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Can small farms benefit from big companies' initiatives to promote mechanization in Africa? A case study from Zambia

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ABSTRACT

After years of neglect, there is a renewed interest in agricultural mechanization in Africa. Since government initiatives to promote mechanization are confronted with major governance challenges, private-sector initiatives may offer a promising alternative. However, given limited scientific studies on such private-sector options such approaches are often viewed skeptically. One concern is that multi-national agribusiness companies take advantage of smallholder farmers. Another concern is that mechanization causes rural unemployment. To shed light on these concerns, this paper analyzes an initiative of the agricultural machinery manufacturer John Deere to promote smallholder mechanization in Zambia through a contractor model. The analysis focuses on the impact of this initiative on farmers who receive tractor services using Propensity Score Matching. The results indicate that farmers can almost double their income by cultivating a much larger share of their land. The analysis suggests that the increased income is used for children's education and more food, but does not result in increased food diversity. The demand for hired labor increases due to land expansion and due to a shift from family labor, including that of children, to hired labor. Questions that require further investigation are identified, including strategies to incentivize tractor owners to provide services, to also increase land productivity, and to avoid new forms of dependency of agricultural laborers that may result from a shift in the timing of the labor demand.

1. Introduction

During the last decade, agriculture has emerged as a top priority on Africa's development agenda. Even though there is some new scope for large-scale farming, especially in the land abundant countries on the continent (Deininger and Byerlee, 2012), smallholder farming systems will have to play the key role for agricultural development in Africa (Birner and Resnick, 2010; World Bank, 2007; Davis et al., 2017). Almost 70% of the farms in Sub-Saharan Africa operate less than two hectares (Deininger and Byerlee, 2011: 28) and they typically do not realize more than 25% of their potential yields (Deininger and Byerlee, 2011: xxxviii). Substantial efforts have been made to close this yield gap, but in recent years, there has been an increasing recognition that it also important to increase the labor productivity in African agriculture in order to reduce poverty (Diao et al., 2018). In most countries of Africa, population density is relatively low, and the theory of induced innovation would predict that mechanization should play an important role in the early phases of agricultural development (Hayami and Ruttan, 1985). Yet African farming systems remain the least mechanized of all continents (Pingali, 2007; Sheahan and Barrett, 2017).

There were substantial efforts to promote mechanization in Africa's agriculture in the 1960s and 1970s, but these efforts were state-led and they largely failed (Pingali, 2007). This negative experience led to a subsequent neglect of agricultural mechanization in development efforts, except for some efforts to introduce animal traction. Likewise, research on the mechanization of smallholder farming systems in Africa became a rather neglected field in the 1990s and 2000s (Diao et al., 2012). Research conducted in the 1990s had shown that machinery has an important role to play in improving farmers' crop management practices, especially by allowing for better tillage, weed control and moisture management (Anderson and Dillon, 1992; Byerlee and Husain, 1993). The institutional dimension of mechanization had always remained a neglected field of research, in spite of overwhelming historical evidence that institutions such as rental markets and cooperative exchange have played a key role in the history of the countries that are now industrialized. As shown by Olmstead and Rhode (1995) for the case of the USA, such institutions were essential to facilitate the access of smallholder farmers to mechanization.

Following the food price crisis of 2008, there has been a renewed emphasis on agricultural development as a top priority in Africa's

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development agenda. This new interest in agriculture has also revived the interest in agricultural mechanization (FAO and UNIDO, 2008; Kienzle et al., 2013; Mrema et al., 2008). Governments in several African countries subsidize the provision of tractor services, often by importing tractors that are then provided at subsidized prices to private sector operators who are expected to provide tractor services to smallholder farmers. A study of such a subsidy scheme in Ghana found that it was not a viable business model for private tractor service providers, in spite of substantial subsidies provided by the government to private operators (Houssou et al., 2013). There is evidence that the often neglected governance challenges of mechanization contribute to the failure of such government-sponsored programs (Daum and Birner, 2017).

Against this background, the question arises as to whether private sector models that do not rely on government support are economically more promising and suitable to benefit smallholder farmers. Based on field observations in Ghana and a review of the international experience, Diao et al. (2014) hypothesized that private sector models have more potential than those that involve state interventions. Many services and inputs for smallholders, such as agricultural extension, require public sector involvement due to market failures (Feder et al., 2011). In contrast, considering that agricultural machinery is a pure private good in which innovations are embodied, machinery services offers specific opportunities for the private sector. However, since tractors are indivisible (unlike other inputs such as seeds and fertilizer), business models such as hire markets are required for smallholders to benefit from mechanization. In recent years, major international agricultural machinery companies, such as John Deere and AGCO, have recognized the new business opportunities in smallholder agriculture in Africa, and they have started to invest in developing their own business models to access this market. There is limited evidence in the literature on the opportunities and limitations of such purely private-sector driven options. Expectedly, civil society organizations are highly skeptical of such initiatives. One reason is a general skepticism that multi-national agribusiness companies may take advantage of smallholder farmers (see, e.g., Martínez-Torres and Rosset, 2010). Another reason is the fear that mechanization may lead to rural unemployment. Such concerns are not new. As Juma shows in his book on "Innovation and Its Enemies" (Juma, 2016), farm mechanization has been one of the most controversial of all agricultural innovations – not only in contemporary times, but also historically. During early waves of state-driven and often subsidized agricultural mechanization in newly independent countries of Sub-Saharan-Africa, the International Labor Organisation warned against potential unemployment effects but such concerns were constrained by a lack of empirical data (ILO, 1973). The concerns continue to be voiced but lack of empirical evidence has remained a constraint (Massey et al., 1993; Bhandari and Ghimire, 2016). Based on theory and insights from historical experience, Binswanger (1986) hypothesized that mechanization can - depending on the access to land and output markets - raise or reduce employment. In the same study, he highlighted that farming operations are typically mechanized step-wise - starting with the biggest labor bottlenecks - which may either raise or reduce the labor requirements for subsequent farming steps. In addition, one should differentiate between different types of labor: The loss of (well-paid) work opportunities for laborers constitutes a problem, but a reduction of child labor and unpaid family work (with opportunity costs) would have to be seen as an advantage. Research-based evidence is, thus, very important to better understand whether smallholder farmers can benefit from private-sector led mechanization initiatives and how such initiatives affect rural employment. Yet, there is a lack of empirical evidence on this topic.

The goal of this paper is to contribute to filling this knowledge gap by presenting a case study of a private-sector led smallholder mechanization initiative in Zambia. We analyze an initiative where the company John Deere, the largest manufacturer of agricultural machinery worldwide, worked with its dealership AFGRI to develop business models that allow smallholder farmers to access tractor services. The approach is to support small and medium-sized enterprises and "emerging farmers" that is medium-size farmers who own between approximately 20 and 200 ha and can afford to purchase a tractor. In our sample, their median farm size was 66 ha. The main form of support is facilitating the financing of the tractor. For 10 of the 21 tractor owners in our sample this has been their first tractor. This has been done through different mechanisms since 2010, including a loan provided by AFGRI with an interest rate below the market rate or by facilitating the linkage with a private bank, using the tractor as collateral. John Deere's dealer AFGRI provides after-sales services such as maintenance services, spare part supply and repairs. While such approaches to provide a dealer credit or facilitate a linkage with a bank are not unusual in the tractor business, the remarkable feature of the initiative by AFGRI and John Deere in Zambia is that they applied this approach to the rather risky customer segment of emerging and medium-size farmers with the explicit goal to facility smallholder mechanization. These customers are more likely to provide tractor services on a contract basis[1] to smallholder farmers than large-scale farmers, who can fully utilize the capacity of a tractor on their own land. However, the experience of John Deere and AFGRI indicates that service provision by tractor owners does not simply happen without further efforts, even though it is a common practice in countries where mechanization is well established. According to Sheahan and Barrett (2017), only around 1% of households across all countries of the Living Standard Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) engage in tractor rental market. A recent study by Baudron et al. (2019) suggests that the demand for mechanization may be much higher than often assumed and that current low levels of mechanization may be due to market imperfections, such as failures to make mechanization accessible. To encourage service provision to smallholder farmers, John Deere and AFGRI linked up with two non-governmental organizations (NGOs). One is MUSIKA, an NGO focused on linking smallholders with business enterprises, and the other is the Conservation Farming Unit (CFU), an NGO focused on promoting conservation agriculture. MUSIKA has supported service provision by providing business training to the tractor owners, where the need to reach high machinery utilization rates was highlighted. CFU facilitated the formation of groups of smallholder farmers who wanted to access tractor services, thus reducing the transaction costs that arise for reaching smallholders. In our sample of 21 tractor owners, 12 provided services to smallholder farmers. On the average, they served approximately 60 smallholder farmers in an average maximum radius of 40 km).[2]

