Center for
Development Research
University of Bonn

ZEF-Discussion Papers on
Development Policy No. 297

Ashok Gulati and Ritika Juneja

Farm Mechanization in Indian Agriculture with Focus on Tractors

Bonn, September 2020

Ashok Gulati and Ritika Juneja, Farm Mechanization in Indian Agriculture with Focus on Tractors, ZEF – Discussion Papers on Development Policy No. 297, Center for Development Research, Bonn, September 2020, pp. 30.

ISSN: 1436-9931

Published by:
Zentrum für Entwicklungsforschung (ZEF)
Center for Development Research
Genscherallee 3
D – 53113 Bonn
Germany
Phone: +49-228-73-1861
Fax: +49-228-73-1869
E-Mail: zef@uni-bonn.de
www.zef.de

The authors:
Ashok Gulati, Indian Council for Research on International Economic Relations (ICRIER). Contact: agulati115@gmail.com; agulati@icrier.res.in

Ritika Juneja, Indian Council for Research on International Economic Relations (ICRIER). Contact: ritikajuneja93@gmail.com; rjuneja@icrier.res.in

Acknowledgements

The authors would like to sincerely thank and appreciate Abhinav Jain’s contribution to this study. Abhinav was initially a part of the team when data collation and processing were being undertaken. But he had to leave mid-stream for his higher studies and, therefore, could not be with us for the analysis and writing of this discussion paper. We would also like to thank the Tractor and Mechanization Association (TMA) for providing us with relevant data along with useful insights that helped us immensely to understand and analyze the dynamics of tractor use in Indian agriculture. Finally, we would also like to express our deep appreciation and gratitude to the “Program of Accompanying Research for Agricultural Innovation” (PARI) and the German Federal Ministry of Economic Cooperation and Development (BMZ) for funding the study.

Abstract

Indian agriculture is dominated by smallholders. With an average holding size of just 1.08 hectares (ha) (in 2015-16), and 86 percent of holdings being of less than 2 ha in size, Indian agriculture transformed the country from functioning 'ship-to-mouth' during the mid-1960s to being a net exporter of agri-produce today. This would not have been possible without the onset of the Green Revolution post-1965, which resulted in increased foodgrain production and productivity. Among various inputs such as seeds, irrigation and fertilizers, the productivity of farms also depends greatly on the availability and judicious use of farm power by the farmers. Between the mid-20th century and 2013-14, India witnessed a tremendous shift away from traditional agriculture processes to mechanized processes. Today, 88 percent of the total farm power comes from tractors, diesel engine pump-sets, electric pump-sets and power tillers (2013-14). Additionally, India has emerged as the largest manufacturer of tractors in the world, followed by the USA and China. But how has farm mechanization, especially the use of tractors, evolved in India over time? What were the key drivers of the demand for tractors? And how efficiently are the tractors being used in terms of usage by number of hours/year? Given the high cost of tractors, it is also interesting to see how far they have penetrated the small and marginal holdings, i.e., the issues of inclusiveness, financial viability and sustainability. These are some of the key questions that are addressed in this study.

Our analysis shows that farm mechanization in India, especially the use of tractors, has made commendable progress. With major policy changes, entry of private farm machinery manufacturing companies and foreign collaborations, farm power availability increased from 0.25 kilowatt per hectare (kW/ha) in 1951 to 2.02 kW/ha in 2017. Furthermore, the contribution of mechanized sources to farm power increased from some 3 percent in 1951 to 88 percent in 2013-14, replacing human and draught power. In addition, the production of tractors increased significantly from a meager 880 units in 1951 to about 900,000 units in 2019. This has transformed India from being a net importer of tractors through the 1960s and 1970s to being an exporter of tractors, exporting some 92,000 units in 2019. In terms of inclusiveness, although larger farms are more mechanized, the Input Census data (2011-12) reveals that even in the category of small and marginal holdings (less than 2 ha), an average of roughly 44 percent of farmers use farm machinery (e.g., tractors, diesel engine pump sets, electric pump sets and power tillers). This is a good achievement, but further improvements are always possible and major attempts in this direction are already underway with heavy policy support through Custom Hiring Centres (CHCs). However, the fact that farm machinery is expensive also raises concerns over whether it is financially viable and sustainable to own and use on smallholder farms. It is therefore important to look at unfolding innovations providing farm machinery services through 'CHCs' and 'Uberization' models. These innovations make farm machinery and equipments perfectly divisible as a service to all classes of farmers at the doorstep at affordable cost on a ‘pay per use’ basis. This seems to be the future of farm machinery usage in India, if it is developed as a sustainable business model with due support of policy and finance.

Keywords: Farm Mechanization, Tractors, Custom Hiring Centres, Uberization

JEL codes: Q1, Q12, Q15, O31

Executive Summary

In a smallholder agriculture like India's, it remains a challenge to raise productivity and increase farmers' incomes through agri-operations. It requires continuous upgrading of technology and innovations for easy access to modern inputs at reasonable costs. Farm mechanization in agriculture is one such catalytic instrument that can facilitate higher output and productivity by converting many erstwhile subsistence farmers working on small holdings using human and animal power into vibrant commercial farmers using mechanized sources of farm power. This can ensure timely farm operations, reduce losses and improve agricultural incomes, which may further incentivize farmers to increase cropping intensity and diversify in agriculture. Thus, farm power is an essential input in agriculture for carrying out different field operations efficiently. This study primarily focuses on the evolution of farm mechanization, with the prime focus on tractors, its efficiency in usage, its reach to small and marginal holders, and its financial viability and sustainability. It also tests the hypothesis that certain key drivers influence the demand for tractors using appropriate econometric tools, and highlights the innovations in the institutional set-up for use of tractors in a manner that can help agriculture in general and smallholders in particular.

The evolution of tractor use in Indian agriculture can be traced back to before the country's independence and can broadly be classified into three phases – (1) Before the Green Revolution; (2) Post Green Revolution; and (3) After the tractor industry was fully de-licensed and freed from any controls. After the introduction of steam tractors in 1914 for the reclamation of wasteland and the eradication of 'Kans'[1], in 1947, the Central Tractor Organization (CTO) was set up to promote the use of tractors in agriculture. The beginning of the domestic production of tractors in India is however marked by the entry of five manufacturing companies namely Eicher Tractors Ltd.; Tractors and Farm Equipment Ltd. (TAFE); Gujarat Tractors Ltd.; Escorts Ltd.; and Mahindra & Mahindra Ltd. using foreign collaborations. As a result, domestic production of tractors rose from a meager 880 units in 1961-62 to 5,000 units in 1965-66. However, the real breakthrough came with the onset of the Green Revolution that created demand for farm machinery, both for groundwater irrigation through pump sets (electric and diesel) and tractors for several field operations, leading to major transformation from human and draught power to mechanized farm power for better performance and higher productivity. To meet growing needs, the Government facilitated additional entrepreneurs to begin farm machinery manufacturing in the country. Another watershed event in the evolution of the tractor industry was the total de-licensing of the tractor manufacturing in 1991. As a result, both the production and competition in the industry increased, and in the financial year (FY) 2018-19, India produced almost

[1] The dictionary meaning of the term 'Kans' is an Indian grass of the genus *Saccharum,* used in some areas for fodder, thatching, etc., and being a troublesome weed in other areas.

900,000 tractors. These figures are indicative of the growing importance of the Indian tractor industry, which went from just 880 units in 1961-62 to about 900,000 units in 2018-19 and thereby became the largest tractor manufacturer in the world. The study also estimates the drivers of demand for tractors and further examines farm mechanization from the angles of efficiency in its usage (i.e., hours/year), inclusiveness in terms of its reach to small and marginal holders, and its financial viability and thus economic sustainability. Judged on these three parameters, it appears that agricultural mechanization in India is constrained by the increasing fragmentation of land that puts a damper on the 'economies of scale'. Most micro-studies reveal that tractors are used for 500-600 hours per year against an economic annual norm of 1,000 hours. This indicates an over-capitalization of farms. On inclusiveness, higher costs of tractors, compared to non-mechanized farming, make it difficult for smallholders to purchase the machines. This makes the ownership model inefficient, non-inclusive, and financially unsustainable. A possible way forward to avoid these pitfalls is the unfolding innovation of "Uberization" and Custom Hiring Centres (CHCs) for Farm Machinery, i.e., extending farm mechanization as a service on demand based on a 'pay per use' model. This can ensure easy accessibility of cutting-edge technology suited to the crop and soil profile, even for smallholders. Both the national and state governments are already encouraging these CHCs through large subsidization programs, but whether such policy leads to an efficient use of farm machinery in an economically viable manner, including services being rendered to smallholders, is yet to be seen.

Table of Content

List of Figures and Tables

List of Abbreviations

CHCs	Custom Hiring Centres
CPI – AL	Consumer Price Index - Agricultural Labour
CTO	Central Tractor Organization
FaaS	Farming as a Service
FertC	Fertiliser Consumption per Hectare
FMTTIs	Farm Machinery Training and Testing Institutes
FY	Financial Year
GIAR	Gross Irrigation Ratio
Ha	Hectare
hp	Horsepower
ICAR	Indian Council of Agricultural Research
Kms	Kilometers
KVKs	Krishi Vigyan Kendras
Kw/ha	Kilo Watt per Hectare
MIDH	Mission for Integrated Development of Horticulture
M & M	Mahindra & Mahindra
NIAR	Net Irrigation Ratio
NMAET	National Mission on Agricultural Extension & Technology
NMOOP	National Mission on Oilseeds and Oil Palm
OLS	Ordinary Least Square
PPP	Public Private Partnership
RD	Replacement Demand
RKVY	Rashtriya Krishi Vikas Yojana
INR/hour	Indian Rupees per Hour
SMAM	Sub-Mission on Agricultural Mechanization
TAFE	Tractors and Farm Equipment Ltd
TMA	Tractor and mechanization Association
WPI	Wholesale Price Index

