common being in the range of 30 to 40 (Mohan 1986). Between 2000 and 2012, available statistics on the distribution of the horsepower of tractors sold in India (Figure 3.3) indicate that, while the shares of higher-powered

tractors have been slowly on the rise, the 30-to-40-horse range still accounts for the largest share (more than 40 percent).

Such relative stability of tractor horsepower distribution in India during the study period is important as well because our analysis focuses on tractor density rather than on tractor use intensity (either on farms owned by tractor owners themselves or on neighbors' farms through custom-hiring services), the latter of which would be a better statistic but is more difficult to obtain. Horsepower is one important predictor of how much farmland or how many farm households are served by a given tractor. Generally speaking, tractors with higher horsepower can serve greater areas and farmers per unit because they are more powerful and can prepare land in a shorter time frame. If tractor horsepower remains relatively stable over time, the overall tractor use intensity through own-tractors and through custom-hiring services combined may be relatively linearly related to the changes in tractor density.

Importantly, given that the common horsepower of tractors has remained relatively steady during the study period, the analysis based on tractor density in the next section offers clearer implications on the overall tractor capacity and thus the level of mechanization in India.

Figure 3.3 Breakdown by horsepower of tractors sold in India between 2000 and 2012



Source: CSAM (2014).

The considerable growth of domestic tractor manufacturing in India constitutes an important dimension of the country's tractor industry. Whereas India has had an advantage in terms of the potential domestic market size, such growth in domestic manufacturing has not always occurred in other developing countries. It is beyond the scope of this paper to provide a deep analysis of the supply-side issues of India's tractor market, but it is worth mentioning that the growth of domestic manufacturing industries is likely to be one of the important phenomena associated with the spread of tractors in India.

Table 3.4 summarizes the evolution of tractor manufacturers in India. The recent high growth in tractor use in India is due in part to the timely availability of low-cost technology adapted to the local context. The establishment of several tractor manufacturing industries in the 1970s and 1980s helped develop and adapt affordable tractor technology suitable to India's specific farming context than the type of four wheel tractors available in early 1970s and 1960s (Singh 2015). The growing number of tractors in India has been increasingly supplied by domestic manufacturers. After starting its first production of farm tractors in 1961, India is now one of the largest tractor market in the world, with annual sales in the domestic market of about 0.6 million tractors, all produced within the country. India accounts for more than 30 percent of the global tractor market, which is estimated at a market value of about US\$6 billion annually, and also is the largest producer of tractors globally (ICIC 2015; Grant Thornton India 2015). The market growth has also involved the manufacturing of indigenous tractors, including Swaraj tractors, which were designed by a public-sector institution (the Central Mechanical Engineering Research Institute) in the 1970s (Aurora and Morehouse 1972; Pray and Nagarajan 2014).

Table 3.4 Major tractor manufacturers and their collaborators in India with year of first entry and 2014–2015 Indian market share

SN	Manufacturer	Collaborator/partner	Year of entry in India	Approximate market share in India in 2014–2015
1	Eicher Tractors Ltd.	Gebr. Eicher Tractor, West Germany	1961	
2	Gujarat Tractors Ltd.	Motokov-Praha, Czechoslovakia	1963	
3	TAFE	Massey Ferguson, United Kingdom	1961	20
4	Escorts Ltd.	MolimportArazawaZakladyMechaniczneUrsus, Poland	1964	9
5	Mahindra and Mahindra Ltd.	International Harvester, United Kingdom	1965	30
6	Escorts Tractors Ltd.	Ford, United Kingdom	1971	
7	Hindustan Machine Tools	Motokov-Praha, Czechoslovakia	1971	
8	Kirloskar Machine Tools	Klochner-Humboldt Deutz, Germany	1974	
9	Punjab Tractor Ltd.	CMERI, INDIA	1974	9
10	Pittie Tractor Ltd.	Own know-how	1974	
11	Harsha Tractor Ltd.	Moto Import, Russia	1975	
12	Auto Tractor Ltd.	British Leyland, United Kingdom	1981	
13	Pratap Steel Rolling Mill	Own know-how	1983	
14	VST Tillers	Mitsubishi, Japan	1983	
15	United Auto Tractor Ltd.	UzinaTractoural, Romania	1986	
16	Asian Tractor Ltd.	Own know-how	1989	
17	Bajaj Tempo Ltd.	Own know-how	1987	
18	International Tractors (Sonalika)	Own know-how	1998	10
19	Larsen and Tourbo Ltd.	John Deere, United States	1999	10
20	New Holland Tractor	New Holland Tractors, Italy	1999	
21	Greaves Ltd.	SAME Deutz-Fahr, Italy	1999	

Source: Compiled by authors from Jain (2006); updated market sales from other sources for recent years.

Note: The combined market share of TAFE and Eicher is 22%. “Year of entry in India” is the first year the respective company started producing/manufacturing tractors in India. Due to closures and mergers with other manufacturers, many manufacturers that set up plants in the 1970s and the 1980s are no longer producing their own brands of tractors). Table here lists only those brand of tractors (or manufacturing company) that still are producing tractors for the sale in 2014-15. Some of the companies have less than 2-3 % of market share, which are not reflected in the table.

4. FACTORS ASSOCIATED WITH TRACTOR DENSITY GROWTH IN INDIA

We now conduct a simple analysis of the factors associated with tractor density growth across the 14 major states in India between 1982 and 2012. First, we describe the overall methodology, analytical tools, and variables used. We then describe data sources for the deriving set of variables used.

Overall Methodology

Factors associated with tractor densities in the 14 major states of India are analyzed by means of a panel model; for our unit of analysis we use an aggregate state-level annual data series for 30 years⁶ from 1982 to 2012. The 14 states examined accounted for more than 90 percent of the national agrarian-sector economic activities in India.