At the current stage, the smallholder farmers typically use tractor services to mechanize the most labor-intensive activity in crop production, which is ploughing. Alternatively, if farmers practice conservation agriculture, they use tractor services for ripping.[3] The tractors are often also used for a labor-intensive post-harvest activity: maize shelling. Other steps in crop production, such as weeding, pest control and harvesting continue to rely on hand labor or animal traction.

The overall objective of this study was to assess the economic and social impact of providing tractor services on smallholder farmers under this initiative by John Deere, AFGRI, MUSIKA and CFU (hereafter referred to as the JD initiative) and to calculate the effect on total labor

[1] This is mostly on cash basis but some also provide services on credit basis (either cash or in-kind). This is similar to the provision of animal draught services.

[2] According to the tractor owners who do not provide services one reason where high transaction costs of offering services to smallholder farmers. Another reason is the synchronic timing of farming. Tractor owning rippers have a larger time window to offer ripping services but tractor owners owning ploughs stated to focus on their own field first.

[3] Ripping is a technique of conservation agriculture where tillage is reduced to using a narrow implement, similar to a spike, which creates a planting furrow without turning the soil.

requirements, taking into account that farmers may expand crop production when they access tractor services. Since a randomized control trial approach was not feasible, we used Propensity Score Matching (PSM) to assess the effects of accessing tractor services on smallholder farms. We focus on the effect of the initiative on smallholder farmers, considering that the effects are contested in the policy debate, as highlighted above. Examining different models under which private sector companies can foster the sale of tractors to promote the contracting of tractor services was beyond the scope of this study, but will be an interesting topic for future research.

2. Background information

With an average population density of 22 inhabitants per km^2, Zambia is one of the most sparsely populated countries in Sub-Saharan Africa.[4] Agriculture supports the livelihoods of 60–70% of the population (Tembo and Sitko, 2013: 2). On the average, Zambian farmers own 3.2 ha (ha) of land (Tembo and Sitko, 2013: 20), but due to labor and other constraints, they usually do not cultivate all their land. Overall, agriculture is dominated by smallholder farmers as 95% of the farms cultivate less than 5 ha (Sitko and Jayne, 2014: 194). However, during the past decade, there has been a rapid increase in the number of medium-scale farmers who cultivate between 5 and 20 ha of land. They are referred to in Zambia as “emergent farms.” A recent study found that “between 2001 and 2011 the population of emergent farmer households in Zambia grew by 62.2%, vastly outstripping the 33.5% growth rate of the total smallholder population.” (Sitko and Jayne, 2014: 194).

So far, access to agricultural machinery such as tractors and processing machines is very low in Zambia. According to a nationally representative survey conducted by IAPRI in 2015, only 1.8% of all households used mechanical power in their farm operations. On the average, 36.5% use animal traction. The underutilization of the country’s agricultural potential results in widespread poverty among the rural population. 78% of the rural households live below the poverty rate of 1.25 USD per day, and for female-headed households, the rate is almost 85% (IAPRI, 2015: 114-115). As in other African countries, there has been an increasing interest in agricultural mechanization in Zambia in recent years. For example, in 2011, the Ministry of Agriculture and Livestock started a Tractor Mechanization Fund in collaboration with the FAO and the Zambian National Farmers Union (ZFNU)[5] and the country hosts AgriTech Expo Zambia, a major trade fair for agricultural machinery.

3. Methods

According to current standards of program evaluation, a randomized control trial would be the preferred approach to assess the impact of the JD Initiative on smallholders. Since the Initiative was not implemented in such way, a survey was conducted and the Propensity Score Matching (PSM) approach was used to assess the impact of participation in the Initiative on the income and the use of the income by smallholder farmers (Khandker et al., 2010; Caliendo and Kopeinig, 2008). PSM allow to reduce self-selection bias due to observed characteristics but cannot address bias due to unobserved characteristics (see De Janvry et al., 2010; Janvry and Sadoulet, 2016 for a discussion on PSM). To addressed the later point, by testing different model specifications and matching algorithms as well as supporting our findings with economic theory, an extensive literature review and using qualitative methods.

To better understand social dynamics within households and communities, the team also used qualitative methods. Specifically, focus group discussions were conducted, in which Participatory Impact Diagrams were constructed (Kariuki and Njuki, 2013). Participatory Impact Diagrams are a technique that relies on visualizing the perceived impacts of the participants using a large sheet of paper. Positive as well as negative impact chains are indicated on the paper in the form of tree structure (similar to a mind map), which then serves as a basis for further discussion. The team held 13 such focus group discussions with men and 12 with women. The discussions focused on the impact of mechanization at the community level. Therefore, the impact of households who do not use mechanization services was captured as well. Such households may be affected indirectly, especially though changes in the demand for agricultural labor.

Consequently, the research design for the study was based on the following combination of methods: (1) a survey among a sample of farm households that receive and did not receive tractor services; and (2) focus group interviews in selected communities, where smallholders had used tractor services provided under the Initiative. These two methods constituted the trunk of the data collection for this paper. In addition, we used: (3) semi-structured interviews with representatives of the organizations involved in the JD Initiative and (4) in-depth interviews with a sample of farmers who had purchased a tractor, which were used to obtain additional background information.

3.1. Sampling strategy and data collection

The following sampling strategy was applied: The tractor owners were randomly sampled from the six (out of the eight) Zambian provinces, where the JD Initiative was implemented. A total of 21 tractor owners were interviewed, the number per province was proportional to the total number of farmers who had participated in the Initiative. The interviews with the selected tractor owners revealed that 12 out of the 21 selected tractor owners provided services to smallholders. The smallholders for the household survey were selected as follows: In each location, eight farmers were selected who received services from a tractor owner who had participated in the JD Initiative. They are referred to as “participants” here. For the control group, five farmers who do not receive services were randomly selected from the same locations. The five households from the control group could use mechanization services offer by other service providers, but this was rarely the case. As the control households are located within the service area of the emerging farmers, they are potentially affected by the mechanization scheme in an indirect way (spill-over). To assess this effect, three additional control group households from a close-by community were selected, as well. In total, 121 households that use tractor services under the Initiative (“participants”) and 129 households that do not use tractor services were included in the household survey. The survey was conducted by the research team in face-to-face interviews with the farmers using hand-held computer devices.

3.2. Analysis

To assess the impact of the mechanization scheme on farm household income and food consumption, a Propensity Score Matching (PSM) approach was used (cf. Khandker et al., 2010; Caliendo and Kopeinig, 2008). The main impact measure of interest, the average treatment effect on the treated (ATT_J), is estimated according to:

$$ATT_J = E[y_{1j}|JDMech_j = 1] - E[y_{oj}|JDMech_j = 1] \quad (1)$$

where y_{1j} is the value of the outcome of farm household j after benefiting from the John Deere (hereafter *JD*) tractor service provider and y_{oj} is the outcome of the same farm household j if the household did not benefit from the JD Initiative.