1. Introduction

Indian agriculture is predominantly characterized as smallholder agriculture with the average farm holding size showing a continuous decrease from 2.28 hectares in 1970-71 to 1.08 hectares in 2015-16 (Government of India, 2015-16). Overall, 86 percent of total holdings cover less than 2 ha each, i.e. they are categorized as small and marginal, accounting for about 47 percent of all agricultural land in 2015-16, the latest year for which official data is available (Government of India, 2015-16). With such small holding size, large sized, high-cost farm machinery like tractors does not seem to be an appropriate choice. At the same time, India has emerged as the largest producer of tractors in the world, followed by the USA and China, producing about 900,000 tractors and exporting more than 92,000 tractors during the Financial Year (FY) 2019 (April 2018-March 2019) (Tractor and Mechanization Association, 2019). Not only this, India has also experienced a significant shift away from human and draught animal power in farming towards mechanical and motorized power. According to available statistics, in 1951, about 97.4 percent of farm power was coming from human and draught animals, but in 2013-14 their contribution had reduced to about 12 percent while that of mechanical and electrical sources had increased from 2.6 percent in 1951 to about 88 percent in 2013-14 (Singh S., R.Singh, & S.Singh, 2014). Most importantly, tractors now contribute about 48 percent of the total farm power. What led to this dramatic change towards mechanical power, specifically tractors, in Indian agriculture, is a story of transformation in Indian agriculture that may provide lessons for many smallholder economies of South and South-East Asia as well as Sub-Saharan Africa. In order to understand this transformation, it is necessary to revisit the Green Revolution of the mid-1960s. The introduction of high yielding varieties of wheat and rice was accompanied by a rising need for irrigation (Government of India, 2017). Farmers who were open to these new grain varieties soon realized that the traditional water lifts, which were driven by draught animals or operated manually, could not meet the water demand of the high yielding varieties. Lift irrigation was, therefore, quickly mechanized through the use of electric motor or diesel engine powered pumps. This was followed by the extensive use of tractors for primary tillage and transport, as well as of tractor-powered or self-propelled harvesting equipment to save time and labor in the race to grow at least two crops (Kharif and Rabi) in time. In 1961-62, India produced only 880 tractors with the support of foreign collaborations, and imported another 2,997 units (Randhawa, 1986; Singh G., 2015). But as the Green Revolution spread, food grain production and productivity increased in the country, raising agricultural incomes. This in turn created demand for farm machinery, both for groundwater irrigation through pump sets (electric and diesel) and tractors for several field operations. This led to one of the major transformations in Indian agriculture, replacing human and draught power with new motorized farm machinery for better performance and higher productivity.

In this study, we explore how India achieved its current levels of farm mechanization, with primary focus on tractors. We use simple Ordinary Least Square (OLS) regression analysis to test our hypothesis regarding the significance of various driving factors such as farmers' incomes, long-term agricultural credit, real price of tractors, relative price of tractors with respect to cost of agriculture labor, and structural changes, on the demand for tractors. Further, we evaluate the emerging trend and government policy shift towards the institution of "Uberization of Tractors" that promises a leap forward for more efficient utilization of tractors on farmers' fields at lower costs. We also look at how this is giving smallholder farmers access to modern farm machinery, and whether this business model is scalable and financially sustainable.

The study is organized as follows: In Section 2, we present a brief review of literature on the landscape of farm mechanization in Indian agriculture, with focus on tractorization. Section 3 assesses the drivers of demand for tractors in Indian agriculture. It presents the hypothesis, the methodology, and the regression results. Section 4 critically evaluates the spread of tractors based on three parameters, namely efficiency in their usage, inclusiveness in terms of their reach to smallholders, and sustainability in terms of economic viability. Some of the interesting innovations and government and private company contributions to providing farm mechanization to smallholder farmers at reasonable costs without locking in capital are highlighted in Section 5; and Section 6 presents the conclusion and policy recommendations.

2. Lay of the Land

Farm mechanization plays a key role in improving agricultural productivity and reducing the cost of production by timely farm operations. It saves labor and can reduce losses through better management of valuable inputs, thus enhancing crop output and farm incomes, as well as helping to reduce drudgery in farm operations. According to experts, the status of mechanization has been a barometer for the state of rural economy in a country and is analyzed by the growth of mechanically power-operated farm equipment over traditional human and animal power operated equipment (Government of India, 2018a). As an indicative measurement we therefore show the trend in the availability of farm power in kilowatt or horsepower per hectare. With the increase in cropping intensity, the turnaround time between harvesting one crop and preparing to sow the next is drastically reduced. This necessitates the use of farm machinery to complete farm operations within the limited window of time between crops. India has achieved decent growth in the average farm power availability from about 0.25 kW/ha in 1951 to about 1.35 kW/ha in 2001 and 2.02 kW/ha in 2017, an eightfold increase in 67 years (**Figure 1**). The government has set a target to achieve 4 kW/ha by 2030 (NABARD, 2018).

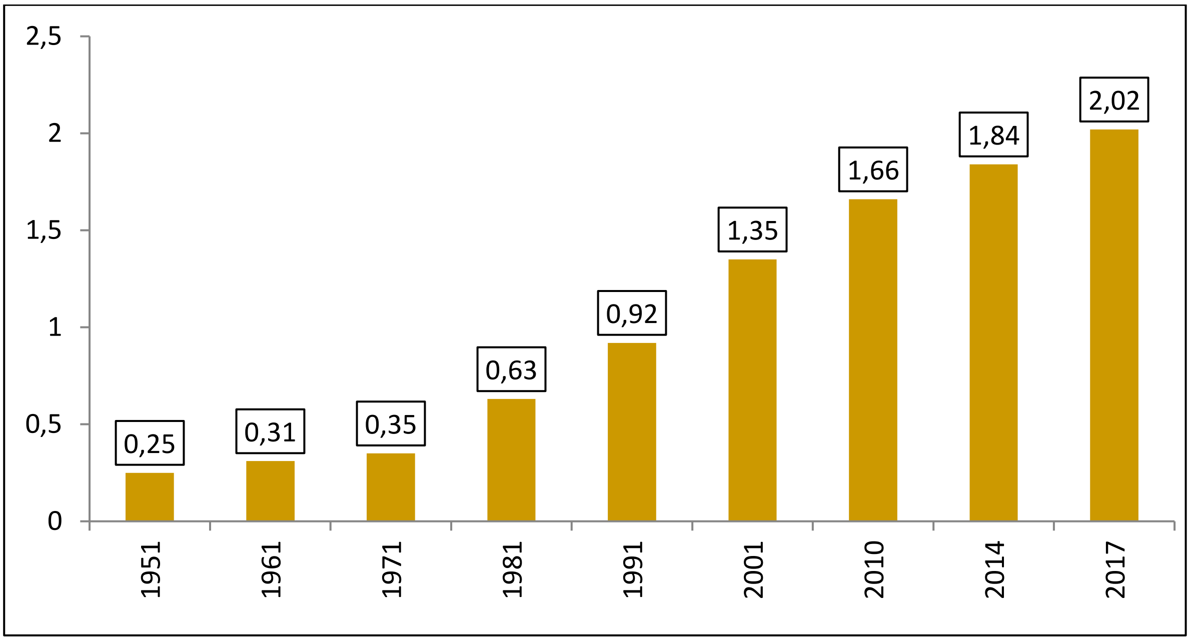

Figure 1: Trend in average farm power availability in India (kilowatt per hectare)

Source: Government of India (2018a).

India has witnessed a clear shift from traditional agriculture practices to more mechanized processes. Broadly, the source of power is categorized as either mobile power, which is used for doing different field jobs, or stationary power, which is used for lifting water and operating irrigation equipment, threshers, shellers/decorticators, cleaners, graders as well as for other post-harvest operations. Mobile farm power comes from human, draught animals, power tillers, tractors and self-propelled machines, whereas stationary power is obtained from oil engines (diesel, petrol, kerosene) and electric motors. Over the last few decades, the use of animal and human power in agriculture-related activities has reduced drastically, for instance from 97.4 percent in 1951 to about 66 percent in 1971 and about 12 percent in 2013-14.[2] At the same time, the contribution of mechanical and electrical sources has increased from 2.6 percent in 1951 to about 34 percent in 1971 and about 88 percent in 2013-14. Out of the total farm power available, tractors contributed about 48 percent in 2013-14 (**Figure 2**).

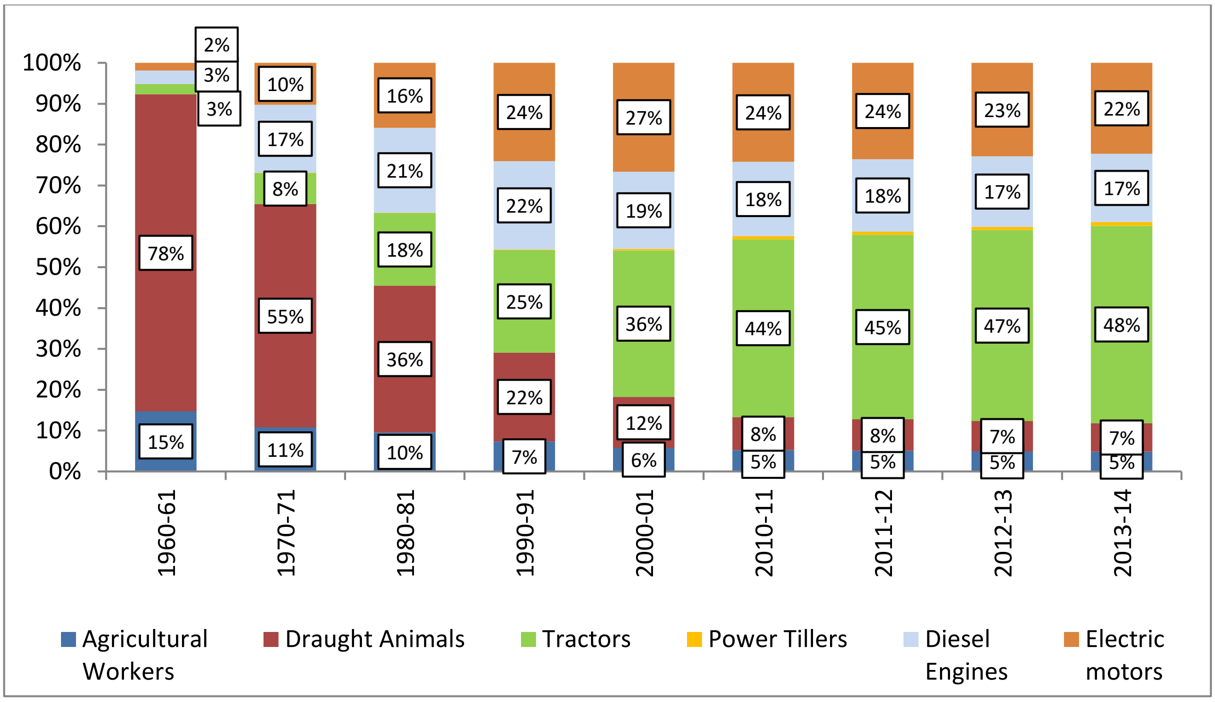

Figure 2: Percentage availability of farm power from different farm power sources

Source: Singh S., R.Singh, & S.Singh (2014).[3]

It may be noted that for converting various sources of farm power into comparable yardstick, it is assumed here that one human power is equal to 0.05 kW; one draught animal power equals 0.38 kW; one tractor equals 26.1 kW; one power tiller equals 5.6 kW; one electric motor equals 3.7 kW; and one diesel engine equals 5.6 kW (Singh S., R.Singh, & S.Singh, 2014). Thus, of all these forms of farm power, tractors are the most powerful. Given that the growth in the tractor industry has been quite high, especially after the Green

[2] 2013-14 is the latest data available.

