Status of Appropriate-Scale Mechanization in Zambia and Zimbabwe

A report produced for the ACASA project and the CGIAR Regional Initiative, Ukama Ustawi: Diversification in East and Southern Africa

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Contents

Abstract

Unlocking the potential of smallholder agricultural productivity hinges on the pivotal role of mechanization, serving as the cornerstone to raise crop yield and improve livelihoods. However, evidence is thin on fit-for-purpose appropriate mechanization in the south of the Sahel. This study used a quantitative survey to understand the status of appropriate-scale mechanization in Zambia and Zimbabwe. In both countries, 50 service providers participated in the survey together with 210 farmers who used mechanization services and 219 farmers who did not. We find that farmers who used mechanization services had higher maize yield and higher household incomes. But there are nuances. First, mechanization service providers are older, predominantly male, and more educated. Second, the distributional effects show that hiring mechanization is associated with statistically significant higher outcomes in the 75th and 95th percentiles of income and yield. These results point to a need for structured promotion approaches that allow all farmer types to equally benefit from mechanization services. There is a need for more work on the economics of appropriate scale agricultural mechanization to further understand profitability and returns to investments.

Keywords: Service provider, two- and four-wheel tractor, sheller, transport, impact, smallholder farmers.

Introduction

Mechanization is necessary to improve productivity and production efficiency of smallholder agriculture and for sustainable and resilient agricultural sectors. Agricultural mechanization refers to the use of machinery and equipment to either replace or assist manual labor in various agricultural operations across entire agri-food value chains from land preparation, planting, spraying, fertigation, harvesting, processing, and transportation of produce (Van Loon et al., 2020). Farm mechanization refers to the use of machines to perform farm operations like land clearing, land preparation, weeding, harvesting and post-harvest handling. It is restricted to operations that happen on the farm, while agricultural mechanization is broad and considers the use of machinery in entire agric-food value chains. Mechanizing agricultural operations streamlines tasks, leading to higher productivity and effectiveness.

Embracing agricultural mechanization addresses labor constraints, improves production efficiencies, reduces production costs, enhances the timeliness and quality of farm operations, and reduces drudgery (Zhou & Ma, 2022). Machines perform tasks faster, with greater precision and on a larger scale compared to manual labor. Tractors, for instance, can plough fields more evenly and faster, while saving time and effort. Various machinery, such as planters, harvesters, and irrigation systems, streamline field activities, minimize wastage, and increase productivity with timely operations (Sayed et al., 2022). For example, planting, cultivating, and harvesting crops can be expedited with the use of appropriate machinery, enabling farmers to capitalize on favorable weather conditions to maximize crop yields. Mechanization empowers farmers to work on larger land areas and scale up operations (Liao et al., 2022; Takeshima et al., 2020; Wang et al., 2020). The ability to cover more ground efficiently allows for expanded production, improved market competitiveness, and enhanced profitability. Moreover, agricultural machinery facilitates precise operations, contributing to enhanced crop quality (Dhiman & Dhiman, 2015; Luo et al., 2016).

Mechanization reduces the demand for manual labor, which can be advantageous in places where labor is scarce with higher wages (Gauchan & Shrestha, 2017). Following the Theory of Induced Innovations (Ruttan & Hayami, 1973), as labor becomes scarce or expensive, labor-saving options like mechanization take over labor-intensive or labor-using alternatives use of hand hoes. Such a switch frees farmers of physical exertion and allows them to utilize their resources more efficiently. In addition, mechanization can assist farmers in adapting to climate change (Sims & Kienzle, 2016). For example, irrigation can reduce the effects of droughts, while mechanized, planting and harvesting can optimize precise and timely agricultural production in shifting climatic conditions, increasing resilience, and lowering risks associated with weather fluctuations. Given its potential merits, agricultural mechanization has incredibly good political support to increase food production and productivity to meet growing demand. The support for agricultural mechanization is highest in Africa where there is a greater need to increase food production to feed a growing population. In support of the current drive towards mechanization, nascent evidence shows that demand for mechanization is rising in Malawi (Tufa et al., 2023), in Zambia and Zimbabwe (Ngoma et al., 2023) and that investments in mechanization raise productivity (Omulo et al., 2022). In addition, farmers that access mechanization services tend to have better income earning opportunities due to increased land under cultivation (Adu-Baffour et al., 2019). Despite some positives, there is a need to bolster the evidence to support the current drive to mechanize smallholder agriculture in Africa. The study responded to this call. It was carried out under the auspices of the *Understanding and Enhancing Adoption of Conservation Agriculture in Smallholder Farming Systems of Southern Africa (ACASA) project* and *the CGIAR Regional Initiative, Ukama Ustawi (UU): Diversification in East and Southern Africa*. These two initiatives are among several development efforts that seek to find sustainable ways to scale out proven sustainable intensification practices and mechanization options by facilitating the creation of an enabling institutional and policy environment in east and southern Africa. The ACASA project is funded by the Norwegian Agency for Development Cooperation (Norad) and implemented by the International Institute of Tropical Agriculture (IITA) and the International Maize and Wheat Improvement Centre (CIMMYT) in Malawi, Zambia, and Zimbabwe. Fieldwork was done in parts of Zambia and Zimbabwe, where mechanization has been promoted using the service provider model over the past 2 – 5 years.