The underlying estimation problem of Eq. (1) can be represented as a treatment-effects model of the form:

$$y_{jt} = \alpha_j + \tau_t + \boldsymbol{\beta}'\boldsymbol{x_{jt}} + \delta JDMech_j + \varepsilon_{jt} \quad (2)$$

[4] http://data.worldbank.org/indicator/EN.POP.DNST.

[5] See http://www.znfu.org.zm/tractor_mechanization.

Table 1
Outcome and explanatory variables used for impact assessment.

Variable name	Variable description
Outcome variables	
Net on-farm income	Farm gross margin
Yield	Per hectare seasonal crop output
Land ownership increment	Increase in land size owned
Farm input used (fertilizer, herbicides, seeds)	Changes in the quantities of farm inputs used
Household expenditure (Food, non-food household needs, education, health, recreation)	Average amount of money (in ZMW) spent on daily needs over stipulated periods
Food Intake (Food diversity, Food consumption frequency)	Quantity, quality and frequency of food consumed by respondent household. The frequency weighted diversity score is calculated using the frequency of consumption of different food groups consumed by the household the day before the survey (WFP, 2008)
Explanatory variables	
Farming experience	Number of years of farming
Off-farm business participation	Farmer's involvement in off-farm businesses: 1 = Yes, 0 = No
Size of household	Total count of household members above age 5 years of age
Gender of household head	Gender of the household: 1 = male, 0 = female
Education level of household head	Years of schooling
Land cultivated	Cultivated land per capita – total cultivated land divided by total members of household
Access to extension service	Farmer's has access to private, public or third sector extension service: 1 = Yes, 0 = No
Access to credit facilities	Farmer's access to credit/loan facility: 1 = Yes, 0 = No
Market access	Amount of travel time (in minutes) required to access nearest village market
Group membership	Farmer's membership in a social or political group such as a farmer cooperative: 1 = Yes, 0 = No
Household asset index	Total count of household assets, e.g., solar panels, bicycles owned by farmer
Livestock ownership	Total number of cattle owned by farmer before mechanization scheme. Weighted using Tropical Livestock Unit conversion factors (Jahnke, 1983)
Farmer willingness to invest	Percentage of an amount of money that a farmer is willing to invest in any venture of choice considering potential losses and gains

$$JDMech_j^* = \boldsymbol{\gamma}'\boldsymbol{w_j} + u_j$$

$$JDMech_j = \{1,\ if JDMech_j > 0\ \ and\ \ 0\ \ if\ \ otherwise\} \quad (3)$$

$$Prob(JDMech_j = 1) = F(\gamma' w_j) \quad (4)$$

$$Prob(JDMech_j = 0) = 1 - F(\gamma' w_j) \quad (5)$$

where $JDMech_j$* is a latent unobserved variable whose counterpart, $JDMech_j$, is observed in dichotomous form only; $JDMech_j = 1$ represents a user (i.e. a farmer who decides to hire services) of JD tractor service provider (that is, treatment) and $JDMechj = 0$ represents non-user of the facility (that is control); $\boldsymbol{x_j}$ is the vector variable determining the outcome of the JD Initiative, $\boldsymbol{w_j}$ is the vector variable determining the probability of being a user of the JD mechanization facility which includes the list of explanatory variables given in Table 1 below; α_j and τ_t respectively captures the individual and time-specific effects; $\boldsymbol{\beta}$ and γ are the vectors of parameters measuring the relationships between the dependent and independent variables; ε and u are the random components of the respective equations. The functional form (F) may take the form of a normal, logistic or probability function.

A two-stage weighted estimation approach was used. In stage one, Eq. (3) is estimated using a probit model to obtain the propensity scores, which are then used as weights in a second stage estimation of Eq. (2), based on matched treatment and control observations identified in stage one. Of the 4 matching algorithms commonly proposed in literature (Caliendo and Kopeinig (2008), for a detailed overview), the variant of radius matching (Dehejia and Wahba, 2002) was applied for the second stage estimation. This method has an advantage of using only as many units as are available within a caliper (c), allowing for more matching options, hence improving matching quality (Caliendo and Kopeinig, 2008). Rosenbaum and Rubin (1985) recommends caliper (c) used to be one-fourth the share of the standard deviation (s.d) of the probability model of the propensity score (c = 0.25*s.d).

The matching procedure must be able to balance the distribution of the relevant variables in both control and treatment groups. Rosenbaum and Rubin (1985) suggest calculating the standardized bias (SB) before and after matching. A bias reduction below 3% or 5% after matching is considered acceptable (Caliendo and Kopeinig, 2008).

In calculating the treatment effects and their standard errors, the bootstrapping method (with 500 replications) was employed, as used in most of the literature. The ATT of participating in the JD Initiative is defined by the use of a John Deere tractor at least for land preparation. The *ATTs* of the program were obtained by estimating the models using data from the sample described above, which included 121 tractor service users and 129 households who do not use these services. The data refer to the 2014–2015 cropping season. The outcome variables and the explanatory variables used for the assessment are shown in Table 1.

4. Results

The first subsection of this section presents descriptive statistics, comparing the treatment and the control group. Since this comparison does not control for a possible sample selection bias, the findings of Section 4.1 should be seen as background information for the PSM analysis, which is presented in Section 4.2. Section 4.3 presents a matching quality and sensitivity analysis and Section 4.4 deals with the results of the focus group discussions.

4.1. Descriptive results

Table 2 presents information about the socio-economic characteristics of the of the surveyed smallholder farmers. The table indicates that smallholders who receive tractor services have similar characteristics as those who do not receive services. The differences shown in the table were not statistically significant. The findings indicate that participation in the JD Initiative was not biased towards the larger ones among the smallholder farms. However, the data suggest that the schemes are implemented in areas where smallholder farmers tend to have somewhat larger holdings and higher education levels than on the national average (cf. IAPRI, 2015).

Table 3 shows that the farmers who receive mechanization services cultivate almost the entire arable land that they own, whereas the farmers in the control group cultivate only 60%. According to the farmers this is due to labor shortages. According to the farmers

Table 2
Socioeconomic characteristics of surveyed smallholder farmers.

Variable[a]	Participants (N = 121)	Control group (N = 129)	Total (N = 250)
Age of household head (years)	50.0	47.0	48.4
Farming experience (years)	20.1	21.0	20.6
Off-farm business participation (yes/no)	46%	40%	43%
Number of household members	7.4	7.4	7.4
Female household heads (%)	22%	18%	20%
Education of household head (years of schooling)	8.3	7.2	7.7
Total land owned (ha)	10.8	9.2	10.0
Access to extension service (percent)	74%	65%	70%
Access to credit facilities (yes/no)	13%	15%	14%
Access to markets (minutes of walking time)	30.9	30.5	30.7
Indicator of farmers' willingness to invest	79%	81%	80%

[a] See Table 1 for an explanation of the variables.

Table 3
Differences in agricultural practices and outcomes.

	Participants (n = 121)	Control group (N = 129)	Difference[a]	Statistical significance[b]
Arable land owned (ha)	7.1	6.1	16%	no
Arable land cultivated (ha)	6.5	3.7	76%	yes
Percent of owned land cultivated	92%	60%	53%	–
Beginning of land preparation	30. Sept	6. Nov	–	–
Use of fertilizer for maize (kg/ha)	260	190	37%	yes
Percent of farmers using herbicides	63%	24%	162%	–
Use of herbicides for maize (litres/ha)	2.3	2.4	−4%	no
Maize yields (metric tons/ha)	3.1	2.5	24%	yes

[a] Difference is calculated as the difference between the values for participants and control group divided by the value of the control group.
[b] Yes indicates that difference in mean values is statistically significant at the 5% level.

cultivating more land now, this land was mostly fallow land before and a small share was land that was rented out before. Moreover, the participants are able to start land preparation much earlier than the control group. We did not ask about planting dates during the household survey but the results from the focus group discussions suggest that this allows farmers to plant more timely.[6] The amount of fertilizer that the participants use is almost 40% higher than that of the control group. The share of farmers who apply herbicides is 63% among the participants as compared to 24% in the control group.

