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Agricultural Mechanization and Gendered Labor Activities across Sectors

Micro-evidence from Multi-country Farm Household Data

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Contents

Abstract

Gender differences in the engagement of work activities across sectors are important elements of gender inequality in rural livelihoods and welfare in developing countries. The role of production technologies, including agricultural mechanization, in addressing gender inequality, is increasingly explored. Knowledge gaps remain, however, including, how agricultural mechanization differentially affect labor engagements across sectors. This study aims to partly fill these knowledge gaps through micro-evidence from 8 countries (Ethiopia, Ghana, Nigeria, Tanzania, India, Nepal, Tajikistan and Vietnam), using several nationally representative panel data and supplementary data, and applying Correlated-Random-Effects Double-Hurdle models with Instrumental-Variables. We find that the use of tractors and/or combine harvesters by the household induces greater shift from farm activities to non-farm activities by female members than by male members. While statistical significance varies, these patterns generally hold consistently across all 8 countries studied. These patterns also seem to hold across different farm sizes. While these are short-term relations, agricultural mechanization proxied by tractor and/or combine harvesters is one of the important contributors to gendered rural livelihood. Future studies should more closely investigate underlying mechanisms and implications of these patterns.

Keywords: agricultural mechanization, tractors and combine harvesters, gender, labor, correlated-random-effects double hurdle model, panel data

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1 Introduction

Gender differences in the engagement of work activities across sectors are important elements of gender inequality in rural livelihoods and welfare in developing countries (Klasen 2019; Quisumbing et al. 2019). Technologies, among others, are some of the important factors affecting such gendered differences in engagements in work activities across sectors. Among various technologies, agricultural mechanization can potentially have significant effects on such outcomes, given its direct relationship with labor activities. The importance of linking gender and agricultural mechanization has been emphasized in recent studies. Fischer et al. (2018) describes how developing community is re-conceptualizing mechanization as part of sustainable development (Sims et al., 2016) and as socially embedded and highly gendered (van Eerdewijk and Danielsen, 2015). Based on lessons from the past, sustainable mechanization is described as a demand-driven, participatory and context-specific process that requires the involvement of all stakeholders, including women (Houmy et al.,2013). Recent review studies (e.g., Vemireddy & Choudhary 2021) also find that mechanization has been considered one of the most relevant labor-saving technologies for women (in addition to agricultural practices and inputs like agrochemicals). Governments in developing countries are also increasingly exploring ways to promote agricultural mechanization as part of the instruments to achieve gender-inclusive agrifood system transformation. For example, in October 2019, the government of Burkina Faso, in collaboration with the African Union, launched an initiative to advance mechanization to better meet women's needs and contribute to their empowerment in agriculture (IFPRI 2020 p.70).

Knowledge gaps, however, have remained substantial as to how agricultural mechanization is actually associated with gender differences in labor activities across sectors. In laying out structurally the analytical issues of rural mechanization, Gass & Biggs (1993) emphasized the importance of focusing on gender consequences, impacts, and constraints in ex-post analyses. Despite such growing importance, the limited availability of reliable data had long been one of the challenges in gender implications of rural mechanization R&D in assessing its impacts on women's employment, empowerment, and income-earning opportunities (Gass et al. 1997). Vemireddy & Choudhary (2021) find that the evidence remains scarce regarding the linkages between gender and labor-saving technologies in general, and agricultural mechanization in particular, with relatively limited focus on, for example, labor productivity differentials across women and men due to mechanization and the role of labor-saving technology in empowering women in agricultural operations. Few studies use robust quantitative techniques to measure the gendered differences in impacts of mechanization adoption on other household-level variables such as nutrition, childcare, etc. (Vemireddy & Choudhary 2021). Furthermore, while studies focusing on certain labor-saving technologies like seeds and agrochemicals, or stationary mechanization (such as milling or processing) of various agrifood commodities have offered relatively more insights on gendered labor use, similar insights were relatively limited for more mobile mechanization like land preparation by tractors (Vemireddy & Choudhary 2021). The available evidence, therefore, has been limited to anecdotal or qualitative, indicative evidence.

This study aims to fill this knowledge gap by providing micro-level evidence of gendered labor outcomes of agricultural mechanization in multiple countries. Specifically, we analyze the effects of farm households' use of tractors and/or combine harvesters on engagements by members of these households in agricultural and nonagricultural work activities, and assess how these patterns differ across gender of these household members. We obtain such evidence from nationally representative data from four African countries (Ethiopia, Ghana, Nigeria, and Tanzania), two Asian countries (Nepal and Vietnam), and data from particular regions in two additional Asian countries (semi-arid region of India and southern Tajikistan). The collective evidence from these countries offers rich insights applicable to broad socioeconomic contexts. We apply correlated random-effects (CRE) double-hurdle models combined with instrumental variables (IV) methods, which better characterize differential processes of engagements in work activities at extensive and intensive margins, and minimize the biases due to potential endogeneity of the use of tractors and/or combine harvesters. Our results, as are discussed in detail, suggest that the use of these machines on-farm leads to a relatively greater reduction in engagements in agricultural work activities and relatively greater engagements in nonagricultural activities by women than men.

The remaining part of this paper consists of the following sections. Section 2 describes the empirical methods, while section 3 discusses data and descriptive statistics. Section 4 presents the results. Lastly, section 5 concludes. In addition, Appendices present supplementary results and a detailed literature review for gendered effects of agricultural mechanization.

2 Empirical analyses of the associations between agricultural mechanization and gendered differences in labor use

2.1 Empirical models

We estimate associations between tractor adoptions and individual household members' labor use using double-hurdle (DH) models initially developed by Cragg (1971). A DH model is appropriate in our case because the outcome of our interest, labor time allocated for agriculture and other work activities by individuals, is often significantly truncated at 0, and using a standard least square model would lead to biased estimates. A DH model is also superior to other truncated regression like Tobit, as it can allow different effects of mechanization and other explanatory variables on whether to work and how much to work. Specifically, we estimate

$$d_{hit} = \alpha_d + \beta_M M_{ht} + \beta_X X_{hit} + \beta_Z Z_{ht} + f_d(c_{hi}) + \varepsilon_{hit}. \tag{1}$$

through either standard or instrumental-variable (IV) probit regressions, and estimate

$$y_{hit} = \alpha_y + \gamma_M M_{ht} + \gamma_X X_{hit} + \gamma_Z Z_{ht} + f_y(c_{hi}) + \upsilon_{hit}. \tag{2}$$

through either standard or IV-truncated regressions (described below). Whether an individual i in household h engaged in work activities in the agricultural sector, or other sector in year t (d_{hit}), and the amount of work engaged by them (y_{hit}) are regressed on an indicator M_{ht} which takes the value of 1 if h used tractors (as well as combine harvesters in India data) at t, controlling for other exogenous factors that are individual-level (X_{hit}) and household-level (Z_{ht}). Other parameters α's, β's, and γ's are estimated coefficients, while ε_{hit} and υ_{hit} are idiosyncratic shocks. ε_{hit} and υ_{hit} can have non-zero correlation with each other.

The notations $f_d(c_{hi})$ and $f_y(c_{hi})$ represents correlated-random-effects (CRE), i.e., effects of the averages of M_{ht}, X_{hit} and Z_{ht} across all survey rounds, as suggested by Mundlak (1978) and Chamberlain (1984), and double-hurdle models in recent studies (e.g., Ricker-Gilbert et al. 2011; Takeshima & Nkonya 2014). Importantly, X_{hit} and Z_{ht} include not only time-variant variables, but also time-invariant variables, which is a feature enabled by a CRE-double-hurdle model.

2.1.1 Average partial effects

From the estimated results from CRE-double-hurdle models, we compare average partial effects (APE) on the (a) probability that individual i engages in work activities in the agricultural sector or all sectors, and (b) how much labor time the individual i engages in each sector. Specifically, (a) and (b) are computed as

$$APE_{a,hit} = \frac{\partial P(Y_{hit} > 0 | X_{hit}, Z_{ht})}{\partial M_{ht}} = \beta_M \phi(A_{hit}) \quad (3)$$

$$APE_{b,hit} = \frac{\partial E(Y_i | X_i)}{\partial M_i} = \beta_M \phi(A_{hit}) \times \left\{ B_{hit} + \sigma \times \lambda \left(\frac{B_{hit}}{\sigma} \right) \right\} \\ + \Phi(A_{hit}) \times \gamma_M \left[1 - \lambda \left(\frac{B_{hit}}{\sigma} \right) \left\{ B_{hit} + \sigma \times \lambda \left(\frac{B_{hit}}{\sigma} \right) \right\} \right]. \quad (4)$$

where $\phi(\cdot)$ and $\Phi(\cdot)$ are standard normal density function and standard normal distribution function, respectively, $\lambda(\cdot) = \phi(\cdot)/\Phi(\cdot)$, σ is the estimated standard deviations of idiosyncratic error term υ_{hit} in the truncated regression (2). A_i and B_i are predicted values of the right-hand side terms in (1) and (2), respectively. β_M and γ_M are the estimated coefficients of the effects of tractor adoption, as defined in (1) and (2).

