



The rapid rise of agricultural mechanization in Myanmar

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ABSTRACT

The past decade has seen a resurgence of interest in the role of mechanization in agricultural development. This literature has given rise to debates over the design of institutions and policies to facilitate accelerated mechanization, the role of outsourcing services in overcoming problems of access to machinery, and questions regarding the future of smallholder agriculture. We contribute to these debates using two pairs of complementary demand side (farm household) and supply side (agricultural machinery retailer) surveys, implemented in Myanmar in 2016 and 2017 across two major agro-ecological zones. Our analysis provides evidence that extremely rapid agricultural mechanization took place during the period of political and economic reforms from 2011 to 2020. In both zones surveyed, use of machinery for land preparation, harvesting, and threshing was close to scale-neutral due to a dynamic outsourcing services market. Rather than representing a single transformational change, mechanization's broad appeal to farm households results from an accumulation of incremental, overlapping, complementary advantages. These include labor savings, reduced drudgery, convenience, increased speed and timeliness of operations, improved ability to manage weather-related risks, and reduced loss of grain during harvesting. We provide examples of policies on trade, finance, and land tenure that contributed to this transformation with practical implications for ongoing policy debates on mechanization in other countries, and suggest some generalizable lessons.

1. Introduction

Literature on the green revolution placed mechanization at the heart of agricultural development, as part of the productivity enhancing package of fertilizer, improved seed, and irrigation (Mrema et al., 2009), but the subject subsequently slipped from global research and policy agendas. The past decade has seen a resurgence of interest (e.g. Diao et al., 2020; Justice and Biggs, 2020; Mandal et al., 2017; Biggs and Justice, 2015). Conditions that are generating, or seem poised to generate, demand for farm mechanization have emerged in countries with limited initial penetration by green revolution technologies, reorienting the geographical focus of the mechanization debate. Recent examples of research on agricultural mechanization in 'new' geographies include Cambodia (Yagura, 2020), Ethiopia (Berhane et al., 2017a), Ghana (Takeshima et al., 2018), Mozambique (Cabral, 2021), Nepal (Paudel et al., 2019), and Nigeria (Takeshima et al., 2020).

Use of agricultural machinery is growing in African countries where

land is relatively abundant and wages are increasing, (e.g. Ghana, Nigeria), but has yet to approach rates seen during periods of mechanization growth in Asia, prompting the search for new policies and strategies to accelerate uptake (Diao et al., 2020). At the same time, the belief that smallholder farmers cannot benefit from mechanization is persistent (Daum and Birner, 2020). A perceived lack of agricultural transformation in some parts of Africa has led observers to advocate formation of larger commercial farms which, they argue, are more easily able to adopt productivity-enhancing technologies including agricultural machinery (Collier and Dercon, 2014).

In countries that experienced both the first wave of the green revolution and structural transformation (e.g. Thailand, China), rural populations have been hollowed out by migration and are aging rapidly, in landscapes comprised mainly of small and fragmented farms (Rigg et al., 2016). In such contexts, access to labor saving agricultural machinery, often facilitated by the growth of outsourcing services, may contribute to the continued viability of smallholder farming (Rigg, 2019;

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Takeshima, 2017; Zhang et al., 2016).

This contemporary context gives rise to three major themes in the ‘new wave’ of mechanization literature: First, agricultural mechanization in ‘new’ geographical contexts, and the design of institutions and policies to facilitate its acceleration (e.g. Daum and Birner, 2017; Diao et al., 2014; Kahan et al., 2017; Mottaleb et al., 2017; Van Loon et al., 2020). Second, the role of outsourcing services in overcoming problems of machine access, and farm size constraints to mechanization (e.g. Adu-Baffour et al. 2019; Aryal et al., 2020; Berhane et al., 2017b; Liu et al., 2020; Yang et al., 2013; Zhang et al., 2017). Third, the role of mechanization in sustaining, or undermining, smallholder agriculture (e.g. Paudel et al., 2020; Otsuka et al. 2016; Rigg 1998; Takeshima, 2018; Wang et al., 2016; Yamauchi, 2016).

Myanmar is a new frontier for mechanization research. Until recently, much literature on rural Myanmar painted a picture of deep stagnation. For instance, a study of farm production economics in the country’s main agricultural zones in 2013/14 found that just 1% of households used combine harvesters in paddy cultivation. The report’s authors attributed this finding to a combination of low wages and surplus labor in rural areas, poor infrastructure, a poor regulatory environment, and lack of access to long-term capital among farmers (World Bank, 2016). However, from 2011 to 2020, policy reforms and reintegration into regional and global markets following a half-century of political and economic isolation contributed to increasingly dynamic conditions. These included economic growth averaging 7% per year (ADB, 2018), accelerating outmigration from rural areas (World Bank and LIFT, 2016; Pritchard et al., 2017), and rapid rural transformation (Belton and Filipinski, 2019).

The present paper uses data from two pairs of complementary surveys to assess the effects of these changes in relation to agricultural mechanization in Myanmar. Studies of agricultural mechanization have tended to focus separately on users or providers of machinery. Here, we combine demand side (farm household) and supply side (agricultural machinery retailer) surveys implemented in 2016 and 2017 across two major agroecological zones - a deltaic rice-growing environment, and a rainfed semi-arid zone. This approach allows for triangulation of results, and captures variations in mechanization across two geographies, making findings potentially more generalizable than if focused on a single area.

We make contributions to each of the themes in the new wave of mechanization literature outlined above. First, the study provides a detailed descriptive analysis of an understudied agricultural economy, including evidence of extremely rapid and pervasive recent agricultural mechanization not documented systematically elsewhere. We draw links between these changes and the simultaneous transformations in Myanmar’s economy and policy environment from 2011 to 2020. Second, we show how private outsourcing services have driven the uptake of agricultural mechanization and made access to farm machinery close to scale neutral at the point of use. Third, we consider the implications of these findings for the viability of smallholder agriculture in Myanmar, and identify factors conditioning uptake of agricultural machinery beyond simple substitution of capital for labor.

The paper is organized as follows. First, we summarize the survey methodologies. Second, we analyze temporal changes in the ownership and use of agricultural machinery. Third, we present data on recent trends in the geographical spread of machinery supply businesses and growth of machinery sales. Fourth, we evaluate evidence of demand- and supply-side factors influencing agricultural mechanization in Myanmar. The final section concludes by summarizing the paper’s contributions to the mechanization literature and wider implications for contemporary debates on mechanization policy.

2. Methodology

This paper draws on separate surveys of rural households in two of Myanmar’s most important agricultural zones, the Ayeyarwady Delta

and the Dry Zone, and agricultural machinery supply businesses in these zones. The geography of both zones and the survey methodologies are summarized below. Survey instruments, metadata, and datasets from all four surveys may be accessed through Harvard Dataverse¹.

2.1. Geography

Myanmar is bisected North to South by the Ayeyarwady River. The Dry Zone is a semi-arid area along the river’s middle course, and one of the country’s most important agricultural regions. Dry Zone farming systems can be divided into rainfed ‘upland’ (“ya”) comprised of mostly low rolling hills with gentle slopes, and flat, irrigable ‘lowland’ (“le”) officially designated as land for paddy cultivation. Upland accounts for approximately two-thirds of agricultural land in the Dry Zone, with lowland comprising most of the remainder (Hein et al. 2017). Oilseeds and pulses are the dominant upland crops - most importantly, sesame, groundnut, pigeon pea, chickpea, and green gram. Lowland is used mainly for paddy cultivation. Monsoon paddy is the main lowland crop. Dry season paddy is concentrated in a few townships (sub-districts) with reliable access to irrigation (Mather et al., 2018). Myanmar’s second largest city, Mandalay, is located in the Dry Zone.

The Ayeyarwady Delta is located several hundred kilometers due south of the Dry Zone. The Delta is an expanse of low-lying alluvial land crisscrossed by waterways, often referred to as Myanmar’s ‘rice bowl’. Monsoon paddy is the dominant crop, with irrigated paddy and non-irrigated pulse crops (black gram and green gram) grown post-monsoon (Cho et al. 2017). Yangon city, Myanmar’s largest commercial center, is located in the eastern Delta. Together, the Delta and Dry Zone form a “core” agricultural corridor, running down the center of the country.

