Received: 12 May 2022 | Revised: 1 December 2022 | Accepted: 18 January 2023

DOI: 10.1002/jid.3767

RESEARCH ARTICLE

JOURNAL OF INTERNATIONAL DEVELOPMENT WILEY

Smallholder farmers' willingness to pay for two-wheel tractor-based mechanisation services in Zambia and Zimbabwe

Hambulo Ngoma[1] | Paswel Marenya[2] | Adane Tufa[3] | Arega Alene[3] | Lovemore Chipindu[1] | Md Abdul Matin[1] | Christian Thierfelder[1] | David Chikoye[4]

[1]International Maize and Wheat Improvement Center (CIMMYT), Southern Africa Regional Office, Harare, Zimbabwe

[2]International Maize and Wheat Improvement Center (CIMMYT), Nairobi, Kenya

[3]International Institute of Tropical Agriculture (IITA), Nairobi, Kenya

[4]International Institute of Tropical Agriculture (IITA), Southern Africa Research Hub (SARAH), Lusaka, Zambia

Correspondence
Hambulo Ngoma, International Maize and Wheat Improvement Center (CIMMYT), Southern Africa Regional Office, P.O. Box MP163, Mt. Pleasant, Harare, Zimbabwe.
Email: h.ngoma@cgiar.org

Funding information
Norwegian Agency for Development Cooperation (NORAD)

Abstract

Mechanisation is back among top development policy priorities for transforming African smallholder agriculture. Yet previous and ongoing efforts ubiquitously suffer from lack of scientific information on end-user effective demand for different types of mechanical innovations to inform public investment or business development programmes. We assess smallholder farmers' willingness to pay (WTP) for two-wheel tractor (2WT)-based ripping, direct seeding and transportation using a random sample of 2800 smallholder households in Zambia and Zimbabwe. Applying the Becker–DeGroot–Marschak Mechanism (BDM) experimental auctions, we find that at least 50% of sample households in Zambia and Zimbabwe were willing to pay more than the prevailing market prices for ripping. In nominal terms, sample households in Zimbabwe were willing to pay more than those in Zambia for the different services. Empirical results suggest that wealth is the strongest driver of WTP for tillage and seeding 2WT services while labour availability and using animal draft power reduce it. These findings imply a need to (i) raise awareness and create demand for 2WT-based services in an inclusive business manner that does not create perverse incentives and (ii) better target mechanisation to operations with comparative advantage, using approaches that bundle 2WT-based and other mechanisation services with asset-agnostic credit schemes or other interventions meant to overcome asset-mediated barriers.

KEYWORDS
demand, mechanisation, targeting, two-wheel tractor, Zambia, Zimbabwe

JEL CLASSIFICATION
Q12, Q18

1 | INTRODUCTION

Mechanisation is back among top policy priorities to transform African agriculture after a long period of attempts and partial failures. From the assumption that mechanisation can help change (e.g., reduce drudgery by retiring the hoe), intensify and improve agricultural productivity and production in sub-Saharan Africa (Baudron, Misiko, et al., 2019), African heads of state and government affirmed their commitment to include mechanisation as a core component for ending hunger by 2025 during the Malabo declaration in 2014.[1] In this sense, and to transform mostly smallholder farming systems in sub-Saharan Africa, mechanisation is viewed as key to agricultural development. Pingali (2007) characterises past mechanisation efforts in Africa into three epochs between 1945 and 1980s. These mechanisation epochs were led by governments (colonial or post-independence) and provided tractors to individual farmers and in some instances through cooperatives, government-run mechanisation programmes, credit schemes or government hire services. These interventions failed primarily because they only focused on the supply side where the main emphasis was to make tractors available (Pingali et al., 1987), without first understanding farmers' effective demand for tractors and availability of ancillary support services. As a result, and because the demand side for spare parts and after-sale services was largely ignored, the number of tractors plummeted, mechanisation efforts stalled with most of these tractors abandoned (Pingali, 2007) and in some instances stripped for scrap metal. Interest in mechanising African agriculture waned for much of the 1990s and early 2000s (Baudron, Misiko, et al., 2019; Diao et al., 2016; Pingali, 2007). It could be argued that there were no well-thought business models through which *tractorisation* could be achieved.

Given prior challenges, the current drive to mechanise African smallholder agriculture is cautious and aims to address both supply and demand side factors. On the supply side, there is an emphasis on scale-appropriate mechanisation where machines adapt to prevailing farm sizes in the region (Baudron et al., 2015). It is argued that the large four-wheel tractors tried in the past were only suitable for large-scale commercial farming but not suitable for the smallholders. Instead, two-wheel tractors (2WTs) were considered fit for the purpose given the small average farm sizes in the region, low purchase and maintenance costs (Baudron et al., 2015). There are also efforts to develop markets for appropriate machines by supporting research and development (R&D), linking local companies to global suppliers, capacity development and training of private sector to adapt machines and to fabricate some attachments locally to minimise lead times in the supply chains and to provide effective after-sale, maintenance and repair services. Other complementary efforts include creating enabling policy frameworks that address rampant market failures (e.g. unavailability of credit caused by information asymmetry) in the mechanisation subsector and creating

[1] 31247-doc-malabo_declaration_2014_11_26.pdf (au.int)

incentives for private sector participation. An example is facilitating access to credit for machinery and tax rebates on machinery imports (Baudron, Nazare, & Matangi, 2019).

On the demand side, a major focus is on demand creation through demonstrating the use and versatility of 2WTs and by making these machines accessible in the local communities through encouraging the establishment of local service providers. To avert disappointments encountered in prior mechanisation efforts, there are suggestions that donors, development partners (NGOs, research organisations) and governments should play facilitatory and supportive or catalytic roles and provide financing options, R&D and an enabling policy and institutional environment that facilitates mechanisation in the initial phases, while the private sector should drive the mechanisation agenda (Baudron et al., 2015; Daum & Birner, 2020; Diao et al., 2016; Pingali, 2007; Pingali et al., 1987).

There are several reasons for the current push for mechanisation in Africa. National governments are geared to intensify agricultural production given rising land pressures and food demands amidst climate change, and climate smart agricultural practices such as conservation agriculture are part of national policies in most countries in the region (Giller et al., 2015). One consequence of these efforts is an increase in land prices arising from active land markets (Jayne et al., 2021), rising rural wages (Daum & Birner, 2020) driven in part by out-migration and increased demand for agricultural labour and high land-labour ratios (Diao et al., 2016). Another potential driver for mechanisation is the increased push for conservation agriculture whose minimal land disturbance practices can be accomplished by 2WTs more efficiently while reducing drudgery (Baudron et al., 2015). Other potential drivers include the rapid increase in medium-scale farms (5–100 ha) who are better resourced and the developing rural nonfarm sectors (Jayne et al., 2016). The emergence of medium-scale farms and burgeoning rural nonfarm sectors is absorbing labour in most places, leading to labour scarcity and rising opportunity cost for family farm labour (Jayne et al., 2016). These changes offer great opportunities to leapfrog mechanisation.

In sum, these unfolding labour and land market changes in Africa favour capital-using and labour-saving mechanisation options. In addition, improving market access conditions in the region and a nearly doubling of growth in agricultural production value between 2000 and 2018 in sub-Saharan Africa (Jayne & Sanchez, 2021) and improved availability of 2WTs from local private sector dealers (Baudron et al., 2015) can facilitate mechanisation. This optimism is, however, juxtaposed by debates on the extent of the effective demand for mechanisation in Africa (Pingali, 2007) given, for example, rising land-labour ratios and low cropping intensities (Baudron, Misiko, et al., 2019; Binswanger-Mkhize & Savastano, 2017; Sims & Kienzle, 2015). Thus, it is of policy relevance to first ascertain the extent of the demand for 2WT-based mechanisation prior to full-scale interventions. This will also serve to inform spatial targeting on *what* operations need to be mechanised and *where* the best-bet interventions sites are. In essence, this analysis provides some guidance in terms of where mechanisation is likely to succeed in southern Africa, using the cases of Zambia and Zimbabwe.

While this analysis focuses on 2WTs, we recognise that animal traction is still very common in these countries and it will remain an important source of farm power. As such, we agree with Daum et al. (2022) in stating that animal traction will remain an important part of smallholder mechanisation and with Baudron, Nazare, and Matangi (2019) that animal traction is part of appropriate scale mechanisation. Although evaluating the merits of 2WTs over animal traction or the profitability of 2WTs (see Baudron, Nazare, and Matangi (2019)) or whether 2WTs should leapfrog animal traction (Daum et al., 2022) is beyond the scope of this paper, motorised sources of farm power are becoming more relevant in the context of rising animal diseases and declining animal herds in southern Africa (Baudron, Nazare, & Matangi, 2019). It should also be noted that animal traction is not ubiquitous in southern Africa. Cattle, which is mostly used for traction, are most prevalent in southern Zambia and the central plateau of Zimbabwe (Baudron, Nazare, & Matangi, 2019).

Given that the success of any mechanisation effort hinges on there being effective demand for it (Pingali, 2007) and since the service provider model is more appealing than individual ownership of tractors (Baudron et al., 2015; Baudron, Nazare, & Matangi, 2019; FACASI, 2016), we explore the extent to which smallholder farmers are willing to pay for 2WT-based land preparation, direct seeding and transportation services in Zambia and Zimbabwe. This assessment combines what Pingali (2007) calls 'power-intensive operations' such as land preparation (ripping and transportation using a 0.5-ton trailer attached to a 2WT within a 20-km radius) and 'control-intensive' activities such as ripping and hand seeding, and direct seeding. We estimate wilingness to pay (WTP) using the Becker–DeGroot–Marschak mechanism (BDM) (Becker et al., 1964) which is incentive compatible because it induces truth-telling and allows individuals to reveal their maximum WTP amounts (Horowitz, 2006). BDM auctions have been used to access WTP in various contexts; for example, see De Groote et al. (2011), Morawetz et al. (2011) and Lusk and Shogren (2007).