Based on a review of past studies on tractor adoption and diffusion in South Asia and globally, selected agricultural sector policy, structural and agrarian structural factors, infrastructural variables, and per capita income-related variables were taken as potential factors associated with the diffusion of farm tractors across the states of India. Since the individual states vary from each other in terms of agrarian structure, we use a fixed-effects panel specification (Greene 2003) as shown in equation 1:

$$\begin{aligned} TD_{it} = & a + e_i + \beta_1 Labor\ Density_{it} + \beta_2 Wage_{it} + \beta_3 Land\ Holding_{it} \\ & + \beta_4 Crop\ Intensity_{it} + \beta_5 Agricultural\ Credit_{it} + \beta_6 NSDPPC_{it} \\ & + \beta_7 Irrigation\ Intensity_{it} + \beta_8 Literacy_{it} + \beta_9 Growth\ on\ NSDPPC_{it} \\ & + \beta_{10} Time\ Trend_{it} + u_{it}, \end{aligned} \quad (1)$$

where i = cross-section unit 1 to 14 (for each state); t = time period, $t = 1$ to 31 (1982 to 2012); a is common intercept; and e_i represents unobserved state fixed effects, which are possibly correlated with other exogenous variables included. For example, agroecological factors (level of rainfall, number of crop-growing days, soil structure, and so forth) and sociocultural factors would be more state-specific and each of them would affect the level of farm machinery use (and tractor density). However, these factors are time-invariant and would not change much over a short time. The

⁶Such data on tractor use and other policy variables comparable across the 14 states are not available for earlier years (the 1960s and 1970s) for all of the states of India. Hence, we restrict our retrospective analysis here back to 1982.

effects of these variables are controlled by a state-specific intercept term in a fixed-effects panel model. β are other parameters, and u_{it} is the idiosyncratic error term.

The dependent variable TD_{it} is “tractor density” measured as the number of tractors in state i per 1,000 hectares of net sown crop area in year t . There are variations in geographical size and economic activity across the states of India. Thus, the tractor density variable is taken here for comparisons of tractor use across the states; it is free from scale and the size of the crop area in a state, as it is a normalized variable.

As noted above, the individual intercept e_i captures the effects of unobservable characteristics specific to a state; they are expected to vary across the states but not over the time, so they are time-invariant in nature—such as state-specific agroecological and agroinstitutional factors. In addition, given the federal structure of India, agricultural development activities are largely state mandated, with minimal intervention from the central government, and as a result public-sector agriculture and farm mechanization policies and programs, and public expenditures on agricultural activities, including rural credit and financial subsidies to farmers for purchasing farm machinery, vary greatly from one Indian state to another.⁷ At any moment in time, these state-specific programs and policies have huge impacts on the adoption and spread of agricultural technologies, including tractor and farm implement density across the states.⁸

Other variables in equation 1 consist of factors related to key policy, institutions, and agrostructural settings. A time trend variable ($t = 1$ for 1982 and 31 for 2012) is added separately to control for effects of time-variant factors that are common across all states. The variables used in this study (annual data series across the 14 states) were compiled using secondary sources of data that are available in various publications of government agencies in India. Some historical data points were obtained from the Indiastat data depository (www.indiastat.com/default.aspx). In Table 4.1 we

⁷State government rural credit policies on agricultural implements vary greatly across the states. In addition, states differ hugely from one another in terms of culture, qualities of public institutions, rural infrastructural development level, agrarian institutions, and local governance factors. For such policy modeling, the fixed-effects form of a panel is preferred more than a random-effects model (Greene 2003).

⁸We also used the Hausman test to check the appropriateness of a fixed-effects versus a random-effects model. The Hausman test chi-square value was 14.36 with a p -value of 0.026; hence, we could not accept the H_0 : the difference in the coefficients is not systematic. Hence, the Hausman test supports the fixed-effects model for the datasets we have used.

provide a summary of the variables used in the analysis, along with their corresponding sources of information.⁹

Table 4.1 Variables used in the study and their data sources

SN	Variable—indicators and specifications	Data sources and specification of variables by sources	Remarks
1	Tractor data by state ^a	Bhalla and Singh (2012); India, Ministry of Transport, Road, and Highway	This consists of registered tractors ^b on an annual basis from 1994 to 2012.
2	NSA (net sown area in hectares) and GCA (gross cropped area in hectares)	Various agricultural statistics publications of India, Ministry of Agriculture	
3	Real wage rate (in rupees per day) at current prices	Various issues of the labor inquiry report, published by India, Labor Bureau	
4	Agricultural labor number (or The number of people working in agriculture for wage employment)	Various census survey reports of the Indian government	Annual data series between two census points are constructed by interpolation using semi-logistic growth rate.
5	Average size of operational holding	Various agricultural census survey reports (5-yearly) conducted by India, Ministry of Agriculture	Annual data series are constructed by interpolation using semi-logistic growth rate.
6	Agricultural institutional credit	Yearly agricultural credit extended by scheduled commercial banks in a state. ^c Source: Annual publications of Reserve Bank of India.	
7	Gross irrigated area (in hectares) and net irrigated area (in hectares)	Various agricultural statistics publications of India, Ministry of Agriculture	Gross irrigated area is divided by net irrigated area in percentage term.
8	Net state domestic product per capita at current prices	Various issues of the economic survey of the Planning Commission of India	
9	Literacy rate (in %)	Various census survey reports of the Indian government. Annual data series are derived by interpolation using semi-logistic growth rate.	