Median farm sizes in both zones, as reported in our household surveys, are modest at around 2 ha. Mean farm sizes in the Delta are larger than in the Dry Zone, averaging 4.1 ha and 2.8 ha respectively². Farms are mainly owner operated. Sharecropping, land rentals, and absentee landlordism are rare (c.f. Boutry et al., 2017). Farming in both zones is strongly commercially-oriented. All major crops yield large marketed surpluses (Belton and Filipinski, 2019; Cho et al., 2017). Rates of landlessness are significant in both zones, but higher in the Delta than the Dry Zone (58% and 40% respectively). Boutry et al. (2017) and Pritchard et al. (2019) report similar rates of landlessness, resulting variously from; foreclosure on debts during the great depression of the 1930s, the stringently enforced paddy procurement policy during the socialist era, land confiscations under post-socialist military rule, and everyday processes of fragmentation due to subdivision of landholdings at inheritance (Boutry et al., 2017; Mark and Belton, 2020; Vicol and Pritchard, 2020).

2.2. Survey methods

2.2.1. Demand side surveys

Demand side analysis draws on our two household surveys, supplemented by scoping interviews in both zones. The surveys were fielded to generate information on cropping systems, farming practices, and the state of the wider rural economy. Each survey instrument included modules on ownership of agricultural machinery (including machine type, year of purchase, purchase value), and captured detailed plot-level data on machine use (by crop, task and season, duration and cost of use, and whether owned or rented) for a single ‘sample parcel’. Household-level data on machinery use is based on machine use on the sample

¹ The datasets can be accessed via the following URLs: demand side [Delta](#); [Dry Zone](#); supply side [Yangon](#); [Dry Zone](#)

² We calculate agricultural landholdings based on access, not ownership. Rental markets for cropland are very limited in both zones, so this choice makes little difference to average farm size.

parcel selected for each household. In addition, we captured recall data on use machinery for land preparation and harvesting during the year of the survey, and five and ten years earlier. Surveyed households were asked whether any current or former members had ever migrated for work, and reported the details for each migrant including their year of first migration.

The Delta household survey was fielded in May 2016. The questionnaire was designed to elicit information on crop agriculture and fish farming. Forty village tracts³ in four townships (Kayah and Twantay, Maubin and Nyaungdon) were selected purposively based on an assessment of the types of farm (fish and crop) present in each. All selected village tracts fell within approximately 60 km of Yangon. For second-stage sampling, 78 enumeration areas (EA) in these village tracts were drawn at random by probability proportional to size from the sampling frame of the national population census of 2014, with help from staff of the Department of Planning (Fig. 1). Following a complete listing of households, eight farm and seven non-farm households were selected at random for interview in each EA. Respondents from 1,102 households (of which, 329 crop farming households) were interviewed. Farms surveyed represented the entire population of crop farming households in the 40 selected village tracts. Sample weights were applied during analysis.

The Dry Zone household survey was conducted in April and May 2017. Four townships (Budalin, Myittha, Magway and Pwintbyu), were selected purposively following scoping, to provide coverage of the major Dry Zone crops and farming systems (Fig. 1). EAs were drawn at random from the sample frame of the national census, making data statistically representative of the rural population in the four townships. A census of households was conducted in every selected EA to serve as the final sample frame for randomized selection of households. One hundred communities and 1578 rural households (including 936 crop farming households) were selected randomly for interview. Sample weights were applied.

2.2.2. Supply side surveys

The supply side section of the paper draws on data from two surveys of agricultural machinery retail businesses. We considered all businesses selling any agricultural machinery as machinery retailers. These were identified during field visits, by snowball sampling, and from searches of business directories and online. We did not impose a minimum business size for inclusion in the survey. Some selected businesses sold both agricultural machinery and non-agricultural machinery (e.g. generators). Apart from threshers, many of which are manufactured locally, most farm machinery marketed in Myanmar is imported, mainly from China and Thailand. A few large machinery retailers manufacture basic components (e.g. trawlerji chassis, metal two-wheel tractor wheels) to assemble with more complex imported parts. Small workshops manufacturing components and businesses reselling spare parts or offering only mechanical repairs were excluded from the survey.

The first survey was implemented in Yangon in July 2016. Scoping interviews indicated that most of Yangon's agricultural machinery retailers were located in a single commercial compound, constituting by far the largest 'cluster' of machinery retailers in Myanmar. A census of these businesses identified 30 agricultural machinery retailers. Three declined to be interviewed, giving a sample of 27. The second survey was conducted in December 2017, in the five main urban centers in the Central Dry Zone - Mandalay, Monywa, Shwebo, Magway and Pakkoku. Sixty-one agricultural machinery retailers were identified. Four declined to be interviewed, giving a sample of 57. Instruments for both surveys were designed to elicit information on annual quantity and value of machinery sales by type of machine over the preceding five years, provision and conditions of customer finance, and the location and date of

establishment of all the branches operated by each business.

In mid-2018 follow up phone calls and visits were made to businesses included in the first survey to update information on establishment of branches. Data from both sets of businesses were pooled to give a composite picture of the spatial and temporal distribution of machinery retailers. Almost all the larger machinery retailers in Myanmar operate branches in Yangon or Mandalay, meaning that the surveys captured information on a large share of national agricultural machinery sales. Eighty-four machinery retailers were interviewed across the two surveys, out of a universe of 242 branches identified by survey respondents.

3. Results

Below we present results from the two pairs of household surveys and machinery retailer surveys. All data presented in the tables and figures originates from our own surveys.

3.1. Demand side

3.1.1. Sequence and timing of mechanization

Ownership of agricultural machinery has grown quickly in both Delta and Dry Zone from a very low base, accelerating particularly rapidly from 2010 onwards. The changing composition of machines over time is consistent with the generalized sequence of mechanization, whereby stationary "power intensive" operations such as pumping water and threshing are mechanized before mobile "control intensive" operations such as harvesting (Pingali, 2007; 2008).

In the Delta, mechanization began with two-wheel tractors (power tillers, used mainly for land preparation in paddy cultivation) and water pumps (used for many purposes, but most importantly irrigating dry season paddy). Ownership of these items grew little from 1996 to 2007, but subsequently increased sharply. Acquisition of mechanical paddy threshers and trawlerji (farm vehicles running on two-wheel tractor engines) by Delta households began in the mid-2000's. Acquisition of four-wheel tractors increased markedly after 2008 but remained at a fairly low level. Combine harvesters – the most control intensive machines utilized – did not appear until 2014 (Table 1).

Mechanization in the Dry Zone followed a similar generalized pattern to the Delta, but with differences in the composition of machinery that reflect differences in agro-ecology. Similar to the Delta, two-wheel tractors and water pumps were the first machines to be used widely, and over a similar timeframe. In the Dry Zone, the number of water pumps acquired was about half the number of two-wheel tractors, in contrast to the Delta, where numbers of water pumps exceeded two-wheel tractors. This reflects more limited availability of water in the Dry Zone. The timing of acquisition of threshers follows a similar trend in both zones, but threshers account for a smaller share of machines owned in the Dry Zone than in the Delta, consistent with the lower prominence of paddy in Dry Zone farming systems (Table 1).

Acquisition of four-wheel tractors in the Dry Zone began later than in the Delta, but has grown very rapidly since 2010, in line with the uptake of these machines for cultivation of non-paddy crops. None of the Dry Zone households surveyed had ever owned a combine harvester, reflecting the lesser role of paddy in the cropping systems of the townships surveyed, as compared to the Delta. Ownership of large machinery (four-wheel tractors and combines) remains rare in absolute terms, but the rate of recent growth has been very rapid. For example, more than half of all four-wheel tractors in the Dry Zone were purchased in just two years (2015–2016). Given the large engine sizes of these machines relative to two-wheel tractors, this represents a massive increase in mechanical power. The total value of purchased machines has also increased dramatically over time. By 2017, four-wheel tractors accounted for most of the capital invested in agricultural machinery in the Dry Zone, underlining the speed of the shift to mechanized traction. Similar trends were apparent in the Delta for combine harvesters.

³ A village tract is the lowest level administrative unit in Myanmar, usually comprising 5–10 villages.