We contribute to existing literature on smallholder mechanisation in southern Africa by assessing WTP for mechanisation in the context of conservation agriculture systems using an approach that simulates a real market for 2WTs. This approach is necessary given that 2WTs are still not very common in southern Africa and, therefore, allows an *ex-ante* assessment of potential effective demand. To the best of our knowledge, this is the first paper to use the more efficient, incentive compatible BDM approach to assess WTP for mechanisation in the context of conservation agriculture in the region. This is in contrast to Paudel et al. (2019) who used contingent valuation in a similar analysis in Nepal.

1.1 | Smallholder mechanisation in Zambia and Zimbabwe

Zimbabwe and Zambia are appropriate for this analysis given their long history with agricultural mechanisation from the pre- to post-independence times. Governments led early mechanisation efforts in both countries by providing subsidised or free tractors (Pingali, 2007). To the best of our knowledge, these noble efforts were not informed by rigorous demand estimation. Interest in mechanisation was rekindled in the two countries in the late 1990s and early 2000s driven in part by development organisations, donors, private sector and governments. National credit schemes were setup to help farmers access credit to finance the purchase of agricultural equipment and inputs. An example is Lima Bank in Zambia, which would later close operations in 1997 due to nonperforming loans. Besides, the International Maize and Wheat Improvement Centre (CIMMYT) and the Food and Agriculture Organization (FAO) have been at the forefront of promoting appropriate scale mechanisation in the region (e.g. FACASI, 2016; FAO and AUC, 2019).

In Zambia, the Farmer Input Supply Response Initiative (FISRI) project and its successor, the Conservation Agriculture Scaling Up (CASU) project implemented by the Ministry of Agriculture with technical support from FAO facilitated access to 60 hp tractors for selected services providers and provided electronic vouchers to participating lead farmers which could be redeemed for tractor-based ripping services and other inputs and implements at participating agro-dealers (Sims & Kienzle, 2015).[2] The projects also provided market linkages for participating farmers. The Conservation Farming Unit partnered with AFGRI Equipment Zambia and John Deere to provide tractors on loan to selected lead farmers who would provide ripping services to other farmers in the vicinity from about 2011. About the same time, the Zambia National Farmers Union (ZNFU) launched a revolving fund that provided loans to farmers to help them acquire agricultural machinery (Sims & Kienzle, 2015). In 2008, the ZNFU partnered with some commercial banks to launch the Lima Credit Scheme which provided loans to smallholder farmers, including for buying machinery (WorldBank, 2019).

Experiences from these mechanisation schemes in Zambia are mixed. While some closed due to nonperforming loans, for example, the Lima Credit Scheme (WorldBank, 2019), others have had significant impacts on beneficiaries. For example, Adu-Baffour et al. (2019) found that farmers who received mechanisation services from the AFGRI-John Deere tractor scheme in Zambia significantly increased their household incomes and yield, and were more willing to invest in other inputs like fertilisers. Omulo et al. (2022) also found that hiring four-wheel tractors to mechanise conservation agriculture was more profitable than conventional tillage, again highlighting the potential for mechanisation hire services.

Zimbabwe followed a somewhat different trajectory of agricultural mechanisation than Zambia. There have been and still are several agricultural mechanisation programmes focused on large four-wheel tractors and accessories (Shonhe, 2022) in Zimbabwe compared to Zambia. Following pre-independence mechanisation efforts that

[2]https://www.fao.org/emergencies/resources/documents/resources-detail/en/c/168673/

were tilted towards white commercial farmers in Zimbabwe (Pingali et al., 1987), the post-independence government introduced several initiatives to mechanise smallholder agriculture including the group tractor programme, district development fund, and the agricultural rural agencies (Shonhe, 2022). There have been other schemes introduced more recently, for example, one by AFGRI and John Deere—like the one in Zambia,[3] the farm mechanisation programme funded by the Reserve Bank of Zimbabwe and the Belarus farm mechanisation facility to mention a few.[4] Overall, structural adjustment programmes of the early 1990s, the land reforms initiated in the 2000s and other related challenges hampered the success of most of these mechanisation initiatives in Zimbabwe (Shonhe, 2022).

Both Zambia and Zimbabwe have benefited from the current surge in 'appropriate scale' mechanisation focusing on 2WTs led in part by international R&D partners and national governments. For example, CIMMYT implemented the Farm mechanisation and Conservation Agriculture for Sustainable Intensification (FACASI) project to promote appropriate scale mechanisation in East and Southern Africa including in Zimbabwe.[5] The project run from 2013 until 2019. 2WTs were part of the mechanisation options promoted by the project through facilitating the establishment of service providers in the project areas. Since then, CIMMYT has implemented other projects that promote the use of 2WTs in conservation agriculture systems including the R4 Rural Resilience project in Zimbabwe and the Sustainable Intensification of Smallholder farming Systems (SIFAZ) project in Zambia. Some of the current efforts are geared towards synthesising and consolidating this large body of information to inform current and future mechanisation efforts in the context of conservation agriculture, sustainable intensification and mechanisation efforts therein. The project from which data for this paper were generated, the *'Understanding and Enhancing Adoption of Conservation Agriculture in Smallholder Farming Systems of Southern Africa (ACASA)'*, is designed to help understand these complex drivers and codify them into actionable information for research, policy and practice in Southern Africa.

These projects and those by other partners like FAO address both demand and supply side constraints to agricultural mechanisation. They focus on demand creation on one side while concomitantly working with suppliers to develop their capacity to offer after-sale maintenance and repair services in the region. The Zimbabwean government has since bought in and plans to invest USD 5 million to import 2WT mechanisation packages to support scaling of conservation agriculture activities in the country.[6] Most of the donor-supported initiatives in Zambia and Zimbabwe aim to crowd in private sector participation to ensure sustainability. Empirical evidence on whether this has been the case remains scanty.

Thus, while Zambia and Zimbabwe followed somewhat different trajectories in pushing agricultural mechanisation, both countries have had experiences with government-led and private sector innovations. Both countries currently are focus areas for appropriate scale mechanisation that includes 2WTs. This makes Zambia and Zimbabwe appropriate places to assess demand for 2WT services.

2 | CONCEPTUAL FRAMEWORK

The theories of induced innovation (Ruttan & Hayami, 1973) and the evolution of farming systems (Boserup, 1965) can explain mechanisation development and its potential demand. According to the induced innovation theory, changes in the prices of the main factors of production—land, labour and capital—lead to the substitution of scarce and more expensive factors with abundant and cheaper factors. Changes in factor prices lead to innovations that use more of the cheaper factor and less of the more expensive ones. In the case of mechanisation, rising population and the resulting increase in the demand for food, developing rural nonfarm sectors and out-migration work in tandem to raise land and labour prices. In turn, according to the induced innovation theory, this would require substituting capital-using technologies like machines for land and labour using alternatives like hand hoeing and conventional

[3]https://african.business/2020/08/agribusiness-manufacturing/john-deere-deal-revives-zimbabwe-mechanisation-hopes/
[4]http://www.xinhuanet.com/english/2020-10/01/c_139410586.htm
[5]https://www.aciar.gov.au/sites/default/files/project-page-docs/final_report_fsc-2012-047.pdf
[6]Personal communication with an agricultural mechanisation engineer in Zimbabwe.

ploughing. This proposition finds support in the different mechanisation trajectories followed by densely populated countries like Japan *[and, China and Bangladesh]* where labour was abundant and cheap in the 19th century compared with other less densely populated countries in Europe and the US (Binswanger, 1986). Thus, it can be conjectured from the foregoing that labour and land endowments and access to capital matter in farmers' decisions whether to mechanise or not.

The Boserup hypothesis suggests that land scarcity will only trigger innovations beyond a threshold that is determined by population pressure. In the absence of population pressure, farmers tend to extensify production before they intensify (Boserup, 1965). The two theories are thus complementary in predicting that mechanisation is only likely to occur with labour scarcity and high land to labour ratios. Other important drivers for mechanisation include demand for labour in nonagricultural enterprises, improved market access (both local and international), demand elasticity for agricultural produce and access to capital (Binswanger, 1986; Diao et al., 2016). We follow the induced innovation theory and the evolution of farming systems and conceptualise that farmers' WTP for 2WT mechanised services is a function of land, labour and capital, market access and other farm and socio-demographics factors.

3 | DATA AND METHODS

3.1 | Data sources and sampling strategy

Data used in the analysis were obtained from household surveys conducted in Zambia and Zimbabwe under the ACASA project. A multistage sampling scheme was used. In stage one, one to two districts were selected per agro-ecological zone per country based on the presence of ongoing or past CA interventions. To the extent possible, the two districts were selected to have contrasting market access conditions. In stage two, two or three camps/wards and villages were selected per district using the criteria above, and in stage three, a random sample of a predetermined number of households was selected for interviews using sampling frames or lists of households per village drawn from village heads and agricultural extension officers.

Stages one and two were done in consultation with various national CA stakeholders and government agencies. Study areas in Zambia were selected in consultation with the Ministry of Agriculture (MoA) and the Conservation Farming Unit (CFU), whereas those in Zimbabwe were selected in consultation with the Department of Agricultural, Technical and Extension Services (AGRITEX) and the National CA Task Force.

Overall, the study covers 17 districts with 7 in Zambia (Mpongwe, Serenje, Mumbwa, Kaoma, Choma, Siavonga and Chipata) representing three agro-ecological zones and 10 districts in Zimbabwe (Bubi, Chiredzi, Gokwe South, Kwekwe, Masvingo, Matobo, Murewa, Nyanga, Shamva and Zaka) representing five agro-ecological zones. The final sample includes 2862 households of which 1407 households were interviewed from 56 sample villages in Zambia and 1455 from 60 sample villages in Zimbabwe. Sample households were well spread across the countries (Figure 1). Suffice to emphasis here that the surveys were done in areas known to have had large CA investments in the target countries. Such interventions were either ongoing at the time of the survey in 2021 or were active within the past 10 years.

3.2 | Variables

There are four outcome variables of interest. These include WTP amounts per ha for ripping only, ripping and seeding, direct seeding and WTP amounts for transportation per 0.5 ton and within a 20-km radius (Table 1). Because BDM auctions simulate a real market, summary statistics (discussed latter) are the most available revealed preferences of the respondents for the services offered and give unbiased WTP estimates, in the absence of actual observations (Lusk & Shogren, 2007).