Source: Various, as follows:

^a Tractor use by state from 1982 to 1994 is compiled by adjusting annual tractor sales statistics, taking the base of tractors available in each state in 1982 from Bhalla and Singh (2012). We have deducted 10% of the total tractor use annually to account for depreciation—tractors that would normally be discarded from service.

^b In India, most tractors (four-wheel tractors) used by farmers are registered at the respective state-level road and transportation agency. In addition, tractor-trading companies have to register tractors just before selling them to potential buyers (farmers). Without a registration, farmers cannot drive their tractors on the road, even a rural road.

^c The institutional credit used here does not include loans from cooperatives and regional rural banks, as those data are not publicly available consistently for all of the states over the 30-year time period used in the analysis.

⁹One of the variables, agricultural institutional credit, is constructed using annual agricultural credit disbursed by scheduled commercial banks in a state, as compiled by the Reserve Bank of India, which does not include credit flow from cooperatives or regional rural banks or credit from private financial companies attached to tractor companies. The total credit flow from all of these agencies for tractor purchases may be a better variable. However, data on the total agricultural credit from all of the private and public institutions are not publicly available in India consistently for all states for the 30 years selected here. In addition, rural households commonly secure loans from various sources to buy a tractor such as tractor traders' attached financing schemes and so forth. Thus data limitations prevent us from taking this variable. Future studies on the topic could disaggregate data at the district level, which could provide more information.

In Table 4.2 we describe each associated factor, its specification, its unit of measurement, and its expected association with tractor density.

Table 4.2 Variables used in the regression model estimated, their unit of measurement, and their expected relationship with tractor density

SN	Variable	Specification	Unit of measurement	Expected sign with tractor density variable
1	Labor density	Agricultural labor density (number of agricultural labor per hectare of net sown area)	Number of labor per hectare	Negative
2	Wage rate	Agricultural labor real wage rate	Rupees per day (in 2009–2010 const. prices)	Positive
3	Landholding	Average size of operational holding	In hectares	Positive
4	Cropping_ Intensity	Cropping intensity in one-year lag period ($t - 1$)	In percentage	Positive
5	Agricultural credit	Agricultural institutional credit (lending) in a state in a year (at const. prices of 2009–2010)	In 1,000 rupees per hectare	Positive
6	NSDPPC	Net state domestic product per capita (at constant prices in 2009-2010)	Rupees per capita per annum	Positive
7	Irrigation_ Intensity	Irrigation intensity in one-year lag period ($t - 1$)	In percentage	Positive
8	Literacy	Literacy rate in percentage	In percentage	Positive
9	Growth of NSDPPC	Annual growth in net state domestic product per capita (at constant prices in 2009-2010s)	In percentage	Positive
10	Time trend	Time trend (1–31) (1982 = 1 and 2012 = 31)	In number	?

Source: Authors.

Note: All variables are measured as annual average for each of the 14 states selected for the analysis.

Due to large differences in scale and level of progress across the 14 states, model 1 may suffer from inefficiency associated with heteroscedasticity and autocorrelation in the idiosyncratic error term u_{it} . We therefore estimate it employing Driscoll-Kraay standard errors (Cameren and Trivedi 2010; Hoechle 2007).

Results

We first conduct a simple analysis to assess correlations between tractor density (TD_{it}) and a set of factors, using the Pearson pairwise correlation method. Correlation coefficients are estimated at 10-year intervals (that is, in 1982, 1992, 2002, and 2012). While simple correlations do not control for other factors, they provide rough insight into how each factor may be related to the variation in tractor density and how such relations might have changed over time. The results are summarized in Table 4.3. By and large, the magnitude of the coefficients between tractor density and agrarian-related factors has declined over time. In addition, the decreasing magnitude of the correlation coefficients

between TD_{it} and the agrarian variables suggests the declining importance of farm-sector factors for tractor use growth in a place (state) over time, which is plausible due to the industrial and service sector growth in India over the years. The correlation coefficient between labor wage rate and tractor density was positive early on, but it weakened over time and is not significant at the 10 percent level in 2002 or 2012. Meanwhile, the correlation between tractor density and operational size turned from insignificant to significant in 2002. These patterns suggest the existence of some underlying dynamics between tractor density and other key factors, which are likely to be complex, and this is another reason we focus only on the associations rather than determinants of tractor density.

Table 4.3 Dynamics of correlation between tractor density and selected factors at different decadal points (1982, 1992, 2002, and 2012)

SN	Determinant	Correlation coefficient (<i>r</i>)			
		1982	1992	2002	2012
1	Tractor density x real wage rate (rupees/day)	0.60** (0.023)	0.662*** (0.009)	0.039 (0.892)	0.02 (0.935)
2	Tractor density x agricultural labor density (number agricultural laborers/hectare)	-0.38 (0.174)	-0.343 (0.234)	-0.463* (0.094)	-0.37 (0.199)
3	Tractor density x avg. operational holding (hectares)	0.438 (0.118)	0.446 (0.110)	0.654** (0.011)	0.639** (0.013)
4	Tractor density x intensity of irrigation (%)	0.714*** (0.004)	0.867*** (0.0001)	0.669*** (0.009)	0.468* (0.092)
5	Tractor density x cropping intensity (%)	0.794*** (0.0007)	0.771*** (0.001)	0.637** (0.014)	0.594** (0.026)
6	Tractor density x scheduled commercial bank credit (rupees/hectare)	0.382 (0.178)	0.343 (0.229)	0.256 (0.377)	0.053 (0.857)
7	Tractor density x net state domestic product at current price (NSDP in thousands of Rs.per capita)	0.702*** (0.005)	0.621** (0.017)	0.509*** (0.063)	0.345 (0.227)
8	Tractor density x growth in NSDP (%)	-0.541** (0.045)	-0.117 (0.691)	-0.113 (0.701)	-0.3223 (0.261)
9	Tractor density x literacy rate (%)	-0.178 (0.195)	-0.012 (0.968)	-0.057 (0.847)	-0.133 (0.650)

Source: Authors' estimations.