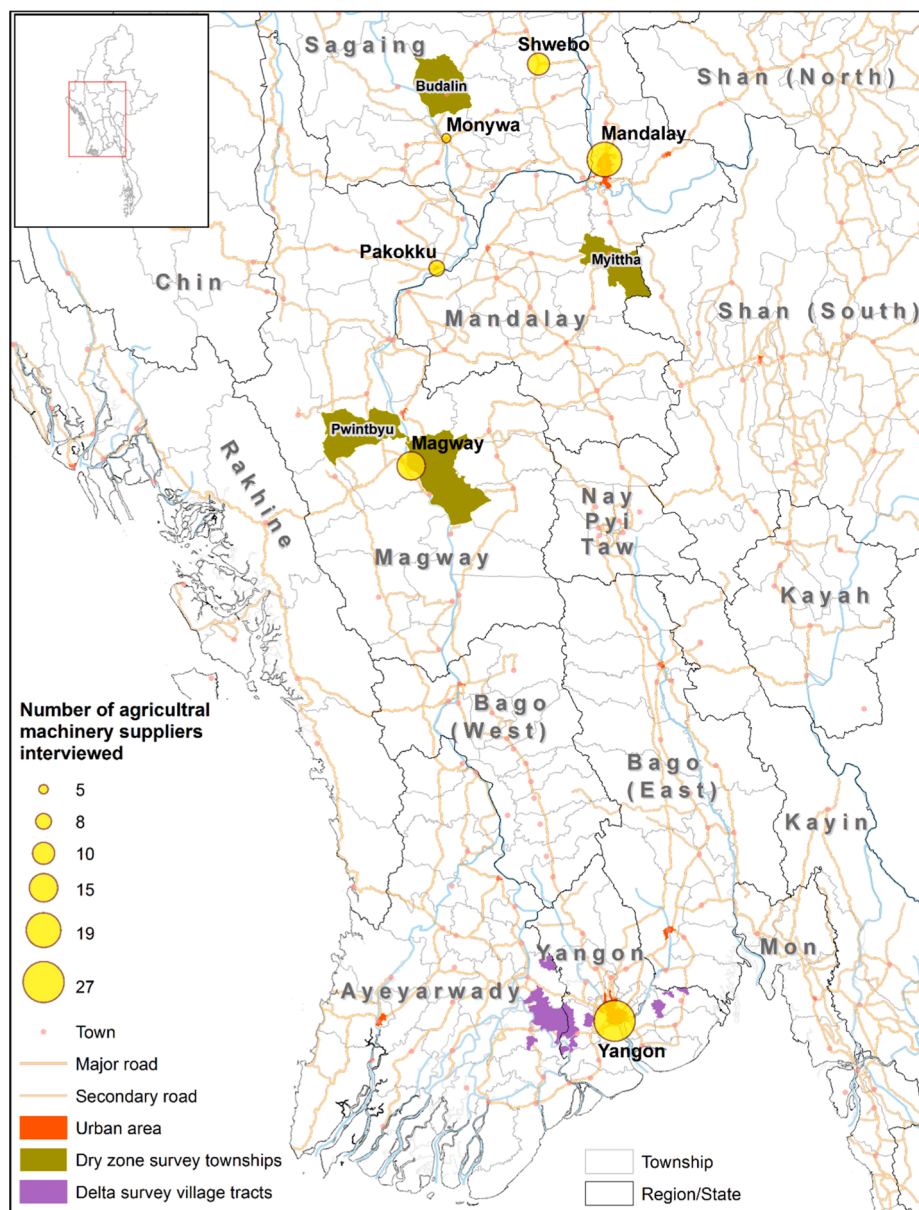


Fig. 1. Map Delta and Dry Zone household and agricultural machinery retailer survey locations.

3.1.2. Rental markets and farm size

Despite recent growth in agricultural machinery purchases, absolute levels of ownership remain low for most types of machine. The likelihood of owning a machine is highly correlated with landholding size. For example, in the Delta in 2016 only 1% of all surveyed households owned a four-wheel tractor or combine harvester. No households in landholding tercile 1 (the third of landed households with the smallest landholdings) owned a four-wheel tractor or a combine, rising to 20% and 7%, respectively, among households in tercile 3 that made use of these machines. Similar results were evident for four-wheel tractor ownership in the Dry Zone (Table 2).

Ostensibly this finding supports the conclusion, common in the ‘first wave’ of agricultural mechanization literature, that machines are “lumpy” inputs that require high levels of initial capital investment and “reach their lowest cost of operation per unit at relatively large areas”, thus favoring adoption by large farms (van Zyl et al. 1995: 3). This logic led Pingali (2007: 2790) to argue, with reference to Southeast Asia, that “in the absence of land consolidation and the re-design of the rice land to form large contiguous fields, the prospects for large-scale adoption of

the harvester-combines are limited.”

To the contrary, our data show that the growth of outsourcing services has enabled farms in Myanmar to mechanize irrespective of machine ownership and largely independent of farm size. Eighty-nine percent of machinery used by farmers in the Dry Zone, and 60% in the Delta, is rented. This regional difference reflects relatively high levels of ownership of two-wheel tractors in the paddy-dominated Delta, but in both zones four-wheel tractors and combine harvesters are accessed almost exclusively by renting (Table 2). There is no statistically significant difference in use of two-wheel tractors and four-wheel tractors by landholding tercile in either the Delta or the Dry Zone, and no difference for combine harvesters in the Dry Zone or threshers in the Delta: the likelihood of a household using these machines is largely independent of landholding size. In the Dry Zone, tercile 1 households (the smallest third of farms) are significantly more likely to use a thresher than those in tercile 3, likely due to differences in crop choice.

The rapid growth of machinery rental markets has allowed smallholders to access many of the benefits of agricultural machinery use (e.g. labor savings, timely completion of activities) derived by machine

Table 1

Number of machines acquired per 10,000 landed households[‡] in Delta and Dry Zone survey locations, by time period.

	'96- 98	'99- 01	'02- 04	'05- 07	'08- 10	'11- 13	'14- 16
Delta							
Water pump	97	176	14	155	850	805	797
2-WT	122	28	157	131	609	454	844
Thresher	0	3	112	193	171	160	275
Trawlerji	0	0	27	33	204	480	81
4-WT	0	0	26	6	41	26	21
Combine	0	0	0	0	0	0	107
Dry Zone							
Water pump	4	12	47	40	10	146	138
2-WT	33	12	57	118	50	261	296
Thresher	0	9	36	66	43	12	12
Trawlerji	7	0	0	9	19	8	34
4-WT	7	0	0	0	6	50	91
Combine	0	0	0	0	0	0	0

[‡] Source: Own surveys. Machinery ownership rates per 10,000 households estimated using survey weights.

owners with relatively large landholdings. These findings suggest that land consolidation is not a precondition for the widespread uptake of even quite large agricultural machinery where outsourcing services exist. We also find no evidence of accelerated land consolidation occurring due to the introduction of agricultural machinery, which might be expected if only large farms were able to utilize these technologies and gained an advantage by doing so. Liu et al. (2020) report similar findings from Vietnam, as do Basnet et al. (2021) for Bangladesh, India, and Nepal. In fact, average farm sizes in both the Dry Zone and the Delta are falling, due to sub-division at inheritance (Belton et al. 2021; Boutry et al. 2017).

The role played by mechanization outsourcing in Myanmar has parallels elsewhere in Asia. In Bangladesh, where average farm sizes are roughly five times smaller than in Myanmar (Hossain and Bayes. 2009; Boutry et al. 2017), rental markets enable 80% of farmland to be tilled by two-wheel tractor despite just 3% of households owning such a machine (Biggs et al. 2011). Similarly, despite small and fragmented

landholdings, farmers in China have outsourced activities such as harvesting to specialized mobile mechanization service providers, who travel throughout the country to harvest crops at very competitive prices (Zhang et al., 2017).

A vibrant informal private sector dominates the outsourcing services market in Myanmar. The rapid emergence of these small businesses reflects the existence of dense kin and community networks that serve as conduits for information (Faxon, 2020), magnified by the spread of mobile phone and internet communications that accelerated at extreme speed from 2014 (Belton et al. 2021). The extent and strength of these informal ties contrasts with generally low levels of trust in strangers and government institutions due to Myanmar's repressive political history.

Rental of small machines (e.g. two-wheel tractors and threshers) is offered mainly by farm households with medium or large landholdings, within the immediate vicinity of their villages. Large farms are the main outsourcing providers for large machinery, and often acquire machines principally to rent out to others. Four-wheel tractor owners usually service farms in the surrounding area, whereas combine harvester owners often provide services both locally and in more distant locations. For example, after providing services to nearby villages, combine owners from the Dry Zone use rented trucks to transport machines to other rice farming regions, including the Delta. Combine harvester owners from the Delta also provide outsourcing services to the Dry Zone. Combine owners often locate customers in distant locations through agents local to those areas, who earn a commission for recruiting customers through their networks of personal contacts, organizing harvesting schedules, and collecting payments (Belton et al. 2018; Phyto et al., 2019).

Although the government's Agricultural Mechanization Department (AMD) offers some machinery rental services, none of the households surveyed in the Delta reported using them, and only nine farmers did so in the Dry Zone (<1% of all machinery rentals). Machine rental by formal private businesses (e.g. machinery retailers) is also very limited. This pattern seems to reflect advantages that informal outsourcers with well-developed social networks in rural communities have in terms of flexibility and responsiveness, offering advantages over centralized models of service provision. Decentralized private service provision may provide other advantages. In her detailed study of green gram producers in Yangon, Okamoto (2008) reported that farmers favored rental

Table 2

Share of farm households using agricultural machinery in the past 12 months[±], by landholding tercile and machine ownership status (%).