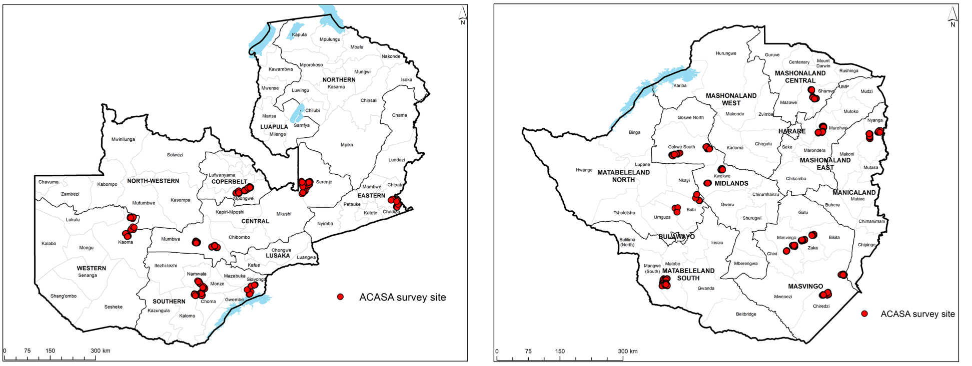

FIGURE 1 Map of the study areas in Zambia and Zimbabwe.

Following the conceptual framework developed above, we controlled for several covariates within the limits of the available data. Even if we do not have factor prices in the data, we attempted to test the induced innovation and Boserup hypotheses by controlling for labour availability (number of adults and number working off farm), whether a household faced labour challenges during land preparation, planting and weeding and whether a household accessed credit. We also controlled for wealth variables using an asset index and a social network index to check if social capital would directly influence WTP. We also controlled for several other socio-economic and demographic variables. Because cognitive ability influences WTP (Lusk & Shogren, 2007), we controlled for whether a household is aware or knows about 2WTs. Since animal draft power is the most prevalent source of farm power in the study countries, we also controlled for whether a household has ever used animal draft power for tillage, planting, weeding and transport. We also controlled for whether a household used minimum tillage (MT), the main component for conservation agriculture. In the spirit of the induced innovation and Boserup hypotheses, we expected households facing labour challenges and land constraints, those who accessed credit and are wealthy to be willing to pay higher amounts. We expected education and age to increase WTP given a higher comprehension capacity and reduced physical strength associated with these variables, respectively. However, the effects of these demographic variables are ambiguous a priori on WTP for transportation. A priori, we expected access to animal traction to reduce WTP for 2WTs.

3.3 | BDM mechanism procedures

We estimated WTP for appropriate mechanisation in CA systems using BDM auctions. BDM is a simple and intuitive, incentive compatible method used to elicit WTP in applied economics. At the core of BDM is the expected utility hypothesis which suggests that if utilities associated with alternative possible outcomes are known for a given subject, then it is possible to predict their choices (Becker et al., 1964; Kahneman et al., 1990). BDM is thought to be incentive compatible because it induces truth-telling and allows individuals to reveal their maximum WTP amounts (Horowitz, 2006; Lusk & Shogren, 2007). The procedure is simple. After a detailed activity description with examples and trial runs, an individual is asked to 'bid' for the activity. The activity's price is then randomly drawn from a distribution of prices. This distribution of prices is based on actual market prices and is not known to the respondent. If the bid amount is above the price, the individual wins the activity and pays the drawn price or loses the activity, otherwise. Unlike contingent valuation which is hypothetical, BDM simulates a real market where goods and services are exchanged with real money, and therefore, decisions made by participants have consequences (Lusk & Shogren, 2007).

To accommodate mechanisation activities and given the scarcity of 2WTs in the study areas and the fact that the survey was done during the dry season, we modified the standard BDM procedures and monetised the services that farmers won. The BDM procedure included 2WT-based per ha ripping, ripping and seeding, direct seeding and transportation for 0.5 tons within a 20-km radius. The modification is such that if farmers won the ripping service, they do

TABLE 1 Summary statistics of variables used in the estimations.

Variable name	Description	Zambia (*n* = 1401)			Zimbabwe (*n* = 1425)			Pooled sample (*n* = 2825)		
		Mean	SD	Median	Mean	SD	Median	Mean	SD	Median
Dependent variables										
WTP, ripping (USD/ha)	Willingness to pay, ripping (USD)	18.93	11.37	18.18	51.49	27.94	50.00	35.35	26.88	25.00
WTP, rip and seed (USD/ha)	Willingness to pay, rip and seed (USD)	28.46	17.26	27.27	68.90	32.13	62.50	48.71	32.77	37.50
WTP, direct seed (USD/ha)	Willingness to pay, direct seeding (USD)	25.92	17.49	22.73	57.66	30.52	50.00	41.70	29.48	36.36
WTP, trans (0.5 t within 20 km)	Willingness to pay, transport (USD)	5.75	5.10	4.55	11.84	6.64	10.00	8.80	6.66	6.82
Independent variables										
Age, hh head	Age, household head in years	48.32	14.16	48.00	54.21	14.96	53.00	51.32	14.87	50.00
Education, hh head	Education, household head in years	7.28	3.45	7.00	7.72	3.61	8.00	7.50	3.54	8.00
Female, hh head (yes = 1)	Female headed household (yes = 1)	0.23	-	-	0.34	-	-	0.29	-	-
Number, male adults	Number of male adults per household	1.49	1.09	1.00	1.39	0.97	1.00	1.44	1.03	1.00
Number, female adults	Number of female adults per household	1.60	0.93	1.00	1.53	0.81	1.00	1.56	0.87	1.00
Number working off farm	Number working off farm per household	2.10	3.29	0.00	1.71	2.51	0.00	1.90	2.92	0.00
Landholding size (ha)	Total cultivated, fallow, and virgin land	6.30	9.18	4.00	2.47	2.03	2.00	4.35	6.87	2.63
Ever used ADP	Ever used draft power for tillage or transport	0.91	-	-	0.94	-	-	0.93	-	-
Asset index	Index for productive assets[a]	−0.00	0.15	−0.02	−0.00	0.15	−0.02	−0.00	0.15	−0.02
Social network index	Index for social network connections[a]	−0.00	0.22	−0.01	0.00	0.24	−0.02	−0.00	0.23	−0.01
Faced labour constraints (yes = 1)	Whether a household faced labour constraints	0.79	-	-	0.54	-	-	0.66	-	-

TABLE 1 (Continued)

		Zambia ($n = 1401$)			Zimbabwe ($n = 1425$)			Pooled sample ($n = 2825$)		
Variable name	Description	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median
Know about 2WTs (yes = 1)	Whether a household know about 2WTs	0.62	-	-	0.32	-	-	0.47	-	-
Accessed credit (yes = 1)	Whether a household accessed credit	0.41	-	-	0.24	-	-	0.32	-	-
Used MT (yes = 1)	Whether a household used minimum tillage	0.80	-	-	0.94	-	-	0.87	-	-

Note: The *n* reduced after trimming off the top 95th percentile for Zimbabwe and 99th percentile for Zambia who WTP amounts seemed implausible. Retaining these in the analysis does not significantly change the empirical results. The social network index is a composite of variables including the numbers of years the household head has lived in the current village, the number of relatives and nonrelatives that a household can rely on in and outside their village, number of friends in leadership positions, membership to a farmer organisation and whether the household head or spouse is related to the chief/headman. Both indices were constructed using factor analysis.

Abbreviations: MT, minimum tillage; WTP, willingness to pay.

[a]The asset index is a composite variable constructed from ownership of productive assets such as ploughs, oxcarts, rippers, hand hoes, knapsack sprayer, shovel, bicycle, vans/lorry, ax, and so on.

not get the actual service but instead win a nontrivial amount of money (about $5) that is enough to cover rural daily wage labour. Here are the steps followed in conducting the BDM exercise with farmers:

- **Step 1:** We described a farm operation service (ripping, ripping and seeding, and direct seeding) including how long it will take to do the operation per ha and transportation of 0.5 ton within a 20-km radius. We showed farmers pictures of operations in case they were not familiar with the services described. This process continued until farmers were comfortable with the four options.
- **Step 2:** We then asked farmers to bid for each service. That is, farmers indicated how much they can pay for the service, considering how much it would normally cost to do the same using alternative means, for example, manual labour or animal draft power.
- **Step 3:** Once steps 1 and 2 are completed for each service, one of the services was randomly picked to be played for real money. Here, farmers randomly selected a number between 1 and 4, where 1 was for ripping, 2 for ripping and seeding, 3 for direct seeding and 4 for transportation.
- **Step 4:** Once a service is randomly selected to be played for real cash in step 3, a price for the service is drawn from an unknown (to the farmer) distribution of prices for the service.[7] **If a farmer's bid is higher than the randomly drawn price, she/he wins a token worth $5**. Thus, farmers had an incentive to bid their true WTP.

3.4 | Analytical framework

Because BDM auctions do not give starting values, the WTP amounts given by respondents are dispersed (Table 1). We can write a parsimonious estimable function of WTP as follows:

$$\begin{aligned} WTP_{ij} = \beta_0 + \mathbf{W}_i\beta_1 + \mathbf{X}_i\beta_2 + \beta_4 credit_i + \beta_5 laborC_i \\ + \beta_6 know + \beta_7 landh_i + \beta_8 socialk_i + \beta_9 adp_i + \beta_{10} used\_MT_i + \mu_i \end{aligned} \tag{1}$$

[7]The distribution of prices is unknown to the farmers but not the researcher. These were constructed based on prevailing average prices gathered for the four services in the study areas prior to the survey. Only 15%, 17%, 11% and 48% won bids for ripping, ripping and seeding, direct seeding and transportation, respectively.

where WTP_{ij} is the willingness to pay for household *i* for mechanisation services *j*, *j* = *1*–*4*. The vector ***W*** captures labour availability, wealth (asset index) and ***X*** includes all socio-economic and demographic variables. *Credit*, labor*C*, *know*, *landh*, *socialk adp* and *used_MT* capture access to credit, labour constraints, knowledge on 2WTs, landholding size, social capital, use of animal draft power and min till, respectively. We also controlled for country and district dummies to capture fixed effects, for pooled and country specific regressions. All variables in Equation (1) are as defined in Table 1.