Note: The correlation analysis is done using the Pearson pairwise correlation method using Stata software.

Figures in parentheses represent the p-value of parameter estimates. NSDP = net state domestic product.

*** = significant at the 1% level; ** = significant at the 5% level; * = significant at the 10% level.

We summarize the results of the fixed-effects panel model 1 in Table 4.4. We show the marginal effects (coefficients) of independent variables in the left-hand column, followed by average elasticity values of each factor in the right-hand column. Elasticity shows a percentage change in the tractor density variable associated with a percentage change in an independent variable, which allows us to obtain a unit-free interpretation of the degree of association.

Table 4.4 Factors associated with tractor density across states, 1982 to 2012

<i>Independent variable</i>	Marginal effect (1982–2012)	Elasticity value at sample mean
Intercept (average of all)	-417 ^{***}	—
Agricultural labor density (number of laborers/hectare)	-7.63 ^{NS}	-0.27 ^{NS}
Real wage rate (rupees/day/per person)	-0.19 ^{***}	-0.85 ^{***}
Average size of operational holding (hectares)	22.92 ^{***}	1.87 ^{***}
Cropping intensity _(t-1) (%)	0.35 ^{***}	2.17 ^{***}
Agricultural credit (1,000 rupees/hectare)	-0.064 ^{NS}	-0.028 ^{NS}
Net state domestic product per capita (NSDP PC) in 1,000 rupees	0.42 ^{***}	0.60 ^{***}
Irrigation intensity _(t-1) (%)	-0.13 ^{**}	-0.79 ^{***}
Literacy rate (in %)	0.015 ^{NS}	0.042 ^{NS}
Annual growth rate of NSDP PC (in %)	-0.1 ^{***}	-0.03
Time trend (1 to 31)	1.75 ^{***}	18.00 ^{***}
R-squared (within)	0.68	
F statistic	316 ^{***}	
Total number of observations = 420		
Total number of years = 31 (1982–2012)		
Total states (panel) = 14		

Source: Authors' estimations.

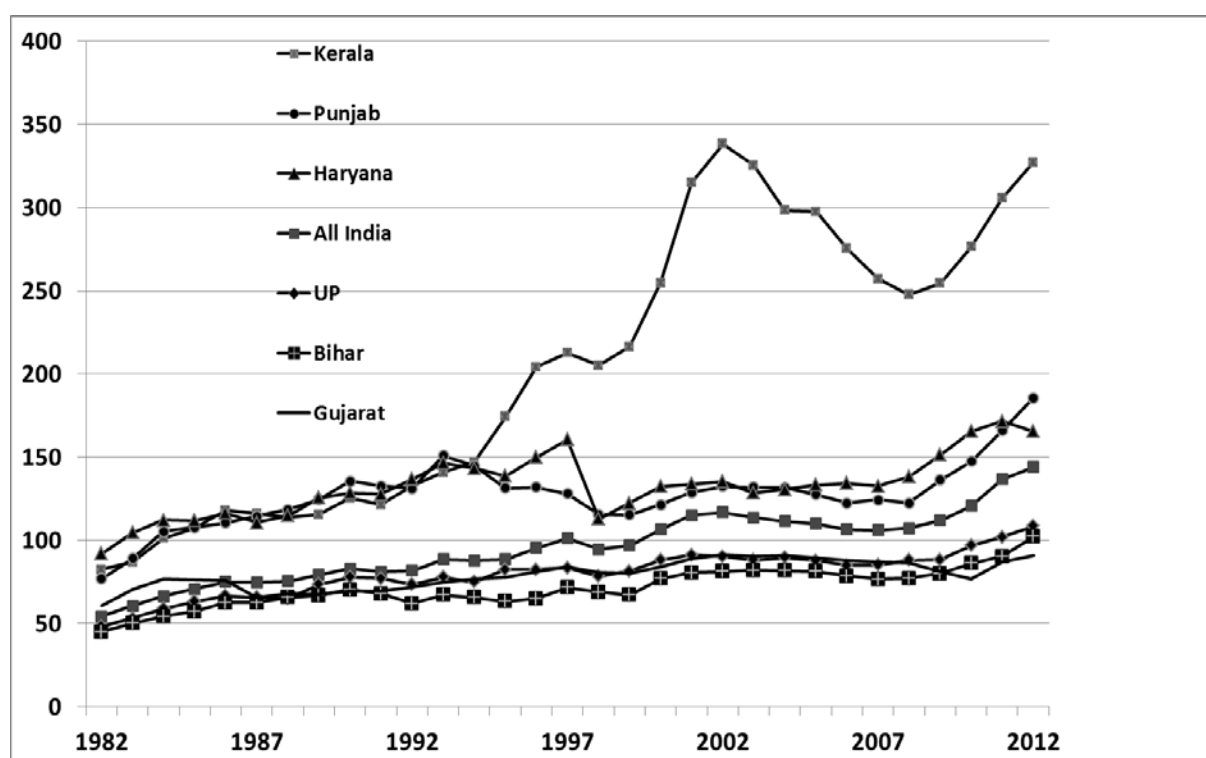
Note: The regression was estimated as a fixed-effects panel model with Driscoll-Kraay standard error, which allows for correction of both heteroscedasticity and autocorrelation (details in Hoechle 2007). The model is estimated with the maximum autoregressive lag of 3. The average elasticity value is estimated after running the model. The elasticity value reported is the average of a series of elasticity values generated at the sample mean of the dependent variable and each point of the independent variables by Stata software. The signs ^{***}, ^{**}, and ^{*} indicate significance at the 1%, 5%, and 10% levels, respectively. The sign NS means not significant at the 10% level.