	Tercile 1			Tercile 2			Tercile 3			All terciles		
	Using	Owned	Rented	Using	Owned	Rented	Using	Owned	Rented	Using [‡]	Owned [‡]	Rented [‡]
	Delta [±]											
Two-wheel tractor	76	15	85	72	35	65	70	90	10	73	43*	57
Four-wheel tractor	18	0	100	23	8	92	24	20	80	21	10*	90
Thresher	41	3	97	47	15	85	41	56	44	43	23*	77
Combine harvester	43	0	100	49	0	100	62	7	93	51*	3*	97
Any machine	96	12	88	96	32	68	97	81	19	96	40*	60
Farm size range (ha)	<0.1 – 0.9			1.0–3.2			3.3–33.6			<0.1 – 33.6		
Mean farm size (ha)	0.7			2.2			7.1			4.1		
N (households)	110			111			108			329		
	Dry Zone [±]											
Two-wheel tractor	30	11	99	26	29	71	26	60	40	27	30*	70
Four-wheel tractor	50	0	100	44	0	100	54	10	90	50	4*	96
Thresher	39	1	99	34	2	98	22	10	90	33*	3*	97
Combine harvester	8	0	100	11	0	100	9	0	100	9	0	100
Any machine	80	4	96	72	9	91	79	22	78	78	11*	89
Farm size range (ha)	<0.1 – 1.2			1.2 – 2.8			2.8 – 21.7			<0.1 – 21.7		
Mean farm size (ha)	1.8			2.0			5.9			2.8		
N (households)	339			282			315			936		

Note: [±] Interviews were conducted in mid-2016 in the Delta and mid-2017 in the Dry Zone. The recall period for data presented in this table is the 12 months preceding each survey. Significance calculated for *using* and *owned* only.

[‡] *Using* is the share of crop farming households that owned or rented machinery, per group. *Owned* and *rented* are shares of *using* households that owned or rented machinery, per group.

* Indicates that, for this parameter, there was a statistically significant difference between terciles at the 5% level (for at least one of the possible pairwise tests, T1 vs. T2, T1 vs. T3 or T2 vs. T3).

services provided by four-wheel tractor owners over those offered by both AMD and the Myanmar Economic Holdings company (a large military enterprise) due to the poor maintenance of machines from the latter two sources, and the ‘negligence’ of their operators, which was ascribed to the low wages they received.

3.1.3. Inter-zone differences in the form and extent of mechanization

Despite similarities across zones in the timing and pace of agricultural mechanization there are important zonal differences in the utilization of agricultural machinery that reflect variations in agro-ecology and associated crop choice. Paddy cultivation has undergone by far the most complete mechanization.

The most pronounced inter-zonal difference is the extent to which tractors have been used as a substitute or complement for animal draft power. In areas of the Delta surveyed in 2016, machinery had almost completely replaced animal traction in farming. Nearly all households (98%) reported using machinery for land preparation in the 12 months preceding the survey, compared to only 12% of farm households who used draft animals (Table 3). These findings contradict the traditional view that most farm households in Myanmar still rely on buffalo to plow paddy fields (Woods, 2013: 2). A similar recent shift from animal to machine traction is also reported by Soe and Kyaw (2019) in the uplands of southern Shan State. Based on a survey of maize and pigeon pea farmers they found that machines have nearly replaced draft animals in land preparation, with around 80% of surveyed households using only machines for this purpose, and 10% using draft animals.

A contrasting scenario prevails in the Dry Zone in 2017, where widespread uptake of tractors coexists with continued use of draft animal power for land preparation by almost all farmers. Three-quarters (76%) of farm households reported using both machines and draft animals, while 22% relied exclusively on draft animals, and just 2% used machinery only. This pattern appears to reflect differences in crop choice and soil type between the zones. Scoping interviews with farmers indicated that, particularly when cultivating sesame and groundnut, tractors are used primarily to break up hardened soils during initial plowing, while draft animal power is preferred for subsequent harrowing and inter-cultivation. Similar findings are reported by Berhane et al (2017) in Ethiopia.

The types of machinery used are strongly influenced by the dominant cropping systems in the two zones. Two-wheel tractors are deployed mainly in rice cultivation for puddling flood-irrigated soils, because heavier four-wheel tractors tend to sink into the muddy ground. Four-wheel tractors are preferred for preparing land for planting rainfed crops on soils that require more power to break apart on first plowing. As a result, in the Delta, 73% and 21% of farm households made use of two-wheel and four-wheel tractors, respectively, whereas in the Dry Zone corresponding shares were 27% and 50%.

Even more pronounced differences are found in harvesting and threshing. In the Delta, use of machinery for this purpose is almost as widespread as the use of machinery for land preparation. Half of farm

households (51%) surveyed in 2016 used a combine harvester, while 43% used mechanical threshers (i.e. at least 90% of farms made use of machinery for harvesting or threshing, given that combines also thresh). This level of uptake is remarkable, considering that just 0.5% and 6% of Delta households used combines and threshers, respectively, in 2010 (Win et al., 2018). In contrast, in the Dry Zone one third of farm households surveyed used mechanical threshers for harvesting crops, and only 11% used a combine harvester. Phyto et al. (2019) report very similar levels of combine harvester use based on a survey conducted in 2017, finding that 55% of farm households in the Delta and 10% in the Dry Zone had used a combine harvester that year, up from 11% and 2% in 2014.

Paddy is grown by nearly all crop-farming households in the Delta, compared to only half in surveyed areas of the Dry Zone, and occupies a much larger share of cultivated land in the former. To date, with the partial exception of green gram, there is little mechanized threshing and no mechanized harvesting of any crop other than rice in the two zones. Consequently, the pool of users of harvesting and threshing machinery is much smaller in the Dry Zone than in the Delta. The extent of mechanization in paddy production varies by season in both zones. In the Delta, 19% of farm households made use of combines to harvest the monsoon paddy crop in 2015, as compared to 35% of households who used combines during the following dry season⁴. In the Dry Zone, only 13% of paddy farming households used a combine during the monsoon season in 2016, as compared to 41% of households that grew paddy during the following dry season (though far fewer households grow dry season rice than monsoon rice).

Inter-seasonal variation is explained in part by the spatial concentration of paddy cultivation and harvesting services in irrigated or naturally well-watered areas, where large contiguous areas of paddy give outsourcing service providers access to high concentrations of customers. Higher rates of combine harvester use during the dry season may also be linked to the ability to harvest and thresh paddy quickly, allowing the subsequent monsoon paddy crop to be planted in time. Respondents in the Dry Zone reported that combine harvesting can reduce the palatability and volume of rice straw used as fodder for draft animals (c.f. Samarsinghe, 2021), making some Dry Zone farmers unwilling to use combines on monsoon paddy, which provides the bulk of straw for the year (Mather and Belton, 2018).

3.2. Supply side trends

This section focusses on the supply side of agricultural mechanization, tracking the spatial and temporal spread of machinery supply businesses, and growth and regional variation in machine sales.

3.2.1. Spatial and temporal spread of machine retailers

Machinery supply businesses were first established in urban centers adjacent to the ‘core’ rice growing regions that were first to begin the process of mechanization. Over time retail outlets have radiated outward to reach parts of the Dry Zone specializing in non-rice crops, finally extending to more ‘peripheral’ zones in upland and border areas. The number of machinery supply outlets jumped 338% between 2008 and 2018, up from 72 to 315, while the number of townships served by machinery retailers rose from 36 to 88 (27% of townships in the country) (Fig. 2). As a result, agricultural machinery has become locally available for purchase over progressively greater swathes of Myanmar, contributing to accelerating uptake. We recognize the potential for some ‘survivor bias’ in our sampling methodology as enterprises that went

Table 3
Share of farm households using machinery and draft animals in Delta and Dry Zone, by activity and year (%).

	2007/8	2012/13	2016/17	2016/17	Sample size
	Using machine	Using machine	Using machine	Using animal	
Land Prep.					
Delta	35	72	98	12	329
Dry Zone	11	32	74	83	1024
Harvesting					
Delta	5	10	57	1.5	329
Dry Zone	<1	3	12	2	1024

⁴ Most farm households in the Delta grow a monsoon rice crop followed by a post-monsoon pulse crop. In low-lying areas inundated by monsoon flooding, most households grow a single post-monsoon rice crop. Relatively few households double crop rice, and not all of these use a combine in both seasons. The share of farm households using a combine to harvest rice in any season is 51%.