Because all outcome variables have a few zeros and are very dispersed and because the price ranges were set within what was reported in pilot projects and by the nascent service providers, we estimated Equation (1) using the Tobit regression model with both below and upper censoring. The lower censoring point is zero while the upper censoring point is the 95th percentile of each outcome variable for the pooled sample and for each country. We considered observations above the 95th percentile to be outliers and possibly are protest bids.

4 | RESULTS AND DISCUSSION

Prior to assessing demand for mechanisation, we first assess labour shortages for different farm operations among sampled households and the prevalence, use and knowledge of different kinds of mechanisation options among sample farmers.

4.1 | Labour constraints and demand for mechanisation

Weeding and land preparation are the top farm operations for which most farmers face labour constraints (Table 2). About 62% and 43% of sample farmers in Zambia and Zimbabwe, respectively, faced labour constraints during weeding. This is followed in second place by land preparation for which 50% and 20% of the farmers faced labour constraints in Zambia and Zimbabwe, respectively. In Zambia, between 20% and 32% of farmers interviewed faced labour challenges for transportation, harvesting, planting and fertiliser application and shelling and/or threshing. Harvesting and planting and fertiliser application are the other important farm operations where at least 14% of sample farmers faced labour shortages in Zimbabwe.

Labour constraints for land preparation appeared more of a problem in Serenje and Mpongwe districts in Zambia, and in Murewa and Bubi districts in Zimbabwe. Weeding-related labour constraints were more prevalent in Kaoma and Serenje in Zambia and Nyanga and Murewa in Zimbabwe. In terms of what to mechanise and where, these findings imply that weeding and land preparation should be prioritised in both countries and in districts where these are major constraints if there is enough demand (more later). Thus, both power- and control-intensive operations need to be looked at simultaneously instead of the former first and then the latter, as suggested in Pingali (2007). Addressing both power and control intensive operations simultaneously makes sense in the context of conservation agriculture systems where labour bottlenecks are a huge challenge in the absence of herbicides or when herbicides are improperly used leading to low efficacy in controlling weeds.

4.2 | Prevalence, use and affordability of mechanisation

Draft animal power remains the most known, used, owned, accessible and affordable form of farm power in Zambia and Zimbabwe (Table 3). Over 90% of the sample farmers have used draft animal power. About 37% and 57% of interviewed households in Zambia and Zimbabwe, respectively, own draft animals. Despite being widely known by more than 90% of the farmers, only about 15%–16% of interviewed households have ever used four-wheel tractors and about 1% own these tractors in Zambia and Zimbabwe.

TABLE 2 Percentage of households who faced labour shortages for different farm operations by country and district.

District	Weeding	Land preparation	Transportation	Harvesting	Planting and fertiliser application	Shelling and/ or threshing	*n*
Zambia							
Chipata	63.32	40.20	33.17	29.15	13.07	12.56	199
Choma	62.00	34.50	22.50	36.50	18.50	21.00	200
Kaoma	73.76	58.42	35.15	35.15	27.23	18.81	202
Mpongwe	58.62	64.04	34.98	30.54	36.45	29.56	203
Mumbwa	57.00	55.50	39.50	32.50	15.50	21.50	200
Serenje	62.38	64.36	37.13	36.63	28.22	29.21	202
Siavonga	58.00	36.00	22.50	19.50	11.50	8.00	200
Total	**62.16**	**50.50**	**32.15**	**31.44**	**21.55**	**20.13**	**1406**
Zimbabwe							
Bubi	40.00	24.67	1.33	10.00	23.33	3.33	150
Chiredzi	43.33	23.33	0.67	25.33	4.67	2.00	150
Gokwe South	32.67	6.00	1.33	10.67	2.67	0.67	150
Kwekwe	31.07	18.45	0.00	6.80	3.88	0.00	103
Masvingo	27.33	19.33	2.00	6.67	6.67	2.67	150
Matobo	56.00	24.00	0.00	22.67	27.33	8.67	150
Murewa	57.05	36.24	6.71	30.87	20.13	12.08	149
Nyanga	61.44	18.30	9.80	30.07	19.61	4.58	153
Shamva	30.67	12.00	4.00	16.67	12.00	3.33	150
Zaka	48.00	20.00	1.33	20.00	18.00	8.67	150
Total	**43.16**	**20.27**	**2.82**	**18.35**	**14.16**	**4.74**	**1455**

TABLE 3 Prevalence, use and affordability of draft animal powered and 2WT-based mechanisation services (% households).

	Zambia			Zimbabwe		
	Draft animal power	2W tractors	4W tractors	Draft animal power	2W tractors	4W tractors
Know about	98.44	61.90	96.09	99.66	31.96	96.84
Ever used	91.12	1.84	15.90	94.14	1.94	14.48
Ownership	37.33	0.23	1.26	57.10	0.65	1.06
Accessibility	38.75	27.78	17.21	62.78	18.71	16.67
Affordability	25.67	^	6.51	35.60	^	7.84

Note: Usage (ever used) and ownership are computed for those who know a particular farm power. Accessibility was computed for those farmers who did not hire mechanisation services for 2020/2021 season but have used before, while affordability was computed for those who know about the mechanisation option and think it is possible to hire.
^ statistically invalid, $n < 30$.

The 2WTs are more popular in the study areas in Zambia, known by some 62% of the sample households compared to only 32% in Zimbabwe. However, only about 2% of the sample households have ever used 2WTs and less than 1% own them. These findings have three implications on the current push for 2WTs in southern Africa. First, there is need for more work to raise awareness about and create demand for 2WTs in the region, as suggested by others, for example, Daum and Birner (2020) and Baudron et al. (2015). Stakeholders such as donors and other development partners can play this catalytic role in this initial phase, but they need to let the private sector take over once effective demand is created. Second, because animal draft power is still widely used in the region, getting farmers to transition to 2WTs will require demonstrating the added benefits associated with the switch and making more 2WTs available to rural service providers. These added benefits could be in terms of time saving, incomes and land and labour productivity realised from using 2WTs in contrast to the status quo (e.g. Baudron, Nazare, & Matangi, 2019). Assessing the added benefits of 2WTs compared with animal draft power is beyond the scope of the current paper but a good research area for future work. Readers are referred to Baudron et al. (2015), Baudron, Misiko, et al. (2019) and Baudron, Nazare, and Matangi (2019) on why 2WTs and some benefits of 2WTs. Our analysis focuses on 2WTs and not large four-wheel tractors because the former are more suitable for small landholdings and are more affordable (Baudron et al., 2015). Moreover, four-wheel tractor operators face higher transaction costs in providing services to dissipated smallholder farmers (Adu-Baffour et al., 2019).

Of course, rising labour wages and land scarcity may quicken the transition to more intensified forms of production. But the current low cropping intensities and land-labour ratios (Baudron, Misiko, et al., 2019; Binswanger-Mkhize & Savastano, 2017) and the perception that land is abundant cast doubts. And lastly, drawing from the power shifts in Europe, Japan and United States (Binswanger, 1986), it can be conjectured that 2WTs even if adopted widely will co-exist with animal draft power for some time. In this case, mechanisation should be targeted for specific operations where there is the highest comparative advantage. Clarifying this will require more comparative research on returns to animal draft power- versus 2WT-based as well as 4WT operations, and not comparing returns from 2WTs versus manual systems.

4.3 | Willingness to pay for mechanisation

On average, the sample households in Zambia were willing to pay USD19, USD28 and USD26 per hectare for ripping, ripping and seeding, and direct seeding, respectively, and USD6 for transportation per 0.5 ton within a radius of 20 km (Table 1 and Figure 2). Farmers in Zimbabwe were willing to pay more in nominal terms at USD51, USD69 and USD58 per hectare for ripping, ripping and seeding, and direct seeding, respectively, and USD12 for transportation of 0.5 tons per 20-km radius. Overall, at least 50% of sample households in Zambia and Zimbabwe were willing to pay more than the prevailing market prices for ripping, and 5%–10% were willing to pay more for direct seeding in the

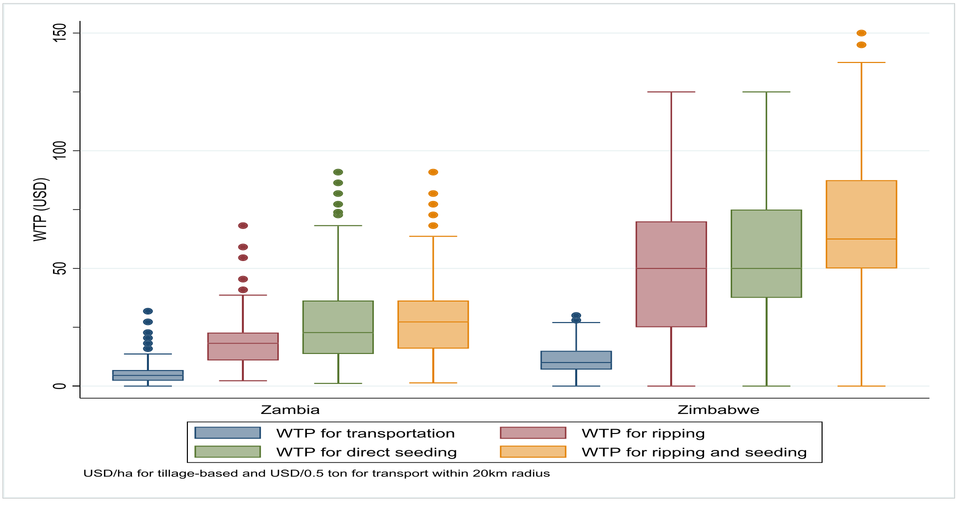

FIGURE 2 Average willingness to pay (USD/ha) for different mechanisation services in Zambia and Zimbabwe.

two countries. Our WTP estimate for 2WT ripping of USD19 is much lower than the USD31 per ha for 4WT-based ripping, but our WTP estimate for 2WT direct seeding of USD26 is close to the estimate USD31 service charge per ha for 4WT direct seed in Zambia (Omulo et al., 2022).