NSDP PC = Net State Domestic Product Per Capita

In Table 4.4, the sign of “agricultural labor density”—measured by number of agricultural laborers per hectare of NSA—is negative suggesting that tractors have spread more in states with lower levels of labor density, *ceteris paribus*; however, the estimated coefficient is not significant at the 10 percent level (p -value = 0.13). This result suggests that tractor density has grown relatively independently of changes in agricultural labor density.

Importantly, the association between the agricultural real wage rate and tractor density across India, conditional on other factors, is negative and statistically significant at the 1 percent level (Table 4.4). This suggests that during the past 30 years, tractors have spread more speedily across states with a lower wage rate than the group of states with a higher wage rate. This is partly driven by the tractor having spread profoundly in states such as Uttar Pradesh, Andhra Pradesh, and Maharashtra, where wages have been lower or have risen more slowly¹⁰ than in India as a whole (Figure 4.1).

Figure 4.1 Variation in real agricultural wage rate across selected states of India from 1982 to 2012 (unit: rupees/day, in constant prices of 2009–2010)



Source: Authors compiled from various publications and statistical reports on labor wage rates published by Government of India (various years).

The result for the labor wage rate in Table 4.4 is contrary to our a priori assumption (Table 4.2). Unlike the findings of past studies that have underscored the importance of a rising labor wage rate for the spread and uptake of tractors in South Asia (Binswanger 1978, 1986; Farrington 1986;

¹⁰The real wage rate of agricultural labor was almost constant in these states over time; it has started to increase at a faster pace in Andhra Pradesh only after 2005 due to the development of farming as well as nonfarm activities in the state.

Jayasuriya, Te, and Herdt 1986), our results suggest that the labor wage paradigm alone may not fully explain the patterns of tractor diffusion in India for the past three decades.¹¹

Previous studies suggested that it was likely infeasible for the average farmer in India and other countries in South Asia during the 1980s and 1990s to replace labor with tractors unless wage levels increased substantially (Binswanger 1978; Jayasuriya, Te, and Herdt 1986). Despite such predictions, farmers in India and in South Asia have invested heavily in farm tractors over the past 30 years, even in places with relatively lower rural wage levels, as our results indicate. Whereas the unavailability of consistent data prevents us from conducting a formal analysis, the observed growth in tractor use under relatively low real wage levels may be due to various factors. First, growth in the demand for tractors might have exceeded past predictions because tractors have been used more and more for functions other than plowing, such as for transporting nonfarm goods or for powering other machinery in the slack season of farming. Second, rather than labor costs, there might have been significant rises in the opportunity costs of using animal draft power for the plowing and threshing of crops, activities that entail not only labor costs but also various other costs of capital and feed (Lawrence and Pearson 2002). Tractors in South Asia might have been more animal-saving than labor-saving, by mostly taking over operations that had been primarily conducted by animals. Third, an institutional innovation leading to growth in the market for hiring-out tractors might have made tractor ownership economically viable, despite India's agricultural sector continuing to be dominated by relatively small farms.

The coefficient of the average size of operational holding (in hectares) is positive and statistically significant at the 1 percent level. This result is consistent with our prior assumption and the findings of previous studies (Binswanger 1986; Singh 2015). Its elasticity value is 1.87 percent, which is fairly very high and means that a 1 percent higher average size of operational holding is associated with 1.87 percent higher tractor density.

¹¹We also ran a simple form of fixed-effects model keeping only two basic variables—"labor wage" and "time trend"—in explaining the tractor density function, where the real wage variable was also negative and statistically significant at the 1 percent level. Thus, the coefficient of "labor wage" is stable and robust across the models.

The coefficient of the cropping intensity variable (lag of one period) is positive and statistically significant at the 1 percent level. Its elasticity value is the highest (2.17 percent) among the determinants selected in equation 1. This is also a plausible result given that tractors can often speed up land preparation and the transportation of harvests, which may make increased production frequency profitable. Simultaneously, areas where crop intensity has been high or rising may benefit from increased tractor ownership or use.

Likewise, the coefficient of the variable “net state domestic product per capita” (NSDP_PC) is positive on the variation of tractor density across the states, and its estimate is significant at the 1 percent level, with an elasticity of 0.6 percent. The sign of the variable NSDP_PC is consistent with our prior assumption. Increased income per capita can lead to rising farmer demand for durable assets such as tractors and other farm machinery, either directly through increased incomes or indirectly through increased demand for agricultural products, which induces more intensive farming operations. The result here suggests that over time, tractor density in India has increased more in states with a higher and faster-growing per capita income, *ceteris paribus*. This also indicates the importance of income and wealth effects in the differential pace of diffusion of a technology such as a tractor (a durable asset) across the states. Moreover, the sign of annual growth rate of NSDP per capita is negative, suggesting that farmers do not buy tractors based only on the growth of income from the previous year, but based on the long-term increase in the level of their income (Table 4.4).