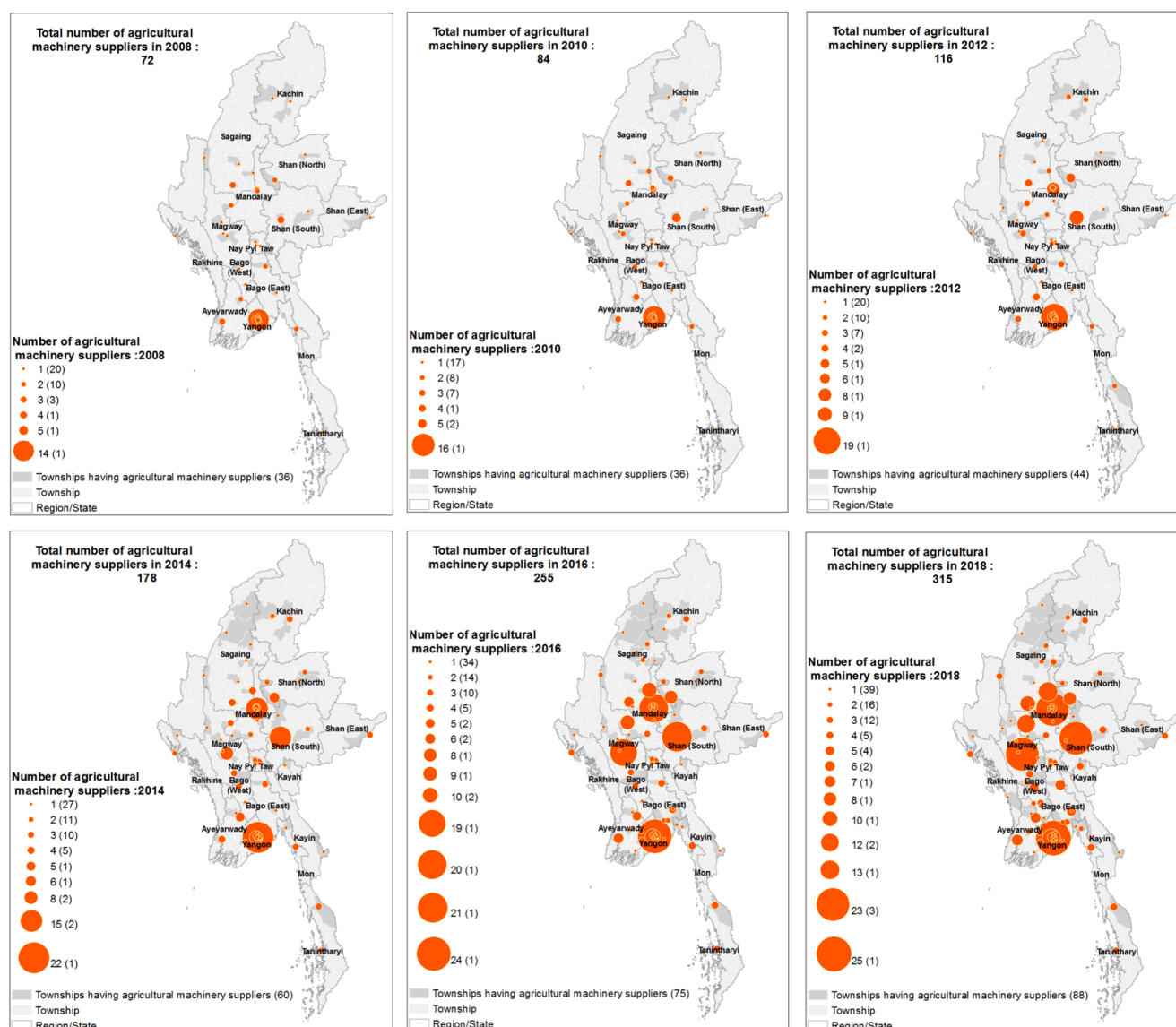


Fig. 2. Location and number of machinery supply businesses, 2008–2018 (Combined Dry Zone and Yangon survey results).

out of business prior to the survey could not be included. However, given the extremely rapid growth of machine retail businesses in the years immediately preceding the surveys and the close match between the results of the supply and demand side studies we are confident that these trends are not inflated dramatically.

During the 1980 s and 1990 s, machinery retail businesses were concentrated in Yangon. Numbers of machinery retailers grew very slowly during this period. From 2000 to 2010 business numbers increased gradually in the Delta, Dry Zone, and southern Shan, but remained concentrated in the Delta (which accounted for more than half of all outlets during this time), especially in Yangon. The first machinery supply businesses outside of these three zones, were established in 2006, in the border/upland states of Mon, Tanintharyi and Rakhine. The number of businesses has continued to climb all zones since this time, but the Delta's share in the national total has fallen, from 42% in 2012 to 34% in 2018.

The Dry Zone experienced an explosion in numbers of machinery enterprises from 2015, as widespread uptake of agricultural machines advanced beyond pockets of irrigated paddy to rainfed areas dominated by pulse and oilseed production. Retailers have sought to open branches in 'new' hinterland areas to extend their customer base as markets for machinery in the country's agricultural heartland have started to

mature. Numbers of machinery supply businesses in the upland and border states have also grown, though more slowly than in other zones, accounting for 23% of the national total in 2018. Much mechanization in the hills and borders is concentrated in upland maize cultivation, in the form of two-wheel tractors and maize threshers (Soe and Kyaw, 2019) (Table 4).

The machinery retail sector has become more concentrated over time. In 2003, 38% of branches were operated by retailers with a single outlet, and the remainder were operated by retailers with 2–10 branches. By 2018, only 16% of branches were operated by retailers

Table 4
Share of machinery businesses by geographical zone (%) (Combined Dry Zone and Yangon machinery retailer survey results).

Zone	2000	2003	2006	2009	2012	2015	2018
Delta	61	63	57	50	42	32	34
Dry Zone	14	20	24	29	34	43	43
Hills/borders	25	18	19	21	24	25	23

Note: Delta = Ayeyarwady, Bago, Yangon. Dry Zone = Magway, Mandalay, Nay Pyi Taw, Sagaing. Hills/Borders = Kachin, Kayah, Mon, Rakhine, Shan, Tanintharyi.

with a single outlet, and almost half were operated by retailers with greater than 10 branches, the largest of which operated 45 branches nationwide.

3.2.2. Composition and growth of machine sales

Growth in sales by machine supply businesses between 2012 and 2016 occurred simultaneously with the upsurge in machine ownership reported in the previous section. The most rapid sales growth occurred from 2014 to 2015, at the same time as the establishment of large numbers of new machinery supply outlets, particularly in the Dry Zone. More than one third (37%) of all machinery supply businesses in the Dry Zone were established during these two years.

The assortment of products stocked by machinery retailers matches regional customer preferences. For instance, four-wheel tractors were stocked by 95% of Dry Zone businesses, but only 44% of those in the Delta. Since 2012, small machines used in rice cultivation (water pumps, two-wheel tractors, and two-wheel tractor engines) have accounted for the bulk of sales volumes for machinery retailers based in Yangon. Sales of four-wheel tractors and combine harvesters grew particularly rapidly after 2014. Annual sales of combine harvesters by machinery retailers in Yangon increased nearly 6000% (from an extremely low base) in four years, with 90% of sales occurring in 2015 and 2016.

In the Dry Zone, four-wheel tractors and their attachments (disc plows and rotary tillers) are the most important items in terms of total sales. Dry Zone machinery supply businesses reported high, briskly growing sales of four-wheel tractors and their attachments throughout 2013–2017, roughly matching sales of two-wheel tractors. Sales of combine harvesters accelerated particularly rapidly from 2015, up 2630% between 2014 and 2017 (Table 5).

By 2017, a greater number of retailers offered a wider assortment of agricultural equipment than at any time before. At least 12 types of agricultural machine and equipment were available from Dry Zone retailers, contrasting with the early 2000s, when engines, light trucks and four wheel-tractors were the only items sold in the Dry Zone. The number of businesses marketing each type of machine has also increased sharply, with all items except trucks available from at least 10 surveyed businesses. The number of brands of machinery has also proliferated as retailers have sought to differentiate themselves. For instance, from 2013 to 2017 the number of four-wheel tractor brands on sale grew from six to 24, while the number of combine harvester brands grew from zero to nine.

However, the 2013–2016 boom in agricultural machinery sales appears to have peaked or plateaued in the Dry Zone in 2017. Sales of four-wheel tractors and combines by Dry Zone machinery retailers were 22% and 16% lower, respectively, in 2017 than in 2016⁵. This pattern was not yet apparent in Yangon at the time of the 2016 survey (Table 5). A study of machinery retailers in Myanmar in 2020 reported a large year-on-year decline in agricultural machinery sales compared to 2019 in both zones. The authors observed that while the COVID-19 pandemic had depressed sales, the market was likely also showing signs of saturation (Takeshima et al., 2020).

4. Factors influencing mechanization

This section of the paper seeks to explain trends outlined above, with reference to key demand- and supply-side factors influencing mechanization, including policies.