4.3.1 | District level WTP for mechanisation in Zambia and Zimbabwe

District level WTP amounts add some nuances. In Zambia, the sample farmers in Kaoma, Mpongwe, Mumbwa and Serenje were willing to pay higher amounts on average for ripping and seeding, and direct seeding than in any other districts (Figure 3). This is not surprising as these have been among the districts where recent mechanisation initiatives in the country were implemented and where more than 50% of sample households lacked labour for land preparation (Table 2). Interviewed farmers in Kaoma, Mpongwe, Mumbwa and Serenje were on average willing to pay USD15–USD25 per ha for ripping, ripping and seeding and direct seeding (Figure 3) and have the highest WTP amounts for all field-based operations. Despite over 30% of farmers in Choma and Chipata districts indicating that they lacked labour for land preparation (Table 2), they have the least WTP amount at about USD17 per ha for ripping. Prevalence of animal draft power in these districts could partly explain the results. The WTP for transport of 0.5 tons within a 20-km radius hovers between USD5 in Chipata district and USD11 in Mpongwe, where 15% and 34% lacked labour for transportation during the 2020/2021 cropping season, respectively.

There are small differences in the WTP amounts between districts in Zimbabwe. Bubi, Matobo and Murewa districts, where more than 24% of farmers interviewed lacked labour during land preparation (Table 2), had the highest WTP for ripping of over USD50 per ha. Farmers in the same districts and Shamva were willing to pay higher amounts for ripping and seeding and direct seeding than farmers in other districts (Figure 3). Despite 23% of farmers in Chiredzi district indicating that they lacked labour for land preparation (Table 2), they have the least WTP amounts for all 2WT-based tillage systems. This could be explained by the higher cattle density in Chiredzi District and lower value of crop production given that the district is mostly arid.

On average, farmers in Masvingo district where 2WTs have been promoted the most using the service provider model had the third lowest WTP amounts for ripping and seeding operations and the second lowest for transportation. Although our survey may not have overlapped 100% with areas where 2WTs have been promoted in the district, this finding calls for caution in demand creation activities. A farmer, during focus group discussions, said that *'they considered demand creation activities as donations and therefore, [farmers] have no incentive to pay for 2WT services.'* The WTP amounts for transportation are highest in Mpongwe and Siavonga districts in Zambia and Nyanga and Murewa districts in Zimbabwe.

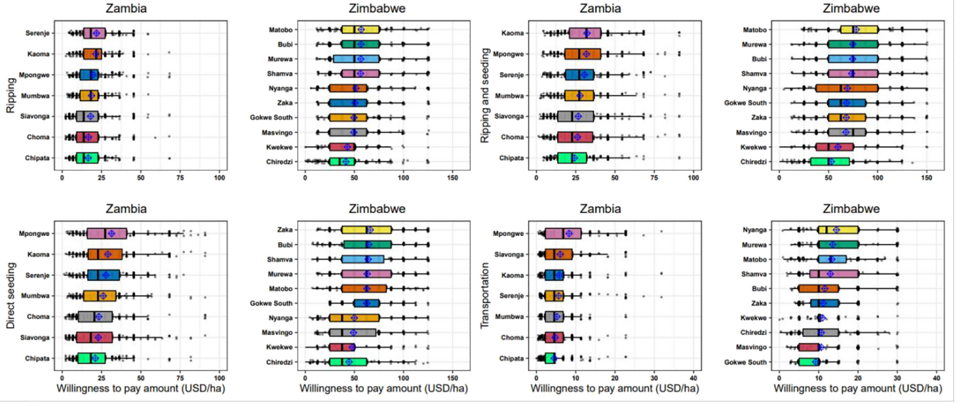

FIGURE 3 Average willingness to pay (USD/ha) for different mechanisation services in Zambia and Zimbabwe.

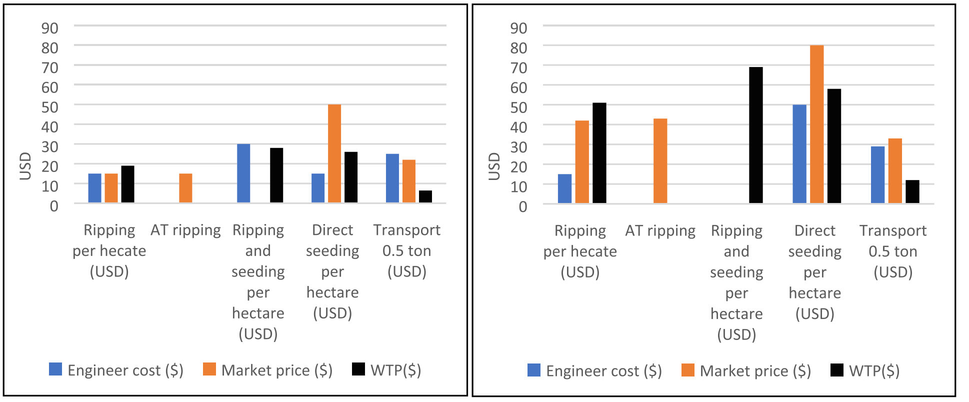

FIGURE 4 Average willingness to pay (WTP) amounts, engineering costs and market prices for different mechanisation services in Zambia (left panel) and Zimbabwe (right panel). *Note*: Data on engineering and market prices were obtained from the mechanisation team in CIMMYT. These data are routinely collected. The numbers presented are averages for 2020/2021 and 2021/2022 seasons or for 2021/2022 season only. Gaps imply that data are not available.

These findings have implications for targeting of mechanisation for the types of services analysed in this paper. In terms of *where* to target, Kaoma, Mumbwa, Mpongwe and Serenje are good candidate districts in Zambia given that farmers in these districts are willing to pay higher amounts for ripping, ripping and seeding, and direct seeding. Among study districts in Zimbabwe, the niche seems to be in Matobo, Bubi and Murewa districts. In terms of *what* to mechanise, ripping and seeding, direct seeding and ripping only have the highest prospects both in Zambia and Zimbabwe for services considered in this study, *ceteris paribus*. These results are only based on 7 districts in Zambia and 10 districts in Zimbabwe covered in the survey and only on four mechanised services. It is possible to have a different ordering if more districts and mechanised services are included, but a sample of over 2800 households improves greatly both the internal and external validity of these results.

When compared with provisional engineering costs (minimum industry estimates of service price to cover fabrication costs and mark ups for engineering and service providers) and market prices (actual prices obtained on the market for the service) for the different services, the WTP estimates for ripping are 27% higher than existing market prices in the sample districts of Zambia (Figure 4). The WTP for ripping is 21% higher than the market price in Zimbabwe. These WTP amounts for 2WT ripping are slightly higher than market prices for animal traction in Zambia and Zimbabwe. In Zambia, animal traction ripping costs about USD15 per ha compared to a WTP of USD19 for 2WT ripping. Farmers in Zimbabwe are willing to pay USD51 per ha for 2WT ripping, and animal traction ripping costs USD43 per ha. However, market prices for animal traction ripping and 2WT ripping are virtually the same in within the study areas in each country. When considering market fundamentals and based on the best available market data, these findings suggest that 2WT-based ripping services have a business case given that the WTP amounts are higher than market prices in Zambia and Zimbabwe. Farmers in Zambia and Zimbabwe are willing to pay 27% and 18% more per ha for 2WT-ripping than the existing market prices for animal traction ripping services.

Based on the market data gathered, transportation and direct seeding services are not considered viable in the areas where the survey was conducted in both countries. These findings merely show that farmers (or customers) interviewed have lower WTP for transportation and direct seeding. A major limitation for transportation is that while our survey only shows a snapshot of farmers' WTP for transportation for a single service at the time of the survey, in reality, transport services are offered throughout the year. As such, the average WTP estimates for 2WT-based transport services mask a lot of variability, and the cumulative income from transport services per year might be substantial. The findings here do not invalidate the potential of transportation services from a service provider perspective who would offer such services throughout the year as opposed to seasonal tillage and seeding services.

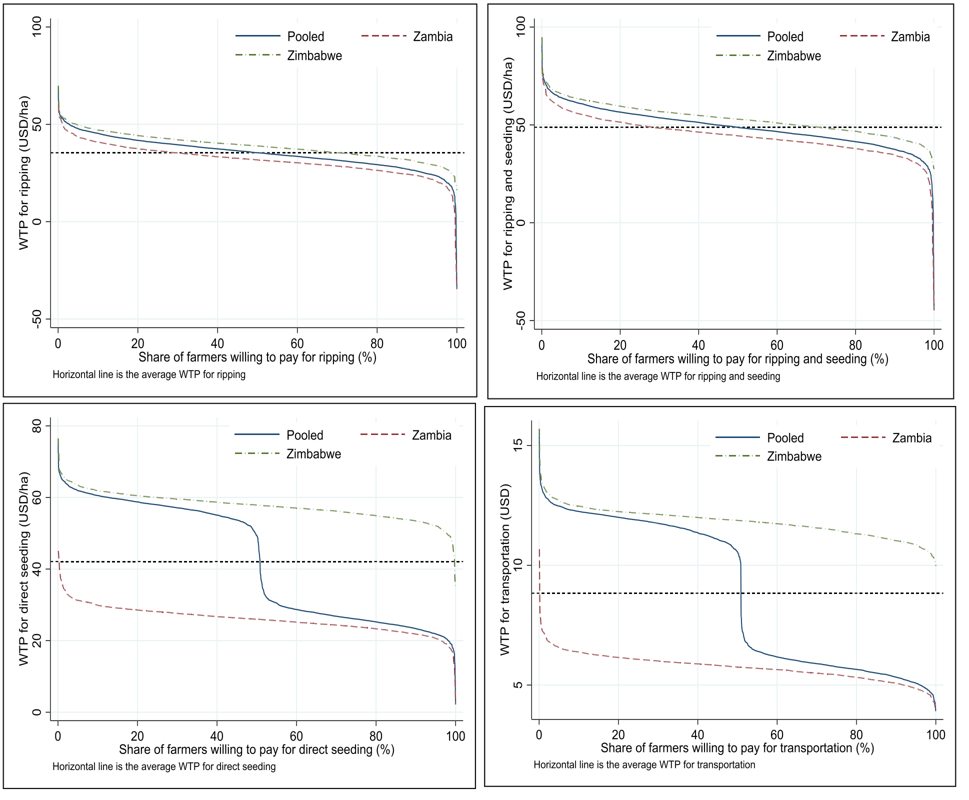

FIGURE 5 Demand curves for two-wheel tractor-based ripping (top left), ripping and seeding (top right), direct seeding (lower left) and transportation (lower right) in Zambia and Zimbabwe.