We then compare the sample averages of APE_a and APE_b among male and female individuals:

$$\Delta E[APE_{a,hit}] = E[APE_{a,hit}] \text{ among female samples across all } t - \\ E[APE_{a,hit}] \text{ among male samples across all } t. \quad (5)$$

$$\Delta E[APE_{b,hit}] = E[APE_{b,hit}] \text{ among female samples across all } t - \\ E[APE_{b,hit}] \text{ among male samples across all } t. \quad (6)$$

If $\Delta E[APE_{a,i}]$ and / or $\Delta E[APE_{b,i}]$ are statistically significantly different from zero, we conclude that the adoption of tractors has gendered-effects on individual labor supply in the agricultural and the other sectors.

Potential endogeneity of tractor adoption term M_{ht}

The consistency of (1) and (2) depends on the assumption that M_{ht} is exogenous to d_{hit} and y_{hit} conditional on X_{hit}, Z_{ht} and $f_d(c_{hi})$ as well as $f_y(c_{hi})$. Controlling for c_{hi} or $f_d(c_{hi})$ and $f_y(c_{hi})$ is likely to reduce the possibility that M_{ht} is endogenous (e.g., Bhattarai et al. 2020; Takeshima et al. 2020). However, this may not always hold. We therefore also estimate (1) and (2) through IV-method, whereby M_{ht} is instrumented by two variables; whether there is at least one tractor owner, and the shares of such tractor owners, in the sample within the enumeration areas where household h is located. These are suitable IVs because proximity to tractor owners often determine the accessibility of tractor hiring services, and have been used in the past mechanization studies (Diao et al. 2020). Through IV-methods, we conduct the test of exogeneity of M_{ht}. If the model fails to reject the exogeneity, we select the results based on standard probit and truncated regression. Otherwise, we select the result based on IV-probit and IV-truncated regression. Past studies used similar IV-based approach in CRE-double-hurdle models (e.g., Ricker-Gilbert et al. 2011; Takeshima & Nkonya 2014).[1]

Additionally, consistency of our analysis requires strict exogeneity, i.e., y_{hit} or ε_{hit} do not affect $M_{h,t+1}$, $X_{hi,t+1}$ nor $Z_{h,t+1}$. We argue that this is less likely to be violated, because most panel data (except India data) are surveyed at least two-years apart, so that any lagged effects of y_{hit} or ε_{hit} are likely to dissipate substantially by the subsequent survey round.[2]

Variables

As is discussed above, while CRE-double hurdle models are applied to panel data, time-invariant variables are included in addition to time-variant variables. A set of variables are selected guided by the literature on agricultural mechanization and gender.

Farm household-level variables (Z_{ht}) consist of household demographics, wealth, agricultural wages, agroecological conditions, and indicators of other local / community-level shocks. Demographic variables include the number of household members by gender and age group (children aged 14 or below, working-age members aged between 15 and 60, and elderly aged above 60), characteristic of household head (age, gender and education level).

Household wealth includes values of agricultural equipment owned, livestock owned, other household assets, and the size of farmland owned or externally distributed (for example, by the communal chief). In addition, the financial shock experienced by the household is proxied by whether the household head was hospitalized at any time during the survey year. For India data, due to the lack of information, we proxied this by whether the household head changed from the previous year.

Agricultural wages are proxied by daily wages for land preparation activities, by male and female laborers, prevailing in the local area.

Agroecological variables include yearly annual rainfall that is time-variant, as well as historical average that is time-invariant. They also include terrain ruggedness and a range of characteristics associated with dominant soils of the locality where households are located, including the shares of different textures (fine, medium, coarse), shares of soils with excess drainage and poor drainage, soil alkalinity, organic content, salinity, and sodicity. These soil parameters were used in past studies on agricultural mechanization (e.g., Takeshima & Liu 2020).

Local / community-level shocks are proxied variably across countries depending on the data availability. These largely consist of the presence in the community, of various development projects implemented, natural disasters. For Nepal and Vietnam, for which community-level information is generally limited, we used changes in distances to key infrastructures as proxies.

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[1]For India data, similar IV-methods are not feasible because samples are clustered into 18 villages with which aforementioned IVs have limited variations. Therefore, for India data, we also estimate results using lagged variables of tractors or combine-harvester uses by the households, in which case endogeneity is less of a concern. Results are found to be robust whether using current or lagged variables.

[2]While India data are surveyed more frequently, machines like tractors used in India are more expensive four-wheel tractors, compared to smaller tractors used in other Asian countries, for which accessibility is more subject to factors that are external to the household (Diao et al. 2020). We therefore argue that specification (1) is consistent for India data as well.

For India data, since the data are clustered in a small number of villages (18 in total), village dummies interacted with year dummies are used to capture local level shocks.

Individual-level variables (X_{hit}) consist of their basic characteristics (age, gender and education completed), health shocks proxied by whether having been hospitalized within the previous 12 months, marital status, whether the spouse lives in the house, and the number of biological children. These variables are also selected as they are considered important in the literature (discussed more in detail in Appendix B), and generally commonly available in the dataset used.

Lastly, year dummies (as well as survey round dummies, and month dummies for India data) are included to capture shocks that are specific to the survey timing.

Estimation model for Ghana data

For Ghana data which are not panel data but repeated cross-section data, we estimate (1) and (2) without CRE-terms $f_d(c_{hi})$ and $f_y(c_{hi})$, since CRE-terms cannot be constructed. We still instrument tractor adoption variable M_{ht} through IVs as described above, so that the potential endogeneity of M_{ht} is still mitigated.

Tajikistan data

Tajikistan data are one-year cross-sectional data but have information on multiple plots and crops for each household, as is described in the next section. We, therefore, estimate plot and crop level model, in which unobserved household fixed effects can be controlled for. We then assume that, conditional on which endogeneity of mechanization adoption may be mitigated. Specifically,

$$y_{hjck} = \alpha + c_h + \beta M_{hjck} + \gamma X_{hjck} + \varepsilon_{ijk} \quad (7)$$

in which y_{hijck} is total male or female labor use by household h on plot j, for crop c, and farming operation k (land preparation, planting / weeding, fertilizer / chemical application, harvesting), M_{hjck} is an indicator whether machines were used by the household on plot, crop and each farming operation, and X_{hjck} is a set of other exogenous variables (plot size, crop dummy and farming operation dummy variables).

3 Data and descriptive statistics

Our primary datasets consist of Living-Standard Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) for Ethiopia, Nigeria, and Tanzania, as well as Living Standard Surveys for Ghana (GLSS), Nepal (NLSS), and Vietnam (VHLSS), all of which are nationally representative. These data are supplemented by The Village Dynamics Studies in South Asia (VDSA) data for Southern India and IFPRI (2018) data on Tajikistan. Table 1 summarizes the units of samples and years of survey rounds that are used in this study.

As was described above, all datasets, except GLSS and Tajikistan data, are panel data. In these data, we use the information from panel sample of individuals aged 15 or above, with nonmissing observations for at least two rounds. While focusing strictly on these samples lead to the omission of certain observations due to attrition, as is discussed later, our results are likely to be robust against attrition. For GLSS, all nonmissing individual observations are used. For Tajikistan, plot and crop level samples are used. With this selection criteria, our primary samples (panel individuals times the number of rounds they are reported) consist of 14,850 for Ethiopia, 55,985 for Ghana, 29,687 for Nigeria, 18,160 for Tanzania, 112,208 for India, 6,072 for Nepal, 30,930 for Vietnam, and 6,344 for Tajikistan.

Agroecological data

Rainfall data come from The Climate Hazards group Infrared Precipitation with Stations (CHIRPS) by Funk et al. (2015). Soil data come from FAO et al. (2012). Terrain ruggedness is computed following Riley et al. (1999) using USGS (1996). These values are extracted for each sample household based on their geographic locations.

3.1 Descriptive statistics

Table 2 summarizes the extent of mechanization use (proxied by the use of tractors) at farm household levels in each country dataset studied. In countries like India, Nepal, Ghana, Tanzania, the tractor adoption rates increased considerably across survey rounds. Even in countries like Ethiopia, Nigeria, or Vietnam, where the adoption rates have relatively stable, there are significant temporal variations at household levels because much of tractor use depends on hiring-service rather than own machines, and the accessibility to such services can vary depending on various factors, including shocks experienced by the nearby tractor owners (e.g., loss or malfunctioning of tractors), or local road closures, among others.