4.1. Structural transformation

The economic literature frames the process of mechanization as induced innovation that occurs when labor scarcity drives up rural labor

costs (Binswanger, 1986; Hayami and Ruttan, 1971; Liu et al. 2020; Pingali, 2007; Rigg, 1998). Although it is not possible to establish causality from the data available, we observe a strong correlation between the timing of rural–urban migration, rising rural wage rates, and the adoption of agricultural machinery in surveyed areas of Myanmar.

The timing of the onset of agricultural mechanization coincides with an uptick in migration that began around 2010 and continued in parallel with rapid urbanization until 2020. Eighty per cent of all the individuals in surveyed areas of the Delta and Dry Zone who had ever migrated did so after 2010. In both zones, migration increased briskly but steadily from 2011 to 2014, before accelerating faster still. More than half of all reported migration in both zones occurred between 2013 and 2016 (Fig. 3). Sixteen percent of households in surveyed areas of the Delta and 24% in the Dry Zone reported having at least one migrating member at the time of interview. Similar figures are reported by other recent studies (CHIME, 2019; Pritchard et al., 2017). Migrants' average age when first migrating is in the early twenties, so they are concentrated disproportionately among the most economically active and productive segments of the labour force. This has resulted in a significant contraction in the pool of available agricultural workers, which was referred to frequently by our respondents. Moreover, in some cases, remittances provide money to purchase machinery (Faxon, 2020), or hire mechanization services.

Labor shortages at key times of the cropping calendar are also reported by Phyo et al. (2019) in both zones covered by this paper. Phyo et al. find that labor available for agriculture in these areas is insufficient to meet farms' requirements, estimating that farms double-cropping rice face an average labor shortfall of 36%, while those growing rice followed by pulses face a shortfall of 29%. They attribute these shortages to simultaneous increases in migration and non-farm employment, noting that self-employment in non-farm enterprises, services, and casual and salaried non-farm work now account for a substantial and growing share of employment.

These observations align strongly with our own surveys that indicate high levels of livelihood diversification, and a proliferation of non-farm enterprises in both the Delta and Dry Zone over the same timeframe as the upsurge in mechanization and migration. This pattern signals growing rural economic opportunities outside the sphere of agriculture, and with them changing expectations, as non-farm work is increasingly preferred to physical labor 'under the sun' (CHIME, 2019; Phyo et al., 2016; Faxon, 2020). Improvements in access to post-primary education since 2011 likely also reduced the supply of agricultural workers by delaying age of first entry into the workforce. For example, in rural the Dry Zone the share of 17-year-olds completing Grade 8 jumped from 35% in 2010, to 60% in 2017 (Belton and Filipinski, 2019).

These changes appear to be responsible for a sharp increase in real agricultural wages. Recall data from our surveys shows that real wages for causal farm workers (adjusted for inflation) increased by 37% in surveyed areas of the Delta over the period 2011–2016, and 39% in the Dry Zone from 2012 to 2016 (Fig. 4). Hired labor is one of the largest categories of expenditure even among small farms, amounting to approximately 20–30% of production costs depending on the crop, and almost all farms in the Delta (95%) and Dry Zone (93%) employ casual workers (Cho et al., 2017; Mather et al. 2018). Increasing real wages therefore seem to have provided a major incentive to farmers to mechanize the most labor intensive parts of crop production where possible.

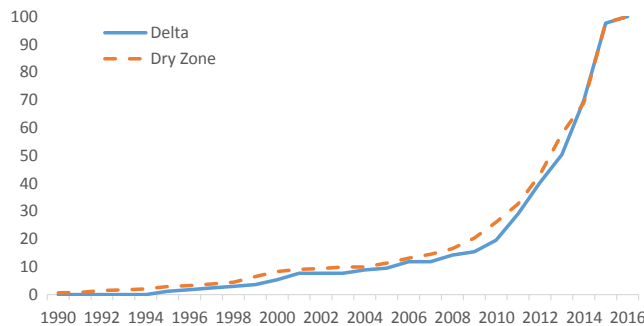
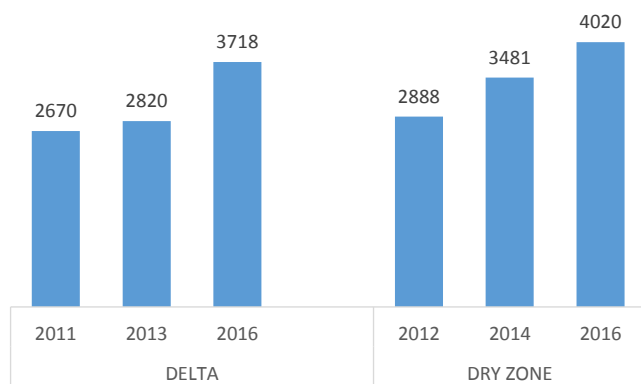
The use of combine harvesters for paddy cultivation results in significant labor savings during harvesting and threshing. For farms in the Dry Zone this is equivalent to a saving of 18 person days/ha as compared to manual harvesting and mechanized threshing, and a saving of 28 person days/ha relative to manual harvesting and threshing (Mather and Belton, 2018). Phyo et al. (2019) report similar results. Labor savings of this magnitude are equivalent to a substantial reduction in labor costs, and the real cost per hectare of hiring combine harvester services has remained relatively constant, even as real wages climbed sharply (Belton et al. 2017).

⁵ Sales figures were collected during December 2017, so likely slightly underrepresent total sales for 2017.

Table 5

Total annual sales of surveyed machinery supply businesses in Yangon (2012–16) and Dry Zone (2013–17).

	Yangon										
Item	2012	2013	2014	2015	2016	2017	% change (‘12–13)	% change (‘13–14)	% change (‘14–15)	% change (‘15–16)	% change (‘12–16)
4-WT	275	420	870	1662	3200	–	53	107	91	93	1064
2-WT	4959	6450	7457	8772	13,824	–	30	16	–28	18	179
Water pump	960	1035	2551	2585	4150	–	8	146	–6	1	332
Engine/ dynamo	4025	10,512	60,255	56,518	94,876	–	161	473	303	–6	2257
Combine	0	40	237	955	2372	–	–	493	303	148	5830
Reaper	305	335	860	1351	1244	–	10	157	57	–8	308
Thresher	0	30	220	167	46	–	–	633	–24	–72	53
Trawlerji	1692	1840	2500	2500	3700	–	9	36	0	48	119
	Dry Zone										
Item	–	2013	2014	2015	2016	2017	% change (‘13–14)	% change (‘14–15)	% change (‘15–16)	% change (‘16–17)	% change (‘13–17)
4-WT	–	1045	1320	2771	4278	3584	26	110	54	–16	243
2-WT	–	440	2678	1978	3338	3190	509	–26	69	–4	625
Water pump	–	110	155	130	171	146	41	–16	32	–15	33
Engine/ dynamo	–	480	2690	2002	1969	2672	460	–26	–2	36	457
Combine	–	0	15	140	523	407	–	833	274	–22	2613
Reaper	–	10	10	229	248	273	0	2190	8	10	2630
Thresher	–	0	10	21	31	56	–	110	48	81	460
Trawlerji	–	5	263	345	349	553	5160	31	1	58	10,960

**Fig. 3.** Cumulative share of migrants by year of migration and place of origin (%).**Fig. 4.** Average daily wage rates for casual agricultural labor in the Delta (2011–2016) and Dry Zone (2012–2016), in MMK at constant 2016 prices.

However, labor substitution appears insufficient to explain the rapid uptake of tractors in land preparation. Labor savings from mechanization of land preparation are quite small, ranging from 2.5 person-days per hectare for groundnut, to 9 person-days per hectare for sesame, and most of labor saved is family labor, so cash savings are limited (Mather and Belton, 2018). Indeed, Belton and Filipinski (2019) estimate that in the Dry Zone, where land preparation accounts for most

mechanized agricultural activity, farm households have reduced the costs of hiring agricultural wage labor by only 8% on average of due to mechanization. This observation highlights the importance of other factors in shaping demand for agricultural machinery. We outline these below.

4.2. Timeliness, speed, drudgery, risk, and yields

Data from our survey of Dry Zone households points to a mix of benefits associated with mechanization besides simple reductions in labor costs. These include: (1) Increased speed of operations and reduced drudgery; (2) Enhanced timeliness of key activities; (3) Improved ability to manage weather related risks; (4) Reduced losses of grain during harvesting.