[3] Sources stated in the article - Singh R S. 2013. Custom Hiring and Scope of Entrepreneurship Development in Farm Machinery, AMA, 44 (2): 26-32.; Singh Surendra; Singh R S; Singh S P. 2010. Farm Power Availability and Agriculture Production Scenario in India. Agricultural Engineering Today, Vol. 34 (1): 9-20.; Singh R S; Singh S P; Singh Surendra (2009). Sale of tractors of different makes in India. Agricultural Engineering Today, 33 (3): 20-37.

Revolution, and even higher after the tractor industry was de-licensed in the 1991 economic reforms, it is not surprising to see a fast replacement of human and draught power by tractor power in farm operations.

However, the picture does not appear as rosy when one considers the percentage of farm holdings by major size groups using different types of farm machinery **(Table 1)**. The latest data for this type of information is available from the Input Survey of 2011-12 (Government of India, 2016). What this data reveals, is that an average of roughly 44 percent of holdings use tractors, 6 percent use power tillers, 22 percent use diesel motors and only 16 percent use electric motors. In a way, this also reflects the scope for further expansion of farm machinery in Indian farms.

Table 1: Percentage of operational holdings using power operated machinery by major size groups (2011-12)

Size group (ha)	Diesel engine pump sets	Electric pump sets	Power tiller	Tractors used for agri. purposes/ wheel tractors
Marginal (Below 1.0)	23%	13%	5%	44%
Small (1.0-1.99)	18%	22%	7%	43%
Semi-medium (2.0-3.99)	19%	26%	7%	44%
Medium (4.0-9.99)	19%	30%	7%	54%
Large (10 and above)	19%	29%	7%	67%
All Groups	22%	16%	6%	44%

Source: Authors' calculation using data from the Input Survey 2011-12, Government of India (2016).[4]

Moreover, the proportion of holdings using tractors was the highest (67 percent) in large holdings followed by medium (54 percent), semi-medium (44 percent), marginal (44 percent) and small (43 percent) holdings. That is, with an increase in holding size, tractorization on the farm increases.

2.1. Indian Tractor Market

In the history of Indian Agriculture, the introduction of agricultural tractors dates back to 1914 when Punjab's Agricultural Minister at the time, Sardar Joginder Singh, introduced steam tractors for the reclamation of wasteland and eradication of 'Kans' (Mehta, Chandel, Jena, & Jha, January 2019). In 1947, the Central Tractor Organization (CTO) and a few state

[4] http://inputsurvey.dacnet.nic.in/RNL/nationaltable7.aspx

tractor organizations were set up to develop and promote the use of tractors in agriculture (Singh, 2015) . In 1951, the tractor industry was included in the "core sector" of the planned economic development, which marked its strategic importance. Until 1960, the demand for tractors was met entirely through imports, mainly from East European countries (Singh, 2015). In 1961, two companies namely Eicher Tractors Ltd. (in collaboration with Gebr, Eicher Traktorenfabrik, West Germany) and Tractors and Farm Equipment Ltd. (TAFE) (in collaboration with Messey Ferguson, UK) started manufacturing tractors in India. Further, in 1963, Gujarat Tractors Limited Tractors and Bulldozers Limited (in collaboration with Motokov-Praha, Czechoslovakia) followed by Escorts Ltd. (in collaboration with Moloimport Warazawa Zaklady Mechaniczne Ursus, Poland (1964)) were also set up for the domestic production of tractors. In 1965, Mahindra & Mahindra Ltd. (a major player in the automobile sector) collaborated with International Tractor Company of India Ltd. which was itself set up in the year 1963 in collaboration with UK's International Harvesters (Singh, 2015). As a result, the domestic production of tractors rose from 880 units in 1961-62 to 5,000 units in 1965-66. However, to protect farmers' interests, the Government imposed in 1967 a statutory price control on domestically produced tractors (Singh, 2015) which was later revoked in 1974.

To meet the growing demand for tractors fueled by the Green Revolution, the Government decided to invite additional entrepreneurs into tractor manufacturing in 1968. In 1971, Escorts established Escort Tractors Ltd. and started manufacturing Ford tractors in collaboration with Ford, U.K. Several other domestic manufactures such as VST Tillers & Tractors Ltd. etc. also invested in the industry and started domestic production. The real breakthrough came in 1974, when Punjab Tractors Ltd. became the first public sector company to start manufacturing tractors with indigenous technology (Mehta, Chandel, Jena, & Jha, January 2019) and produced the first agricultural tractor 'Swaraj'. During this period, the Government ensured adequate rural lending through the expansion of commercial banks in remote villages for the overall agricultural development. As a result, the tractor market expanded rapidly. Production crossed the 30,000-mark in 1974-75 **(Figure 3)**. Further, in 1982, the indigenous Mahindra brand of tractors was launched and the company became the market leader in the tractor industry.[5] As a result, during the 1980s, India started exporting tractors, mainly to African countries (Singh, 2015).

In 1991, another watershed event in the transformational story of Indian tractor industry took place: A complete de-licensing of tractor manufacturing in India increased competition in the industry. The growth in the tractor production was accompanied by an increase in the number of models produced to meet the diverse needs of the farmers, ranging from 21 horsepower to 50 horsepower (hp) tractors. In this way, the Indian tractor industry has developed and emerged as the largest market worldwide (excluding sub 20 hp belt driven tractors used in China), followed by the USA and China (Tractor and Mechanization

[5] https://www.business-standard.com/company/m-m-365/information/company-history

Association, 2019). The production of tractors in India has grown to almost 900,000 units in 2018-19,[6] and Mahindra & Mahindra (M&M) has emerged as the largest tractor manufacturer with a total share of about 40 percent (FY, 2019) followed by TAFE (with Eicher Motors) – 18.4 percent[7] – and others players like VST, International Tractors, Force Motors and Escorts in the country.

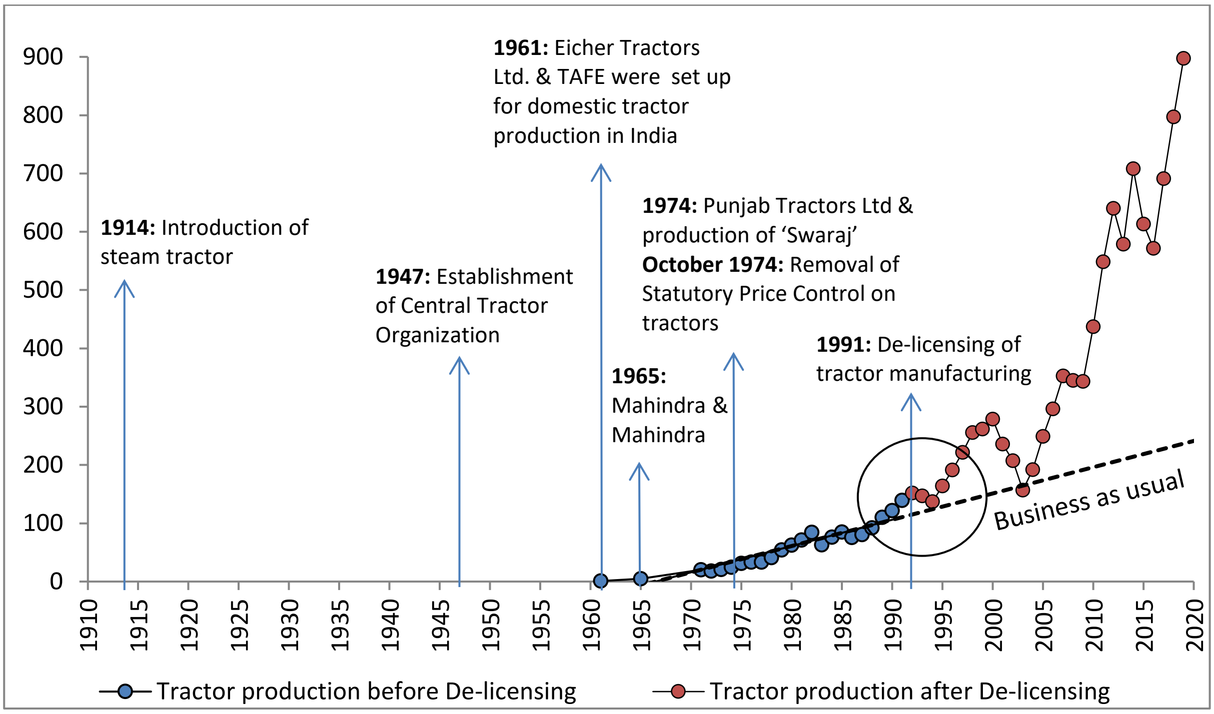

Figure 3: Yearly production of tractors (in '000 units)

Sources: 1961-62: Government of India (2018b); 1965-66: Singh (2015); Indian Mirror (2019) and 1970-71 to 2016-17: ICAR (2016).[8]

Although tractor sales cannot be taken as the only measure of farm mechanization, they reflect the reach of farm mechanization to a great extent. At national level, the sale of tractors has increased considerably from 33,000 units in 1970-71 to 273,000 units in 2000-01. After this there was a slight decline in the trend mainly due to unfavorable weather conditions, e.g. droughts, in many parts of the country **(Figure 4).** But soon thereafter, sales soared rapidly and touched a peak of about 878,000 units in 2018-19. India also exports tractor units to other countries across the world. In 2018-19, the country exported about 92,000 tractors, primarily to African countries and ASEAN countries where soil and agro-climatic conditions are similar to India (Tractor and Mechanization Association, 2019).

[6] http://apps.iasri.res.in/agridata/16data/chapter6/db2016tb6_3.pdf

[7] https://auto.economictimes.indiatimes.com/news/automotive/farm-equipment/tractor-sales-growth-pace-hits-three-year-low-in-fy19/69093089

[8] Source cited: 1. Tractor and Mechanization Association (TMA), New Delhi data. 2. Information received from the ICAR-Central Institute of Agricultural Engineering, Nabi Bagh, Berasia Road, Bhopal. Due to the unavailability of production data for 2017-18, it is assumed equal to the sales in that year, i.e. at 796.9 units.