The sign of the coefficient of the “agricultural institutional credit” variable is negative, but it is statistically insignificant. Although institutional credit and rural financing have been considered important government policy instruments for providing incentives to farmers to purchase tractors and other farm machinery in India (Sarkar 2013; Ghosh 2010), the result in this study does not provide strong support for that argument. The insignificant effect of institutional credit may be due to the limited penetration of banks and institutional financing in rural India. There are often complex administrative processes for financing loans to farmers, as well as high transaction costs to an ordinary farmer in availing him- or herself of low-cost institutional financing for tractors and related farm machinery. This is also consistent with the findings elsewhere that personal savings, rather than

loans or credit, often constitute the primary financial source for tractor purchases in developing countries (Takeshima et al. 2015).¹²

The sign of the coefficient of irrigation intensity (one lag period) is negative (-0.13), with an elasticity value of -0.79 , and also statistically significant at the 1 percent level. Past studies have reported that tractors were adopted more in areas with secure irrigation facilities (Binswanger 1978, 1986; Sarkar 2013; Singh 2015). This could be the case when one examines tractor adoption in farming situations in the states of Punjab and Haryana, where both tractor density and irrigation intensity are at very high levels compared with other states of India. The result from pan-India coverage in Table 4.4 does not provide support for this case—that is, when we add the many states together. Rather, our finding suggests that diffusion of the tractor (tractor density) in India is more widespread, including an increasing pace of tractor penetration in dry regions of India in recent days, than what was observed in the early phase of tractor diffusion in the 1970s and early 1980s, when tractors in India had already been purchased largely by farmers in irrigated Green Revolution pockets in the North.

The coefficient of “literacy rate” (percentage of rural literacy in a state) on the variation of tractor density is positive, albeit insignificant. This may reflect the fact that education matters only in relatively modern farming systems (Pudasaini 1983), and that at an early stage of mechanization, farming systems in India may not have quite reached that level yet. At the same time, increased incomes from tractor investments might not have been sufficient to induce a significant investment in the education of household members. Nevertheless, this result suggests that tractor ownership may spread regardless of the educational level of the population.

The coefficient of the variable “time trend” is positive (1.75) and with a very high elasticity value (17.5 percent), which indicates a very steep growth trend of tractor density across India. In the regression model estimated, the time trend variable ($1 = 1982$ to $31 = 2012$) controls for other nationwide factors that linearly affect tractor density levels over time. Those may include

¹²In India, state governments provide several kinds of financial subsidy for farm machinery tools and attachments, but historically, the government subsidies for tractors have been almost negligible—less than 10 percent in most states. In addition, India’s tractor industry has functioned as an unregulated industry at least since 1990 (Singh 2015). Likewise, unlike the case of other machinery attachments, farmers in India do not purchase a tractor just because of the government subsidy (authors’ field observation).

improvements in general technologies at the international or India level, including manufacturing technologies for tractors or implements or production technologies that universally raise tractor use efficiency, among others.

Based on the F statistic and associated p -value, associations between tractor densities and factors included in the model are jointly significant. The adjusted R -square of 0.68 is also fairly high, suggesting that the model exhibits significant explanatory power, considering the nature of the aggregate scale of variables included and the pan-India scale of coverage of analysis.

5. CONCLUSIONS AND IMPLICATIONS

The level and process of penetration of four-wheel farm tractors across India in the last four to five decades is a fascinating story in the literature of development economics, with profound implications for agricultural and rural development programs in many other developing countries in Asia and Africa. In the 1970s and 1980s, during the early phases of diffusion of Green Revolution technologies in South Asia, serious doubts and reservations were raised about the economic viability of farm tractor use in South Asian countries, including India. In fact, in the 1970s and 1980s, early on in the diffusion of tractor technology in India, several studies reported that the farm tractor would not be an economically viable technology for Bangladesh, India, Nepal, the Philippines, and several other countries unless the rural labor wage rose to substantially higher levels (Jayasuriya, Te, and Herdt 1986; Binswanger 1978, 1986).

Despite the relatively low-rural-wage-rate economy, the use of tractors (particularly four-wheel tractors) has spread widely across several states of India in the last 30 to 40 years. This study conducted a simple assessment of growth in tractor use and ownership in India, through international perspectives, qualitative assessments of tractor diffusion across states, and a state-level panel data analysis of the factors associated with tractor density between 1982 and 2012.

Our assessment suggests that the boom in tractor use in India is somewhat unique compared with the United States or Japan, in that such growth has occurred at relatively low wage rates and while a substantial majority of the workforce has remained in the agricultural sector. The growth in tractor densities has been led in part by the considerable growth of domestic manufacturing industries, which is characterized by competition among a large number of manufacturers. The spread of tractors across the states of India during the past 30 years is positively associated with cropping intensity, size of operational holding, and per capita income in a state. We find that tractors have spread both in irrigated (favorable) regions and in rainfed and dryland (unfavorable) regions of India. Likewise, we find that institutional low-cost credit is not a binding factor for the spread of tractors across India. This could be due to flexible financing schemes made available to farmers by both private and public institutions for purchasing tractors via installment payments.

The results imply that a relatively low rural labor wage rate may not be a binding factor for the viable use of tractors by smallholding farmers in India and in South Asia, contrary to the findings and suggestions in many earlier studies (see Jayasuriya, Te, and Herdt 1986; and Binswanger 1978, 1986). Although a formal analysis is precluded due to the unavailability of consistent data, these findings could be due to several factors—growth in the multipurposing of tractors, changes in relative costs between tractor use and animal traction use rather than changes in labor wages, and institutional innovations in hiring services. Such factors were not predicted well in the aforementioned earlier literature but may have enabled growth in four-wheel tractor use in the smallholder-dominated sector. Future studies should investigate these hypotheses more formally. Nevertheless, the findings imply that smallholding farmers in India and in other developing regions can use tractors and other farm machinery effectively even in economies characterized by low rural wages.