First, mechanization reduces the amount of time required to complete key activities. Preparing 1 ha of land for planting with draft animals takes an average of 31 h, compared to 10 h with a two-wheel tractor, and 3 h with a four-wheel tractor (Soe and Kyaw, 2019). By reducing the duration of these tasks, mechanization reduces the amount of physically demanding work that members of farm households must perform. As the amount of hired labor and the opportunity cost of family labor saved by mechanized land preparation is quite small, extremely widespread uptake of machines for land preparation suggests that farm households may consider their drudgery-reducing characteristics at least as important as utility enhancing effects such as lower expenses or higher margins (van der Ploeg, 2013). A further advantage of mechanical tractors is that they require only occasional maintenance and outlay on fuel, whereas draft animals must be cared for constantly, with daily feeding, watering, and washing requiring an average of 1.5 h of family labor each day. Fodder is often purchased, and hired labor and veterinary expenses may be required, equating to an average outlay of \$58 per year by households owning draft animal (Soe and Kyaw, 2019).

Second, labor scarcity can make it difficult to marshal sufficient workers to perform time-dependent tasks. Some farmers seek to avoid this problem by offering advance wages to workers one to two months before harvest to guarantee their availability (Okamoto et al., 2021). Although this practice remains quite common in both Delta and Dry Zone, it can be difficult for farmers to raise sufficient funds to pay advances, and most workers are not contracted in advance. In contrast, our scoping interviews suggest that mechanization services can be scheduled some days or weeks in advance and that, particularly for

harvesting, payment is often made after crops have been sold, ensuring greater timeliness and reducing cash flow problems for farm households.

Third, timeliness and speed of operations can facilitate risk management. In the Delta, timely harvesting of the monsoon rice crop is important for farmers planting a post-monsoon pulse crop that is reliant on residual soil moisture. The timing of planting and harvesting is even more significant in the Dry Zone, where most farming is rainfed and weather patterns can be highly variable from year to year (Matsuda, 2013). Excessive or inadequate rainfall early or late in the cropping cycle, or heavy rain while the crop is drying, cause frequent and sizeable crop losses. Approximately one-quarter to one-half of Dry Zone farmers report weather-related yield losses for most major crops (Mather et al. 2018). Growers of dry season paddy and groundnut who used a tractor were less likely to report any pre- or post-harvest crop losses than those using only draft animals, suggesting that mechanization may help to moderate these risks. For example, 29% of dry season paddy farmers who made use of a tractor reported crop losses, as compared to 40% of those who did not. Among groundnut growers, the numbers were 16% and 33%, respectively.

Fourth, farmers using combine harvesters report higher yields than those using mechanized threshers, and farmers using mechanized threshers report higher yields than those who thresh paddy manually. During dry season, Dry Zone combine harvester users obtained 640 kg more paddy per hectare more than households practicing manual harvesting/threshing (a 19.5% yield difference). The yield gap between households using combines and those using mechanized threshers stood at 400 kg/hectare (11%) (Mather and Belton, 2018). Farmers interviewed during scoping research were well aware of these gains, which they attributed to reduced spillage of grain during harvesting and threshing, implying higher realized yields through reduced waste and loss, rather than increases in biological productivity.

4.3. Financing and machinery prices

On the supply side, access to formal financial services has made it easier for potential buyers to purchase agricultural machinery, while the real price of machinery has fallen steadily since the removal of import restrictions. These developments have placed agricultural machine ownership within the reach of a growing, though still small (in relative terms) segment of the rural population.

Two main forms of consumer finance are available for agricultural machinery: (1) hire-purchase loans offered by machinery retailers using their own working capital; (2) hire-purchase arrangements offered by private banks and other commercial financial institutions in partnership with machinery retailers. Financing from banks has helped to overcome liquidity constraints for machinery retailers and their customers. Banking regulations prevent businesses from borrowing more than the value of their fixed assets, making it difficult to extend large volumes of credit, particularly for four-wheel tractors and combines, which cost from \$13,000 to \$31,000 on average, depending on brand and country of origin. Hire-purchase arrangements, offered by banks to customers, using machinery retailers as intermediaries, overcome this problem. Hire purchase customers are vetted by machinery dealers, which serve as guarantors to the bank, helping to overcome the information asymmetry problem identified by Binswanger & Rosenzweig (1986). Customers make a down payment and repay the remaining principle in installments with interest, usually over one to two years. Hire-purchase loans remove the need for buyers to save the entire cost of a machine before making a purchase. Borrowing from informal lenders to fund machine purchases at rates of interest averaging around 5% per month (60% per year) would likely make both personal use and rental service provision unviable and was almost never reported by respondents. In contrast, interest on loans issued by commercial lenders in Myanmar is capped at 13% per annum.

Banks first began to offer hire-purchase loans for agricultural machinery in 2013. The number of banks providing this type of finance

increased quickly, from five in 2014 to 11 in 2017. Throughout this period two banks, Yoma and MCB, dominated the provision of hire purchase finance. Yoma accounted for 41% of partnerships with machinery dealerships in 2014, rising to 48% in 2017, while MCB accounted for 23% of partnerships in 2014, remaining constant at 24% in 2017. Uptake of these financial services has been swift. Almost all (94%) machinery supply businesses surveyed in the Dry Zone in 2017 offered some form of hire-purchase financing, among which 84% did so in partnership with banks. By 2016, most sales of combine harvesters and four-wheel tractors by retailers in Yangon (77% and 68%, respectively) were financed by hire-purchase loans from banks. Even higher levels of utilization were reported in the Dry Zone in 2017, where bank-supported hire purchase accounted for 98% of combine harvester sales and 62% of four-wheel tractor sales. In contrast, hire-purchase finance direct from machinery retailers to customers accounted for just 5% and 2% of four-wheel tractor and combine harvester sales in Yangon in 2016, and 16% and 2% in the Dry Zone in 2017. (Table 6).

In parallel over the same period, machinery - which is nearly all imported - became more affordable. This reflects the increased supply of machinery at competitive prices, primarily from neighboring China and Thailand, as well as Myanmar's policy of not levying tariffs on imports of agricultural inputs, including machines and machine parts. The real (inflation adjusted) average cost of purchasing a water pump, as reported by households in the Dry Zone, dropped from \$800 in 2007 to less than \$300 in 2017, an average reduction of \$50 per year, while the cost of a two-wheel tractor dropped from nearly \$3000 to well below \$1000 over the same period. Households in the Delta reported similar figures.

4.4. Policies and interventions

Changes in the accessibility of machines and finance for machine purchases stem mainly from policy changes implemented during Myanmar's 2011-2020 reform period. Donor-supported interventions played a complementary role.

Prior to 2012, private banks were not allowed to extend credit to farmers (OECD, 2014). Relaxation of these restrictions played a critical role in enabling the provision of formal finance for machinery purchases. Myanmar's Farmland Law, passed in 2012, played a complementary role. The Farmland Law made agricultural land use rights transferrable, allowing land use rights certificates ("Form 7") to be used as collateral for formal loans. This change overcame an important obstacle to accessing finance, at least in lowland regions where a high percentage of farm households possess formal title to the lands they occupy (Boutry et al, 2017). However, ownership and use of two-wheel tractors has also increased rapidly in upland Shan State, where most land is untitled and thus inadmissible for use as collateral for bank loans (Soe and Kyaw, 2019). This suggests that, while likely contributing to the acceleration of the mechanization process, particularly for larger and more expensive machines, formal land titling is not a precondition for widespread mechanization.

Table 6
Share of Yangon (2016) and Dry Zone (2017) machinery supplier sales, by source of finance and machine type (%).

Source of finance	Combine harvester	Four-wheel tractor	Two-wheel tractor
Yangon			
Bank (hire purchase)	77	68	35
Dealership (hire purchase)	2	5	17
Customer (paid in full)	22	27	48
Dry Zone			
Bank (hire purchase)	98	62	74
Dealership (hire purchase)	2	16	17
Customer (paid in full)	0	22	9

Many banks now offer hire-purchase loans for agricultural machinery, but provision of hire-purchase finance is dominated by Yoma Bank, which accounted for almost half of partnerships with surveyed machinery retailers in 2017. Yoma Bank's prominence is linked to a program initiated by one of Myanmar's main development actors, the Livelihoods and Food Security Trust Fund (LIFT)⁶. LIFT allocated \$18 million to Yoma's hire-purchase portfolio for financing of agricultural equipment in 2016, to serve as a buffer against any losses incurred. This investment encouraged Yoma to reduce size of down payments on agricultural machinery and increase the average duration of loans from 1 year to more than 2.5 years. Sales made under the scheme from 2016 to 2018 had a total value of approximately \$122 million, including 4,002 tractors and 967 combine harvesters (Yoma Bank, 2019). This is equivalent to 86% of the four-wheel tractors and 103% of the combine harvesters sold by machinery retailers surveyed in the Dry Zone in 2016 and 2017 (Table 5).