Table 3 summarizes the descriptive statistics for outcome variables of our interests d_{hit} and y_{hit}. These figures are reported in days for Nigeria and India, while hours for all the other countries. As for figures including non-agricultural sector, for most countries we focus on hours worked on all sectors including the agricultural sector. For Nigeria and India, we focus on the number of days worked exclusively in the nonagricultural sectors. This is because, when counted in days rather than hours, the number of days worked alone may not precisely reflect the extent engaged in the agricultural and nonagricultural sector, respectively. Similarly, reference periods in original data vary from the past 7 days to the past 12 months, depending on the country. The percentage share of individuals engaged in each sector's activities is higher if reference periods are longer, because the longer the coverage period, the more likely it is that the individual is engaged in work activities for at least 1 hour.

Figures in Table 3 suggest that, about 30 ~ 70% of individuals 15 years or older (although higher for countries with longer reference periods) engaged in agricultural activities during the reference periods. Typically, the intensity of activities ranges around 15 ~ 30 hours, or 1.5 ~ 4 days, per 7 days. In Nigeria and India, a fraction of these individuals engaged exclusively in the nonagricultural sector, and if so, worked for 5 ~ 6 days per 7 days. In other countries, about 40 ~ 80% of individuals engaged in activities in either the agricultural or the nonagricultural sector, and if so, worked around 25 ~ 40 hours per 7 days.

Table 4 summarizes the descriptive statistics of other variables. Figures are nominal values, and converted into current US dollars. For countries with nationally representative data, as expected, most individuals are in smallholder farm households who are asset-poor. Agricultural wages are also low, ranging from USD 0.6 / day in Ethiopia to USD 5.6 / day in Vietnam. Typically, about half are married and having a spouse living physically in the households, with 1 or more biological children who require primary childcare responsibility from the respondent. About 3 ~ 21% of individuals experienced hospitalization during the 12 months leading up to the survey.

Tajikistan data consist of mostly horticulture farm plots, most of which are small with a median size of 0.03 ha, or 300 m^2. Approximately 75% of sampled plots are cultivated with vegetables, including potatoes and tomatoes as two major crops, as well as 20% of plots on which many field fruits are cultivated. Table 6 summarizes the labor and machine uses on these plots for different farming operations (land preparation, planting/weeding, fertilizer/chemical application, harvesting. More female workers, both family members, and hired workers, are used for harvesting than male workers, while gender differences for other operations are relatively small. For each farming operation, machines are used in approximately 20 – 30% of sampled plots, and where used, machines are typically used for 2 – 7 hours per plot depending on the operations.

4 Results

Table 7 through Table 15 present the estimated effects of tractors or combine-harvester adoptions on gendered-differences in the engagement in the agricultural and non-agricultural sectors (except Tajikistan for which results are presented separately). The effects of other covariates are secondary interests and summarized in Table 17 and Table 18 in Appendix A.

For the extents of engagement in work activities, while our focus is on the signs and their statistical significance, we report standardized coefficients calculated as a proportion to the median values in Table 3 to allow some comparisons across countries.

Endogeneity of the use of tractors is tested, and if endogenous, results based on IV-methods are presented. As was discussed earlier, for India data, for which IV-methods are not feasible, we also estimated results using lagged variables of tractors or combine-harvester uses by the households, in which case endogeneity is less of a concern. Results are found to be robust whether using current or lagged variables.

Table 7 and Table 8 show the differences between women and men in the effects of households' use of tractors or combine-harvesters on whether and by how much they engage in agricultural, nonagricultural, or any-sectors work activities. Negative values indicate that women are less likely to engage in corresponding work activities, and if they do, engage to a lesser extent. Table 7 reports the results that are more efficient but rely on more restrictive assumptions that effects of other covariates do not vary across gender of individuals (Model 1), while Table 8 reports the results that are less efficient but are under more relaxed assumptions that effects of other covariates also vary across gender (Model 2). The results suggest that, for a majority of countries, the use of tractors or combine-harvesters by their households leads to a significantly lower likelihood and extent of engagement in agricultural activities by women relative to men. While the magnitudes and statistical significance of these effects somewhat vary across countries, the signs are generally consistent, and there are barely any statistically significant coefficients of opposite signs. These results also generally hold in both Table 7 and Table 8, suggesting their robustness.

Table 7 and Table 8 also suggest that, use of tractors and / or combine-harvesters often led to greater likelihood and the extent of engagements by women in the nonagricultural sector, than by men. In Nigeria and India, we have direct evidence as shown. For other countries, generally insignificant effects for all-sectors combined with significantly negative effects on the agricultural sector, suggest indirectly that, on balance, use of tractors by the household led to greater likelihood and the extent of engagements by women than men in the nonagricultural sector.

Robustness against attrition

Our results are also likely to be robust against sample attritions, as indicated by Table 9. Table 9 shows the average proportions of samples missing due to attritions across survey rounds, and the effects of mechanization adoption on the gender-differences in attrition patterns in the following survey round. Attrition rates are somewhat substantial, ranging between 5 ~ 40 %, possibly due to our focus on individual rather than household panels. However, importantly, the patterns of attritions are relatively independent of mechanization use in the previous rounds, as indicated by generally statistically insignificant coefficients shown. Where statistically significant, mechanization use in previous survey rounds led to a relatively higher share of women than men missing in the following survey rounds. These patterns are consistent with the assumptions that, mechanization adoptions induced more women to out-migrate to other areas, where they may be more likely to be engaged in nonagricultural activities than agricultural activities. In such cases, while biases may exist, directions of biases are such that unbiased estimates rather reinforce the results in Table 7 and Table 8.

Robustness across different farm sizes

Table 10 through Table 13 show that the aforementioned gendered-effects on the engagements in agricultural work activities also hold generally regardless of relative farm sizes measured by the sizes of own farm and land that is distributed by the community. Again, such robustness also holds between more efficient estimates under a stricter assumption of homogenous effects of other coefficients across gender, or less efficient estimates under relaxed assumptions.

Effects in absolute terms

Table 7 through Table 13 focus on relative differences between women and men, which only offer partial pictures. Table 14 and Table 15 the effects in absolute terms. These results suggest that, in absolute terms, households' use of tractors and/or combine-harvesters do not lead to increased engagements by women in the agricultural sector activities. Rather, quite often, it leads to reduced engagements in the agricultural sector, and increased engagements in the non-agricultural sector.

Effects of other covariates

As was mentioned earlier, the effects of other covariates are of secondary importance in our analyses. Table 17 and Table 18 show the statistically significant signs of each covariate across countries. The prevalence of statistically significant signs suggests that including these covariates significantly mitigated omitted variable biases. While signs of some covariates are relatively consistent across countries, some are heterogeneous across countries and gender, suggesting that these covariates also effectively control for inherent heterogeneity in individuals' decisions to engage in agricultural and nonagricultural work activities, reducing the biases in estimated effects of mechanization on such decisions and differences across gender.

Results for horticulture farmers (Tajikistan)

Table 16 summarizes the estimated associations between machine use and labor use of female and male workers, estimated at plot-crop levels. Generally, labor use is somewhat positively associated with machine use, approximately 15-23 percent higher among machine used plots. There are, however, somewhat different patterns across gender. Generally, for female workers, machine use is relatively greatly associated with longer work hours for fertilizer or chemical applications, while for male workers, machine use is relatively more associated with longer hours for planting / weeding or harvesting work. Generally, however, gender differences in planting/weeding and harvesting labor are more significant than those in fertilizer / chemicals applications. While it is beyond the scope of this study to examine the underlying causes for such differences, the results weakly suggest that mechanization reduces the relative share of female labor in horticulture farming in Tajikistan. Furthermore, results also suggest weakly that, the aforementioned positive associations among female workers are somewhat weaker in households that exhibit higher women's empowerment in agriculture (WEAI) index.

5 Conclusions

The role of technologies in labor allocation across sectors is an important element of livelihood improvement in developing countries. Agricultural mechanization, including the adoption of tractors or combine-harvesters, is a potentially important process that affects labor activities on-farm and in the other sectors in developing countries.

Knowledge gaps remain as to how adoptions of tractors or combine-harvesters differentially affect engagements in agricultural work activities across gender. This study aimed to partly fill this knowledge gap by providing micro-evidence based on household and individual data across 4 countries in SSA and 4 countries in Asia, including several nationally representative panel data.

The results suggest gender-differentiated outcomes. The use of tractors and/or combine harvesters by the household induces relatively more shift from farm activities to non-farm activities by female members than by male members. Such effects generally hold after addressing the potential endogeneity of the use of these machines, as well as gendered-differentiated labor responses to other exogenous shocks. While statistical significance varies, these patterns generally hold consistently across all 8 countries studied. These patterns also seem to hold across different farm sizes, although they are somewhat clearer among smaller farms.