Problem Statement

The drive to mechanize African agriculture heightens, albeit with some gaps in our understanding of the economics of appropriate scale mechanization. Yet, this is the bottom line used by farmers when deciding whether to adopt mechanization or not. In deciding whether to adopt mechanization, farmers weigh the costs and benefits of various technologies and machinery. In doing so, farmers choose where it makes the most sense to invest to maximize returns.

While it is believed in general that mechanization can improve agricultural production efficiency and productivity (Kirui, 2019; Sampene et al., 2022), it is still unclear how these effects vary across different farmer groups and different mechanization value chain actors such as: service providers, farmers that received mechanization services etc. The availability of labor and the dynamics of the agriculture industry are critical in determining the profitability of mechanization. Understanding labor market dynamics assists farmers in determining whether mechanization is a viable option in situations with limited labor availability and high wages. Further, understanding the economic consequences of mechanization helps policymakers and stakeholders in developing effective policies to manage anticipated labor market shifts. It also enables stakeholders to make informed decisions, optimize resource allocation, and build supportive policies for sustainable agricultural development.

Despite the potential for agricultural mechanization, its uptake remains limited and evidence of its impact among smallholders remains scanty. There is a lack of comprehensive understanding of the business case for mechanization and its impacts on livelihoods among smallholder farmers. This study was designed to contribute towards filling these gaps using case studies from Zambia and Zimbabwe. The primary objective of the study was to assess the business case of mechanization for service providers and the impacts of mechanization on productivity and livelihoods for farmers who accessed mechanization services. Specifically, the study assessed the (i) kinds of services hired out by whom and when, and (ii) impacts of mechanization on livelihoods and land productivity. We hypothesized that: *(i) there is no significant increase in yields for smallholder farmers who use mechanization compared to those who do not utilize mechanization services; (ii) smallholder farmers adopting mechanization do not experience a notable rise in income when compared to those relying solely on manual labor;* and that *(iii) factors such as farm size, crop type, rural wages, access to credit, and training opportunities do not play a significant role in influencing the decisions of smallholder farmers to adopt appropriate-scale mechanization in Zambia.*

Methods

Sampling and data collection methods

Fieldwork was done between June and August 2023 in both Zambia and Zimbabwe. Sampling in both countries included a blend of purposive and simple random sampling methods. In Zambia, the survey was conducted in June 2023 in Mazabuka and Monze districts in the Southern province; Chipata, Lundazi, and Sinda districts in the Eastern province; and in Senga Hill and Mbala districts in Northern Province. Sampling was multistage, where the initial stage involved purposefully selecting all three provinces, seven districts and eleven camps where CIMMYT has been implementing mechanization activities through the service provider model since 2020. At the time of the survey, there were 20 mechanization service providers across these locations.

Within each province, respondents were selected randomly across four categories: individual mechanization service providers, group/cooperative service providers, farmers who accessed mechanization services, and other farmers who did not access mechanization services. Sampling frames for each category were drawn from up-to-date lists of mechanization service providers and farmers they serviced, and from the Ministry of Agriculture for other farmers. In total, 227 respondents were selected across the four categories: fifteen individual mechanization service providers; two group/cooperative service providers; 105 farmers who accessed mechanization services; and 105 farmers who did not access mechanization services. To ensure representation, five individual mechanization service providers were randomly sampled from each province. For both the treatment and control groups, an equal number of farmers who accessed mechanization services and those who did not were randomly sampled in Eastern, Northern, and Southern provinces. Group/cooperative-based mechanization services are not prevalent in most intervention districts; thus, interviews were conducted with only one group in Mbala district and one in Lundazi district.

In Zimbabwe, fieldwork was done in June 2023 in Shamva, Bindura, Makonde, and Masvingo districts where CIMMYT has implemented mechanization activities through the service provider model since 2020. Among these districts, there were forty-two service providers (SPs), with Masvingo having the highest at 32, and the remaining eight were distributed across Shamva (2), Bindura (2), and Makonde (4). Thirty-three (33) SPs were randomly selected without consideration of the district or ward of origin. Additionally, 24 farmers who utilized mechanization services from SPs and 24 farmers who did not use mechanization services, residing in villages adjacent to the SPs, were randomly selected per district. Interviews were conducted with irrigation schemes, cooperatives, or groups providing mechanization services to farmers. Overall, two groups were interviewed in Shamva, four in Masvingo, one each in Bindura and Makonde, respectively. The overall sample in Zimbabwe was 252, categorized as follows: thirty-one individual SPs, two groups, 105 farmers who accessed and used mechanization services from SPs, and 114 farmers who did not use mechanization services (Table 1). Figure 1 shows the spatial locations of households interviewed.