Exemption of agricultural equipment and machinery from import controls, beginning in 2012, has been particularly significant. Imports of agricultural inputs, including machinery, were exempt from import tariffs even before the reform period. However, until 2012 agricultural machinery (along with many other categories of goods) was subject to strict controls by the Ministry of Commerce, which issued import licenses only if companies could produce export receipts of equal value to the items imported, severely restricting scope for large-scale trade (WTO, 2014; Htay, 2016).

Except for the LIFT-Yoma scheme, the initiatives listed above were part of wider policy reforms that did not seek specifically to boost agricultural mechanization. Their effectiveness can be contrasted with attempts to intervene directly in the provision of machinery rental services and marketing. From 2010 to 2017 AMD invested heavily in purchasing agricultural machinery with the intent of providing rental services to farmers. Expenditure on machines and associated costs accounted for 18% of the total budget of the Ministry of Agriculture Livestock and Irrigation by the end of this period. Despite its large investment, AMD is only able to meet a fraction of total demand for mechanization services, and the machinery offered often does not include brands most preferred by farmers. Accessing services through AMD can be more complicated and time consuming than doing so through private providers, which are numerous, highly decentralized, and flexible in responding to customer needs. A report from the World Bank (2017: 63) notes that "very few farmers have access to AMD's rental services". This observation is supported by our own survey in the Delta, in which no respondents reported having made use of machine rental services provided by AMD.

The Department of Cooperatives (DOC) has also sought to accelerate mechanization, by providing hire-purchase finance arrangements, using a \$100 million loan from a South Korean company to finance the purchase of agricultural machinery. Machines distributed under this agreement were manufactured by the company that provided the loan (World Bank, 2017). According to several of our respondents, the scheme had a preferential four-year hire-purchase term and low rate of interest, but the manufacturer failed to provide spare parts or after-sale repair services, and the equipment was said to be poorly suited to use under local conditions. Demand for the machines was somewhat limited as a result, particularly for combine harvesters.

5. Discussion and conclusions

This paper contributes to the 'new wave' of literature on agricultural mechanization using two pairs of complementary demand-side (farm household) and supply-side (agricultural machinery retailer) surveys from Myanmar's two main agricultural zones. Myanmar offered an ideal vantage point to survey the process of agricultural mechanization in

'real time', as changes that took decades to play out in some other countries occurred in scarcely five years. We draw the following conclusions that link our results to key themes in the literature.

First, we find many similarities between Myanmar with other Asian countries where rapid agricultural mechanization has occurred. Key elements are tightening rural labor markets linked to urban growth, rural out-migration, and expanding rural non-farm employment, in an agrarian context where large numbers of small farms are already well-integrated into markets, including the market for farm labor. These changes tend to come bundled together with, and to be reinforced by, the development and expansion of rural transport and communications infrastructure, electrification, and access to education.

On the demand side, these changes appear to contribute to induced innovation, as predicted by the classic mechanization literature. This is especially evident in the case of rice harvesting, leading to cost savings and/or 'releasing' family labor for other work. However, a variety of factors contribute to mechanization's appeal to farmers. Mechanization is can facilitate quicker and timelier planting and harvesting. These advantages may assist farmers in managing risks that become more pronounced in a context of labor scarcity and climatic variability. A further, and somewhat overlooked aspect is the reduction in physically demanding work that farm households must perform, including caring for draft animals, in a setting where agricultural work is increasing viewed as undignified (Faxon, 2020). Further, with the growth of outsourcing services and mobile communications, the convenience of summoning a machine operator by phone, rather than contacting and overseeing multiple casual workers, may be at least as significant as purely economic calculus. Rather than representing a single transformational change, mechanization's broad appeal to farm households seems to result from an accumulation of incremental, complementary advantages, the whole of which is perhaps greater than the sum of the individual parts.

On supply side, similar to countries including China (Zhang et al. 2017), Thailand (Cramb and Thepent, 2020), Bangladesh (Mottaleb et al. 2017), and Nepal (Takeshima, 2018), rapid mechanization has coincided with the growth of decentralized, self-organized, private outsourcing services, provided primarily by rural machinery owners. Indeed, mechanization on such a wide geographical scale within such a short duration, in an agrarian setting comprised mainly of small and medium sized farms, would be likely have been impossible without the emergence of these actors. Services provided are tailored to the requirements of this client base, making machinery accessible to farms of all sizes at prices similar to or below those paid for manual labor or animal traction. Machinery owners and outsourcers have benefitted from the proliferation of agricultural machinery retailers throughout all major agricultural zones. Retailers have been enabled by lack of barriers to the import of agricultural machinery and spare parts. Coupled to Myanmar's location adjacent to China and Thailand – both major agricultural equipment manufacturers – this ensures direct access to a range of relatively inexpensive 'off the-shelf' technologies developed to suit similar agrarian conditions.

Extremely high levels of uptake within a very short space of time in varied agroecological settings suggest strongly that farmers find machines useful, and that the modality by which the machines are accessed is appropriate to the contexts in which the farmers operate. While mechanization alone may not be sufficient to guarantee the long-term viability of small farms in Myanmar, these farms would face greater difficulties responding to the challenges of labor scarcity, rising rural wages, and climate variability if they were unable to access machinery on demand. Importantly, while machine rental services may offer a pathway to accumulation for the larger farms that typically operate such business, our results do not suggest a zero sum game in which small-holder users of these services are disadvantaged.

With respect to implications for efforts to support mechanization elsewhere, the single most critical supply side intervention of the past decade in Myanmar has been the liberalization of import restrictions on

⁶ A multi-donor trust fund.

multiple categories of goods, including agricultural machinery. Similar effects have been reported in Bangladesh, where removal of restrictions on importing Chinese pumps and diesel engines after a cyclone in 1988 was followed by an upsurge in use (Mottaleb et al., 2016). The lack of tariffs placed on imported agricultural equipment and spare parts in Myanmar is helpful, but less fundamental than the ability of retailers to import equipment on demand. However, Myanmar's location adjacent to countries that manufacture and export large quantities of relatively low-cost agricultural machinery with appropriate designs is more difficult to replicate in other geographical contexts.

The decision to allow banks to offer hire-purchase loans was a key policy that affected both the demand- and the supply-sides (as machine owners are often simultaneously customers of machinery supply businesses, and outsourcing service providers) by facilitating access to substantial amounts of formal credit. Amendment of the Farmland Law to enable land use rights certificates to be used as collateral for bank loans was complementary to this move. These changes have been particularly consequential for large, expensive machines such as combine harvesters and four-wheel tractors, and helpful but not a precondition for the uptake of smaller machines such as two-wheel tractors, which have become increasingly affordable over time. Similar findings are reported in Cambodia, where a recent upsurge in combine harvester outsourcing services has been linked to an increase in the availability of high value loans through 'microfinance' lenders, collateralized using farmland (Yagura, 2020).

Broad macro or meso scale policy interventions aimed at enhancing the 'enabling environment' have tended to bring about bigger responses than those specifically aimed at promoting agricultural mechanization. A notable exception is the LIFT-Yoma loan guarantee scheme, that accelerated an ongoing process of machine acquisition by lowering barriers to loan access. These efforts contrast with the more limited success of attempts to intervene directly in machinery supply via public private partnerships or direct provision of rental services. It is worth reiterating that very few farmers in Myanmar access mechanization via state-owned hire centers, given that many governments in 'new' geographical contexts devote significant resources to promoting such schemes.

Finally, the agro-ecologies in Myanmar that mechanized first and most completely are rice-growing lowlands, particularly the well-watered deltaic and dam-irrigated areas where double-cropped paddy is concentrated. Gradual uptake of water pumps, two-wheel tractors, and threshers preceded the spread of combine harvesters and four-wheel tractors in these areas. These technologies have subsequently penetrated increasingly peripheral geographies and been taken up in production of non-rice crops, particularly for land preparation. This sequence suggests that attaining a critical mass in clusters where conditions are particularly ripe for mechanization can give rise to spillovers to other regions, as equipment becomes more widely available at lower cost, undergoes "proof of concept", and is promoted in more distant areas by machinery retailers and outsourcers as original clusters approach saturation. Attempts to establish mechanization in new geographies should be cognizant of these dynamics and seek to encourage the development of mechanization clusters in areas with optimal conditions, as a prelude to subsequent expansion.

CRedit authorship contribution statement

Ben Belton: Conceptualization, Methodology, Investigation, Writing - original draft, Supervision. **Myat Thida Win:** Formal analysis, Investigation, Writing - original draft. **Xiaobo Zhang:** Conceptualization, Investigation, Writing - review & editing, Supervision. **Mateusz Filipski:** Formal analysis, Investigation, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial

interests or personal relationships that could have appeared to influence the work reported in this paper.

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