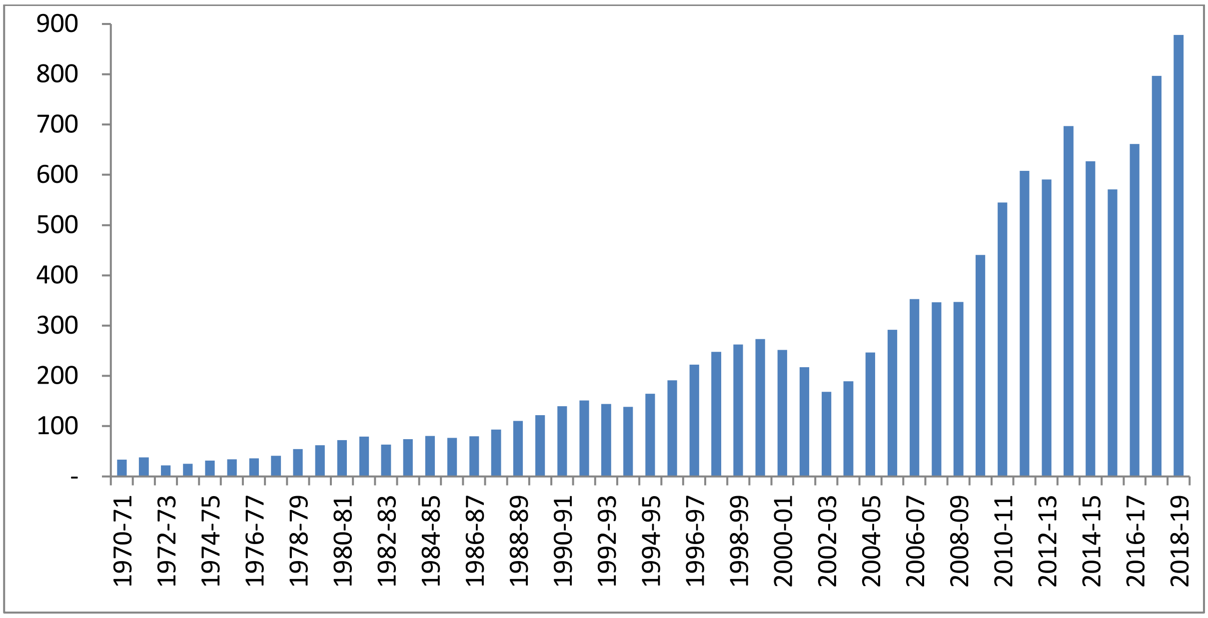

Figure 4: Yearly sales of tractors (in '000 units)

Source: Agricultural Engineering and Produce Management (2016) and Tractor and Mechanization Association (2019).

Within the tractor market, the 41-50 hp segment, is the largest selling unit, followed by the31-40 hp segment **(Figure 5)**. A significant jump in the volume of the tractor industry shipment of 41-50 hp tractors has been witnessed since 2009-10, peaking in 2013-14.

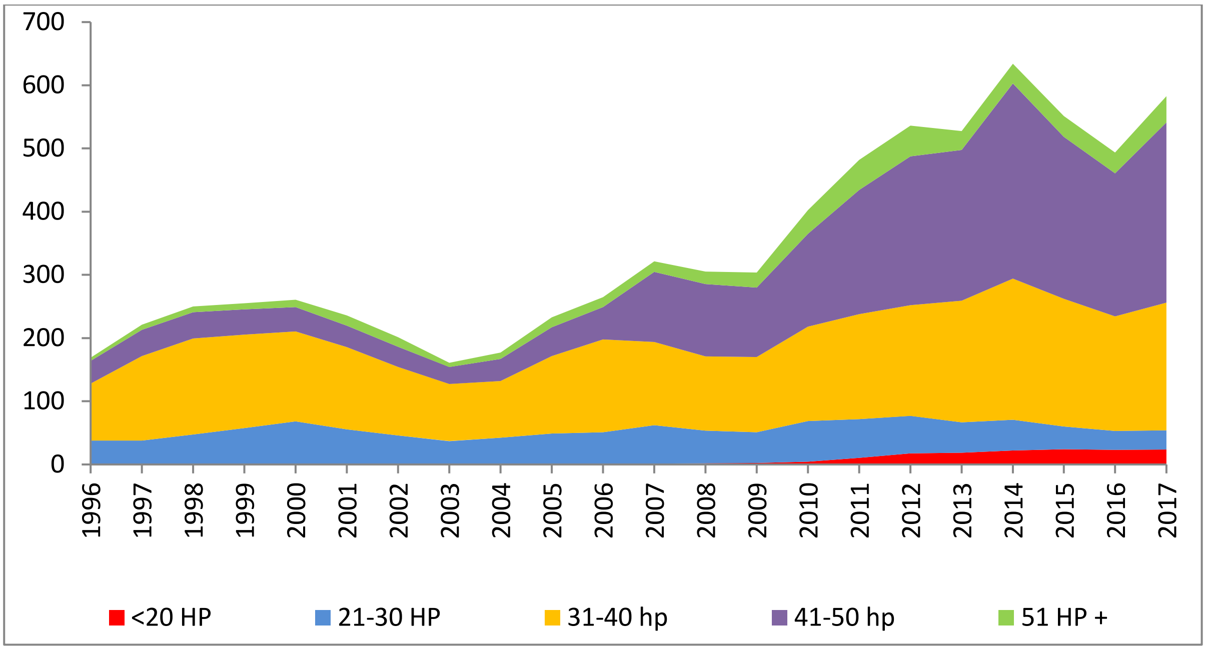

Figure 5: Horsepower wise yearly sales of tractors (in '000 units)

Source: Tractor and Mechanization Association (2019).

2.2. Tractor Density in India

A state-wise comparison of tractor density in 2017-18 shows great disparity across states **(Figure 6).** At the national level, there are about 50 tractors per thousand hectares[9]. Haryana, Andhra Pradesh, Punjab, Bihar and Uttar Pradesh have higher density compared to the national average. However, there is still a scope to increase tractor density in North-Eastern states which are currently lagging behind. Also, Punjab, which used to be among the major tractor markets in the country especially during the Green Revolution period, is now experiencing a slowing in the growth of tractors per thousand hectares, which could be due to a weak haulage and replacement demand that needs deeper research.

[9] The tractor density in 2017-18 has been calculated by adding domestic sales of tractors between 2005-06 and 2017-18 (under the assumption that the average life of a tractor is 13 years) and then dividing them by the gross cropped area (GCA) in 2015-16. For simplicity, authors have assumed replacement demand as 13 years because the exact life of tractor is not known with certainty. It may vary somewhere between 8 years to 15 years, as per different studies.

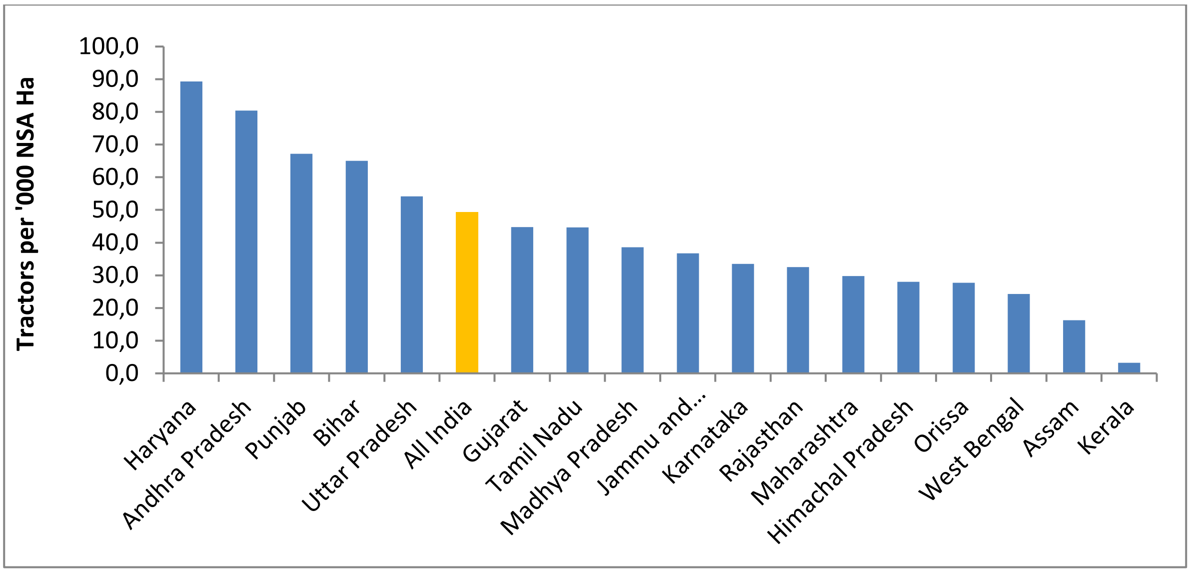

Figure 6: Tractor density by state (tractors per '000 hectares)

Source: Tractor and Mechanization Association (2019) and Government of India (2015).

Figure 7 further shows that there is a prevalence of 41-50 hp tractors across major states such as Maharashtra, Tamil Nadu, Punjab, Andhra Pradesh, Uttaranchal, West Bengal and Kerala etc. and of 31-40 hp tractors in states like Odisha, Gujarat, Bihar and Rajasthan.

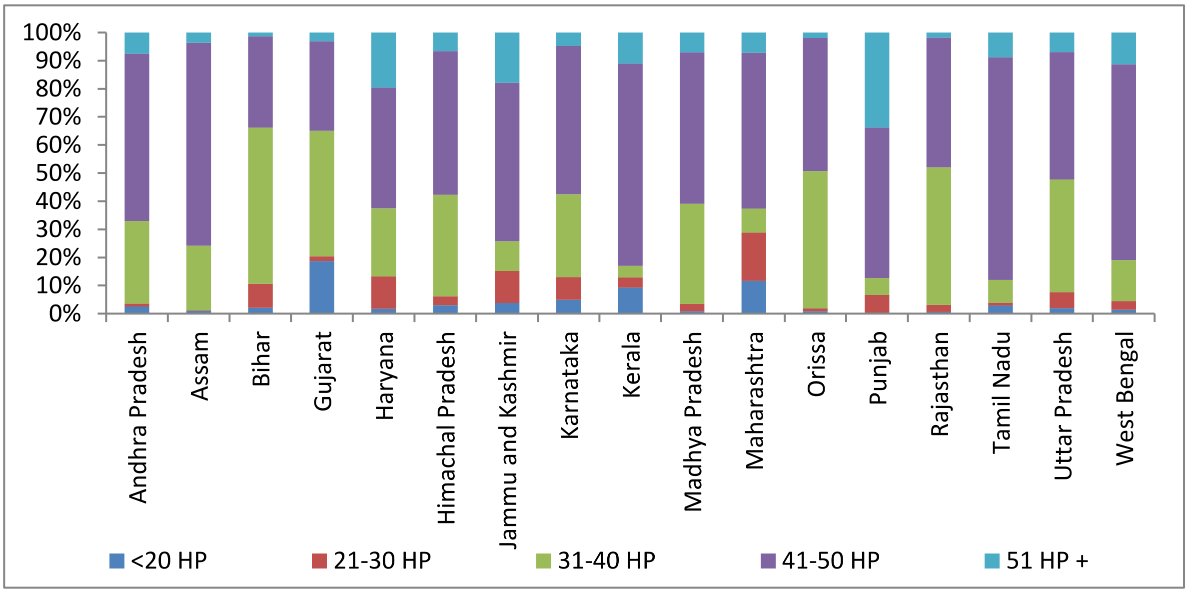

Figure 7: Percentage share of various horsepower tractors in the total sale of tractors across major states in 2016-17

Source: Tractor and Mechanization Association (2019).