Lastly, the significance of state-level fixed effects suggests that state-specific factors and state-level institutions play an important role in the different levels of intensity of tractor use across the states of India. Such factors may include access to rural roads and infrastructure, presence of a rural market network, and agroecological factors like soil fertility and soil quality, which may also provide incentives to farmers to use tractors more intensively. We could not include these variables in our study because data are not available consistently for all of the states on an annual basis for the 30 years of time selected for the analysis. This is a limitation of our analysis since such factors could have changed considerably over the study period. Authors of future studies on the topic may choose to address this issue by focusing analysis by grouping states into four to five groups and running the model on a few states at a time. Considering the several unsettled issues regarding tractor and farm machinery use by smallholding farmers in developing countries, the study findings are expected to contribute to the literature and in particular to agricultural rural development studies in South Asia and globally.

REFERENCES

- Agarwal, B. 1984. "Tractors, Tube Wells, and Cropping Intensity in the Indian Punjab." *Journal of Developmental Studies* 20 (4): 290–302.
- Aurora, G. S., and W. Morehouse. 1972. "Dilemma of Technological Choice: The Case of the Small Tractor." *Economic and Political Weekly* 7 (31–33): 1633–1644.
- Barker, R., R. W. Herdt, and B. Rose. 1985. *The Rice Economy of Asia*. Washington, DC.: Resources for the Future.
- Bhalla, G. S., and G. Singh. 2012. *Economic Liberalization and Indian Agriculture: A District-Level Study*. New Delhi: Sage.
- Bhattarai, M., and S. Pandey. 1997. "The Economics of Wheat Production in the Rice–Wheat System in Nepal." In *Applications of Systems Approaches at the Farm and Regional Levels*, edited by P. S. Teng, M. J. Kropff, H. F. M. ten Berge, J. B. Dent, F. P. Lansigan, and H. H. van Laar, 45–52. Dordrecht, Netherlands: Kluwer Academic.
- Biggs, S. and Justice S. 2015. *Rural and Agricultural Mechanization: A History of the Spread of Small Engines in Selected Asian Countries*. IFPRI Discussion Paper 01443. Available at <http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/129214>
- Binswanger, H. 1978. *The Economics of Tractors in South Asia: An Analytical Review*. New York: Agricultural Development Council; Hyderabad: International Crops Research Institute for the Semi-Arid Tropics.
- . 1986. "Agricultural Mechanization: A Comparative Historical Perspective." *World Bank Research Observer* 1 (1): 27–56.
- Cameren, A. C., and P. K. Trivedi. 2010. *Microeconometrics Using Stata*. Stata Press, USA.
- CSAM (Centre for Sustainable Agricultural Mechanization). 2014. "Country Pages." Accessed June 2, 2017. http://un-csam.org/cp_index.htm.
- Department of Agriculture Cooperation & Farmers' Welfare (DAC&FW). 2016. All India Reports on Inputs Survey. Ministry of Agriculture Cooperation & Farmers' Welfare. New Delhi. India.
- Diao, X., J. Silver, and H. Takeshima. 2016. *Agricultural Mechanization and Agricultural Transformation*. IFPRI Discussion Paper 01527. Washington, DC: International Food Policy Research Institute.
- Economic Planning Agency. 1962. *Keizai Bunseki*. Economic Planning Agency, Government of Japan.
- FAO (Food and Agriculture Agency of the United Nations). 2013. *Mechanization for Rural Development: A Review of Patterns and Progress from Around the World*. In *Integrated Crop Management*, vol. 20-2013. Rome: FAO. Accessed June 20, 2016. www.fao.org/docrep/018/i3259e/i3259e.pdf.
- . 2017. FAOSTAT. Rome: FAO.
- Farrington, J. 1986. "Mechanization Policy and the Impact of Tractors in South Asia: A Review." In *Small Farm Equipment for Developing Countries. Proceedings of the International Conference on Small Farm Equipment for Developing Countries: Past Experiences and Future Priorities, 2–6 September 1985*. Manila: International Rice Research Institute.
- Foster, A. D., and M. R. Rosenzweig. 2011. *Are Indian farms too small? Mechanization, agency costs, and farm efficiency*. Mimeo. Economic Growth Center, Yale University New Haven CT.
- Ghosh, B. K. 2010. "Determinants of Farm Mechanisation in Modern Agriculture: A Case Study of Burdwan Districts of West Bengal." *International Journal of Agricultural Research* 5 (12): 1107–1115.
- Grant Thornton India. 2015. *Transforming Agriculture through Mechanisation: A Knowledge Paper on Indian Farm Equipment Sector*. New Delhi.
- Greene, W. H. 2003. *Econometric Analysis*. 5th ed. Upper Saddle River, NJ, USA: Prentice Hall.
- Harrington R. E. 1975. Agricultural Engineering and productivity. In *Annual Proceedings of American Association for the Advantage of Science*. January 30.
- Hayami, Y., and V. W. Ruttan. 1985. *Agricultural Development: An International Perspective*. Baltimore and London: Johns Hopkins University Press.