Table 1: Survey sample details

Province	Service Providers	Famers who used mechanization services	Famers who did not use mechanization services	Overall
Zambia				
Eastern	6	36	36	78
Northern	6	35	35	76
Southern	5	34	34	73
N	*17*	*105*	*105*	*227*
Zimbabwe				
Shamva	2	14	1	17
Bindura	2	10	6	18
Makonde	2	1	32	35
Masvingo	27	80	75	182
N	*33*	*105*	*114*	*252*

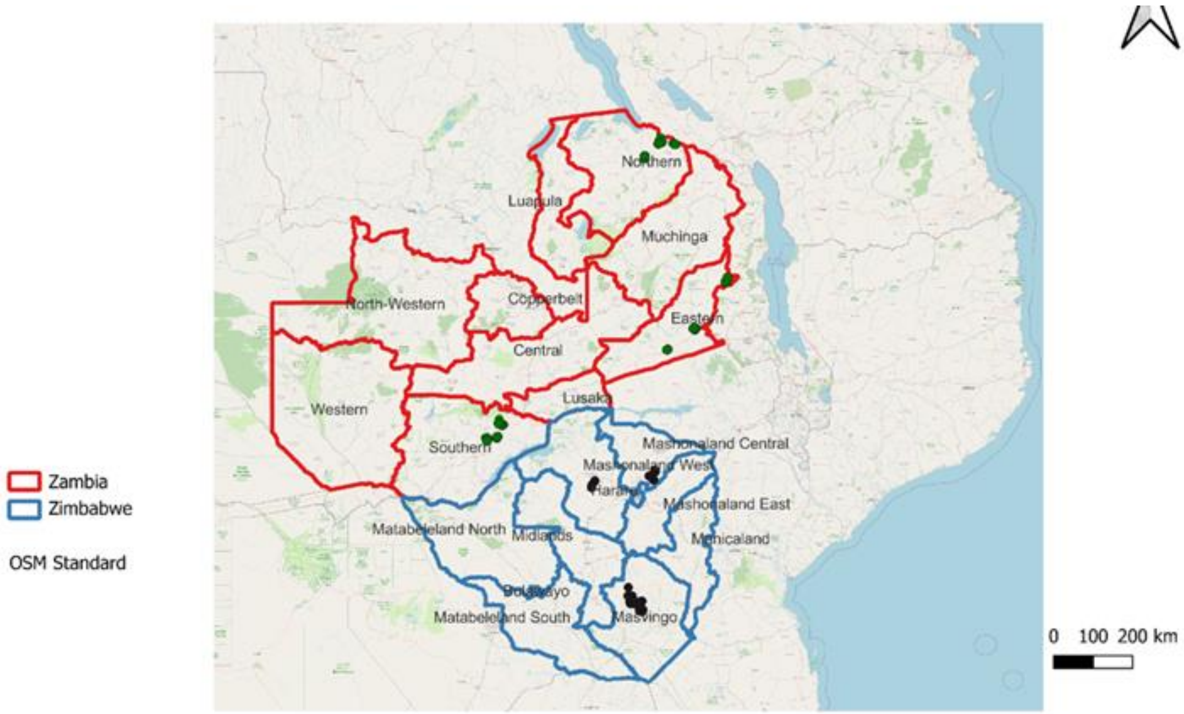

Figure 1: Location of households interviewed in Zambia and Zimbabwe

Analytical strategy

We used two analytical approaches in this paper. First, we used a probit model to assess drivers of farmers' decisions to adopt mechanization or to use mechanization services. The dependent variable for this estimation is a binary variable that takes a value of 1 if a farmer used mechanization services for a given activity. Second, we used the instrumental variable conditional quantile treatment effect (IVQTE) of Firpo, Fortin, and Lemieux (2009). The outcome variables of interest are yield and income, used as livelihood indicators. Studying the distributional impacts beyond the mean is important because farmers are heterogeneous and means do not capture the spread.

Results

Sample characteristics and descriptives statistics

This section provides key descriptive statistics about the sample and explores specific statistical distinctions in socioeconomic and demographic attributes between those who used mechanization services (treatment) and those who did not (control). Summary statistics for service providers are provided in Table 2. Most (over 90%) of the fifty (50) service providers interviewed were male heads of households aged 55 years on average. SPs are well educated having completed 13 years of formal education and with an average household size of 7 members. SPs in Zambia had larger farms averaging 19 hectares compared to 3 ha for SPs in Zimbabwe.

Table 2: Summary descriptive statistics of service providers in the sample

	Zambia		Zimbabwe		Overall	
	mean	n	mean	n	mean	n
Household size	8.88	17	6.00	33	6.98	50
Age household head	48.29	17	59.09	33	55.42	50
Age of household member	21.97	17	32.58	33	28.97	50
Education of household head	11.53	17	13.21	33	12.64	50
Female household head, %	0.00	17	12.12	33	8.00	50
Number of male adults	1.94	17	1.85	33	1.88	50
Number of female adults	1.94	17	1.73	33	1.80	50
Number of children	4.41	17	2.36	33	3.06	50
Never married household head, %	0.00	17	0.00	33	0.00	50
Monogamously married household head, %	70.59	17	87.88	33	82.00	50
Polygamously married household head, %	29.41	17	6.06	33	14.00	50
Divorced household head, %	0.00	17	0.00	33	0.00	50
Widowed household head, %	0.00	17	6.06	33	4.00	50
Land ownership, ha	19.20	17	3.35	33	8.74	50
Dependency ratio	87.30	17	77.55	33	80.87	50

Source: survey data

Farmers who access mechanization services and those who did not are similar in both Zambia and Zimbabwe (Table 3 and 4). The only differences are that farmers who accessed mechanization services in Zambia were more educated and a larger proportion was polygamously married. Further, farmers that accessed mechanization had larger land holdings at 20 hectares compared to 12 hectares among those who did not access mechanization. In Zimbabwe, farmers who accessed mechanization services were significantly older at 56 years compared to those who did not access mechanization services (Table 4). We do find any other statistically significant differences between treatment and control in terms of other covariates.