The demand curves are downward slopping as would be expected for all the 2WT-based services (Figure 5), implying that the proportion of farmers willing to pay for these services reduces as the payment amount increases. As stated before, the average WTP amounts are higher in Zimbabwe than in Zambia.

4.4 | What explains WTP for mechanisation?

Several factors determine farmers' WTP for mechanisation in the pooled sample (Table 4), in Zambia (Table 5) and Zimbabwe (Table 6). As expected, education is associated with higher WTP for direct seeding in the pooled sample (Table 4) and transportation in the Zimbabwe sample (Table 6). Educated households are also expected to have a better ability to process new information and gain faster understanding of innovations such as mechanisation, leading to higher WTP for such. As such paying for 2WT-based services maybe a preferred option for such households. The age of the household head is negatively associated with WTP for ripping and transportation in the pooled sample (Table 4) and in Zambia (Table 5), ripping and seeding in Zambia (Table 5) and for transportation in Zimbabwe (Table 6). This suggests that households headed by younger and perhaps more enterprising heads are more likely to use 2WTs for MT services and transportation.

Households headed by females are willing to pay significantly lower amounts for ripping and seeding and direct seeding. This could be explained by the fact that either these activities are deemed to be male dominated activities or perhaps, that female headed households do not have as many endowments or control over funds as do male headed households to afford to pay for these services. This result is suggestive of gendered effects on farmers' WTP for

TABLE 4 Tobit model average partial estimates of the determinants of smallholder farmers' WTP for 2WT-based services, pooled sample.

	(1) Ripping	(2) Ripping and seeding	(3) Direct seeding	(4) Transportation
Age, hh head	−0.05* (−1.76)	−0.02 (−0.42)	0.02 (0.61)	−0.02** (−2.42)
Education, hh head	0.16 (1.58)	0.02 (0.16)	0.24* (1.70)	0.05 (1.48)
Female, hh head	−0.93 (−1.03)	−3.12** (−2.48)	−0.97 (−0.85)	0.16 (0.66)
Number, male adults	−1.18*** (−3.25)	−1.83*** (−3.51)	−0.53 (−1.11)	0.15 (1.37)
Number, female adults	0.47 (1.17)	0.49 (0.82)	−0.18 (−0.33)	0.02 (0.18)
Number, working off farm	0.17 (1.64)	0.29* (1.88)	−0.25* (−1.82)	0.14*** (4.04)
Landholding size (ha)	0.01 (0.25)	−0.03 (−0.34)	0.05 (0.79)	−0.00 (−0.35)
Ever used ADP (yes = 1)	−1.23 (−0.93)	−0.84 (−0.46)	−4.82*** (−2.64)	−1.19** (−2.57)
Asset index	12.30*** (4.59)	19.26*** (4.76)	12.04*** (3.26)	2.00*** (2.61)
Social network index	0.44 (0.27)	0.24 (0.11)	−9.46*** (−4.43)	−0.04 (−0.10)
Faced labour constraints	0.39 (0.47)	1.77 (1.55)	−0.34 (−0.31)	0.23 (1.04)
Know about 2WTs (yes = 1)	−0.31 (−0.45)	0.56 (0.56)	−0.97 (−1.06)	−0.08 (−0.37)
Accessed credit (yes = 1)	0.08 (0.11)	1.53 (1.52)	−1.87** (−2.10)	−0.14 (−0.66)
Used MT (yes = 1)	2.21*** (2.75)	2.04* (1.69)	0.79 (0.71)	- -
Zambia (yes = 1)	−29.48*** (−36.30)	−40.39*** (−34.87)	−28.93*** (−27.55)	−5.64*** (−24.20)
Lower limit	0	0	0	0
Upper limit (95th percentile)	88	125	100	23
Censored observations	142	139	210	98
Observations	2632	2613	2600	2745

Note: Robust *t*-statistics in parentheses. Base country is Zimbabwe; dependent variables are amounts in USD, estimated using Tobit model.

Abbreviations: MT, minimum tillage; WTP, willingness to pay.

***$p < 0.01$. **$p < 0.05$. *$p < 0.1$.

2WTs-based mechanisation services that should be addressed at promotion to ensure gender and social inclusivity. This is contrary to Baudron, Misiko, et al. (2019) who found no gendered gaps in labour and land productivity (and not WTP), but it is consistent with other literature that confirm the persistence of gender gaps in agriculture in the region (Andersson Djurfeldt et al., 2013; FAO, 2011).

Households with more adult males are willing to pay significantly lower amounts for ripping and ripping and seeding in the pooled sample and in Zimbabwe (Tables 4 and 6). This finding suggests that labour availability reduces the willingness to pay for 2WT-based ripping services. In a sense, this is in line with predictions of the induced innovation hypotheses—even if our analysis uses only proxies of factors prices (Hayami & Ruttan, 1971). Off farm work can have contrasting effects on WTP for mechanisation. It is expected to increase WTP in places with high opportunity cost of labour and to lower WTP in places where the opportunity of labour for working on the farm is low. Our results for the Zambia subsample conform to the first line of thought. Having more household members working off farm significantly increased WTP for all services offered (Table 5). Another possible explanation for the positive effects is that off farm work helps improve liquidity and raises the opportunity cost of family labour. This in turn enables and induces farm households to hire in 2WT-based services. While positive for transportation in Zimbabwe, off farm work significantly reduces WTP for direct seeding (Table 6). This is suggestive of low opportunity cost of labour for direct seeding done with different options such as manual labour or animal traction in Zimbabwe.

TABLE 5 Tobit model average partial estimates of the determinants of smallholder farmers' WTP for 2WT-based services in Zambia.

	(1) Ripping	(2) Ripping and seeding	(3) Direct seeding	(4) Transportation
Age, hh head	−0.07*** (−2.83)	−0.06* (−1.73)	−0.01 (−0.37)	−0.01* (−1.71)
Education, hh head	0.01 (0.11)	−0.16 (−1.15)	0.10 (0.73)	−0.03 (−1.01)
Female, hh head	−0.48 (−0.58)	−2.20* (−1.78)	−2.91*** (−2.59)	−0.29 (−1.00)
Number, male adults	−0.13 (−0.42)	−0.71 (−1.40)	−0.51 (−1.02)	0.12 (1.01)
Number, female adults	0.54 (1.51)	0.38 (0.71)	0.20 (0.37)	−0.01 (−0.07)
Number, working off farm	0.22** (2.57)	0.42*** (3.41)	0.41*** (3.25)	0.14*** (4.10)
Landholding size (ha)	−0.00 (−0.04)	−0.01 (−0.19)	−0.02 (−0.39)	−0.00 (−0.09)
Ever used ADP (yes = 1)	−1.88* (−1.66)	−2.23 (−1.34)	−5.51*** (−2.83)	−0.18 (−0.39)
Asset index	3.41 (1.47)	8.34** (2.30)	5.63 (1.55)	1.20 (1.40)
Social network index	1.41 (1.03)	4.88** (2.29)	−2.30 (−1.14)	0.04 (0.08)
Faced labour constraints	0.61 (0.78)	−0.01 (−0.01)	−0.63 (−0.55)	−0.27 (−0.96)
Know about 2WTs (yes = 1)	−0.04 (−0.06)	−0.41 (−0.44)	1.32 (1.39)	−0.82*** (−3.51)
Accessed credit (yes = 1)	0.11 (0.18)	1.71* (1.92)	−0.00 (−0.00)	−0.49** (−2.23)
Used MT (yes = 1)	1.70** (2.33)	2.54** (2.35)	0.54 (0.48)	
Siavonga (yes = 1)	1.80 (1.49)	1.57 (0.87)	0.57 (0.34)	1.05*** (2.61)
Chipata (yes = 1)	0.19 (0.17)	−1.69 (−1.08)	−1.26 (−0.84)	−0.34 (−0.99)
Kaoma (yes = 1)	4.35*** (3.84)	5.50*** (3.34)	5.64*** (3.42)	0.87** (2.33)
Mumbwa (yes = 1)	1.75 (1.64)	1.01 (0.62)	2.61* (1.66)	0.49 (1.49)
Mpongwe (yes = 1)	2.00* (1.69)	3.76** (2.06)	7.27*** (3.91)	3.20*** (6.29)
Serenje (yes = 1)	4.60*** (4.07)	3.22* (1.95)	3.97** (2.53)	0.56 (1.43)
Lower limit	0	0	0	0
Upper limit (95th percentile)	45	68	68	18
Censored observations	74	64	62	67
Observations	1290	1289	1291	1363

Note: Robust *t*-statistics in parentheses. Base district is Choma; dependent variables are amounts in USD, estimated using Tobit model.

Abbreviations: MT, minimum tillage; WTP, willingness to pay.

***$p < 0.01$. **$p < 0.05$. *$p < 0.1$.

Wealth is the most significant driver of WTP which seems logical as those households with more wealth assets can afford to outsource 2WT-based services. Households with a high asset index are willing to pay significantly more for all 2WT-based services in the pooled sample (Table 4) and for ripping and seeding in Zambia (Table 5) and ripping, ripping and seeding and direct seeding in Zimbabwe (Table 6). This is an important finding and implies a need to deliberately craft inclusive business models for 2WT-based and other mechanisation services to farmers. If access to these services remains wealth-/asset-mediated (implying binding liquidity constraints that only asset-endowed households can overcome), business models that bundle these services with asset-agnostic credit schemes or other interventions meant to overcome asset-mediated barriers should be considered. This is key for the sustainability and profitability of the current wave of scale-appropriate mechanisation in the region. However, if viewed from another angle of gender and social inclusion, this finding calls for innovative approaches to ensure that mechanisation is accessible to

TABLE 6 Tobit model average partial estimates of the determinants of smallholder farmers' WTP for 2WT-based services in Zimbabwe.