The implications of these gendered effects of mechanization on labor engagements across sectors must be investigated in future studies. A relative shift by women into non-farm activities induced by mechanization can potentially help narrow gender-gap in labor productivity and empowerment, if non-farm activities in fact provide relatively higher returns to female labor. However, if this is an outcome of female labor displacement, women may be simply taking up lower productivity activities even if these activities are in the nonfarm sector. Identifying these underlying mechanisms is critical to better understanding the roles of agricultural mechanization on gendered livelihood outcomes.

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Table 1. Countries and datasets used, as well as units of analyses

	Ethiopia	Ghana	Nigeria	Tanzania	India (VISA)	Nepal	Vietnam	Tajikistan (mostly horticulture)
Level	Individual	Individual	Individual	Individual	Individual	Individual	Individual	Household,
Additional disaggregation								plot, crop
Data	LSMS-ISA	GLSS	LSMS-ISA	LSMS-ISA	VDSA	NLSS	VHLSS	IFPRI
Years	2011 2013 2015	2013 2017	2010/11 2012/13 2015/16 2018/19	2008 2010 2012 2014	2010-2014	1995 2003 2010	2010 2012 2014 2016	2018

Source: Authors.

Table 2. Shares (%) of farm households using tractors and/or combine harvesters

Country	**Years**	**Tractors**[a]	**Combine harvester**
Ethiopia	**2011/12**	N/A	N/A
	2013/14	2.9	N/A
	2015/16	3.2	N/A
Ghana	**2013**	13.7	N/A
	2017	15.0	N/A
Nigeria	**2010/11**	4.3	N/A
	2012/13	2.5	N/A
	2015/16	3.7	N/A
	2018/19	4.2	N/A
Tanzania	**2008**	3.4	N/A
	2010	9.1	N/A
	2012	12.9	N/A
	2014	16.6	N/A
Nepal	**1995**	4.9	N/A
	2003	14.8	N/A
	2010	24.5	N/A
Vietnam	**2010**	53.5	N/A
	2012	54.0	N/A
	2014	51.1	N/A
	2016	52.4	N/A
India[b]	**2010**	43.5	10.1
	2011	56.0	10.6
	2012	55.6	12.5
	2013	56.3	12.6
	2014	64.5	10.9

Source: Authors' computations based on various datasets. N/A = not available.
Note: India figures are not nationally representative.
[a]Figures for Vietnam are based on hiring of agricultural machines.
[b]Figures for India are converted to annual level.

Table 3. Labor work patterns of members 15 years old or above (equivalent to 7 days)

Sectors	Countries	Ethiopia	Ghana	Nigeria	Tanzania	India	Nepal	Vietnam
	Original reference periods	Past 7 days	Past 7 days	Past 7 days	Past 12 months	Past 1 month	Past 12 months	Past 12 months
	Units	hours	hours	days	hours	days	hours	hours
Agriculture	%	40.021	31.237	47.063	69.888	72.419	54.718	59.432
	Median (> 0)	16.750	20.000	3.740	24.000	1.500	29.000	19.178
	Mean (> 0)	26.615	19.697	3.862	25.193	1.873	32.158	22.157
Nonagricultural sectors	%			14.644		22.419		
	Median (> 0)			6.444		6.000		
	Mean (> 0)			5.429		5.362		
All sectors	%	43.815	47.676		76.227		65.519	71.372
	Median (> 0)	24.000	30.000		27.616		37.000	40.274
	Mean (> 0)	27.993	31.857		28.802		37.355	39.060
Sample size		14,850	55,985	29,687	18,160	112,208	6,072	30,930

Source: Authors' computations based on various datasets.

Note: For Ethiopia in which figures are from post-planting activities, we assumed the raw reported figures correspond to 2 months (half of typical production season length of 4 months),and converted them into 7 days equivalent.

Table 4. Descriptive statistics of other exogenous variables (for all adult members 15 or older) (all survey rounds combined)

Variables	Ethiopia	Ghana	Nigeria	Tanzania	India	Nepal	Vietnam
Household size (count)							
0-14 (Female)	1.165	1.274	1.390	1.510	0.659	1.185	0.472
0-14 (Male)	1.223	1.386	1.527	1.460	0.740	1.209	0.510
15 – 60 (Female)	1.633	1.849	1.947	1.848	2.012	1.920	1.531
15 – 60 (Male)	1.705	1.725	1.733	1.805	2.199	1.743	1.556
61 or above (Female)	0.087	0.143	0.173	0.222	0.209	0.212	0.250
61 or above (Male)	0.133	0.155	0.272	0.215	0.251	0.234	0.185
Age of head (years)	47.352	50.329	54.049	50.699	49.714	48.889	50.351
Gender of head (female = 1)	0.222	0.175	0.122	0.199	0.039	0.069	0.157
Education of head (years)	2.563	4.090	5.246	5.415	5.477	1.851	6.002
Household assets (current USD)[c]	PC[a]	634.323	300.081	PC[a]	410.425	139.204	704.262
Agricultural capital (current USD)[c]	PC[a]	7.089	8.571	8.957	53.895	14.175	27.380
Livestock value (current USD)[c]	321.061	135.585	107.814	106.891	656.085	288.954	156.385
Annual rainfall (current, mm)	1044.574	1092.178	1089.202	942.609	696.222	1482.694	1752.504
Farmland owned / externally distributed (ha)[c]	0.442	1.619	0.519	1.416	1.600	0.591	0.403
Financial shocks (yes = 1)	0.206	0.084	0.042	0.052	0.010	0.138	0.268
Wages (adult male) (current USD / day) [c]	0.988	4.014	3.327	2.786	0.443 per hour	1.510	5.580
Wages (adult female) (current USD / day)[c]	0.635	3.077	3.267	N/A	0.268 per hour	1.248	4.876
At least one tractor owners in the sample in the same EA (yes = 1)	0.077	0.066	0.081	0.218	N/A	0.088	0.501[b]
Sample share of tractor owners in the same EA (1 = 100%)	0.009	0.021	0.016	0.003	N/A	0.014	0.303 [b]
Rain (historical average, 1980-2009)	1074.462	1090.119	1184.124	1042.590	N/A	1334.192	1543.047
Soil characteristics							
Texture (% fine)	35.541	6.278	4.880	36.660	N/A	4.372	30.272
Texture (% medium)	63.543	72.860	59.171	55.024	N/A	90.554	65.506
Texture (% coarse)	0.392	20.863	35.659	7.885	N/A	5.074	4.222
Drainage (% of soil with excess drainage)	0.392	1.139	11.743	6.461	N/A	0.219	1.605
Drainage (% of poor drainage)	0.392	1.839	22.385	13.170	N/A	32.140	45.221
Soil alkalinity (pH)	6.466	5.853	6.028	5.950	N/A	5.970	5.552
Organic content (g / kg of soil)	1.145	0.889	0.885	1.467	N/A	2.036	1.453
Salinity (deciSiemens per metre)	0.238	0.114	0.222	0.089	N/A	0.118	0.146
Sodicity (% of soil)	1.508	0.209	3.017	2.451	N/A	1.698	2.829
Terrain ruggedness (index)	216.8023	1.586	27.112	5.444	N/A	240.539	146.651
Individual level							
Age (years)	34.456	36.833	36.323	35.588	34.631	39.730	40.221
Gender (female = 1)	0.514	0.477	0.498	0.519	0.483	0.517	0.511
Education (years completed)	2.587	4.090	4.534	5.125	6.830	2.538	7.078
Delivered a baby in the last 12 months (yes = 1)	N / A	N / A	0.008	0.025	N / A	0.036	0.025
Marital status (married = 1)	0.514	0.485	0.547	0.455	0.724	0.799	0.344
Hospitalized in the last 12 months (yes = 1)	0.152	0.068	0.026	0.055	N / A	0.114	0.211
Biological children (count)	1.386	1.317	1.420	1.240	0.763	1.431	N / A
Spouse lives in the house (yes = 1)	0.477	0.495	0.533	0.512	0.699	0.753	N / A
Sample size	14,850	55,985	29,687	18,160	112,208	6,072	30,930

Source: Authors' computations based on various datasets. N / A = not available.

[a]"PC" denotes the first principal component score computed using the number of asset items owned, as the data for these countries do not allow computation of imputed values of asset items.

[b]For Vietnam, figures are based on major agricultural equipment (including tractors) for which farmers consider depreciation costs.

[c]For these variables, sample medians are reported, while others are sample averages.

Table 5. % of Tajikistan sample households growing different horticulture crops

Vegetables	Potato	Tomato	Fruits
75	29	22	20

Source: Authors.