Table 3. Mean difference tests between farmers who accessed mechanization services and those who did not in Zambia

	Farmer, accessed mechanization services		Farmer, did not access mechanization services		mean-diff	T-stat
	n	mean	n	mean		
Household size	105	6.638	105	6.448	0.190	0.451
Age household head	105	48.543	105	49.695	-1.152	-0.538
Age of household member	105	25.858	105	26.334	-0.476	-0.284
Education of household head	105	10.867	105	9.648	1.219**	2.123
Female household head, %	105	14.286	105	15.238	-0.952	-0.194
Number of male adults	105	1.610	105	1.724	-0.114	-0.813
Number of female adults	105	1.686	105	1.562	0.124	0.875
Number of children	105	3.267	105	3.000	0.267	0.908
Never married household head, %	105	0.000	105	0.000	0.000	.
Monogamously married household head, %	105	71.429	105	78.095	-6.667	-1.110
Polygamously married household head, %	105	17.143	105	4.762	12.381***	2.917
Divorced household head, %	105	4.762	105	2.857	1.905	0.718
Widowed household head, %	105	6.667	105	14.286	-7.619*	-1.808
Land ownership, ha	105	20.183	105	11.932	8.251	1.328
Dependency ratio	105	93.394	105	92.393	1.001	0.108

Source: survey data

Table 4. Mean difference tests between farmers who accessed mechanization services and those who did not in Zimbabwe

	Farmer, accessed mechanization services		Farmer, did not access mechanization services		mean-diff	T-stat
	n	mean	n	mean		
Household size	105	5.038	114	5.184	-0.146	-0.522
Age household head	105	56.543	114	52.175	4.367**	2.419
Age of household member	105	31.376	114	29.549	1.827	1.179
Education of household head	105	10.790	114	10.868	-0.078	-0.149
Female household head, %	105	33.333	114	26.316	7.018	1.134
Number of male adults	105	1.381	114	1.395	-0.014	-0.108
Number of female adults	105	1.571	114	1.412	0.159	1.524
Number of children	105	2.038	114	2.351	-0.313	-1.384
Never married household head, %	105	0.952	114	0.000	0.952	1.042
Monogamously married household head, %	105	65.714	114	74.561	-8.847	-1.432
Polygamously married household head, %	105	1.905	114	2.632	-0.727	-0.358
Divorced household head, %	105	7.619	114	4.386	3.233	1.009
Widowed household head, %	105	23.810	114	18.421	5.388	0.976
Land ownership, ha	105	3.011	113	2.750	0.261	0.891
Dependency ratio	105	75.399	114	86.181	-10.782	-1.138

Source: survey data

Stated Social Networks

In general, service providers had lived in their current villages for at least 30 years by the time of the survey in June 2023. This is much longer than for farmers who accessed mechanization services and those who did not access the mechanization service (Table 5). We find no major differences between those who hired mechanization and those that did not hire in terms of number of relatives and non-relatives that can be relied upon within and outside the villages. A larger proportion of farmers who hired mechanization services had relatives in leadership positions compared to farmers who did not hire mechanization. As would be expected, more than 90% of service providers and more than 70% of farmers that accessed mechanization services accessed advice on mechanization in both Zambia and Zimbabwe.

Table 5: Stated Social Networks from the Survey

	Zambia			Zimbabwe		
	Service provider	Farmer accessed mechanization		Service provider	Farmer accessed mechanization	
		Yes	No		Yes	No
Years lived in village	30.24	25.96	23.03	38.12	33.35	27.04
Relatives within village (number)	8.76	18.49	24.98	5.61	11.96	9.67
Non-relatives within village (number)	9.47	16.41	16.91	16.30	19.34	16.90
Relatives outside village (number)	11.06	11.85	12.50	12.67	16.35	14.83
Non-relatives outside village (number)	8.47	9.04	8.40	9.24	15.36	13.57
Leadership position (relatives) (%)	35.29	43.81	27.62	81.82	70.48	58.77
Can rely on govt support (crop) (%)	76.47	75.24	77.14	57.58	52.38	55.26
Govt support for mech tech (%)	88.24	79.05	71.43	48.48	35.24	44.74
Received mech tech advice (%)	94.12	80.95	62.86	96.97	71.43	55.26
Confidence in extension agents (%)	88.24	83.81	70.48	78.79	78.10	68.42
Confidence in govt officials (%)	3.47	6.94	3.93	4.00	7.50	5.19
n	*17*	*105*	*105*	*33*	*105*	*114*

Source: survey data

Mechanization services hired out by mechanization service providers for Zambia and Zimbabwe

Different mechanization services are provided by service providers in Zambia and Zimbabwe. To make things tractable, we grouped the mechanization services into four main types: transport includes two- and four-wheel based transport, vans/trucks, motorcycle, and oxcart; shelling includes shellers attached to two-tractor tractors and standalone shellers; land preparation includes animal draft power, two- and four-wheel tractor-based ripping, direct seeding, and plowing. Spraying refers to the use of boom sprayers or motorized knapsack sprayers. Using this categorization, we find that transportation services are most popular, followed in second place by shelling services in Zambia and land preparation in Zimbabwe (Figure 2). In third place is land preparation in Zambia and shelling in Zimbabwe. Spray services are the least popular in both countries. While these results shed light into the kind of mechanization services available for hire, readers should keep in mind that these are based on a small sample (n=17 in Zambia and n=33 in Zimbabwe).