- Hoechle, D. 2007. "Robust Standard Errors for Panel Regressions with Cross-Sectional Dependence." *Stata Journal* 7 (3): 281–312.
- ICIC Securities 2015. Farm Mechanization: Way forward for India Agriculture. Sectoral Thematic paper of ICIC Direct. Available at content.icicidirect.com/mailimages/IDirect_FarmMechanisation_ThematicReport.pdf
- Jain Ramesh C. 2006. Tractor Industry in India – Present and Future. Paper presented at roundtable forum for regional agricultural machinery manufacturers and distributors associations, Seoul, Korea, 22-23 Nov. 2006.
- Japan, Ministry of Agriculture, Forestry, and Fisheries. 2017. *Statistics of Agriculture, Forestry, and Fisheries*.
- Jayasuriya, S. K., A. Te, and R. W. Herdt. 1986. "Mechanisation and Cropping Intensification: Economics of Machinery Use in Low Wage Economies." *Journal of Development Studies* 22 (2): 327– 335.
- Joppich, W. G. 1957. "Some Economic Aspects of Farm Mechanization in India." *Economic Weekly*, August 24, pp. 1095–1101. www.epw.in/system/files/pdf/1957_9/33-34/some_economic_aspects_of_farm_mechanization_in_india.pdf.
- Kishor, V., and R. S. Mor. 2001. *Economics of Tractors*. Occasional Paper 18. Mumbai: National Bank for Agriculture and Rural Development. <http://krishikosh.egranth.ac.in/handle/1/2029538?mode=full>.
- Kjeldsen-Kragh, S. 2007. *The Role of Agriculture in Economic Development: The Lessons of History*. Copenhagen Business School Press.
- Lawrence, P. R., and R. A. Pearson. 2002. "Use of Draught Animal Power on Small Mixed Farms in Asia." *Agricultural Systems* 71 (1): 99–110.
- Maggu, A. 1982. "Tractorization in India: Dispelling Some Myths." *Vikalpa* 7 (1): 45–52.
- Mohan C. 1986. "Establishment of the Tractor Industry in India." In *Small Farm Equipment for Developing Countries: Proceedings of the International Conference on Small Farm Equipment for Developing Countries: Past Experiences and Future Priorities 2–6 September 1985*. Manila: International Rice Research Institute.
- Mottaleb, K. A., T. J. Krupnik, and O. Erenstein. 2016. "Factors Associated with Small-Scale Agricultural Machinery Adoption in Bangladesh: Census Findings." *Journal of Rural Studies* 46: 155–168.
- Nagaraj, R. 2003. "Industrial Policy and Performance since 1980: Which Way Now?" *Economic and Political Weekly* 38 (35): 3707–3715.
- Olmstead, A. L., and P. W. Rhode. 2001. "Reshaping the Landscape: The Impact and Diffusion of the Tractor in American Agriculture, 1910–1960." *Journal of Economic History* 61 (3): 663–698.
- Pingali, P. 2007. "Agricultural Mechanization: Adoption Patterns and Economic Impact." In *Handbook of Agricultural Economics*, vol. 3, edited by R. Evenson and P. Pingali. Amsterdam: North-Holland.
- Pray, C. E., and L. Nagarajan. 2014. "The Transformation of the Indian Agricultural Input Industry: Has It Increased Agricultural R&D?" *Agricultural Economics* 45 (S1): 145–156.
- Pudasaini, S. P. 1983. "The Effects of Education in Agriculture: Evidence from Nepal." *American Journal of Agricultural Economics* 65 (3): 509–515.
- Rao, C. H. 1972. "Farm Mechanisation in a Labour-Abundant Economy." *Economic and Political Weekly* 7: 393–395.
- Sarkar, A. 2013. "Tractor Production and Sales in India, 1989–2009." *Review of Agrarian Studies* 3 (1): 55–72.
- Singh, G. 2015. "Agricultural Mechanization Development in India." *Indian Journal of Agricultural Economics* 70 (1): 64–82.
- Singh, G., and W. Chancellor. 1975. "Energy Inputs and Agricultural Production under Various Regimes of Mechanization in Northern India." *Transactions of the ASAE* 18 (2): 252–259.
- Steckel, R. H., and W. J. White. 2012. *Engines of Growth: Farm Tractors and Twentieth-Century US Economic Welfare*. NBER Working Paper 17879. Cambridge, MA, USA: National Bureau of Economic Research.
- Takeshima, H. 2017a. "Custom-Hired Tractor Services and Returns to Scale in Smallholder Agriculture: A Production Function Approach." *Agricultural Economics* 48 (3): 363–372.

- . 2017b. “Transforming West African Agriculture through the Development of Mechanization: What Public Policies?” Keynote address at a workshop organized by the Syngenta Foundation for Sustainable Agriculture and the Foundation for World Agriculture and Rurality, Dakar, February 1. www.syngentafoundation.org/file/4321/download?token=3rjBLsOs.
- Takeshima, H., E. Edeh, A. Lawal, and M. Isiaka. 2015. “Characteristics of Private-Sector Tractor Service Provisions: Insights from Nigeria.” *Developing Economies* 53 (3): 188–217.
- Ugwuishiwu, B. O., and A. P. Onwualu. 2009. “Sustainability and Cost of Agricultural Mechanization in Nigeria as Affected by Macro-Economic Policies.” *Journal of Agricultural Engineering and Technology* 17 (2): 44–56.
- University of Arkansas. 2013. *Arkansas Rice Production Handbook—MP192*. Little Rock, AR, USA: University of Arkansas. Accessed July 17, 2017. www.uaex.edu/publications/MP-192.aspx.
- Wang, X., F. Yamauchi, and J. Huang. 2016. “Rising Wages, Mechanization, and the Substitution between Capital and Labor: Evidence from Small Scale Farm System in China.” *Agricultural Economics* 47 (3): 309–317.
- Wiggins, S., and S. Keats. 2015. “Rural Wages in Asia.” Paper presented at the Triennial Meeting of the International Conference of Agricultural Economists, Milan, August 8–14.
- World Bank. 2017. World Development Indicators. Accessed August 1, 2017. <http://data.worldbank.org/data-catalog/world-development-indicators>.
- Zhang, X., J. Yang, and T. Reardon. 2015. *Mechanization Outsourcing Clusters and Division of Labor in Chinese Agriculture*. IFPRI Discussion Paper 01415. Washington, DC: International Food Policy Research Institute.

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