3. Drivers of Demand for Tractors in Indian Agriculture

3.1. Objective

The objective of this study is to examine the factors influencing the demand for agricultural tractors and to evaluate their significance and degree of association with the purchase of agricultural tractors.

In literature on the subject, it is found that the demand for tractors in Indian agriculture could be influenced by a host of variables, such as farmers' income, real price of the tractors, cost of farm labor, size of the agricultural land holding, availability of affordable agricultural credit and agricultural profitability (Lal & Singh, 2016; Baregal & Grover, 2017). Further a study by Mandal and Maity (2013) shows that the replacement cycle of tractors significantly influences the demand for tractors. Therefore, in order to investigate the major factors determining the demand for tractors in India, we carry out a regression analysis using various combinations of the selected explanatory variables explicated in detail below:

Farmers' Income

Farmers' income plays a major role in determining the demand for farm machinery (Morehouse, 1982; Lal & Singh, 2016). To capture the effect of farmers' income on the demand for farm tractors, we consider three proxy variables, namely the irrigation ratio calculated as the ratio of gross irrigated area to gross cropped area;[10] the irrigation ratio calculated as the ratio of net irrigated area to net sown area;[11] and the fertilizer consumption per hectare, because the time series data for farmers' income is not available. In a study by Baregal and Grover (2017), it is indicated that the gross irrigated area is a significant factor determining the demand for tractors in India, as it is expected that with increasing irrigation cover, the overall productivity and farmers' incomes rise.

Real Price

According to literature on the subject, the purchase price of the tractors influences the input costs and thereby the cost of production (Sivakumar & Kaliyamoorthy, 2014; Lal & Singh, 2016). A study by Baregal and Grover (2017) reveals that the real price of tractors is a significant variable and shows a negative association with the demand for tractors in India. As the time series of the real price of tractors is not available, we use the Wholesale Price

[10] Gross Irrigated Area (GIA) is the total irrigated areas under all crops over the various seasons of the agriculture year (i.e. from July 1 to June 30 of the following year). Under GIA, area irrigated twice/thrice within the same agriculture year is counted as twofold/threefold (Central Water Commission, 2018).

[11] Net Irrigated Area (NIA) is the area irrigated through any source once a year for a particular crop. Areas irrigated more than once within the same agriculture year are counted only once (Central Water Commission, 2018).

Index (WPI) of tractors as a ratio to the general Wholesale Price Index of all commodities to capture its impact of the demand for tractors in this study.

Relative Price

Since tractors compete with labor in agriculture (Vanzetti & Quiggin, 1985), the cost of labor measured as real farm wages is assumed to capture the substitution price effect on the demand for tractors. We calculate the relative price of tractors as the ratio of the Wholesale Price Index of tractors to the real wage rate.

Replacement Cycle

The replacement cycle of a machine is defined as the estimated technical working life until the full exhaustion of their estimated services (Lips, 2017). In simple words, it is the time period of utilization before it is replaced. According to the empirical literature, a shorter and continuous replacement cycle of tractors is a crucial factor to boost tractor demand (Mandal & Maity, 2013). In this analysis, we assume a replacement cycle of 13 years.

Availability of Credit

Institutional credit plays a critical role in financing the purchase of any machinery. According to Pingali (2004), "nearly 95 per cent of purchases of mechanised power in India were through loans taken from banks and agricultural institutions." Studies have even found that an increase in supply of long-term credit leads to an increase in the sale of tractors (Sarkar, 2013). According to literature on the subject, the availability of adequate farm credit is an important determent for the demand for tractors due to the high capital cost involved in the purchase of tractors and other farm machinery (Morehouse, 1982; Lal & Singh, 2016). Therefore, provisions for timely availability of credit should be ensured because tractors directly influence the process of development both on and off farm (Lal & Singh, 2016).

3.2. Data Sources and Methods

This study is entirely based on secondary data for selected dependent and independent variables over a period of 23 years (from 1995-96 to 2017-18). Time series data for yearly sales of tractors is collected from the Tractor and Mechanization Association (2019). Irrigation ratios and fertilizer consumption per hectare are calculated using data from the Land Use Statistics at a Glance, Government of India (2015) and from the statistical database of The Fertiliser Association of India (2019). The data on prices of tractors are computed by dividing the Wholesale Price Index of tractors by the Wholesale Price Index of all commodities, the data for which is obtained from the Office of the Economic Adviser (2019). In order to compute the relative price of tractors, the ratio of the Wholesale Price Index of tractors and the real wage rate is calculated. Further, to compute time series data for the real wage rate at the national level, the weighted average of the nominal wage rates per state are converted to real wage rates using the Consumer Price Index of agriculture labor in each state. Data on the nominal wage rates is taken from the Labour Bureau (2017). To obtain the time series for the replacement demand of tractors, data on sales of tractors is used with the assumption that the replacement demand arises 13 years after the original purchase. Data on the availability of agricultural credit is obtained from the Handbook of Statistics on Indian Economy, Reserve Bank of India (2019).

Thus, the general form of the tractor demand model (log linear) is:

Log Y = a+b1 Log X1 + b2 Log X2 + b3 Log X3 +.....+ bn Log Xn

Where,

Y= Number of tractors demanded

a = Constant term

b1, b 2, b3 ....bn = Elasticities of different explanatory variables

X1, X2, X3, ..., Xn = Explanatory variables

The explanatory variables used in the form of various combinations in the different demand models are listed in **Table 2**.

Table 2: Explanatory variables with description

Variables	Description
Sales	Sales of the tractors (in ‘000 units)
GIAR	Gross Irrigation Ratio
NIAR	Net Irrigation Ratio
FertC	Fertilizer Consumption per Hectare
Real Price	Wholesale Price Index of tractors/Wholesale Price Index of all commodities
Relative Price	Wholesale Price Index of tractors/real wage rate
RD 13yrs	Replacement demand for tractors after 13 years (in ‘000 units)
Credit	Direct long-term credit issued to agriculture and allied activities (INR Billion)

First, we examine the relationship between tractor demand and the different explanatory variables using the Karl Pearson Correlation Matrix **(Table 3)**. The matrix shows a strong and statistically significant relationship of all independent variables with the dependent variable (i.e. demand for tractors), with the exception of the relative price of tractors (i.e. ratio of

WPI of tractors to real wage rate). This shows that in India, when inputs (e.g. irrigation and fertilizers) in agriculture, long-term agricultural credit and the replacement demand of tractors are rising, the demand for tractors is likely to be commensurately good. Further, when the real prices of tractors with respect to prices of all other commodities are low, the demand for tractors is likely to rise.

Table 3: Correlation matrix of selected variables

	Sales	GIAR	NIAR	FertC	Real Price	Relative Price	RD 13yrs	Credit
Sales	1.00							
GIAR	0.92***	1.00						
NIAR	0.92***	0.97***	1.00					
FertC	0.85***	0.91***	0.90***	1.00				
Real Price	-0.94***	-0.96***	-0.93***	-0.87***	1.00			
Relative Price	0.31	0.39**	0.46**	0.63***	-0.32	1.00		
RD 13yrs	0.87***	0.90***	0.93***	0.84***	-0.88***	0.42**	1.00	
Credit	0.88***	0.84***	0.83***	0.66***	-0.85***	0.09	0.69***	1.00

Note: *** significant at 1% level of significance (p-value < 0.01); ** significant at 5% level of significance (p-value < 0.05); * significant at 10% level of significance (p-value < 0.1).
Source: Based on authors' calculations.

Thereafter, we tested the stationarity (unit root test) of these time series using an augmented dickey fuller test (ADF). In all three cases, the original series is found to be non-stationary. We have therefore taken the second difference of these series which made all the time series stationary (no stochastic trend (no unit root) and no deterministic trend (no trend)).

3.3. Results

To estimate the drivers of the demand for tractors, various regression equations using different combinations of explanatory variables were tried separately. Best fit in terms of level of significance of explanatory variables, co-efficient of multiple determination and signs of the variables are highlighted for discussion. The same have been demonstrated in **Table 4**.

In Equation 1, the co-efficient of fertilizer consumption per hectare (proxy of farmers' income) was found to be 1.5 and was significant at the 1 percent probability level, indicating that an increase in fertilizer consumption of 1 percent would raise the demand for tractors by 1.5 percent. The regression co-efficient of the demand for tractors with respect to the relative price came out to be negative 1.2 and was found to be statistically significant at the 10 percent probability level. It revealed that an increase in the relative price of tractors had a negative impact on the demand for tractors, i.e. an increase in the relative price of 1 percent would result in a decrease in the demand for tractors in the country of 1.2 percent. Further, the regression co-efficient of the replacement demand for tractors was found to be 0.41 percent, being statistically significant at the 5 percent probability level, which indicated that an increase in the replacement demand for tractors of 1 percent would result in an increase in the demand for tractors of 0.41 percent.

It is important to note in this time series analysis at national level that 84 percent of the variation in the demand for tractors can be explained through the income proxy variables, the price variables, and the replacement demand variables.

Equations 2 and 3 further show that when the credit variable is used in combination with real price and replacement demand variables, it explains 89-91 percent of the variation in the demand for tractors (over a 23-year period). The equations also show that long-term credit availability and replacement demand (13 years) have a statistically significant and positive impact on the demand for tractors while the real price of tractors has a significant negative impact on the demand for tractors **(Table 4).** This proves our hypothesis that the availability of long-term credit for agriculture and a favorable policy environment have played a major role in fostering increased sales of tractors.

Table 4: Regression results for determining drivers of the demand for tractors in India at the national level

Log Sales	Log FertC	Log Real Price	Log Relative Price	Log RD 13yrs	Log Credit	R square
Equation 1	1.5***		-1.02*	0.41**		0.84
Equation 2		-0.97*		0.5**	0.38***	0.91
Equation 3		-1.54***			0.14*	0.89

Note: *** significant at 1% level (t-value > 2.8); ** significant at 5% level (t-value > 2.0); * significant at 10% level (t-value > 1.7) and # significant at 20% level (t-value> 1.32) with degrees of freedom = (23-1) =22.
Source: Based on authors' calculations.