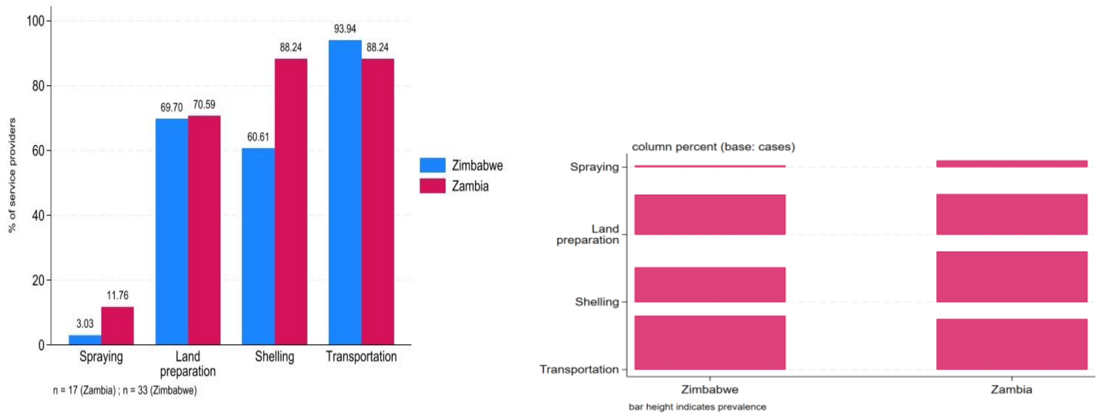

Figure 2: Mechanization services hired in Zambia and Zimbabwe

Mechanization services hire out calendars

The calendars for hiring mechanization services show distinct seasonal variations for different agricultural activities throughout the year. Demand for land preparation services such as ripping and seeding based on animal draft power, two-wheel-tractor, and four-wheel-tractor is highest from September to January (Figure 3). The demand for land preparation involving two- and four-wheel tractors is highest around November to December across the survey districts in Zambia (right panel) and Zimbabwe (left panel).

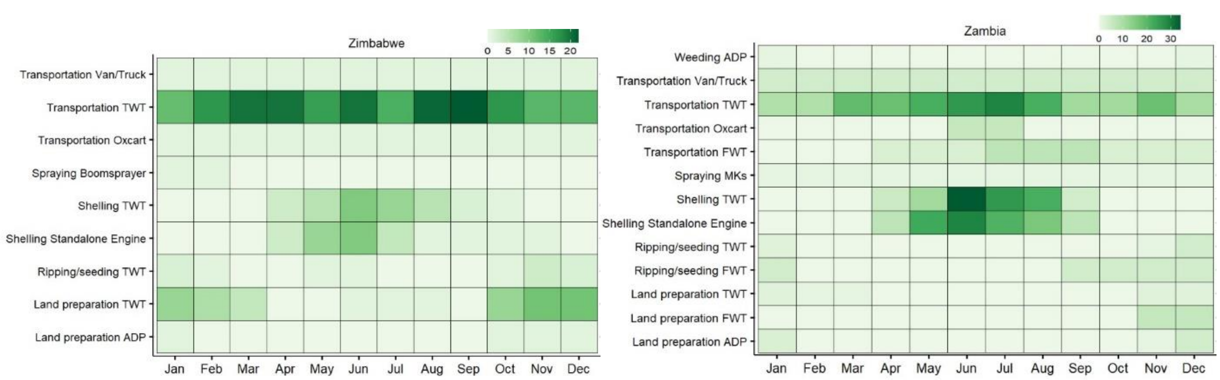

Figure 3: Mechanization services hire calendars

Shelling and threshing, whether based on two-wheel tractor or standalone engines, are most sought after from April to September, with significant peaks between May and July as more farmers participate in the marketing season by selling their produce. There is consistently high demand for transportation using two-wheel tractors throughout the year, with peak periods observed from March to August, which correspond to harvest and postharvest times. Noteworthy peaks for transportation using motorcycles and trucks are observed consistently throughout the year. These patterns are similar across Zambia and Zimbabwe. In addition, results show that transportation using trucks and oxcarts, spraying with boom sprayers, and ripping and seeding using animal draft power show inconsistent demand during the year.