The data also show that the participants achieve maize yields that are 24% higher than those of the control group. This can be because of mechanized tillage enhance timeliness and tillage quality, the later which can contribute to better weed control, better soil moisture management and a higher germination rate of seeds. All of these aspects were mentioned during the focus group discussions (see Section 4.4). In addition, mechanized tillage may encourage fertilizer use and better weed control but these are indirect effect that we will control for with the PSM.[7]

As shown in Table 4, farmers who use mechanization services had a significantly higher total farm income than the control group, whereas the difference in income per hectare was not significant. This finding suggests that the main income effect from accessing tractor services may be due to the increase in cultivated land area, which is made possible by mechanizing soil preparation. The finding from recall questions posed to the treatment group (not reported in the table) suggest that they were indeed able to increase the cultivated land area. Farm households that use tractor services spend, on the average, slightly less on health expenditure, but the difference was not statistically significant. However, service users had significantly higher expenditures on education and food. Based on the survey data, a food diversity score was calculated, which is an indicator of nutritional quality. More diverse diets provide more micro-nutrients, which is important to combat "hidden hunger." The findings indicate that households that access mechanization services do not consume a significantly more diverse diet than the control group. This finding suggests that the additional income that the participants earn is mostly spent on food staple crops. Nutrition education may be required to encourage households to invest their additional income in increased diet diversity.

Table 5 reports differences regarding labor hours between households that access tractor services and those that do not. As indicated above, the differences do not show causal effects, but they give important clues. Interpreting the figures, one needs to keep in mind that the participating households cultivate on the average 76% more land (see Table 3) than the non-participating households. As indicated above, the only two activities for which tractor services are used are land preparation and processing (i.e. maize shelling). Expectedly, the participating households use significantly less labor for land preparation and significantly more labor for harvesting. The table suggests that access to tractor services reduces the labor burden for family labor, including the labor burden of children and women, while it increases the opportunities for hired labor during the harvesting season as a consequence of the expansion in cultivated area. Weeding time is also significantly reduced overall (and increased for hired labor), which reflects the better land preparation (reducing weed growth) and the higher percentage of farmers using herbicides (see Table 3). In our sample, farmers practicing conservation farming, which is associated with higher weed pressure, do use significantly more herbicides than those who do not.[8]

[6] Optimal sowing dates can have a big implication on yield (Low and Waddington, 1991). Sallah et al. (1997), for example, found that a delay in planting of 14 days reduces maize yield by 30% in the Guinea Savanna.

[7] In general the yield response to mechanized tillage depends on the soil type (for example, it is higher for clay soil than sandy soil), on the topo-sequence of the location and the crop (Pingali et al., 1987).

[8] Authors such as Giller et al. (2009) focus more explicitly on the relation between conservation farming and labor dynamics.

Table 4
Differences in farm income, expenditure and nutrition.

Income and expenditures in ZMW	Participants (N = 121)	Control group (N = 129)	Difference[a]	Statistical significance[b]
Farm income total	16,999	7323	132%	yes
Farm income per hectare	2839	2045	39%	no
Farm income per household member	2528	2045	24%	yes
Health expenditure per year	270	340	−21%	no
Education expenditure per term	1730	842	105%	yes
Food expenditure per month	561	299	88%	yes
Food diversity score	6.4	5.8	10%	no

Note: 1 USD equals approx. 10 Zambian Kwacha (ZMW).
[a] Difference is calculated as the difference between the values for participants and control group divided by the value of the control group.
[b] Yes indicates that difference is statistically significant at the 5% level.

Table 5
Differences in labor hours for cultivating and processing all crops.

	Total labor hours	Hired labor hours	Family labor hours	Female family labor hours	Children family labor hours	Male family labor hours
Land preparation	−374***	−22	−348***	−93***	−24***	−231***
Planting	106*	131**	−28	−50**	4	19
Fertilizer application	10	44***	−37	−29**	−6	−2
Weeding	−313***	86**	−418***	−207***	−28**	−183***
Pests/disease control	−16	2	−18	−1	0	−17*
Harvesting	423**	488**	−49	−36	−2	−11
Processing	−218	−117	−88**	−51	−7	−29

Note: Mean difference is the difference between mean values of participant group members and non-participant groups.
* Statistical significance at the 10% level.
** Statistical significance at the 5% level.
*** Statistical significance at the 1% level.

Table 6
Factors influencing participation in mechanization schemes.

Explanatory variables	Average marginal effect (dF/dx)	Standard Error
Off-farm business (yes/no)	0.061	0.0678
Gender of family head (male/female)	0.116	0.0828
Years of schooling	0.022**	0.0097
Access to credit	−0.075	0.0952
Access to extension services	0.094	0.0757
Network group membership (yes_no)	0.198**	0.0936
Access to market	0.001	0.0013
Livestock owned before participation in scheme	0.004*	0.0026
Farmer's investment behavior	0.033	0.1305
LR chi2(12)	19.54	
Prob > chi2	0.029	
Pseudo R-square	0.056	

[1]See Table 1 for an explanation of these variables.
Note: *Statistical significance at the 10% level, ** at the 5% level.

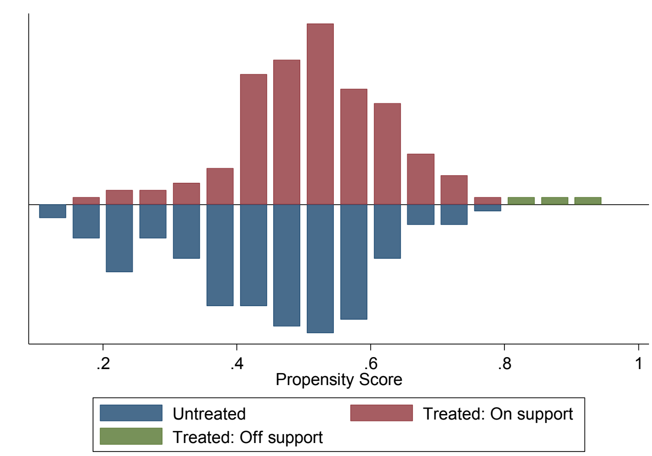

Fig. 1. Estimated propensity score distribution and common support area by pairwise comparison.

4.2. Results of the propensity score matching (PSM) analysis

The first step in the PSM analysis is the construction of a probit regression model, which identifies the factors that are significantly associated with the decision of a farm household to access tractor services. The results displayed in Table 6, which indicates that better educated farmers and farmers who are members in social, religious and political groups are more likely to access tractor services. Farmers who owned more livestock (an indicator of wealth) before the start of the mechanization scheme were more likely to use tractor services, but the magnitude of this effect was negligible.

Using a probit model, the balancing scores for each pairwise comparison of service users with their matching counterfactuals were estimated. The model was used to predict the probability of opting for using tractor services. The model's predictive power can generally be judged to be high and the variables show the expected signs.

Fig. 1 below displays the distribution of the propensity scores and the overlap between the groups. For this pairwise comparison, the figure also shows the cases that were dropped from the analysis in order to avoid bad matches. 3 out of the 121 treated assignments had to be excluded from the analysis.

For the matched sample, the bootstrapping method was applied with 500 repetitions to estimate the standard errors and hence check for distinct variations. Table 7 reports the estimates of the *ATT*. It indicates that using tractor services has a significant positive effect on the on-farm income of the entire household and on the on-farm income per household member. This effect is not only significant, but also large. The difference in household income of approx. 10,000 ZMK per year indicates that the use of tractor services allowed smallholder farmers to more than double their income.

The *ATT* for yield was also significant, which confirms a causal effect of using tractor services on yield. The magnitude of the effect

Table 7
Causal effects of using mechanization services.