Table 6. Descriptive statistics of Tajikistan data (N = 1932)

Variables	Unit	Farming operations			
		Land preparation	Planting / weeding	Fertilizer / chemical	Harvesting
Female labor	person-days / plot	14.4	18.6	7.4	29.7
Male labor	person-days / plot	15.1	17.0	11.3	19.9
Female labor (family)	person-days / plot	7.1	9.1	3.7	13.7
Male labor (family)	person-days / plot	7.2	8.4	5.6	9.8
% machine used	%	26.9	25.2	22.2	25.3
Hours machines are used (median among used farms)	Hours per plot	2	5	2	7

Source: Authors.

Table 7. Standardized average partial effects of household mechanization on labor activities by women (relative difference to men) (Model 1)

Sector of activities	Difference in APE	Ethiopia	Ghana	Nigeria	Tanzania	India		Nepal	Vietnam
						Tractor	Combine Harvester		
Agriculture	Extensive margin	-0.313** (0.156)	-0.057 (0.121)	-0.234*** (0.045)	-0.062*** (0.023)	-0.059*** (0.005)	-0.173*** (0.019)	-0.264* (0.145)	-0.379*** (0.076)
	Intensive margin	-0.156** (0.068)	-0.248* (0.148)	-0.255*** (0.079)	-0.062* (0.036)	-0.063*** (0.011)	-0.202*** (0.034)	-0.180 (0.254)	-0.093*** (0.020)
Nonagricultural sector	Extensive margin			0.099** (0.038)		0.022*** (0.007)	-0.043 (0.139)		
	Intensive margin			0.124*** (0.045)		0.019*** (0.007)	0.003 (0.017)		
All sectors	Extensive margin	0.101*** (0.036)	0.006 (0.129)		-0.560 (0.519)			-0.115 (0.177)	0.033 (0.044)
	Intensive margin	-.004 (0.063)	0.209 (0.158)		-0.622 (0.801)			-0.142 (0.234)	0.003 (0.010)
p-value (H_0: Exogeneity)		.013	.232	.001	.152	N/A	N/A	.003	.002
Sample size		14,850	55,985	29,687	18,160	112,208	112,208	6,072	30,930

Source: Authors. *** 1% ** 5% * 10% †15%.

Note: Extensive margin = probability on whether to engage in work in each sector

Intensive margin = how much to engage in work in each sector

APE = Average partial effects.

Model 1 assumes that effects of other covariates do not vary across gender of individuals, which leads to restrictive but more efficient estimates.

These footnotes also apply to Table 10 through Table 15.

Table 8. Standardized average partial effects of household mechanization on labor activities by women (<u>relative difference to men</u>) (<u>Model 2</u>)

Sector of activities	Difference in APE	Ethiopia	Ghana	Nigeria	Tanzania	India		Nepal	Vietnam
						Tractor	Combine Harvester		
Agriculture	Extensive margin	-0.022 (0.056)	-0.005 (0.014)	-0.063* (0.034)	-0.084** (0.037)	-0.011* (0.006)	0.023 (0.016)	-0.012** (0.006)	-0.027† (0.017)
	Intensive margin	-0.036* (0.019)	-0.005 (0.024)	-0.101*** (0.038)	-0.075* (0.044)	-0.029*** (0.011)	0.029 (0.035)	0.062 (0.541)	-0.039 (0.031)
Nonagricultural sector	Extensive margin			0.048 (0.087)		-0.003 (0.008)	0.010 (0.014)		
	Intensive margin			0.011 (0.085)		-0.002 (0.009)	0.008 (0.019)		
All sectors	Extensive margin	0.210 (0.593)	0.076** (0.032)		-0.050 (0.035)			0.045*** (0.010)	0.011*** (0.004)
	Intensive margin	0.326 (0.471)	0.088*** (0.029)		-0.047 (0.053)			-0.008 (0.062)	0.251* (0.131)
p-value (H_0: Exogeneity) - female		.458	.831	.133	.192	N/A	N/A	.393	.435
p-value (H_0: Exogeneity) - male		.761	.467	.766	.493	N/A	N/A	.565	.565
Sample size		14,850	55,985	29,687	18,160	112,208	112,208	6,072	30,930

Source: Authors. *** 1% ** 5% * 10% †15%.

Note: Extensive margin = probability on whether to engage in work in each sector

Intensive margin = how much to engage in work in each sector

APE = Average partial effects.

Model 2 assumes that effects of other covariates also vary across gender of individuals, which leads to less restrictive but less efficient estimates.

These footnotes also apply to Table ***10*** through Table 15.

Table 9. Effects of tractor or combine-harvester use in current survey round on attrition in the following survey round

Variables	Ethiopia	Ghana	Nigeria	Tanzania	India		Nepal	Vietnam
					Tractor	Combine Harvester		
% of attrition between rounds (average)	21.03	Not panel	24.07	10.07	5.09	5.09	39.75	30.50
Effects of machine use on attrition in the following survey round	4.810*** (1.656)	Not panel	0.224 (0.147)	7.837 (16.042)	-0.088** (0.041)	-0.146 (0.110)	0.055 (0.227)	1.674 (12.139)
Effects of machine use on attrition in the following survey round for female respondents	-1.129* (0.637)	Not panel	-0.190* (0.100)	0.837 (1.446)	0.028 (0.024)	0.015 (0.063)	-0.176 (0.113)	-0.619 (0.744)

Source: Authors. *** 1% ** 5% * 10% †15%.

Table 10. Results for <u>agricultural sector</u> in Table 7 among <u>smaller farms</u> below sample median farm size

Difference in APE	Ethiopia	Ghana	Nigeria	Tanzania	India		Nepal	Vietnam
					Tractor	Combine Harvester		
Extensive margin	-0.417 (0.397)	-0.015 (0.188)	-0.658*** (0.105)	-0.120*** (0.044)	-0.036*** (0.006)	-0.105*** (0.037)	0.004 (0.006)	-0.563*** (0.155)
Intensive margin	-1.418* (0.855)	-0.493* (.269)	-0.523*** (0.121)	-0.113*** (0.027)	-0.033*** (0.009)	-0.068 (0.049)	0.072 (1.080)	-0.136*** (0.041)

Source: Authors. *** 1% ** 5% * 10% †15%.

Table 11. Results for <u>agricultural sector</u> in Table 7 among <u>larger farms</u> below sample median farm size

Difference in APE	Ethiopia	Ghana	Nigeria	Tanzania	India		Nepal	Vietnam
					Tractor	Combine Harvester		
Extensive margin	-0.249† (0.166)	0.012 (0.011)	-0.033 (0.077)	-0.021 (0.023)	-0.065*** (0.009)	-0.152*** (0.028)	-0.388*** (0.111)	-0.436*** (0.048)
Intensive margin	-0.990 (0.712)	-0.011 (0.172)	-0.099 (0.082)	-0.031 (0.034)	-0.094*** (0.016)	-0.227*** (0.036)	-0.256† (0.173)	-0.121*** (0.020)

Source: Authors. *** 1% ** 5% * 10% †15%.

Table 12. Results for <u>agricultural sector</u> in Table 8 among <u>smaller farms</u> below sample median farm size

Difference in APE	Ethiopia	Ghana	Nigeria	Tanzania	India: Tractor	India: Combine Harvester	Nepal	Vietnam
Extensive margin	-0.021	-0.006	-0.092*	-0.125*	-0.025***	0.005	-0.048	-0.030
	(0.143)	(0.024)	(0.056)	(0.072)	(0.005)	(0.038)	(0.057)	(0.038)
Intensive margin	0.013	-0.004	-0.133†	-0.094	-0.037***	0.011	-0.118	-0.047
	(0.023)	(0.034)	(0.091)	(0.076)	(0.014)	(0.048)	(0.403)	(0.048)

Source: Authors. *** 1% ** 5% * 10% †15%.

Table 13. Results for <u>agricultural sector</u> in Table 8 among <u>larger farms</u> below sample median farm size

Difference in APE	Ethiopia	Ghana	Nigeria	Tanzania	India: Tractor	India: Combine Harvester	Nepal	Vietnam
Extensive margin	-0.014	0.001	-0.081**	-0.029	0.008	0.025	-0.982***	-0.028
	(0.088)	(0.024)	(0.033)	(0.038)	(0.010)	(0.026)	(0.308)	(0.023)
Intensive margin	0.001	-0.001	-0.135***	-0.034	-0.018***	0.030	0.305	-0.043
	(0.002)	(0.030)	(0.048)	(0.072)	(0.021)	(0.051)	(0.541)	(0.033)

Source: Authors. *** 1% ** 5% * 10% †15%.