However, another important aspect to note in this time series analysis is the probability of reverse causality between the demand for tractors and farmers' income. According to the empirics, tractors may also increase productivity and thereby income, which in turn may increase the demand for irrigation and fertilizers. To test the reverse causality, we use Grangers Causality Test after generating a Vector Autoregressive Model (VAR). It is thus observed that at the lag of 4 years, we obtain a bidirectional relationship between demand for tractors and proxies of farmers' income, that is, irrigation ratio and fertilizer consumption. This leads us to reject our null hypothesis that GIAR, NIAR and FertC do not cause sales of tractors. Therefore, it validates our hypothesis that with the use of tractors on farms productivity is enhanced, which increases farmers' income and the demand for inputs such as seeds, irrigation, fertilizers etc.

Table 5: Granger causality Wald tests

Equation	Excluded	chi2	df	Prob > chi2
logsales	logNIAR	436.42	4	0.000
logsales	logFert	619.33	4	0.000
logsales	logGIAR	390.07	4	0.000
logsales	ALL	1381.1	12	0.000
logNIAR	logsales	71.893	4	0.000
logNIAR	logFert	205.27	4	0.000
logNIAR	logGIAR	16.098	4	0.003
logNIAR	ALL	526.68	12	0.000
logFert	logsales	45.508	4	0.000
logFert	logNIAR	72.542	4	0.000
logFert	logGIAR	60.575	4	0.000
logFert	ALL	252.55	12	0.000
logGIAR	logsales	100.7	4	0.000
logGIAR	logNIAR	131.53	4	0.000
logGIAR	logFert	82.856	4	0.000
logGIAR	ALL	461.32	12	0.000

In this section, we have tried to pool the cross section and time series data of 15 major states,[12] namely Andhra Pradesh, Assam, Bihar, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, and West Bengal, over a period of 21 years (from 1996-97 to 2016-17) and then run regressions on this pooled data set.

In this regression model, Yt is the yearly sales of tractors, X1 is the irrigation ratio, calculated as GIAR and NIAR, and pooled across 15 major states and time series. Another proxy to capture the income effect on the demand for tractors is fertilizer consumption per hectare. X2 is the relative price of tractors with respect to the state-wise real wage rate (normalized

[12] These 15 selected states account for about 94 percent of the total tractor sales during 2016-17 (TMA, 2019).

using CPI-AL) which captures the price substitution effect on the demand for tractors. Due to a lack of data availability, the replacement demand as well as long-term credit flow to agriculture could not be taken into the account. However, it is expected that even in cross-section time series they will have a significant positive impact on the demand for tractors as observed in the national time series analysis. **Table 5** reports the results of the regressions.

The regression co-efficient of the gross irrigation ratio in Equation 1 (Table 5) was found to be 1.11 percent being statistically significant at a level of 1 percent of probability, which indicated that an increase in the irrigation ratio of 1 percent would result in an increase in the demand for tractors of 1.1 percent. The regression co-efficient of the demand for tractors with respect to their relative price came out negative 1.77 and was found statistically significant at the level of 1 percent probability. It revealed that an increase in the relative price of 1 percent would result in a decline in the demand for tractors in the country of 1.77 percent. In Equations 2 and 3 also, the income proxy variables (irrigation and fertilizers) and the relative price of tractors (WPI) as a ratio of the state-wise real wage rate have a statistically significant effect on the demand for tractors at a level of 1 percent of probability. In the pooled random regression, the R square[13] values do not hold much significance in interpretation. They are therefore not mentioned in **Table 6**.

Table 6: Regression results for determining drivers of the demand for tractors using state-wide pooled data

Log Sales	Log GIAR	Log NIAR	Log FertC	Log Relative Price
Equation 1	1.11***			-1.77***
Equation 2		1.19***		-1.77***
Equation 3			1.11***	-1.93***

Note: *** significant at 1% level (t-value > 2.8); ** significant at 5% level (t-value > 2.0); * significant at 10% level (t-value > 1.7) and # significant at 20% level (t-value> 1.32) with degrees of freedom = (21-1) = 20.
Source: Based on authors' calculations.

Using various combinations through the two models based on both the national Indian time series regression and the cross section (state-wide) pooled regression, it is observed that the income effect (measured through the irrigation ratio and fertilizer consumption per hectare), the price substitution effect (measured in terms of the relative price of tractors as a ratio of the real wage), the structural change effect (measured as the replacement demand after 13 years) and the long-term credit flow effect have a statistically significant impact on the demand for tractors in agriculture.

[13] R square is 0.45 (average).

4. Farm Mechanization: Assessing Impact

In order to assess the impact of farm mechanization, this section begins by first examining the efficiency of tractor use. The efficiency of tractors is usually estimated by their working capacity per unit of time. Second, we assess the tractor inclusiveness quotient that is the reach and coverage of farm machinery across vast areas from marginal farm holdings to small and medium-scale farm holdings. Third, we assess the sustainability of tractorization by looking at how they affect farmer's finances and whether the existing practices are financially viable in the long term.

4.1. Efficiency

The process of agricultural mechanization in India is constrained by the increasing fragmentation of land. The average holding size has continuously fallen from 2.28 hectares in 1970-71 to 1.08 hectares in 2015-16, making individual ownership of agricultural machinery progressively difficult. Further, mechanizing small and non-contiguous groups of small farms is against 'economies of scale', especially for operations like land preparation and harvesting (Mehta, Chandel, & Senthilkumar, 2014). In addition, tractors are generally considered economically viable if they run for about 1,000 hours/year (ENVIS Centre: Punjab, 2015). Most micro-studies on farm mechanization reveal that the utilization is only about 50-60 percent of this norm, indicating an over-capitalization of farms (Gulati, 2019). This in fact raises the cost of production per unit and locks in capital in the medium to the long run. As most tractors (more than 90 percent) are bought on credit, this under-usage makes it difficult for farmers to pay back their debts.

To illustrate this point, we will consider the case of Punjab, one of the most mechanized states in the country with farm power availability of 2.6 kW/ha (Indian Council of Food and Agriculture, 2017), where the majority of farm tasks including ploughing, digging, harvesting, processing, loading, and sorting are done by machines. According to the state Environmental Information System (ENVIS), Punjab, the average annual use of tractors is only 450 hours, far below the recommended 1,000 hours of productive use in agricultural operations (ENVIS Centre: Punjab, 2015). This leads to over-capitalization and under-utilization of farm machinery and equipment, and farmers easily become indebted in the process. This again leads to higher costs of production and a lower net income for farmers, making tractor use economically unviable and difficult to sustain. Though the use of harvester-combines for wheat and paddy has been on the increase, their use leaves uncut straw and stubble in the fields, which is often burnt by the farmers, causing air pollution as well as declining soil fertility, both of which are environmentally damaging.

4.2. Inclusiveness

Land holdings of the majority of Indian farmers are classified as small and marginal. Thus, any purchase of farm machinery and equipment for different farm operations is a significant investment which could get locked in for a long period of time when the machinery is owned. Similarly, the purchase of standalone implements is another persistent issue that has been associated with owning farm machinery. Such implements do not add to overall mechanization, since farmers need different machines and technological interventions at various stages of the crop cycle. Thus, ownership of each and every machine, along with various implements, would not be economically viable for farmers, especially for those with small and marginal holdings. Given that farm machinery is not as perfectly divisible as seeds or fertilizers, the ownership model for farm mechanization is not very inclusive. Moreover, there are wide technology gaps in meeting the needs of various cropping patterns across regions. In the absence of good planning and direction, investment in mechanization may not yield the expected results. Thus, India needs to adopt a policy of selective mechanization under various conditions in different regions to achieve higher productivity (Mehta, Chandel, & Senthilkumar, 2014).

4.3. Financial Sustainability

Financing agricultural machinery is yet another area of concern. High costs of machinery and equipment make it difficult for farmers to purchase all suitable machinery as it increases the fixed as well as the variable costs of farm operations (due to maintenance and depreciation costs). Based on data provided by a New Holland Tractors dealership in Faridabad, Haryana, 35 hp and 55 hp tractors were the most commonly sold tractors. Of these, the 35 hp tractor costs around INR 485,000, while the 55 hp tractor costs INR 755,000. Thus, the high capital costs involved in procuring such machinery is financially unsustainable for farmers, especially for those with small and marginal holdings, who lack adequate capital resources and bank credit for such purchases and who are unable to earn the rate of return over investments in farm machinery. Therefore, there is a need for institutional innovations in providing services of farm mechanization on cost-effective terms as well as for reaching small and marginal farms. This particularly applies to high-cost farm machinery such as harvest combines, sugarcane harvesters, potato combines, paddy transplanters, laser guided land levelers, rotavators etc. that can be spearheaded by private players or by state or central government institutions (Mehta, Chandel, & Senthilkumar, 2014).

5. Innovations in Providing Farm Machinery to Smallholders: "Uberization" and "Custom Hiring Model"

Innovation, in general, could be defined as a new idea, a new policy, a new process or a new product, which breaks into society and/or markets creating more value than the existing ways and products. In this section, we are looking at the game-changing innovation in the institution, where farm equipment or machinery is provided to farmers, especially to those with small and marginal farms, as a service in a timely and effective manner and at affordable cost. The Custom Hiring Model introduced by the present government and the Uberization Model incepted by the private sector are the new innovative on-demand business models that provide farm machinery and equipment (such as harvest combines and tractors) along with operator services to farmers at affordable costs and at any point in time. As mentioned before, it is not economically feasible to mechanize small and non-contiguous land areas, particularly in the case of operations like land preparation, sowing and harvesting. Therefore, as India experiences continuous shrinkage in average farm size from 2.28 ha in 1970-71 to 1.08 in 2015-16, the individual ownership of agricultural machinery becomes progressively less economical and remains beyond the reach of farmers with small and marginal holdings due to their lack of funds. Therefore, the 'Uberization Model' and the 'Custom Hiring Model' can both ensure access to cutting-edge technology suited to the crop and soil profile without high financial input (Ganguly, Gulati, & Braun, 2017). These models are an innovation in the institutional mechanism that can make farm machinery and equipments available to farmers at affordable cost on a 'pay per use' basis. This could further save time and labor, reduce crop production costs and postharvest losses and boost crop output and farm incomes. In addition, it could enable new machines to be used at their maximum capacity, making it an efficient and financially sustainable business.