Outcome variable	Average Treatment effect of the Treated (*ATT*)	Standard Error
Net on-farm income (ZMW)	10,000***	3,460
On-farm income per hectare (ZMW)	685	493
On-farm income per household (ZMW)	1500***	557
Yield (metric tons/ha)	0.41*	0.25
Yearly Expenditure on food (ZMW)	225***	69
Expenditure on education per term (ZMW)	850**	305
Expenditure on basic household non-food household needs (ZMW)	770***	251
Health expenses (ZMW)	−48	119
Expenditure on recreation (alcohol, tobacco, etc.) (ZMW)	−40	25
Skipping meals	−0.16**	0.06
Food Diversity Count	−0.08	0.7
Before and after JD mechanization difference in fertilizer used (MT)	0.3***	0.1

Note: *Statistical significance at the 10% level, **at the 5% level, ***at the 1% level.

Table 8
Indicators of matching quality and sensitivity analysis.
Source: own data.

	SB (%)	SB (%)	% |SB| reduction	Residual Bias	Cases lost to critical selection	Critical levels of gamma
Participants/Control Group	14.5	1.10	92.4	3.9	3	1.1–1.15

Note: Calculation using pstest and rbounds.

(approx. 0.4 metric tons//ha) was also substantial, which supports the findings above on yield effects. However, higher yields did not result in a higher income per hectare, because the treatment effect was not significant for the parameter "on-farm income per hectare". The reason could be that the yield increase was not sufficient to cover the increased costs per hectare arising from using more inputs. This finding confirms the results reported above, which suggest that the main causal impact of accessing mechanization services is allowing smallholders to cultivate a larger share of the land that they own.

The PSM analysis also shows that the increased expenditure in education and food found in the descriptive statistics can be attributed the use of tractor services. The households did not significantly change their expenditure on alcohol or tobacco, which indicates that the farmers used their additional income for the benefit of their families. The findings also indicate the increased income from accessing tractor services allows farm families to skip fewer meals. However, the findings also show that they do not diversify their diets.

As indicated above, the survey included recall data from respondents on selected outcome variables, which include changes in input use, yield and livestock that occurred after accessing mechanization services. For these variables, a double difference *ATT* technique was used to estimate the differences in mean outcomes for these variables. The only significant effect was identified for the use of fertilizer. The *ATT* analysis also confirmed that the farmers who use mechanization services did not purchase additional land; they rather expanded cultivation on the land they already owned.

4.3. Matching quality and sensitivity analysis

As indicated in Section 3, the quality of matching was assessed by calculating the standardized bias (SB) before and after matching. The results (Table 8) show that a very good matching quality was attained. The standardized bias was reduced from 14.5% before matching to 1.1% after matching, which corresponds to a bias reduction of 92.4%. The residual mean bias of 3.9% is within the range of 3–5%, which is suggested in Caliendo and Kopeinig (2008) as an acceptable threshold for remaining bias after matching. The low remaining SB and the high reduction rate of mean SB indicates a good balancing power and hence, good matching results.

We can, however, not rule out the problem that unobservable factors could influence these findings (hidden bias). We are confident that this influence is limited since the choice of variables was based on economic theory and an extensive literature review. Moreover, the results are supported by the qualitative findings, as shown below.

4.4. Results of the focus group discussions

We used qualitative methods to triangulate the findings from the quantitative study and to analyze aspects that cannot be addressed with a purely quantitative study design. As indicted in Section 3, we organized focus group discussions where participants were asked to construct Participatory Impact Diagrams. Table 9 displays the main positive impacts that were identified. Since the researchers did not prompt the respondents to discuss any specific theme, the number of groups who identified a specific impact can be seen as an indicator for the relevance of the respective impact in the areas where the schemes were implemented. As can be derived from Table 9, the communities strongly associate the use of tractors with increased yields. They consider more timely land preparation and the retention of soil moisture due to ripping as major benefits that contribute to increased yields.[9] According to the respondents, these factor and in combination with better land preparation (which reduces weed pressure) reduces the risk of bad harvest, which makes them more willing to invest in complementary inputs such as fertilizers. The cultivation of more land was identified as another positive impact of mechanization.

Table 9 also lists the positive socioeconomic affects that are seen to be the result of the agronomic effects identified above. The majority of both the male and the female focus discussion groups (FDGs) identified increased income as a positive impact of mechanization, which confirms the finding of the quantitative assessment. The Participatory Impact Diagrams suggest that the increased income is also used for purchasing improved seeds, fertilizers and herbicides, which strengthens the effect of mechanization on yields. The FDGs also pointed out that the increased income is used for education, as indicated by the quantitative assessment. According to the FDGs, the increased income is also used for buying household and farm assets as well as personal supplies.

The reduced work load during the time of land preparation was seen as a positive impact by half of the male FDGs and a quarter of the female FDGs. According to the Participatory Impact Diagrams, the main positive effect was that children, who previously had to work on the fields, can now go to school. This is an indication that mechanization contributes to reduced child labor in agriculture. The time saving

[9] Respondents did not mention that tractor plowing increase moisture holding capacity with deep plowing. However, a meta-study by Schneider et al. (2017) suggests that deep tillage can increase plant-available water reservoir. However, effects will depend on soil types and local climates and both optimal ploughing depth and whether or not to plough are debated topics (see Knowler & Bradshaw, 2007).

Table 9
Positive impacts.

Positive impacts identified	Percent of male groups identifying this impact (N = 13)	Percent of female groups identifying this impact (N = 12)	Quotes from the interviews that illustrate the perceptions of the community members
Agronomic			
Higher yield	92%	100%	*"If you do early planting (…) you are likely to get a high yield"*
Early planting und retention of soil moisture due to ripping	92%	75%	*"When you use a tractor…, the moisture content is kept for longer, the germination of maize is good, …"*
Improved land preparation	69%	42%	*"When using a tractor, the depth is better than when using animals…. Even when the rain goes, the plants don't dry up…"*
Cultivation of more land	38%	83%	*"When we use a tractor, we can cultivate a bigger portion of land compared to using animals"*
Socio-economic			
Increased income	92%	100%	*"When you have better yields, you provide for own consumption, you will be able to find money for the children's school fees and for other things… you also have money to buy farming inputs…."*
Reduction of labor demand	54%	25%	*"When using a tractor, just one person is needed, when using animals, lots of people are supposed to do the work"*
Time saved during land preparation	38%	58%	*"It is faster when you use a tractor, …"*
Improved human and animal health	38%	0%	*"When you use a tractor, cattle have enough time for grazing… but when you use them for farming, you might use them from 7 to 11 or 12- they won't have enough time for grazing and resting…"*

Table 10
Negative impacts.

Impacts	Percent of male groups identifying this impact (N = 13)	Percent of female groups identifying this impact (N = 12)	Quotes from the interviews that illustrate the perceptions of the community members
Agronomic			
Yield losses because services were delivered late	31%	17%	*"At the time we need the tractors, they are not available, and so we are forced to plant late."*
Soil degradation (in case of using the plough)	31%	8%	*"Soil fertility is reduced after repeatedly turning the soil surface season after season."*
Socio-economic			
Fewer jobs for agricultural laborers during the land preparation season	54%	8%	*"Before starting hiring a tractor, you used to hire people to come and help you in the fields. Now you have tractors so you won't be hiring the people (…) so that person you used to hire will have a problem because there is no income for him."*
Migration to other areas	8%	0%	*"The leaders of the household migrate to towns and communities where the farm land has been expanded."*
More work load for women	0%	17%	*"Women are doing more work…. because there are more activities after using the tractor, more activities like weeding…"*

during the time of land preparation was also seen as a benefit, especially by female community members According to the Participatory Impact Diagrams, the saved time was mostly used for vegetable gardening, performing household chores, engage in off-farm work and attend social events. Five of the 13 male FDGs felt that mechanization improved their either their own health or the health of their animals. This impact was not identified in female FDGs. The reason might be that male household members have to bear the main drudgery of labor for land preparation, which is the activity that is mechanized. Crop husbandry and harvesting activities, which are mainly carried out by women, are not yet mechanized, as shown above.