Table 14. Standardized average partial effects of household mechanization on labor activities by women (<u>absolute effects</u>) (<u>Model 1</u>)

Sector of activities	Difference in APE	Ethiopia	Ghana	Nigeria	Tanzania	India: Tractor	India: Combine Harvester	Nepal	Vietnam
Agriculture	Extensive margin	-0.581**	0.272	-0.033	-0.027	-0.029***	-0.091**	-0.202	0.072
		(0.280)	(0.480)	(0.032)	(0.022)	(0.004)	(0.017)	(0.438)	(0.272)
	Intensive margin	0.195	0.443	-0.038	-0.254	-0.023***	-0.126***	0.743	-0.153*
		(0.305)	(0.508)	(0.034)	(0.196)	(0.008)	(0.189)	(0.893)	(0.082)
Nonagricultural sector	Extensive margin			0.281**		0.005†	0.001		
				(0.048)		(0.003)	(0.010)		
	Intensive margin			0.335***		0.006*	0.002		
				(0.066)		(0.003)	(0.010)		
All sectors	Extensive margin	-0.048	0.376*		0.005			0.226	0.157
		(.056)	(0.224)		(0.015)			(0.377)	(0.189)
	Intensive margin	-0.006	0.846***		0.556*			0.712	0.019
		(0.067)	(0.195)		(0.314)			(0.656)	(0.037)
p-value (H_0: Exogeneity)		.013	.232	.001	.152	N/A	N/A	.003	.002

Source: Authors. *** 1% ** 5% * 10% †15%.

Note: Extensive margin = probability on whether to engage in work in each sector
Intensive margin = how much to engage in work in each sector

Table 15. Standardized average partial effects of household mechanization on labor activities by women (absolute effects) (Model 2)

Sector of activities	Difference in APE	Ethiopia	Ghana	Nigeria	Tanzania	India: Tractor	India: Combine Harvester	Nepal	Vietnam
Agriculture	Extensive margin	0.053 (0.046)	-0.017[†] (0.011)	-0.055*** (0.032)	-0.019[†] (0.013)	0.015** (0.007)	-0.023* (0.014)	-0.011* (0.006)	0.012 (0.011)
	Intensive margin	0.014 (0.012)	-0.008 (0.016)	-0.091** (0.036)	-0.014 (0.018)	0.046*** (0.009)	-0.039* (0.024)	0.333 (0.645)	0.006 (0.024)
Nonagricultural sector	Extensive margin			0.265*** (0.052)		-0.274 (0.289)	0.012* (0.007)		
	Intensive margin			0.283*** (0.066)		-0.001 (0.003)	0.007 (0.008)		
All sectors	Extensive margin	-0.398 (0.482)	0.882*** (0.222)		-0.004 (0.019)			0.0358 (0.032)	0.865*** (0.242)
	Intensive margin	-0.362 (0.316)	1.318*** (0.265)		0.013 (0.040)			0.006 (0.053)	0.161* (0.083)
p-value (H_0: Exogeneity)		.013	.232	.001	.152	N/A	N/A	.003	.002

Source: Authors. *** 1% ** 5% * 10% [†]15%.

Note: Extensive margin = probability on whether to engage in work in each sector
Intensive margin = how much to engage in work in each sector

Table 16. Estimated associations between machine use and the likelihood of farm labor engagement by gender in Tajikistan (% change (100% = 1))

Variables		Female labor (all)	Male labor (all)	Female labor (family members)	Male labor (family members)	Female labor (all) High WEAI	Male labor (all) High WEAI	Female labor (all) Low WEAI	Male labor (all) Low WEAI
Use machine (yes = 1)		0.180*** (0.056)	0.211*** (0.064)	0.139** (0.057)	0.167*** (0.062)	0.155** (0.075)	0.190** (0.090)	0.177** (0.084)	0.227** (0.094)
Use machine	Land preparation	0.144 (0.093)	0.126 (0.092)	0.113 (0.093)	0.116 (0.086)	0.003 (0.131)	0.179 (0.129)	0.325*** (0.109)	0.098 (0.115)
	Planting / weeding	0.202* (0.108)	0.447*** (0.123)	0.106 (0.109)	0.365*** (0.117)	0.198 (0.169)	0.180 (0.172)	0.132 (0.124)	0.745*** (0.194)
	Fertilizer / chemical	0.152* (0.078)	0.109 (0.109)	0.148* (0.078)	0.078 (0.111)	0.141 (0.107)	0.203 (0.172)	0.133 (0.105)	-0.041 (0.091)
	Harvesting	0.023 (0.111)	0.317*** (0.123)	-0.111 (0.106)	0.190 (0.117)	-0.115 (0.135)	0.319** (0.146)	0.026 (0.182)	0.330 (0.204)
Household fixed effects		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Crop dummy		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Plot dummy		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample size		6344	6344	6344	6344	3172	3172	3172	3172

Source: Authors' estimations. *** 1% ** 5% * 10%

Appendix A: Statistically significant signs of other covariates (with statistical significance at 10%)

Table 17. Ag labor equation: female equation

Variables	Ethiopia		Ghana		Nigeria		Tanzania		India		Nepal		Vietnam	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Household size														
0-14 (Female)			–	–		–	–						+	
0-14 (Male)			–	–	+	+							+	–
15 – 60 (Female)	+	+	–	+		–	–				–			
15 – 60 (Male)			–			+				+				
61 or above (Female)						–	–	–		–	–			
61 or above (Male)			–		+					+		–		–
Age of head				–			+	–	–	–				–
Gender of head	+	+	–	–	+		+		+	+	–		+	
Education of head			–	–		+	–	–				–	–	+
Household assets		–	–	–								–	–	
Agricultural capital			+			–		–	+	+	+		+	+
Livestock value	–		+			+		+		+	+			+
Annual rainfall	–					+	+		–	–	+		+	–
Farmland owned / distributed	+	+			+		+		+			–	+	+
Financial shocks				–						+				+
Wages (adult male)	–	–		–		–		–	–			–		
Wages (adult female)	–			+	+	+						+	–	
Rain (historical average)	+	+	+		+	+		+				+	+	
Soil														
Texture (% medium)	+	+			–	–	+	+						+
Texture (% coarse)	+				–	–		+			+		+	
Drainage (% of excess drainage)					+			–					–	–
Drainage (% of poor drainage)		+	+		+		–				–	+	–	
Soil alkalinity (pH)		–	+			–	–	–					+	
Organic content		+	–		–		+						+	–
Salinity	–	+					+				+			
Sodicity	+	+	–				–							+
Terrain ruggedness	+	+	–			+	+	+			+	+		+
Individual level variables														
Age		–	+	+	+	+	+	+	+	+	–	–	+	–
Education (years completed)	–	–				–		–	–	–	–	–	–	–
Delivered a baby								+			–	–		
Marital status								+		+			+	+
Hospitalized in the last 12 months				–			–	–			–			–
Biological children			+	+	–		+			+	+			
Spouse lives in the house		+	+	+			+		+			+		
Community-level shock	Yes		Yes		Yes		Yes		Yes		Yes		Yes	
CRE terms	Yes		Yes		Yes		Yes		Yes		Yes		Yes	
Year / survey round dummy	Yes		Yes		Yes		Yes		Yes		Yes		Yes	

Source: Authors.
A = IV-Probit equation on whether to engage in work activities in the agricultural sector.
B = Truncated regression on how much to engage in work activities in the agricultural sector.

Table 18. Ag labor equation: male equation

Variables	Ethiopia		Ghana		Nigeria		Tanzania		India		Nepal		Vietnam	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Household size														
0-14 (Female)	+			–		–					–			
0-14 (Male)						+		–	–	+				–
15 – 60 (Female)		+	–	+		–		+					–	+
15 – 60 (Male)			–	+	–		–	–		+			–	–
61 or above (Female)			–	–			–			–		–		
61 or above (Male)		+									–	–	–	–
Age of head	–			–	+	–			–	–	–			
Gender of head	–	+	+						+			+	–	–
Education of head	–		–	–	–	+	–	–		–		–	–	
Household assets			–	–								–	–	
Agricultural capital	–		+			–	+	–						+
Livestock value	–		+	–				+	+	+	+	+		
Annual rainfall	+	+				+	+	–		+		+		–
Farmland owned / distributed	+	+			+	+							+	+
Financial shocks				–		+	–					+		+
Wages (adult male)	+			+		–		–		–		–		
Wages (adult female)				–	+	+							–	
Rain (historical average)		+	+	–		+		+						
Soil														
Texture (% medium)														
Texture (% coarse)	+	+					+				+	+		+
Drainage (% of excess drainage)	+	+		–			+				+	+		–
Drainage (% of poor drainage)				–		–	–						+	
Soil alkalinity (pH)		+	+	+			–					–	–	
Organic content				–		–	–	–			+	+	+	
Salinity			–	–	–			–					+	–
Sodicity	–	–		–			+							+
Texture (% medium)			–	+	–	–	–				–	–	+	+
Terrain ruggedness	+	+	–	+	–	+	+	+			+		+	+
Individual level variables														
Age	–		+	+		+	–		+	+	+	–	+	–
Gender														
Education		–			–	–		–	–	+	–	–	–	–
Delivered a baby														
Marital status			+	+						–	+		+	+
Hospitalized in the last 12 months		+		–				+					–	
Biological children			+	+			+				+	+		
Spouse lives in the house		+	+	+			+			+				
Community-level shock	Yes		Yes		Yes		Yes		Yes		Yes		Yes	
CRE terms	Yes		No		Yes		Yes		Yes		Yes		Yes	
Year / survey round dummy	Yes		Yes		Yes		Yes		Yes		Yes		Yes	

Source: Authors.
A = IV-Probit equation on whether to engage in work activities in the agricultural sector.
B = Truncated regression on how much to engage in work activities in the agricultural sector.