Hire prices for different mechanization options

Land preparation as described above costs about $27 and $50 per hectare in Zambia and Zimbabwe, respectively (Figure 4). Shelling costs about $0.05 and $0.25 per 10 kg while transport costs about $9 per 10 km radius in the survey areas in the two countries. There are differences between the different constituents. For example, ripping and seeding with a four-wheel tractor cost more than doing the same operations using animal draft power or a two-wheel tractor. This is as expected given the differences in fuel required to operate a two-wheel tractor compared to a four-wheel tractor for a given land unit. Overall, mechanization service prices in Zimbabwe are higher than those in Zambia, reflecting a higher willingness to pay for these services. This is in line with findings in Ngoma et al. (2023) suggesting that farmers in Zimbabwe were willing to pay more for different two-wheel tractor-based services than those in Zambia. While the main intention of this section was to elaborate on the profitability of the SP model, the data collected do not permit such an analysis at this stage.

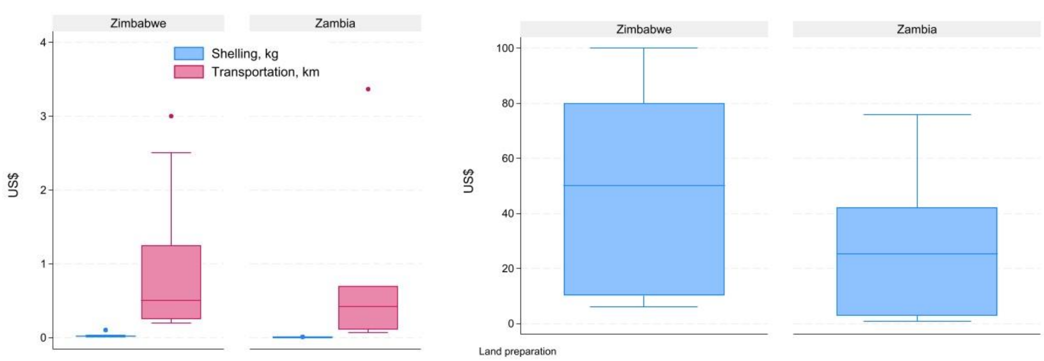

Figure 4: Hire prices ($) for mechanization services in Zambia and Zimbabwe
Source: survey data

Effects of mechanization on livelihoods

As a precursor to the robust econometric assessments, we first compared maize yield among farmers that hired and those that did not hire mechanization services. Farmers who hired mechanization services had significantly higher average maize yield at 2.9 tons compared to 1.7 tons among those who did not hire in Zambia (Figure 5, left panel). We find comparable results in Zimbabwe that farmers who hired mechanization services had higher maize yield than those who did not (1.4 tons vs 1.2 tons), even if the difference is not statistically significant.

In terms of income, farmers who hired mechanization services had higher household incomes than those who did not hire in both Zambia and Zimbabwe (Figure 5, right panel). Household income refers to income from all observed sources (salary, wage, business, remittance, agriculture etc.) over one year. On average, farmers who hired mechanization services earned $2,400 compared to $1,200 household income per year in Zambia. In Zimbabwe, the differences are smaller at $1,700 for those who hired and $1,400 for those who did not hire.

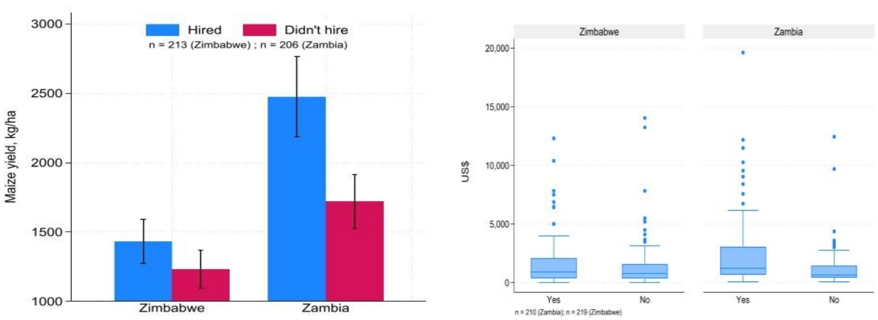

Figure 5: Differences in maize yield (kg/ha, left panel) and household income ($, right panel) for farmers who hired and those that did not hire mechanization services

Factors affecting the adoption of mechanization services

Social capital, labor shortage proxied by hiring labor and rising land prices are associated with significantly higher probabilities of hiring mechanization services (Table 6). Social capital, labor shortages, and rising land prices are associated with 11%, 20% and 15% higher probabilities of hiring mechanization. The age of the household head is used as a proxy for experience, and older household heads are more and less likely to use mechanization services Zimbabwe with the opposite being the case in Zambia (Table 6).

Table 6: Factors affecting the adoption of mechanization services

	Zambia		Zimbabwe		Overall	
	(1) mech	(2) t-stat	(3) mech	(4) t-stat	(5) mech	(6) t-stat
Age of household head	-0.035**	-2.401	0.029**	2.159	0.009	0.447
Education of household head	0.003	0.254	0.007	1.066	0.004	0.779
Land ownership	0.006	1.032	0.451**	2.424	0.010	1.274
Relatives in leadership position (1 = yes)	0.150***	3.444	0.064***	2.823	0.108***	3.683
Access to credit (1 = yes)	-0.045	-0.649	-0.102	-0.449	-0.040	-0.680
Household size	0.075	0.815	0.103	0.741	0.072	0.916
Hired labor (1 = yes)	0.291***	3.437	0.161*	1.936	0.200***	3.898
Total livestock units	0.024*	1.777	-0.061	-1.108	0.006	0.517
Household income	0.090***	3.815	-0.015	-0.898	0.036	1.019
Wage rate worsened (1 = yes)	-0.059	-0.986	0.044*	1.767	0.005	0.107
Cost of land worsened (1 = yes)	0.179**	2.075	0.127***	5.326	0.145***	3.547
Mechanization availability did not improve (1 = yes)	-0.007	-0.101	-0.172*	-1.697	-0.158**	-2.014
Cost of mechanization services worsened (1 = yes)	-0.076	-1.635	-0.195***	-16.172	-0.151***	-2.609
Observations	210		219		429	