The Participatory Impact Diagrams were also used to identify problems that the communities had identified with regard to mechanization. The results are displayed in Table 10. In general, the percentage of FDGs that identified problematic impacts was comparatively low. Only two agronomic problems were identified: late service provision and soil degradation. Four of the 13 male FDGs reported problems because the tractor services were provided too late. In these cases, delayed land preparation resulted in late planting, which in turn led to a sharp yield decrease and thus lower farm incomes. Soil degradation was mentioned in four of the 13 male FDGs and in one of the 12 female FDGs. This problem was associated with the use of the disc plough rather than the ripper.

The main socioeconomic problem associated with mechanization identified by the community members were reduced job opportunities for agricultural laborers at the beginning of the farming season. Farmers who use oxen to provide ploughing services were also seen as being disadvantaged. The community members reported that working opportunities for agricultural laborers in particular dropped during the months of land preparation. However, it was also acknowledged that agricultural laborers benefitted from a higher demand for labor during weeding, fertilizer application and harvesting times. These findings confirm the results of the quantitative analysis on labor use (Table 5). Two out of 12 female FDGs mentioned increasing workload for women from land expansion.

5. Discussion

As indicated above, this study aimed to assess the impact of the JD Initiative, as an example of a private-sector business model, on smallholder farmers. In view of the criticism of such initiatives by NGOs, special attention was paid to a range of potential effects, including income, nutrition, child labor and the potential displacement of labor. As a general disclaimer to the following discussion, one needs to take into account that the study was based on a PSM analysis of cross-sectional data and not on a randomized control trial, which has become the “gold standard” in impact evaluation. We still believe that the results are of interest, considering that empirical studies that deal with pure private-sector initiatives are scarce.

5.1. Income effects

One of the most important findings of this study is the evidence that, on the average, the smallholders who used tractor services were able to double their income because they were able to cultivate a much larger share of the land that they own. The focus group discussions largely confirmed this finding. According the results of this study, accessing mechanization services also increased labor productivity quite substantially. This is an expected benefit, but nevertheless important, considering the concerns about low labor productivity in African agriculture mentioned in the introduction.

The potential of the JD Initiative is particularly promising if one takes the number of smallholders into account that can potentially benefit from one single tractor. One of the tractor owners included in this study served more than 150 smallholders, indicating that, under the conditions in which the JD Initiative was implemented, facilitating access to one single tractor can potentially help to double the income of approx. 150 smallholder farmers. However, this potential was not fully utilized. Altogether, the 21 emerging farmers included into the sample served 693 smallholders, which corresponds to an average of 33 smallholders per tractor. This result indicates the need to conduct more research on the factors that can increase the incentives of tractor owners to provide services to smallholder farmers.

5.2. Social benefits for participating households

The study provides strong evidence that the smallholder farmers who accessed tractor services were able to generate additional income. While increasing income is generally welfare enhancing, it depends on the intra-household division of labor and power relations whether income translates in benefits such as improved nutrition and education, and this division is not independent of how the income is earned (Tavenner et al., 2019; Quisumbing and Maluccio, 2000). While this study provides no evidence on how mechanization affects the control over resources, the results show that income was use for the education of children and food security. Their expenses for food were higher and they were less likely to skip meals, which is an important finding considering high levels of undernutrition in Zambia. It is also worth noting that, according to the survey findings, the participating households did not increase the consumption of alcohol or tobacco. The qualitative findings from the focus group discussions indicate that some smallholders were able to invest their income into off-farm businesses, such as trading livestock or running grocery stores.

5.3. Use of farm inputs and land productivity

The findings suggest that the participating farmers purchased more farm inputs, in particular, fertilizer. This may be because better land preparation (which reduces weed pressure) and more timely land preparation, yields risks decline and the willingness to invest in complementary inputs become higher. However, the fact that tractor users apply higher levels of fertilizer may also reflect the fact that they can no longer fallow land to restore fertility since they cultivate nearly all their land. This may also explain the fact that net income per ha does not increase. The use of tractor services was also found to be associated with an increased use of herbicides. Partly, this may be due to the fact that CFU promoted herbicide use in connection with the introduction of conservation farming. Another reason could be labor shortages during the weeding time that were due to the increase in the area under cultivation. It was beyond the scope of this study to assess to what extent herbicides were used appropriately and safely by the smallholders but this should be carefully monitored.

The study provides evidence that the smallholders were able to increase their yields. According to the PSM analysis this effect was in the range of 0.5 metric tons per ha, which corresponds to a yield increase of approximately 25%. This is less than the frequently mentioned claim that mechanization can double or triple yields but consistent with Pingali et al. (1987) which report yield increases of between 20 and 30% depending on the crop. However, the results indicate that the smallholders who use mechanization services were not able to achieve a higher income per hectare. This finding suggests that farmers may benefit from extension services to use their inputs more effectively.

5.4. Expansion of the cultivated area

The study provides strong evidence that the major mechanism behind the remarkable income increase among the smallholder farmers was the expansion of the land area that they cultivate. In the locations where the evaluation was conducted, smallholders typically own, according to the survey results, between 6 and 7 ha of land. There were no statistically significant differences in land size owned between the farmers who accessed tractor services and the control group. The findings indicate that due to labor constraints, farmers without access to tractor services are not able to cultivate the entire land that they own.

The finding that the income effect was mostly achieved by land expansion has important implications for the up-scaling of the JD Initiative. In general, land is not scarce in Zambia, as has been pointed out in Section 2. In view of the debate about large-scale land acquisitions and "land grabbing", it is important to note that access to mechanization services allows smallholders to make better use of Zambia's underutilized land resources so that this potential is not only left to large-scale investors.

However, one also needs to take into account that not all smallholders can easily expand the land that they cultivate. If they are not able or willing to resettle, they need land resources that are located sufficiently close to the villages in which they are residing. In a recent nationally representative survey, more than 54% of the rural population said that there is no more additional land available to them, despite the existence of underutilized arable land in Zambia (Chisinga and Chopoto, 2015: 36). In the areas where the study was conducted, land availability did not yet seem to be a main constraint yet. The reason may well be that service provision was directed towards locations where land availability for smallholders is still relatively high. These insights suggest that going forward, the mechanization initiatives should not only focus on the expansion of land, but also on increasing the profitability of the land that is already cultivated. This is also important in view of growing concerns that the expansion of land cultivation in Savanna regions can have negative environmental and climate effects (Ceballos et al., 2010; Searchinger et al., 2015).

5.5. Use of intra-household and hired labor

Two types of concerns regarding labor use are associated with mechanization, one referring to the intra-household division of labor and one referring to hired labor. The first concern stems from the fact that, initially, only very labor-intensive farming activities, such as ploughing which are mostly carried out by men, are mechanized, whereas other activities, which are mostly carried out by women and children, such as weeding, are not mechanized. If households expand the area cultivated, this may well result in an increase of the burden of labor for women and children. The evidence provided by the study suggests that this was not the case (Table 5). This is because agricultural activities were much less gendered than assumed by the literature. Land preparation is more done by males and weeding more by females but the difference is, although significant, not a major one (see Tables 11 and 12 in the Appendix). Thus, households with access to tractor services used on the average significantly less household labor from men, women and children than households without access to tractor services. Two factors may account for this result. One factor may be the increased use of herbicides, which reduced the labor requirements for weeding. The other factor may be the use of hired labor for harvesting, as further discussed below. It appears that the increased income achieved by mechanization allowed farm households with access to mechanization services to hire more labor for the non-mechanized activities. However, the findings regarding the labor effects of mechanization have to be interpreted with care, since data on labor use in smallholder farm households are difficult to collect in interviews with recall questions. To address this challenge, Daum et al. (2018, 2019) have conducted a follow-up study on the effects of mechanization on labor use in households. For this study, a picture-based smartphone app was developed that allows household members to record the time they spend on their daily activities in real time.