Appendix B: Literature review

Studies concerning the roles of agricultural mechanization and gender outcomes in agriculture generally focus on (1) how gender-differences in outcomes may arise due to gender differences in pre-mechanization conditions; and (2) how mechanization is associated with different patterns of changes in female labor use in agriculture and other general activities. In discussing (2), studies often focus on the quantitative aspects of such associations (i.e., whether mechanization is associated with less or greater female labor use) and qualitative aspects (i.e., changes in quality of female labor, including empowerment).

B.1. Effects of mechanization inherently vary across gender due to gender-differences in pre-mechanization condition

The literature has long documented the gender differences in various aspects of rural agricultural environments in developing countries (e.g., Doss, 2001; Doss & Quisumbing 2020). Here we highlight briefly the aspects documented in the literature, which are relevant to and have implications on the relationship between agricultural mechanization and women's labor use in the agricultural sector.

Limited access to draft or mechanical power by women or female-headed households, relative to men or male-headed households, is one of the widely reported factors that can lead to gendered outcomes of mechanization (FAO 2011). Women or female-headed households generally own fewer agricultural equipment or draft animals in developing countries.[3] Even when animal power is used by women smallholders, they tend to own fewer draught animals because they are a relatively large capital investment (Murray et al. 2016). Earlier attempts in the 1970s and 80s generally failed to ensure that a representative number of women had access to plows (Gass & Biggs 1993). Developing animal-powered systems tailored to the needs of women (e.g., using donkeys in certain societies) has been considered necessary for directly benefiting women through draft powers (Pryor 1993 p.88). Similarly, Murray et al. (2016) reported in detail how women smallholders in the Nkhamenya and Kabudula Areas of Malawi have limited access to mechanized rural transport.[4] Other studies argue that lower educational levels and technical skills of women also prevent them from using farm machinery (Fischer et al., 2018). However, relatively limited access or use by female-headed households is by no means a universal phenomenon. In Ghana, using three rounds of nationally representative surveys (GLSS 4 – 6), Lambrecht et al. (2018) shows that female-headed households have often been actually more likely to rent in both animals and agricultural equipment than male-headed households, albeit variations over time. Female-headed households, who tend to be less endowed with male labor, may sometimes have higher willingness-to-pay for renting in draft or machine powers, and if informal credit system is reasonably efficient or other barriers are less constraining, they may end up renting in more machines, although, aforementioned examples show that experiences in Ghana may still be somewhat exceptional.

[3] Certain types of female-headed households face even greater constraints in access to mechanical technologies. In Kenya, for example, households headed by single, divorced, or widowed women are the least likely to use animal traction, while female-headed households with a husband living elsewhere can better access animal traction through husband's name and social network, as well as remittance incomes (Wanjiku et al., 2007).

[4] In some African countries like Ghana, so-called "market women" (food crop retailers who are often female) provide farmers with finance to pay for the plowing services in exchange for receiving harvest from them (e.g., Kansanga 2017), evidence is scarce regarding whether these market women significantly support female farmers more than male farmers to access mechanization service.

Cultural and religious factors also lead to gender differences in mechanization. For example, in Hausa female seclusion custom in Northern Nigeria, traditionally, most field agricultural work was done by men, with very little involvement of women (though women engaged in much food processing labor) (Goldman & Smith 1995). Other studies also argue that, by social norms, mechanized tasks may often be regarded as inappropriate for women (Croppenstedt et al., 2013; van Eerdewijk & Danielsen, 2015). In many cultures, plowing with draught animals tends to be considered a male task (Doss, 2001; Murray et al., 2016) or considered taboo in the Tigray region in Ethiopia (Pender et al., 2006). In some societies like Nepal, women have long been banned from using the plow in general, where females using traditional plows for tillage could be highly criticized for low productivity (Paudel et al. 2019).[5]

Past studies also described commonly observed gender-based differences in the access to productive land suitable for cereal production. For example, in parts of Ghana, groundnuts still continue to be the most popular crop among women because they often only get access to less fertile land, which has been passed on to them by men when it is no longer productive for cereal production (Amanor & Idris 2021). This is likely to lead to differential demand for mechanization because certain cereals tend to be mechanized earlier than crops like groundnuts (Takeshima et al., 2013; Alesina et al., 2013). Similarly, in areas with early stages of farming system evolution, where clearing of forest is an important operation before land preparation, female-headed households tend to remain with cropping systems that require less tree-cutting (for example, northern Zambia studied by Holden (2001)). In northern Zambia, female-headed households are generally less endowed with male labor who would typically be engaged in climbing trees and cutting branches. Female-headed households, therefore, resort more to cassava production that is less labor-intensive and requires less tree-cutting than other crops like maize that is more labor-intensive. Recent studies also support the evidence that female-headed households are also quite common in ESA and tend to be labor-constrained (Baudron et al., 2015). In such a setting, the gender effects of mechanization on labor use are ambiguous and can depend on the level of farming system evolution (level of the availability of tree-cleared land for which draught power or machine powers can be readily introduced) and/or changes in cropping systems with inherently different levels of labor use requirements, and thus different demand for mechanization.

Other studies attributed gender differences in mechanization outcomes to gender differentiations in field activities at the pre-mechanization stage. As part of the process of developing agricultural mechanization strategy, Clarke (1998) emphasizes the importance of information on the initial breakdown of the major labor inputs on the basis of whether they are provided predominantly by male or female (or child) labor and whether the labor source is the farm family, exchange labor, or hired labor. During the early days in Japan, land preparation was the heaviest task of the agricultural year and required male labor, while tasks such as weeding

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[5]The gender bias in agricultural machine use is not necessarily limited to developing countries but also found in developed countries, and yet the direction of bias also varies across countries. In Norway, tractors are often perceived to be used more by males and advertised and promoted to male farmers (e.g., Brandth 1995). In contrast, in Japan and the Republic of Korea, by the late 1980s, farm machinery had been frequently operated by female workers, and machinery training courses were given to female operators (Rijk 1989 p.27). Korea had also invested in providing training programs at provincial levels targeting rural youth and women in operational techniques and maintenance on power tillers and small machinery (IRRI 1978 p.141). For certain farm machines like tractors. More studies are therefore needed to examine under what conditions such gender bias in the ownership and use can and should be addressed.

were less restricted time-frame and could be done by women (Francks 1996).[6] Because mechanization of cultivation in the field centered on developing a powered tilling device for land preparation (Francks 1996), mechanization initially helped reducing male farm labor more than female farm labor. Similarly, in Ethiopia, tilling and harvesting activities are more frequently undertaken by men than by women, whereas women have a relatively larger role in weeding (Berhane et al. 2020). In these conditions, since tilling and harvesting activities which are more power-intensive tend to be mechanized before control-intensive activities like weeding, men tend to directly benefit from mechanization before women do.

Alesina et al. (2013) provides related historical perspectives between gender and cropping systems. They find that female tends to be less actively involved in on-farm activities where the plow is used for land preparation rather than a more traditional farming system with shifting cultivation in which land preparation is done by hoes because the use of plow requires more significant upper body strength, grip strength, and bursts of power needed to pull the plow or control the animal that pulls it, for which men have more advantage than women. Alesina et al. (2013) argues that some of the plow-use propensity is associated with the cropping system due to the differences across crops in the suitability of plow use as opposed to more traditional shifting cultivation and use of hoes. In such circumstances, the effect of the further shift to mechanical powers like tractors is expected to have gender-differentiated effects on labor use, albeit with unclear, ambiguous effects across gender.

Broader agroecological conditions are also found to be associated with gender differences in mechanization demand. For example, Alsan (2015) finds that the intensity of female participation in agriculture is significantly higher in areas where TseTse fly is more likely to be present, possibly because, in those areas, the use of plow with draft power is less common. Since the use of draft power often positively affects the transition to machine powers like tractors (Diao et al. 2020), and the presence of TseTse fly can also affect the gendered effects of mechanization on-farm labor use.