Notes: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Impacts of mechanization on livelihoods

We measured livelihoods using household income and maize yield. Without controlling for the endogeneity of access to machinery, we find some positive distributional effects. For the full sample, using mechanization was associated with significantly higher incomes and maize yield in the 75th and 95th percentiles (Table 7). In each case, the effect is larger in the 95th percentile than in the 75th percentile, except for maize yield in some instances, and the effects is larger for household income than for maize yield. For example, using mechanization is associated with 74% –145% more household income and 30 – 32 % higher maize yield. While the descriptive results showed that farmers that used mechanization services had higher incomes and maize yield, multivariate results show that these effects are only significant for farmers in the higher end of the distribution.

Table 7: Effects of using mechanization on household income and maize yield, pooled sample

	Q.25	Q.50	Q.75	Q.95
	Log of household income			
Hired mechanization services	0.109	0.268	0.552***	0.895***
	(0.639)	(1.529)	(2.998)	(4.070)
Constant	6.163***	6.811***	7.658***	8.719***
N	*405*	*405*	*405*	*405*

		Log of maize yield		
Hired mechanization services	0.163	0.101	0.277**	0.261**
	(1.202)	(0.820)	(2.381)	(2.160)
Constant	6.718***	7.276***	7.720***	8.356***
N	397	397	397	397

Notes: T-statistics in parentheses: *** p<0.01, ** p<0.05, * p<0.1

We find differences at sub-country level with the positive effects reflected in the pooled sample only replicated in the Zambia sub-sample (Table 8) and not in the Zimbabwe sub-sample (Table 9). Suffice to mention here these sub-national results are based on small samples and as such, should be interpreted with caution.

Table 8: Effects of using mechanization on household income and maize yield, Zambia sub-sample

	Q.25	Q.50	Q.75	Q.95
		Log of household income		
Hired mechanization services	0.312	0.428*	0.739***	0.840***
	(1.316)	(1.692)	(2.905)	(3.006)
Constant	6.261***	6.828***	7.695***	8.785***
N	*202*	*202*	*202*	*202*
		Log of maize yield		
Hired mechanization services	0.160	0.286*	0.380**	0.521***
	(0.939)	(1.680)	(2.486)	(3.028)
Constant	7.000***	7.439***	7.852***	8.604***
N	198	198	198	198

Notes: T-statistics in parentheses: *** p<0.01, ** p<0.05, * p<0.1

Table 9: Effects of using mechanization on household income and maize yield, Zimbabwe sub-sample

	Q.25	Q.50	Q.75	Q.95
		Log of household income		
Hired mechanization services	0.000	-0.027	0.256	0.438
	(0.000)	(-0.085)	(0.852)	(1.570)
Constant	5.991***	6.823***	7.552***	8.559***
N	*203*	*203*	*203*	*203*
		Log of maize yield		
Hired mechanization services	0.260	-0.005	0.191	0.000
	(1.220)	(-0.026)	(0.962)	(0.000)
Constant	6.447***	7.093***	7.497***	8.006***
N	199	397	397	397

Notes: T-statistics in parentheses: *** p<0.01, ** p<0.05, * p<0.1

Discussion

The study shades light on the status of appropriate-scale mechanization services being offered to smallholder farmers in Zambia and Zimbabwe in areas where CIMMYT is implementing mechanization activities. Several highlights emerge. First, there is demand for land preparation, shelling (threshing) and transport mechanization services in Zambia and Zimbabwe. More than 60% of mechanization service providers hired out land preparation, shelling (threshing) and transportation services to farmers in their communities both in Zambia and Zimbabwe. However, the results show that there are disparities in demand times among different mechanization services in both Zambia and Zimbabwe. For example, shelling services are at their peak around May – July after harvesting while land preparation services are at their peak at the beginning of the season around November to December. The disparities in demand for mechanization based on seasons as depicted in the hiring calendars in Zambia and Zimbabwe highlight the complicated preferences for specific mechanization services, which correspond to distinct periods of increased demand connected with various agricultural operations throughout the year. The demand reflected in this study is in line with findings from previous studies in Zambia and Zimbabwe (Ngoma et al., 2023), Malawi (Tufa et al., 2023) and in Tanzania for shelling services (Kotu et al., 2023).

Second, this study demonstrates that mechanization service providers are highly educated, having completed at least 13 years of formal education. As expected, farmers who hired mechanization services tend to possess higher levels of education compared to those who did not. This correlation between education and access to mechanization services aligns with the findings of Tufa et al (2023), who found that the educational attainment of the household head significantly influences the likelihood of farmers adopting mechanized land preparation services in Malawi and Ngoma et al (2023), who found that education is associated with a higher willingness to pay for direct seeding in Zambia and Zimbabwe.