The findings presented in Table 5 indicate that mechanization did not reduce the demand for hired labor. To the contrary, the results suggest that the demand for hired labor increased for two reasons. One reason is the expansion of the cultivated area, which increased the labor demand for all activities that are not mechanized. The second effect is a shift from family labor to the use of hired labor, which may be due to the income effect of mechanization. This finding indicates that mechanization increases the demand for hired labor under conditions where land expansion is possible. The historical experience analyzed by Binswanger (1986: 33) is well in line with this finding. However, the demand for additional labor will be reduced once crop husbandry and harvesting activities also become mechanized.

The findings from the focus group discussions suggest that the shift in the timing of the labor demand may, however, involve problems. Smallholder farmers who work as laborers used to purchase inputs for their own farm with the money they earned at the time of land preparation. If they work for farmers who use tractor services for land preparation, they have to borrow money from those farmers to purchase their inputs and pay it back in form of labor provided for crop husbandry and harvesting. This shift has introduced a new type of dependency of agricultural laborers, a finding that calls for further investigation.

6. Policy implications

Overall, the findings indicate that private-sector driven initiatives to promote smallholder mechanization in Africa have a considerable potential to increase farm incomes. In line with the literature - and contrary to concerns of the critics of such initiatives, smallholder mechanization increases rather than reduces the demand for hired labor in situations where an expansion of the cultivated area is feasible. This expansion in labor demand will come to an end once land expansion is not feasible any longer. Therefore, a stronger focus on using mechanization to increase land productivity rather than promoting land expansion will be required. As pointed out above, limiting the expansion of land cultivation is also necessary to ensure environmental sustainability. Therefore, it is recommended to assist smallholders in increasing revenues per ha. This goal requires complementary efforts. Providing agricultural extension services to a large number of smallholder farmers can hardly be considered the task of agricultural machinery manufacturers or dealers. Other actors, such as government extension services, need to play a role to reach this goal.

To ensure that smallholder farmers benefit from contractor models, it is essential to better understand the economics of tractor service provision. Some of the tractor owners interviewed for this study pointed out that the transaction costs of providing services to smallholders are a major reason for limited service provision. Tractor owners who provided services to smallholders benefitted from the support of an NGO, which organized smallholders in groups and linked them to tractor owners. ICT tools that follow the "Uber" model such as "Hello Tractor" may help to reduce the transaction costs of providing and accessing tractor service.[10] In addition, tractor owners need the capacity to manage tractors and there may be a threshold of own farm size above which tractor owners do not provide any services any more. These questions open the room for follow up studies, including randomized control trials testing different interventions. For example, such studies could assess what kinds of financial interventions could encourage medium-holding famers who would otherwise not purchase tractors to purchase tractors? Would they need to be trained to understand that

[10] https://www.hellotractor.com/.

higher utilization rates contribute to larger profits? And finally, does organizing farmers reduce transaction costs enough to encourage those who would not have otherwise provided or rented services?

Going forward, it will also be important to pay attention to avoiding potential negative environmental effects of mechanization. In the case considered here, problems of increased soil erosion have been limited because the ripper rather than the disc plough was promoted due to the involvement of CFU. In situations where farmers select the implements without the advice by CFU, they may, however, prefer the plow to the ripper. Extension services to smallholder farmers, as mentioned above, could play an important role in ensuring appropriate soil fertility management on mechanized smallholder farms. This could also be supported via lower tax and tariffs for soil-protecting implements.

Overall, the findings indicate smallholder farmers can benefit from private-sector driven mechanization initiatives, especially when they place efforts on tractor service provision. This does not imply that government have no role to play. The public sector is essential to promote mechanization by providing complementary services, including providing training and agricultural extension to build the capacity of small and medium-size farmers to own and manage tractors and ensuring the environmental sustainability of mechanization through applied research on soil conserving mechanization.

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Declaration of interest statement

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Appendix

See Tables 11 and 12.

Table 11
Per hectare (per 50 kg bag) hour differences for cultivating and processing of all crops.

	Total Labor hours/ha	Hired Labor hours/ha	Family labor hours/ha	Female family labor hours/ha	Children family labor/ha	Male family labor/ha
Land preparation	−219***	−9	−196***	−70***	−14*	−111***
Planting	−11	25**	−35**	−29**	−3	−4
Fertilizer application	−13	6**	−21**	−11**	−4	−5
Weeding	−200***	27**	−222***	−110***	−16***	−97***
Pests/disease control	−29**	1	−31**	−2	0	−6
Harvesting	−14	45***	−34	−11	−3	−20
Processing (per 50 kg)	−4***	−2	−3**	−2***	−1	−1

Note: Mean difference is the difference between mean value of participant group members of the scheme and non-participant groups.
* Statistical significance at the 10% level.
** Statistical significance at the 5% level.
*** Statistical significance at the 1% level.

Table 12
Per hectare (per 50 kg bag) labor use in absolute terms for cultivating and processing of all crops for participants and non-participants.

	Participants						Non-participants					
	Total Labor hours/ha	Hired labor hours/ha	Family labor hours/ha	Male family labor/ha	Female family labor/ha	Children family labor/ha	Total Labor hours/ha	Hired labor hours/ha	Family labor hours/ha	Male family labor/ha	Female family labor/ha	Children family labor/ha
Land preparation	10	1	8	4	3	1	226	10	201	115	73	15
Planting	81	29	51	20	26	4	92	4	86	24	55	7
Fertilizer application	47	7	39	18	18	3	60	1	60	23	29	8
Weeding	174	51	122	51	63	8	375	24	344	148	172	24
Pests/disease control	14	1	13	12	0	0	43	0	43	41	2	0
Harvesting	314	63	244	105	124	15	328	18	278	125	135	18
Processing (hours per 50 kg)	5	11	4	2	2	0	9	12	8	3	3	2
Total	*645*	*163*	*481*	*212*	*236*	*31*	*1133*	*69*	*1020*	*479*	*469*	*74*

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodpol.2019.03.007.