Therefore, the model could not only increase farm power availability but also help to remove the disparities in the availability of farm power between various states as well as between farmers with land holdings of different size categories. Thus, this model could make farm mechanization as a service perfectly divisible, accessible and affordable even to smallholders for whom owning farm machinery may not be economical, thereby increasing the productivity of farms as well as reducing drudgery associated with various farm operations. Consequently, the Custom Hiring model and the Uberization model both hold the potential of being an efficient and equitable way of spreading farm mechanization in Indian agriculture. It seems that both models can help achieve the three-pillared criteria of efficiency, inclusiveness, and financial sustainability.

The genesis of the Custom Hiring Model is the Sub-Mission on Agricultural Mechanization (SMAM) Scheme which was introduced by the Government of India (2016-17) under the umbrella of the National Mission on Agricultural Extension & Technology (NMAET) in 2014-

15. The objective of the scheme was to increase the reach of farm mechanization to farmers with small and marginal holdings and to regions with low farm power, thus compensating for adverse economies of scale, which means high cost of individual machinery ownership for a small holder farmer. Under this program, the central government promoted the establishment of Custom Hiring Centres (CHCs) to provide hiring services of various kinds of agricultural machinery with a financial assistance level (subsidy) of 40 percent (of the machine cost) to farmers, entrepreneurs and societies willing to set up these CHCs (Government of India, 2018c). These CHCs are required to cover a minimum area of 10 ha/day and at least 300 ha in a cropping season (Government of India, 2016-17). Further, to foster the use of hi-tech, high-value machines for higher productivity, the Government promotes the establishment of hi-tech hubs with a financial assistance level of 40 percent (of the machine cost) (Government of India, 2018c). These hubs are required to cover at least 500 ha per cropping season. To promote the establishment of farm machinery hubs (also termed as farm machinery banks) for custom hiring with a minimum of 8 farmers per hub/bank in selected villages, the Government further provides a subsidy of 80 percent of the project cost.[14] The established CHCs and hi-tech hubs will be provided technical assistance from KVKs/manufacturers/Approved Testing Centres, and ICAR centers for maintenance and training (Government of India, 2016-17).

Figure 8 depicts the numbers of CHCs, hi-tech hubs (deals with high end technological agri/farm implements) and machinery banks (operated cooperatively by at least 8 members dealing with agri/farm implements of higher value) established each year across India between the launch of the scheme in 2014-15 and 2018-19. The data is retrieved from an online dashboard by the Ministry of Agriculture & Farmers Welfare of the Government of India to track the progress of the scheme in real time.

[14] The maximum permissible project cost is Rs.10 lakhs per Farm Machinery Bank.

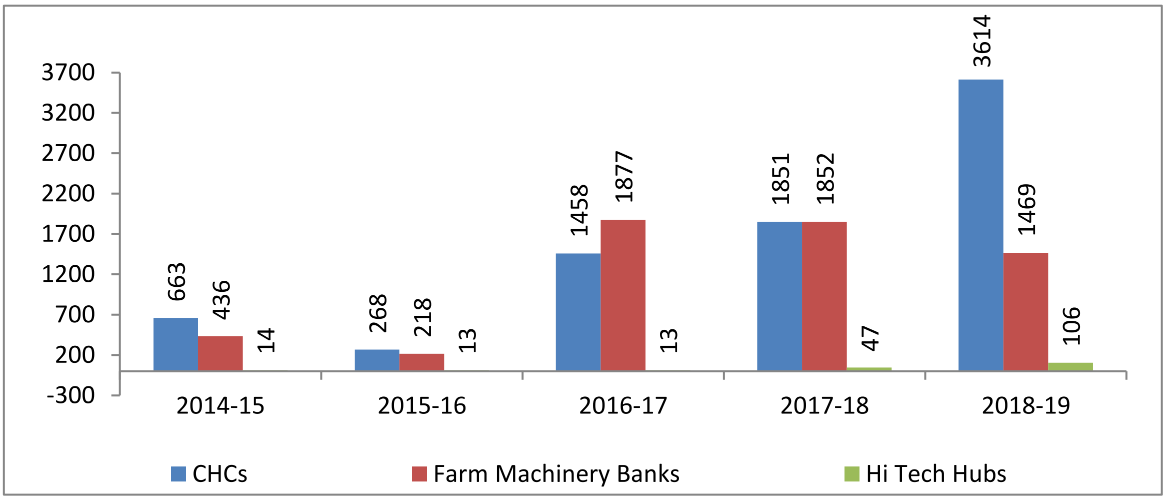

Figure 8: No. of new CHCs, farm machinery banks and hi-tech hubs established between 2014-15 and 2018-19 (as of October 2019)

Source: Government of India Live Dashboard.[15]

In the evaluation and impact assessment study of SMAM, conducted by WAPCOS Ltd. on behalf of the Ministry of Agriculture and Farmers Welfare (Government of India, 2018c), it was found that CHCs provide machinery services within a radius of 10 to 20 Kms from the village where they are established and employ 2 to 3 persons including one driver, one helper and one center manager to carry out field operations which include land levelling, ploughing, seeding, harvesting and threshing. **Table 7** presents the average prevailing rates for hiring equipment.

Table 7: Prevailing custom hiring rates for different implements (2019)

Name of equipment	Hiring charges in local market (INR/hour)	Rate charged by CHCs (INR/hour)
Tractor with rotavators	1200	950
Tractor with cultivators	800	650
Tractor with seed drill	800	700
Power tiller	600	500
Brush cutter without fuel	350 per day	300 per day
Thresher	1000	850
Paddy combine	1400	1200

Source: (Government of India, 2018c).

[15] https://agrimachinery.nic.in/GraphReport/SMAMFmtti/SMAMFmtti.aspx

Farmers who are hiring the equipment revealed in the survey that the charges levied by the CHCs established under SMAM are INR 100/- to INR 200/- per hour less (about 15 to 20 percent lower) than the prevailing hiring charges levied by other players in the local market. Farmers also find it flexible to pay in cash for land preparation and seeding but in case of threshing they pay in kind. In the case of hiring on credit basis, the payment is made at the time of the harvesting and selling of crops (Government of India, 2018c). This reflects that CHCs pose tough competition to private players in terms of hiring charges.

However, it needs to be noted that CHCs have received a subsidy of roughly 40 percent on capital equipment, and by charging 15-20 percent lower rates compared to the informal farm machinery service market, this policy can potentially destroy that vibrant market and make the whole model subsidy-driven. Many of the existing private sector players providing farm machinery services may also turn their private ventures into CHCs to avail this 40 percent subsidy and higher profits despite offering lower rates to farmers. A robust evaluation of CHCs needs to be carried out to examine whether it ensures the efficient use of machinery (say 1,000 hours/year of tractor use), whom it serves (farmers of small or large holdings) and whether these CHCs can be financially viable without the 40 percent subsidy or with a lower subsidy of say 20 percent. We have not come across any such study, and this is an issue that needs further research.

Recently, the Government of India has introduced a CHC Farm Machinery Mobile App to provide farmers with access to farm equipment and machinery available within 50 Kms of their agricultural land. As of October 2019, 44,233 custom hiring service providers (farmers, entrepreneurs and societies) have been registered on this app and more than 120,000 farm equipment are available for rent, which need further scaling up across the country.[16]

The implementation of the Sub-Mission on Agricultural Mechanization (SMAM) program by the Ministry of Agriculture is therefore a step towards ensuring the last-mile reach of farm mechanization to farmers of small and marginal holdings (Government of India, 2018c). However, the growth in CHCs so far seems driven by the large (40 percent) subsidy component. India has yet to see intermediate custom hiring interventions in the crop cycle ranging from sowing to harvesting (Ministry of Agriculture and Farmers Welfare, 2016). Business models in India are at a nascent stage and need to be evaluated properly before scaling them up further.

Besides SMAM, the Government also promotes farm mechanization programs through other missions/schemes such as Rashtriya Krishi Vikas Yojana (RKVY), Mission for Integrated Development of Horticulture (MIDH) and National Mission on Oilseeds and Oil Palm (NMOOP) (Government of India, 2016-17). In addition, the governments of Karnataka, Andhra Pradesh, Madhya Pradesh and Punjab are also promoting CHCs on a Public Private

[16] Government of India Live Dashboard (https://agrimachinery.nic.in/GraphReport/SMAMFmtti/SMAMFmtti.aspx)

Partnership (PPP) basis. For instance, the Government of Rajasthan has partnered with a startup named EM3 Agriservices Private Limited, also called "Samadhan - Techno Kheti", to establish CHCs in the state. In addition to providing farm equipment for rent, EM3 also offers "Farming as a Service" (FaaS) that includes soil analysis, seedbed preparation, sowing, fertilizer application, weed/pest control, top dressing, harvesting and post-harvest operations. Besides Rajasthan, EM3 has footprints in Madhya Pradesh, Uttar Pradesh (Chandauli district) and Gujarat, covering more than 8,000 farms in total. Moreover, there has been increasing participation from private players over the years in providing farm machines on a rental basis as well as related services. For instance, in 2016, M&M incepted its agri-equipment service startup called Trringo with an initial capital of INR 10 crore, on a franchisee-based model to bring in new-age digital technology to the tractor rental business (Singh S., 2017). Until July 2018, 1.7 Lakh plus hours of service have been provided to more than 1.2 Lakh farmers through 100 plus hubs operational within a radius of 7-10 Kms in more than 1,000 villages across five states, namely Gujarat, Rajasthan, Maharashtra, Madhya Pradesh and Karnataka. EM3's agri-services has also come into the space for helping farmers to access cutting edge farm equipment and technologies on a pay-per-use basis on either an hourly or acreage pricing. EM3 basically follows a command on-demand model and allows farmers who own machines such as tractors, harvesters and other mechanical equipment to rent out their assets to farmers with small/marginal holdings in remote parcels who would otherwise be able to access such technology with their limited credit and capital resources. They manage supply-demand, data of inventory owners and potential renters through mechanization and call centers as well as local representatives at the village level. EM3 has established 1,240 Samadhan - FaaS (Farming as a Service) centers operational in Rajasthan, Madhya Pradesh, Uttar Pradesh (Chandauli district) and Gujarat covering about 8,000 plus farms in terms of its service offers. Moreover, Tractors and Farm Equipment Ltd. (TAFE) has set up JFarm Rajasthan, an advanced agri-research center in Bhawanimandi, Jhalawar District in November 2016 as a platform that facilitates the hiring of tractors and modern farm machinery for Rajasthan farmers. TAFE has signed a MoU with the Government to set up CHCs in six identified zones (Bharatpur, Jodhpur, Jaipur, Jalore, Kota and Sikar) across the state (TAFE, 2017). Through the app, tractor and equipment owners (in CHCs) are put in direct touch with the farmers who need farm mechanization services and solutions. The company has aggressive plans to enroll more than 10,000 CHCs within two years of operation and serve more than 500,000 farmers. According to Ms. Mallika Srinivasan, Chairman and CEO of TAFE, "the model has registered more than 450 Custom Hiring Centres and has connected with over 25,000 farmers."