	(1) Ripping	(2) Ripping and seeding	(3) Direct seeding	(4) Transportation
Age, hh head	−0.07 (−1.12)	−0.03 (−0.41)	0.04 (0.62)	−0.03** (−2.07)
Education, hh head	0.32 (1.33)	0.06 (0.19)	0.27 (1.03)	0.13** (2.12)
Female, hh head	−2.66 (−1.51)	−5.06** (−2.44)	−0.97 (−0.53)	0.39 (0.99)
Number, male adults	−2.52*** (−3.28)	−2.48*** (−2.69)	−0.17 (−0.19)	0.23 (1.20)
Number, female adults	1.07 (1.16)	1.57 (1.40)	−0.35 (−0.34)	0.12 (0.58)
Number, working off farm	0.06 (0.18)	0.04 (0.10)	−1.26*** (−3.61)	0.15** (2.03)
Landholding size (ha)	0.46 (0.94)	0.33 (0.59)	0.56 (1.17)	0.15 (1.50)
Ever used ADP (yes = 1)	0.83 (0.27)	1.66 (0.45)	−4.40 (−1.22)	−1.69* (−1.95)
Asset index	19.58*** (3.62)	25.54*** (3.58)	14.15** (2.38)	1.02 (0.78)
Social network index	4.80 (1.44)	1.24 (0.32)	−11.52*** (−3.14)	0.85 (1.23)
Faced labour constraints	−0.26 (−0.16)	2.25 (1.18)	0.43 (0.25)	0.15 (0.41)
Know about 2WTs (yes = 1)	−0.45 (−0.27)	1.01 (0.51)	−2.42 (−1.40)	0.44 (1.13)
Accessed credit (yes = 1)	0.36 (0.21)	1.97 (0.95)	−3.59** (−2.08)	0.22 (0.56)
Used MT (yes = 1)	3.71 (1.25)	0.29 (0.08)	−3.21 (−1.00)	
Chiredzi (yes = 1)	−15.18*** (−4.50)	−22.76*** (−5.81)	−14.50*** (−3.94)	−1.45* (−1.93)
Gokwe South (yes = 1)	−8.43*** (−2.65)	−7.06* (−1.76)	−0.98 (−0.28)	−2.55*** (−3.85)
Kwekwe (yes = 1)	−15.44*** (−5.06)	−17.09*** (−3.88)	−16.93*** (−4.55)	−0.65 (−0.89)
Masvingo (yes = 1)	−7.75** (−2.41)	−8.20** (−2.05)	−11.24*** (−3.14)	−1.24* (−1.72)
Matobo (yes = 1)	−0.12 (−0.04)	2.19 (0.56)	1.75 (0.48)	1.36* (1.81)
Murewa (yes = 1)	−1.63 (−0.48)	−1.72 (−0.42)	−1.29 (−0.35)	1.57** (2.08)
Nyanga (yes = 1)	−6.82* (−1.88)	−7.27 (−1.59)	−10.36*** (−2.74)	2.19** (2.55)
Shamva (yes = 1)	−2.40 (−0.70)	−4.36 (−1.06)	−2.09 (−0.54)	0.94 (1.21)
Zaka (yes = 1)	−6.74** (−2.07)	−7.22* (−1.77)	1.59 (0.42)	−0.32 (−0.48)
Lower limit	0	0	0	0
Upper limit (95th percentile)	113	125	113	25
Censored observations	61	139	59	91
Observations	1342	1324	1309	1382

Note: Robust *t*-statistics in parentheses. Base district is Bubi, dependent variables are amounts in USD, estimated using Tobit model.

Abbreviations: MT, minimum tillage; WTP, willingness to pay.

***$p < 0.01$. **$p < 0.05$. *$p < 0.1$.

marginalised groups such as women and youth. Options for such innovations include group hiring schemes provided by private sector players such as the AFGRI and John Deere Tractor programme (Adu-Baffour et al., 2019; Sims & Kienzle, 2015) or through mechanisation service provider models (FACASI, 2016). Finally, innovations that target labour intensive tasks undertaken by women (e.g. weeding) as opposed to men dominated tasks can help break gender disparities. The risk exists that mechanisation programmes can accentuate gender inequalities in agricultural labour burdens if they focus only in areas where men's labour is concentrated (e.g. land preparation).

As expected, having ever used animal draft power for tillage and transportation services significantly reduces WTP for direct seeding and transportation (Tables 4–6). Given the prominence of draft power as a source of farm power in Zambia and Zimbabwe (Table 1; FAO and AUC, 2019), this result suggests that animal traction and motorised mechanical options will co-exist in the study countries depending on the context. This finding is in line with suggestions by Daum et al. (2022) who argue that 'there is no blue-print for best technologies but only best-fits' and that animal traction remains relevant in the ongoing mechanisation drive in sub-Saharan Africa.

In line with a priori expectations, we find that farmers that used MT, the main component of conservation agriculture, were willing to pay significantly higher amounts for 2WT-based ripping, and ripping and seeding services in the pooled sample and Zambia subsample (Tables 4 and 5). This could be explained by the fact that such farmers are already aware of conservation agriculture and the benefit of 2WTs in implementing CA practices and therefore maybe more willing to pay for mechanised MT and seeding services.

The effects of access to credit, our measure of capital, are mixed. It increases the WTP amounts for ripping and seeding in Zambia (Table 5) but reduces WTP for direct seeding in the pooled sample (Table 4) and in Zimbabwe (Table 6). Because this measure of access to credit does not really say much about the cost of capital, it is difficult to read much into its effects. Suffice to mention that it would appear ripping and seeding requires more cash outlays than direct seeding.

The findings in this paper reflect demand from the perspective of clients or customers, that is, how much customers would be willing to pay for 2WT-based mechanised services at the time of the survey. These results should not be conflated with profitability assessments from the perspective of 2WT owners or service providers who, for example, might provide transportation services throughout the year as opposed to season tillage and planting services. Readers are referred to Baudron, Nazare, and Matangi (2019) on the profitability of 2WT hire services. The findings in this paper are a good guide on *what* to mechanise and *where* and *whom* to target based on potential demand in the study districts.

5 | CONCLUSION

Mechanisation is back among top policy priorities for transforming African agriculture. Past failures in mechanising smallholder agriculture imply a need for systematic analyses to guide policy on targeting and assessing where and for what operations there is effective demand. This paper used the Becker–DeGroot–Marschak (BDM) mechanism experimental auctions that simulate a real market to assess farmers' willingness to pay (WTP) for Two-Wheel Tractor (2WT) -based mechanisation services in 7 and 10 districts of Zambia and Zimbabwe, respectively, with a random sample of about 2800 smallholder households. We focused on ripping only, ripping and seeding, direct seeding and transportation using a 2WT.

We found that weeding and land preparation are the top two farm operations where most farmers face labour constraints and therefore need to be mechanised. About 62% and 43% of sample farmers in Zambia and Zimbabwe, respectively, faced labour constraints during weeding, while 50% and 20% of the farmers faced labour constraints during land preparation, respectively. These differences are observed across districts and between the study countries. For example, most sampled farmers in Serenje and Mpongwe districts in Zambia and Murewa and Bubi districts in Zimbabwe faced labour constraints during land preparation. Weeding-related labour constraints were more prevalent in Kaoma and Serenje in Zambia and Nyanga and Murewa in Zimbabwe among the study sites.

Despite the 2WTs being more popular in Zambia where they are known by some 62% of sample households compared with only 32% in Zimbabwe, only about 2% of sample households have ever used 2WTs and less than 1% own them in study areas across the two countries. On average, the sample households in Zambia were willing to pay USD19, USD28 and USD26 per ha for ripping, ripping and seeding and direct seeding, respectively, and USD6 for transportation per 0.5 ton within a radius of 20 km, whereas those in Zimbabwe were willing to pay more in nominal terms at USD51, USD69 and USD58 per ha for ripping, ripping and seeding and direct seeding, respectively, and

USD 12 for transportation of 0.5 tons per 20-km radius. About half of sample households in Zambia and Zimbabwe were willing to pay more than the prevailing market prices for ripping, and 5%–10% were willing to pay more for direct seeding in the two countries. Among the study districts, the most promising districts for 2WTs (where demand is highest) include Kaoma, Mpongwe, Mumbwa and Serenje in Zambia and Bubi, Matobo and Murewa districts in Zimbabwe.

Compared with market prices for the different services, the WTP estimates for ripping are 21%–27% higher than existing market prices in the sample districts in Zambia and in Zimbabwe. Thus, when considering market fundamentals, these findings suggest that there could be a business case for 2WT-based ripping services in Zambia and Zimbabwe. However, animal traction remains the most prominent source of farm power, and market prices for animal traction ripping and 2WT ripping are virtually the same in both countries. We also found that farmers that have used animal draft power before are willing to pay significantly less for 2WT-based services.

Wealth and binding labour constraints are the strongest drivers of farmers' WTP for 2WT-based mechanisation services. Familiarity with conservation agriculture practices and off farm work is associated with higher willingness to pay. These findings call for action on several fronts: First, there is need for more work to raise awareness on mechanisation and create demand for 2WTs in regions where there is comparative advantage. Given disappointing results for conventional demand creation models, this calls for different approaches. Where WTP is already high and is consistent with potential market price, the activities should be on inclusive market deepening and business development, whereas in areas with low WTP, focus should be on early demand creation based on inclusive business models that do not create perverse incentives or expectations or stunt effective demand. Because animal draft power is still widely used in the study countries, 2WTs will likely co-exist with animal traction for long given the low WTP for 2WTs in areas where animal traction is prevalent.

Second, since 2WTs will likely co-exist with animal draft power systems for some time, mechanisation should be targeted for specific operations where there is the highest comparative advantage. Clarifying this will require more economic analyses on returns to animal draft power—versus 2WT-based operations. Third, as weeding was rated to have the most labour constraints, there is need to develop appropriate machinery and tools for mechanical weed control beyond herbicides, cultivators and hand hoeing (even if that is construed as shallow weeding) to address labour bottlenecks and to assess the most cost-efficient method to control weeds. Finally, there is need to target farmers who can pay for the services. This will crowd in private sector players who are crucial for sustainable smallholder mechanisation in the region. In doing so, other models such as group hire services and/or incentives to tractor owners can be pursued for more inclusive mechanisation. This implies a need to deliberately craft inclusive business models for 2WT-based and other mechanisation services to farmers. If access to these services remain wealth-/asset-mediated only, business models that bundle these services with asset-agnostic credit schemes or other interventions meant to overcome asset-mediated *barriers should* be considered. A conducive policy environment that facilitates mechanisation through tax incentives and smart subsidies is required to sustain the current appropriate scale mechanisation in the region.