References

Anderson, J.R., Dillon, J.L., 1992. Risk Analysis in Dryland Farming Systems. Farm Systems Management Series 2, Food and Agriculture Organization of the United Nations (FAO), Rome.
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. Agron. Sustain. Dev. 39 (2), 17.
Bhandari, P., Ghimire, D., 2016. Rural agricultural change and individual out-migration. Rural Sociol. 81 (4), 572–600.
Binswanger, H., 1986. Agricultural mechanization: a comparative historical perspective. World Bank Res. Observer 1 (1), 27–56.
Birner, R., Resnick, D., 2010. The political economy of policies for smallholder agriculture. World Dev. 38 (10), 1442–1452.
Byerlee, D., Husain, T., 1993. Agricultural research strategies for favoured and marginal areas. Exp. Agric. 29, 155–171.
Caliendo, M., Kopeinig, S., 2008. Some practical guidance for the implementation of propensity score matching. J. Econ. Surveys 22 (1), 31–72.
Ceballos, G., Davidson, A., List, R., Pacheco, J., Manzano-Fischer, P., Santos-Barrera, G., Cruzado, J., 2010. Rapid decline of a grassland system and its ecological and conservation implications. PLoS One 5 (1).
Chisinga, B., Chapoto, A., 2015. Under-appreciated Facts about Zambia's Agriculture: In Chapoto, A., Sitko, J., Nicholas (Eds.), Agriculture in Zambia: Past, Present, and Future. Indaba Agricultural Policy Research Institute (IAPRI), Lusaka, pp. 32–46.
Daum, T., Buchwald, H., Gerlicher, A., Birner, R., 2019. Times have changed: using a pictorial smartphone app to collect time-use data in rural Zambia. Field Meth. 31 (1), 3–22.
Daum, T., Buchwald, H., Gerlicher, A., Birner, R., 2018. Smartphone apps as a new method to collect data on smallholder farming systems in the digital age: a case study from Zambia. Comput. Electron. Agric. 153, 144–150.
Daum, T., Birner, R., 2017. The neglected governance challenges of agricultural mechanisation in Africa–insights from Ghana. Food Security 9 (5), 959–979.
Davis, B., Di Giuseppe, S., Zezza, A., 2017. Are African households (not) leaving agriculture? Patterns of households' income sources in rural Sub-Saharan Africa. Food Policy 67, 153–174.
Dehejia, R.H., Wahba, S., 2002. Propensity score-matching methods for nonexperimental causal studies. Rev. Econ. Stat. 84 (1), 151–161.
Deininger, K., Byerlee, D., 2011. Rising Global Interest in Farmland - Can it Yield Sustainable and Equitable Benefits? Management. World Bank, Washington, D.C.
Deininger, K., Byerlee, D., 2012. The rise of large farms in land abundant countries: do they have a future? World Dev. 40 (4), 701–714.
De Janvry, A., Sadoulet, E., 2016. Development Economics: Theory and Practice. Routledge.
De Janvry, A., Dustan, A., Sadoulet, E., 2010. Recent advances in impact analysis methods for ex-post impact assessments of agricultural technology. A discussion on estimating treatment effects, organized by the CGIAR Standing Panel on Impact Assessment (SPIA), 2 October, 2010, Berkeley, California, USA.
Diao, X., Cossar, F., Houssou, N., Kolavalli, S., 2014. Mechanization in Ghana: emerging demand, and the search for alternative supply models. Food Policy 48, 168–181.
Diao, X., Cossar, F., Houssou, N., Kolavalli, S., Jimah, K., Aboagye, P., 2012. Mechanization in Ghana: Searching for Sustainable Service Supply Models. IFPRI Discussion Paper 01237, International Food Policy Research Institute, Washington, D.C.
Diao, X., McMillan, M.S., Mwangwe, S., 2018. Agricultural labour productivity and industrialisation: lessons for Africa. J. Afr. Econ. 27 (1), 28–65.
FAO & UNIDO, 2008. Agricultural Mechanization in Africa. Time for Action. United Nations Industrial Development Organization (UNIDO) and Food and Agriculture Organization (FAO), Vienna.
Feder, G., Birner, R., Anderson, J.R., 2011. The private sector's role in agricultural extension systems: potential and limitations. J. Agribus. Dev. Emerg. Econ. 1 (1), 31–54.
Giller, K.E., Witter, E., Corbeels, M., Tittonell, P., 2009. Conservation agriculture and smallholder farming in Africa: the heretics' view. Field Crops Res. 114 (1), 23–34.
Hayami, Y., Ruttan, V., 1985. Agricultural Development: An International Perspective. Johns Hopkins University Press, Baltimore, MD.
Houssou, N., Diao, X., Cossar, F., Kolavalli, S., Jimah, K., Aboagye, P.O., 2013. Agricultural mechanization in Ghana: is specialized agricultural mechanization service provision a viable business model? Am. J. Agric. Econ. 95 (5), 1237–1244. https://doi.org/10.1093/ajae/aat026.
IAPRI, 2015. Rural Agricultural Livelihoods Survey: 2015 Survey Report. Indaba Agricultural Policy Research Institute (IAPRI), Lusaka.
ILO, 1973. Mechanization and employment in agriculture: case studies from four continents. Geneva.
Jahnke, H.E., 1983. Livestock production systems and livestock development in tropical Africa. Am. J. Agric. Econ. 65.
Juma, C., 2016. Innovation and its enemies: why people resist new technologies. Oxford University Press, New York.

Kariuki, J., Njuki, J., 2013. Using participatory impact diagrams to evaluate a community development project in Kenya. Dev. Pract. 23 (1), 90–106.
Khandker, S.R., Koolwal, G.B., Samad, H.A., 2010. Handbook on Impact Evaluation: Quantitative Methods and Practices. World (Vol. 41). World Bank, Washington, DC.
Kienzle, J., Ashburner, J.E., Sims, B.G. (Eds.), 2013. Mechanization for Rural Development: A Review of Patterns and Progress from around the World, vol. 20. Food and Agricultural Organization (FAO), Rome.
Knowler, D., Bradshaw, B., 2007. Farmers' adoption of conservation agriculture: a review and synthesis of recent research. Food Policy 32 (1), 25–48.
Low, A., Waddington, S.R., 1991. Farming systems adaptive research: achievements and prospects in southern Africa. Exp. Agric. 27 (2), 115–125.
Martínez-Torres, M.E., Rosset, P.M., 2010. La vía campesina: the birth and evolution of a transnational social movement. J. Peasant Stud. 37 (1), 149–175.
Massey, D.S., Arango, J., Hugo, G., Kouaouci, A., Pellegrino, A., Taylor, J.E., 1993. Theories of international migration: a review and appraisal. Popul. Dev. Rev. 431–466.
Mrema, C.G., Baker, D., Kahan, D., 2008. Agricultural Mechanization in Sub-Saharan Africa: Time for a New Look. Food and Agricultural Organization (FAO), Rome.
Olmstead, A.L., Rhode, P.W., 1995. Beyond the threshold: an analysis of the characteristics and behavior of early reaper adopters. J. Econ. History 55 (1), 27–57.
Pingali, P., 2007. Agricultural mechanization: adoption patterns and economic impact. In: Evenson, R., Pingali, P. (Eds.), Handbook of Agricultural Economics, Volume 3. North-Holland, pp. 2779–2805.
Pingali, P., Bigot, Y., Binswanger, H.P., 1987. Agricultural Mechanization and the Evolution of Farming Systems in Sub-Saharan Africa. John Hopkins University, Baltimore and London.
Quisumbing, A.R., Maluccio, J.A., 2000. Intrahousehold Allocation and Gender Relations: New Empirical Evidence from Four Developing Countries. International Food Policy Research Institute, Washington, DC.
Rosenbaum, P., Rubin, D., 1985. Constructing a Control Group Using Multivariate Matched Sampling Methods That Incorportate the Propnsity Score. American Statistical Association, 30. No. 1.
Sallah, P., Twumasi-Afriyie, S., Kasei, N., 1997. Optimum planting dates for four maturity groups of maize varieties grown in the Guinea savanna zone. Ghana J. Agric. Sci. 30, 63–69.
Schneider, F., Don, A., Hennings, I., Schmittmann, O., Seidel, S.J., 2017. The effect of deep tillage on crop yield–What do we really know? Soil Tillage Res. 174, 193–204.
Searchinger, T.D., Estes, L., Thornton, P.K., Beringer, T., Notenbaert, A., Rubenstein, D., Herrero, M., 2015. High carbon and biodiversity costs from converting Africa's wet savannahs to cropland. Nat. Clim. Change 5 (5), 481.
Sheahan, M., Barrett, C.B., 2017. Ten striking facts about agricultural input use in Sub-Saharan Africa. Food Policy 67, 12–25. https://doi.org/10.1016/j.foodpol.2016.09.010.
Sitko, N.J., Jayne, T.S., 2014. Structural transformation or elite land capture? The growth of "emergent" farmers in Zambia. Food Policy 48, 194–202.
Tavenner, K., van Wijk, M., Fraval, S., Hammond, J., Baltenweck, I., Teufel, N., Kihoro, E., de Haan, N., van Etten, J., Steinke, J., Baines, D., Carpena, P., Skirrow, T., Rosenstock, T., Lamanna, Ng'endo, M., Chesterman, C., Namoi, N., Manda, L., 2019. Intensifying Inequality? Gendered trends in commercializing and diversifying smallholder farming systems in East Africa. Front. Sustain. Food Syst. 3, 10. https://doi.org/10.3389/fsufs.
Tembo, S., Sitko, N., 2013. Technical Compendium: Descriptive Agricultural Statistics and Analysis for Zambia. Lusaka: Working Paper 76, Indaba Agricultural Research Institute (IAPRI).
WFP, 2008. Food consumption analysis: Calculation and use of the food consumption score in food security analysis. Retrieved from www.wfp.org/odan/senac.
World Bank, W.B., 2007. World Development Report 2008: Agriculture for Development. World Bank, Washington, DC.