As a result of the Government's initiative and equal participation from the private sector, farm mechanization has been increasing steadily over the years, which can be seen in the increase in production, sale and exports of tractors from the country. The Custom Hiring Model and innovation in the farm machinery sector therefore hold the potential to drive the next phase of agricultural growth in India. However, a congenial policy framework is required to incentivize the establishment of CHCs as the preferred business model in the country so that the gap between requirement and availability can be bridged efficiently. It goes without saying that raising farmers' awareness and knowledge through various stakeholders in the agriculture supply chain and incorporating farmers' inputs for future implementation of schemes and policies can lead to better value creation.

6. Conclusion and Policy Recommendations

This section brings out inferences derived from the analysis and offers recommendations to make farm mechanization more efficient, inclusive and sustainable:

One of the major concerns in using farm machinery such as tractors in India is the small holding size of agricultural land and increasing fragmentation. The average size of operated land holding in India is 1.08 ha and the majority of the landholdings (86 percent) and operated areas (47 percent) are small and marginal (i.e. of less than 2 ha in size). Moreover, fragmentation of land holding is expected to increase, especially among farmers with small and marginal holdings. Therefore, holding sizes in Indian agriculture do not justify individual ownership and efficient utilization of machines such as tractors (i.e. a minimum of 1,000 hours of productive use in agricultural operations). Another major issue is the limited investment capacity of farmers, which is most prevalent among those with small and marginal holdings. The results of our regression modeling also show that farmers' prosperity and the relative price of tractors (as a ratio to cost of labor) are statistically significant factors that affect the demand for tractors. Thus, given the low incomes of farmers with small and marginal holdings on the one hand and the high capital costs of farm machines and tractors in relation to cost of agricultural labor on the other hand, individual ownership of farm machines, tractors and other equipment become financially unsustainable.

One of the possible ways forward, as highlighted in Section 5, is innovation in providing farm mechanization to farmers based on custom hiring and Uberization models that make farm machinery and equipment available as a service to farmers of all farm categories at the door-step at affordable cost on a 'pay per use' basis. For instance, in some parts of the state Bihar, a company named Claro Energy has introduced a mobile solar pump set service operating under the principle of "pay as you go", i.e. instead of having individual farmers install solar panels, there are provisions for hiring solar panels on a rental basis (like the rental UBER cab service) to generate the energy required for pumping irrigation water for crops.

To increase agricultural productivity, timeliness in farm operations is essential, especially for seedbed preparation and sowing operations to establish a good crop stand in deficient/receding soil moisture conditions. Therefore, providing tractors/power tillers, seed drills/planters and other farm machinery based on custom hiring is the future of farming in India.

The Government of India (2016-17) has already kick-started the efforts towards ensuring the last-mile reach of farm machinery like tractors to all farmers, especially to those with small and marginal holdings, through its Sub-Mission on Agricultural Mechanization (SMAM) Scheme launched in 2014. Under this scheme, the Government provides broad-base technological services to farmers in the form of efficient supply of inputs including agricultural tools, implements and machinery and for extending custom hiring facilities.

However, so far, the growth in CHCs has been modest and seems to be driven by the subsidy support.

Therefore, India has yet to see major custom hiring interventions in the crop cycle ranging from sowing to harvesting to make the model self-sustained (i.e. without any major subsidies). In addition, several private companies are also coming forward and joining the league through the Uberization of tractors and other farm machines and equipment and are looking for adequate government support to scale up their reach and operation.

Thus, institutional innovations of the Custom Hiring and Uberization models make farm mechanization as a service perfectly divisible, accessible and affordable to farmers with all categories of farms and hold potential to efficiently, inclusively and sustainably increase the level of mechanization and tractorization in the country. For this purpose, the government needs to create a conducive policy and institutional environment that provides easy credit access to all farmers, especially to those with marginal and small holdings as well as to unemployed youth who are likely to be most keen to set up custom hiring centers in the villages.

Further, both the Government and the industry should invest in research and development to incorporate new improvements into their designs and products. To tackle regional disparities in the level of mechanization across the country, the Government should further provide financial incentives for farmers to replace primitive hand tools as well as draught animals with improved tools and implements, until this transition picks up speed.

We hope that with these improvements, the farm mechanization system can serve the needs of the farming community even better and be a role model for many smallholder economies in Sub-Saharan Africa as well as in South and Southeast Asia.

7. References

Baregal, V., & Grover, D. (2017). *A quantitative analysis of demand for tractors in India*. Agriculture Update, Volume 12, No. 3, 764-769.

Central Water Commission. (2018). *Irrigation Terminology*. Retrieved September 2, 2020, from nwa.mah.nic.in: https://nwa.mah.nic.in/sdmc/irrigation/08_challenges.htm

ENVIS Centre: Punjab. (2015). *Farm Mechanization*. Retrieved September 2, 2020, from http://punenvis.nic.in/: http://punenvis.nic.in/index2.aspx?slid=258&mid=1&langid=1&sublinkid=974

Ganguly, K., Gulati, A., & Braun, J. V. (2017). *Innovations spearheading the next transformations in India's agriculture*. Germany: Working Paper No. 159, Center for Development Research, University of Bonn.

Government of India. (2015). *Land Use Statistics at a glance.* New Delhi: Directorate of Economics and Statistics.

Government of India. (2015-16). *Agriculture Census.* New Delhi: Agriculture Census Division, Department of Agriculture, Co-operation and Farmers' Welfare.

Government of India. (2016). *Input Survey Report 2011-12*. Retrieved October 30, 2019, from Agriculture Census.

Government of India. (2016-17). *Sub-Mission on Agricultural Mechanization: Operational Guidelines.* Delhi: Ministry of Agriculture and Farmers Welfare.

Government of India. (2017). *National Portal on Mechanization and Technology*. Retrieved October 21, 2019, from http://farmech.gov.in/06035-01-15052006.pdf

Government of India. (2018a). *Doubling Farmers' Income (Volume VIII): Input Management for Resource Use Efficiency & Total Factor Productivity*. New Delhi: Department of Agriculture, Cooperation and Farmers' Welfare, Ministry of Agriculture & Farmers' Welfare.

Government of India. (2018b). National Portal on Mechanization and Technology. Retrieved October 28, 2019, from Need for Farm Mechanization: Study Relating to formulating Long-Term Mechanization Strategy for each Agro Climatic Zone/State in India: http://farmech.gov.in/06035-02-15052006.pdf

Government of India. (2018c). Monitoring, Concurrent Evaluation and Impact Assessment of Sub-mission on Agricultural Mechanization. Gurgaon: Ministry of Agriculture and Farmers Welfare.

ICAR. (2016). *Agricultural Research Data Book*. Delhi: Government of India.

Indian Council of Food and Agriculture. (2017). *Farm Mechanization: Indian Farm Mechanization Market Overview.* New Delhi: India International Centre.

Indian Mirror. (2019). *Indian Tractor Industry*. Retrieved October 30, 2019, from Indian Industries: https://www.indianmirror.com/indian-industries/tractor.html

Labour Bureau. (2017). *Pocket Book of Labour Statistics.* Shimla: Ministry of Labour & Employment, Government of India .

Lal, B., & Singh, A. (2016). *Understanding the Tractor Market: An Exploratory Study in Haryana (India)*. Global Journal of Management and Business Research: E Marketing, 28-34.

Lips, M. (2017). Length of Operational Life and Its Impact on Life-Cycle Costs of a Tractor in Switzerland. MDPI: Agriculture.

Mandal, S. K., & Maity, A. (2013). *Current Trends of Indian Tractor Industry: A Critical Review*. Applied Science Reports, Volume 3, No. 2, 132-139.

Mehta, C. R., Chandel, N. S., & Senthilkumar, T. (2014)*. Status, Challenges and Strategies for Farm Mechanization in India*. Agricultural Mechanization in Asia, Africa & Latin America, Volume 45, No.4, 43-50.

Mehta, C. R., Chandel, N. S., Jena, P. C., & Jha, A. (January 2019). *Indian Agriculture Counting on Farm Mechanization.* Ama, Agricultural Mechanization in Asia, Africa & Latin America, Volume 50, No.1, 84-89.

Ministry of Agriculture and Farmers Welfare. (2016). *Farm Mechanization in India: The Custom Hiring Perspective*. New Delhi: FICCI and Yes Bank.

Morehouse, W. (1982). *Dilemma of Technological Choice Revisited: Case of Combine Harvester*. Economic and Political Weekly, Volume 17, No.35, 83-84.

NABARD. (2018). *Sectoral Paper on Farm Mechanization*. Mumbai: Farm Sector Policy Department, NABARD Head Office.

Office of the Economic Adviser. (2019). *Wholesale Price Index (WPI)*. Retrieved September 2, 2020, from eaindustry.nic.in: https://eaindustry.nic.in/

Pingali, V. (2004). *Input Management, State of Indian Farmer: A Millennium Study.* New Delhi: Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India.

Randhawa, M. S. (1986). *A History of Agriculture in India: 1947-1981.* New Delhi: Indian Council of Agricultural Research.

Reserve Bank of India. (2019). *Handbook of Statistics on Indian Economy.* Mumbai: Reserve Bank of India.

Sarkar, A. (2013). *Tractor Production and Sales in India, 1989–2009*. Review of Agrarian Studies.

Singh, G. (2015). *Agricultural Mechanisation Development in India*. Indian Journal of Agricultural Economics*,* Volume 70 , No.1, 64-82.

Singh, S., R. Singh, & S. Singh. (2014). *Farm Power Availability on Indian Farms.* Agricultural Engineering Today, Volume 39, No.1, 48-52.

Sivakumar, V., & Kaliyamoorthy, S. (2014). *Factors Influencing the Purchase of Agricultural Tractors: An Empirical Study*. IOSR Journal of Business and Management, Volume 16, No.1, 42-46.

TAFE. (2017). *TAFE launches 'JFarm Services' – a custom hiring platform*. Tractors and Farm Equipment Limited (TAFE) (p. 2). Kota, Rajasthan: TAFE.

Tractor and Mechanization Association. (2019). *Indian Tractor Industry*. Retrieved September 1, 2020, from tmaindia.in: http://www.tmaindia.in/tractor-industry.php

The Fertiliser Association of India. (2019). *Statistics*. Retrieved September 2, 2020, from faidelhi.org: https://www.faidelhi.org/statistics/statistical-database

Vanzetti, D., & Quiggin, J. (1985). *A Comparative Analysis of Agricultural Tractor Investment Models.* Australian Journal of Agricultural Economics, Volume 45, No.3, 122-141.