There is scope for more work on the economics of 2WT hire services. While there are positive indications (e.g. Baudron, Nazare, & Matangi, 2019) and positive demand in this paper, there is need to evaluate the profitability of 2WT hire for the full range of land preparation, planting, weeding, postharvest and transport services. This should be compared with similar services provided by animal draft power where applicable, to address the main question of whether 2WTs can leapfrog animal traction.

ACKNOWLEDGEMENTS

This study was supported by the Royal Norwegian Government through the Norwegian Agency for Development Cooperation (NORAD) who funded the project *Understanding and Enhancing Adoption of Conservation Agriculture in Smallholder Farming Systems of Southern Africa (ACASA)*, grant P1925 under the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Additional logistical support was made available through the CGIAR Research Program on Maize Agrifood Systems (CRP MAIZE; www.maize.org). We are grateful to all government and private sector partners and numerous research assistants who facilitated fieldwork. We are also grateful for comments from Frédéric Baudron, the editor and two anonymous reviewers. The views expressed here are those of the authors and do not necessarily reflect the views of the funding organisations or the authors' affiliations.

CONFLICT OF INTEREST STATEMENT

The authors are solely responsible for any errors in this paper and declare no competing interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

This study received approval from Zambia's institutional review board: ERES Converge. No similar board was found in Zimbabwe at the time.

ORCID

Hambulo Ngoma https://orcid.org/0000-0002-7050-9625
Adane Tufa https://orcid.org/0000-0001-9801-6526

REFERENCES

Adu-Baffour, F., Daum, T., & Birner, R. (2019). Can small farms benefit from big companies' initiatives to promote mechanization in Africa? A case study from Zambia. *Food Policy*, *84*, 133–145. https://doi.org/10.1016/j.foodpol.2019.03.007

Andersson Djurfeldt, A., Djurfeldt, G., & Bergman Lodin, J. (2013). Geography of gender gaps: Regional patterns of income and farm–nonfarm interaction among male- and female-headed households in eight African countries. *World Development*, *48*, 32–47. https://doi.org/10.1016/j.worlddev.2013.03.011

Baudron, F., Misiko, M., Getnet, B., Nazare, R., Sariah, J., & Kaumbutho, P. (2019). A farm-level assessment of labor and mechanization in Eastern and Southern Africa. *Agronomy for Sustainable Development*, *39*, 17. https://doi.org/10.1007/s13593-019-0563-5

Baudron, F., Nazare, R., & Matangi, D. (2019). The role of mechanization in transformation of smallholder agriculture in Southern Africa: Experience from Zimbabwe. In R. A. Sikora, E. R. Terry, P. L. G. Vlek, & J. Chitja (Eds.), *Transforming agriculture in Southern Africa*. Routledge. https://doi.org/10.4324/9780429401701-21

Baudron, F., Sims, B., Justice, S., Kahan, D. G., Rose, R., Mkomwa, S., Kaumbutho, P., Sariah, J., Nazare, R., Moges, G., & Gérard, B. (2015). Re-examining appropriate mechanization in Eastern and Southern Africa: Two-wheel tractors, conservation agriculture, and private sector involvement. *Food Security*, *7*, 889–904. https://doi.org/10.1007/s12571-015-0476-3

Becker, G. M., Degroot, M. H., & Marschak, J. (1964). Measuring utility by a single-response sequential method. *Behavioral Science*, *9*, 226–232. https://doi.org/10.1002/bs.3830090304

Binswanger, H. (1986). Agricultural mechanization: A comparative historical perspective. *The World Bank Research Observer*, *1*, 27–56. https://doi.org/10.1093/wbro/1.1.27

Binswanger-Mkhize, H. P., & Savastano, S. (2017). Agricultural intensification: The status in six African countries. *Food Policy*, *67*, 26–40. https://doi.org/10.1016/j.foodpol.2016.09.021

Boserup, E. (1965). *The condition of agricultural growth. The economics of agrarian change under population pressure*. London, George Allen and Unwin.

Daum, T., & Birner, R. (2020). Agricultural mechanization in Africa: Myths, realities and an emerging research agenda. *Global Food Security*, *26*, 100393. https://doi.org/10.1016/j.gfs.2020.100393

Daum, T, Seidel, A., Awoke, B., & Birner, R. (2022). Animal traction, two-wheel tractors, or four-wheel tractors? A best-fit approach to guide farm mechanization in Africa. Hohenheim working papers on social and institutional change in agricultural development. Hohenheim, Germany: University of Hohenheim. https://doi.org/10.2139/ssrn.4092687

De Groote, H., Kimenju, S. C., & Morawetz, U. B. (2011). Estimating consumer willingness to pay for food quality with experimental auctions: The case of yellow versus fortified maize meal in Kenya. *Agricultural Economics*, *42*, 1–16. https://doi.org/10.1111/j.1574-0862.2010.00466.x

Diao, X., Silver, J., & Hiroyuki, T. (2016). *Agricultural mechanization and agricultural transformation* (Vol. 1527). International Policy Rsearch Institute (IFPRI).

FACASI. (2016). Business Models of Two Wheel Tractors in Southern and Eastern Africa, FACASI Technical Working Papers. Farm Mechanization and Conservation Agriculture for Sustainable Intensification (FACASI), International Maize and Wheat Improvement Center (CIMMYT), Addis Ababa, Ethiopia.

FAO. (2011). *Women in agriculture: Closing the gender gap for development, The State of Food and Agriculture 2010-11*. Food and Agriculture Organisation (FAO).

FAO and AUC. (2019). *Sustainable agricultural mechanization: A framework for Africa—Synopsis*. Food and Agriculture Organization (FAO) and African Union Commision (AUC).

Giller, K. E., Andersson, J. A., Corbeels, M., Kirkegaard, J., Mortensen, D., Erenstein, O., & Vanlauwe, B. (2015). Beyond conservation agriculture. *Frontiers in Plant Science*, *6*, 870. https://doi.org/10.3389/fpls.2015.00870

Hayami, Y., & Ruttan, V. W. (1971). *Induced innovation in agricultural development*. Center for Economics Research, Department of Economics, University of Minnesota. 55455.

Horowitz, J. K. (2006). The Becker-DeGroot-Marschak mechanism is not necessarily incentive compatible, even for non-random goods. *Economics Letters*, *93*, 6–11. https://doi.org/10.1016/j.econlet.2006.03.033

Jayne, T. S., Chamberlin, J., Holden, S., Ghebru, H., Ricker-Gilbert, J., & Place, F. (2021). Rising land commodification in sub-Saharan Africa: Reconciling the diverse narratives. *Global Food Security*, *30*, 100565. https://doi.org/10.1016/j.gfs.2021.100565

Jayne, T. S., Chamberlin, J., Traub, L., Sitko, N., Muyanga, M., Yeboah, F. K., Anseeuw, W., Chapoto, A., Wineman, A., Nkonde, C., & Kachule, R. (2016). Africa's changing farm size distribution patterns: The rise of medium-scale farms. *Agricultural Economics*, *47*(S1), 197–214. https://doi.org/10.1111/agec.12308

Jayne, T. S., & Sanchez, P. A. (2021). Agricultural productivity must improve in sub-Saharan Africa. *Science*, *372*, 1045–1047. https://doi.org/10.1126/science.abf5413

Kahneman, D., Knetsch, J. L., & Thaler, R. H. (1990). Experimental tests of the endowment effect and the coase theorem. *Journal of Political Economy*, *98*, 1325–1348. https://doi.org/10.1086/261737

Lusk, J. L., & Shogren, J. F. (2007). *Experimental auctions: Methods and applications in economic and marketing research*. Cambridge University Press. https://doi.org/10.1017/CBO9780511611261

Morawetz, U. B., De Groote, H., & Kimenju, S. C. (2011). Improving the use of experimental auctions in Africa: Theory and evidence. *Journal of Agricultural and Resource Economics*, *36*(2), 263–279.

Omulo, G., Birner, R., Köller, K., Simunji, S., & Daum, T. (2022). Comparison of mechanized conservation agriculture and conventional tillage in Zambia: A short-term agronomic and economic analysis. *Soil and Tillage Research*, *221*, 105414. https://doi.org/10.1016/j.still.2022.105414

Paudel, G. P., Kc, D. B., Rahut, D. B., Khanal, N. P., Justice, S. E., & McDonald, A. J. (2019). Smallholder farmers' willingness to pay for scale-appropriate farm mechanization: Evidence from the mid-hills of Nepal. *Technology in Society*, *59*, 101196. https://doi.org/10.1016/j.techsoc.2019.101196

Pingali, P. (2007). Chapter 54 agricultural mechanization: Adoption patterns and economic impact. In R. Evenson & P. Pingali (Eds.), *Handbook of agricultural economics* (pp. 2779–2805). Elsevier.

Pingali, P., Bigot, Y., & Binswanger, H. P. (1987). *Agricultural mechanization and the evolution of farming systems in Sub-Saharan Africa*. Johns Hopkins University Press.

Ruttan, V. W., & Hayami, Y. (1973). Technology transfer and agricultural development. *Technology and Culture*, *14*, 119–151. https://doi.org/10.2307/3102398

Shonhe, T. (2022). The politics of mechanisation in Zimbabwe: Tractors, accumulation and agrarian change. *The Journal of Peasant Studies*, *49*, 179–199. https://doi.org/10.1080/03066150.2021.1918114

Sims, B., & Kienzle, J. (2015). Mechanization of conservation agriculture for smallholders: Issues and options for sustainable intensification. *Environments*, *2*, 139–166. https://doi.org/10.3390/environments2020139

WorldBank. (2019). *Agriculture finance diagnostic*. World Bank, Washington, DC. © World Bank, World Bank, Washington, DC.

How to cite this article: Ngoma, H., Marenya, P., Tufa, A., Alene, A., Chipindu, L., Matin, M. A., Thierfelder, C., & Chikoye, D. (2023). Smallholder farmers' willingness to pay for two-wheel tractor-based mechanisation services in Zambia and Zimbabwe. *Journal of International Development*, *35*(7), 2107–2128. https://doi.org/10.1002/jid.3767