Third, this study shows that factors such as farm size (land ownership) play a significant role in influencing smallholder farmers' decisions to adopt appropriate-scale mechanization in Zimbabwe. This is in line with results by Kirui (2019) and Chapoto et al. (2014) that show a positive relationship between large farm size and adoption of agricultural mechanization services. However, social capital, labor shortage (as measured by hiring labor) and rising prices land prices increase the likelihood of the farmer hiring mechanization services. These results confirm the prediction of the induced innovation theory which suggests that cheaper factors tend to replace more expensive ones. As land and labor becomes expensive, intensification and labor-saving options such as mechanization become attractive. The contrasting findings on age are as expected because the age of the household head is used as a proxy for experience. In Zambia, where small scale mechanization is more recent, age is associated with reduced probability of hiring mechanization compared to Zimbabwe where farmers have more experience with small-scale mechanization and this increases the likelihood of hiring mechanization services in that country.

Fourth, our findings refute our initial hypothesis that there is no significant increase in yields for smallholder farmers who use mechanization compared to those who do not, as well as our second hypothesis that smallholder farmers who use mechanization do not experience a significant increase in income when compared to those who rely solely on manual labor. The findings show that farmers who used mechanization services had higher maize yields and income compared to those that did not both in Zambia and Zimbabwe. These findings are similar with earlier research that have demonstrated that mechanization among smallholder farmers enhances yields, productivity, and creates profitable prospects for farmers (Adu-Baffour et al., 2019; Hamilton et al., 2022; Paudel et al., 2019; Peng et al., 2022). The nuance that these findings add is to show the distributional effects, where these effects are only statistically significant in the higher end of the income and yield percentiles. These results point to a need for structured promotion approaches that allow all farmer types to benefit from mechanization services.

Fifth, prices for mechanization services are more on the higher side in Zimbabwe compared to Zambia. For example, land preparation costs about $50 per hectare in Zimbabwe while the same costs about $27 per hectare in Zambia and shelling costs about $0.05 per 10 kg in Zambia and $0.25 per 10 kg in Zimbabwe. It is important to note that the differences in currencies used in the two countries could be a key factor in why prices for mechanization services between the two countries are different as Zimbabwe uses the US$ while Zambia uses the Zambian Kwacha (ZMW) which has depreciated against the US$ in the recent past. In general, higher prices in this paper are in line with Ngoma et al (2023) who found that farmers in Zimbabwe were willing to pay more for different mechanization services compared to those in Zambia.

In sum, our findings add to the growing evidence base that support agricultural mechanization's capacity to increase agricultural productivity and sustainably intensify agriculture among smallholders in Zambia and Zimbabwe and can guide evidence-based policies and actions targeted at enhancing food security, poverty eradication and agricultural development.

Conclusion

Unlocking the potential of smallholder agricultural productivity hinges on the pivotal role of mechanization, serving as the cornerstone in increasing yield and steering the trajectory toward export oriented agricultural development. This study used a quantitative survey to understand the status of appropriate-scale mechanization in Zambia and Zimbabwe. In both countries, 50 service providers participated in the survey together with 210 farmers who used mechanization services and 219 farmers who did not.

This study underscores the distinctive characteristics of mechanization service providers (SPs), predominantly male heads of households, 55 years on average, highly educated, and own relatively larger farms, averaging 19 hectares in Zambia and 3 hectares in Zimbabwe. The spectrum of services offered by these providers varies, with transportation services ranking highest, followed by shelling and land preparation. The fluctuating demand for specific services across the season mirrors peaks aligned with critical agricultural activities such as land preparation, shelling, and transportation, further emphasizing the relevance of mechanization during these pivotal farming periods.

The findings from this study suggest that integrating smallholder mechanization holds significant promise in improving agricultural productivity, fostering income generation, and promoting long-term agricultural intensification. In addition, this study adds valuable insights for agricultural policymakers, researchers, and development practitioners, contributing to the growing reservoir of knowledge on the transformative potential of mechanization in smallholder agriculture in sub-Saharan Africa. As a result, evidence-based policies and interventions derived from this study can help contribute to improving regional food security and promote sustainable agricultural development.

Because if the data challenges encountered, there is need to implement an effective monitoring and evaluation system to continually analyze the impact of mechanization services on the productivity and income of smallholder farmers. Such a system would aid policymakers and stakeholders in making informed decisions and improvements to effectively support the sector. Policymakers should consider formulating policies aimed at fostering the growth of smallholder mechanization. This may encompass incentives for service providers and adopters through for example, some credit schemes and market access arrangements for value chain actors including end users, service providers and manufacturers. This can be complemented with regulatory frameworks ensuring fair competition and initiatives to overcome any barriers hindering widespread mechanization adoption.

There is scope for more work on the economics of appropriate scale agricultural mechanization to further understand profitability and returns to investments. While we find positive indications in this study on mechanization demand and its positive relationship with yield and income, there is need to evaluate the economics of different mechanization services and models beyond the areas covered in this study to allow for a broader understanding of costs and returns on mechanization services in Zambia and Zimbabwe.

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