Recent studies based on detailed household-level surveys in Africa, however, suggest that women's shares of farm labor provided are generally not related to cropping systems or type of farming activities (Palacios-Lopez et al., 2017). They show that women's shares of farm labor are instead positively associated with greater farm ownership share by women or higher education status of women, suggesting that land tenure rights and human capital of women may also be some other factors that can give rise to gendered outcomes of technologies including mechanization.

B.2. Mechanization and changes in women's labor use

Several studies focus more directly on the directions of associations between mechanization and female labor use. Broadly speaking, these studies show either (1) negative associations with female farm labor use or (2) positive associations in female farm labor use, as well as (3) associations with changing nature of female labor.

[6]Importantly, while this was the situation in early Japan, the situations in other countries may be different. For example, more recent studies argue that planting and weeding operations can be time-sensitive, which need to be completed during a narrow window of time in the crop cycle (Pingali 2007, p.2790).

B.2.1. Studies showing that mechanization is associated with reduced female farm labor use

Some recent studies provide cross-country level evidence that, agricultural mechanization generally reduces vulnerable employment for women and children (Zhou & Ma 2021). Applying panel fractional response model to cross-country panel data from the World Bank, Zhou & Ma (2021) shows that, between 1991 and 2009, the growth in the number of agricultural machinery and tractors had significantly reduced the share of vulnerable female employment in total female employment in 130 countries around the world.

Several studies show some indicative evidence that mechanization of land preparation activities is associated with reduced female farm labor use. Kumar et al. (2018) show that a significant drop in land preparation and sowing cost in India due to the adoption of power tillers that replaced bullocks and manual laborers, including women. In Tanzania, Mrema et al. (2020) show that 2WTs have reduced the time spent by families on their paddy fields during the cropping season, mean-ing that women can return from the farm early and work on household chores or go to the market. Even when mechanization is limited to land preparation activities and not adopted for the subsequent activities, women sometimes perceive the overall reduction in their drudgery to be significant. For example, in a recent case study in Eastern-Southern Africa (Baudron et al. 2019), women regard that more timely and appropriate land preparation done by machines rather than manual labor clears the way for early crop establishment and enables better (and cheaper) planting, weed control, and timeliness in other field operations.

A few other studies provide indirect evidence on the effects of mechanization other than field activities. For example, Lazaro et al. (1999) showed indicative evidence that in Tanzania, mechanized forage chopping reduced women's labor time associated with forage chopping as a result of both mechanizations of cutting and forage collection, although more recent studies shed light on deeper implications on gender dynamics (e.g., Fischer et al. 2018).

Concerns over reduced female employment

While the above studies interpreted the reduced female labor use in farming, associated with mechanization, as a positive outcome, some other studies have been more concerned about reduced "employment" of women.

In the 1970s and 1980s, relatively wider concerns were shared in the literature regarding how mechanization would displace female labor (e.g., Dauber & Cain, 1981; Gass et al., 1997). Similarly, in the 1970s and early 1980s, the spread of mechanical rice milling was considered as displacing women workers, including Indonesia (Timmer 1974, Collier 1974) and Bangladesh (Binswanger 1986). Mechanized rice mills were also considered to have contributed to redistribution of income from poor rural women to rural male entrepreneurs, with significant deterioration of female welfare (Greeley 1989; Gass et al. 1997). This was considered to have had negative effects on the overall demand for women workers because women workers in these countries during that time often had few alternative employment options due to social customs, such as social restrictions (purdah) on work outside the household (Binswanger 1986; IRRI 1986 p.91). In fact, although qualitatively, it was found during the 1980s that real wages for women had fallen in areas where rice mills were introduced in Bangladesh (IRRI 1986 p.93). Pingali (2007 p.2798) also emphasizes that in Bangladesh, such negative effects were particularly common for women from landless families who relied on traditional milling as primary sources of wage incomes. However, Pingali 2007 (, p.2798) also argues that, under certain conditions, women may still appreciate increased leisure time.

Similar interpretation continues to be made in modern-day India: Mehrotra & Parida (2017) argues that, overall, the growing mechanization in agriculture has been associated with reduced overall female employment due to reduced female employment in farming and insufficient replacement by employment in the non-farm sector. Mehrotra & Parida (2017), however, also argues that increased female education could reverse the trend and lead to a sufficient increase in female employment in the non-farm sector.[7]

B.2.2. Studies showing that mechanization is associated with relatively greater female farm labor use

There are also studies showing some evidence that mechanization is rather associated with greater use of female farm labor. Some studies argue that due to the sequential nature of mechanization adoption, mechanization of one activity could increase the overall workload for subsequent activities that do not get mechanized at the same time. Gass et al. (1997) cite a study in India by Mukhopadhyay (1989), which links the introduction of mechanized plowing to an increase in cultivable acreage and hence in other arduous cultivation tasks (manuring, weeding, harvesting, threshing, pest control) performed by women. In Nepal, tractor adoption growth between 1995 and 2010 was often found to increase rather than decrease the overall use of labor provided by adult female household members and/or hired labor (Takeshima & Justice 2020, p.309). This was found to be partly associated with a relative decrease in off-farm income earnings for resource-poor smallholders, partly as a result of the reduced time spent by adult female household members in off-farm activities (Takeshima & Justice 2020 Table 9.16).

Similar examples are described for other types of mechanization, including the mechanization of fodder chopping in Tanzania (Fischer et al., 2018). Fischer et al. (2018) argues that chopped fodder is often used in combination with stall-feeding of the animals, which, according to Bain et al. (2018), is often carried out by women can still be labor-intensive compared to grazing. Fischer et al. (2018) also cited a study in Uganda (Kiyimba 2009) where women had little control over time saved from the introduction of mechanized forage choppers and rather increased their time working on husbands' fields.

Self & Grabowski (2009), in estimating the effects of agricultural technologies on child labor in India, finds that, while mechanical technologies reduced male child labor significantly, they did not find such effects on female child labor. However, Self & Grabowski (2009) argued that this was partly because female children had been less extensively involved in farming than male children prior to mechanization, suggesting that the effects on female child labor may be more substantial in societies where their involvement in farming is more extensive.

Where access to mechanization is unequal between men and women, mechanization may not significantly reduce (or may even increase) more primitive tasks associated with higher drudgery for women. Such outcomes are often possible because women tend to have less access to draught power or machines in developing countries.

[7] However, the opposite has been observed in countries like the Philippines. For example, in Central Luzon, females were considered to be relatively suited to nonfarm activities, and, consistently, households with a higher share of female members were more likely to shift to non-farm income-earning activities (Quisumbing et al., 2004; Takahashi & Otsuka 2009). In such a setting, while the direct effects of mechanization on female labor use in farming are ambiguous, the effects on overall female employment are likely to be generally positive.

B.2.3. Studies emphasizing the changes in the quality of female labor and empowerment

A significant number of studies focus more on the narratives that, while mechanization may sometimes increase female labor use in farming, it may be associated with greater empowerment or economic livelihood rather than a mere increase in drudgery.[8] As is described elsewhere, the contribution of mechanization to women depends on the equality of access to mechanization (Doss 2001; Murray et al. 2016). Mechanization, if made appropriately available to women, can often empower women and raise their labor productivity. If women can access appropriate mechanization technologies, it is more likely to reduce labor work with greater drudgery.

Successful downsizing of machines often contributes to expanding women's scope of farming tasks, including in areas where raising women's labor productivity has become critical due to accelerated male outmigration and intensifying male labor shortage. For example, the spread of smaller and lighter weight mini-tillers (smaller than two-wheel tractors) in recent years in Nepal have expanded scopes for women, including elderly women, to take up the roles of plowing (Justice & Biggs 2020). Mini-tillers can be easily transported from one plot to another and are easy for women to use thanks to their small size and lightweight (Paudel et al. 2019). Mini-tillers are also cheaper, fit within the small-loan credit limits often faced by women's microfinance groups (Biggs & Justice 2015). Similarly, in SSA, where tractors available are mostly 4wt and larger, scholars argue that 2WT technologies have the potential to benefit women (Kahan et al., 2018). In China, where mechanization with smaller machines has spread widely, female household heads are more likely to use farm machines relative to male household heads (Ma et al. 2018). Ma et al. (2018) argue that this is partly due to limited off-farm employment availability for a female who resorts to farming intensification, including the use of mechanization.[9]

Amanor & Iddrisu (2021) argues that the recent rise of tractor plowing in Ghana has partly enabled individual farmers to establish farms without access to a large labor force. They argue that this has led to the relative decline of the authority of the lineage elder who used to mobilize farm labor force among extended family, and empowered the younger males and women instead who have better means to run individual farms relying on mechanical power.[10]

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[8]Similar effects of increased female labor use as the result of mechanization are also reported in modern-day developed countries. For example, in the US, the improved mechanization process of vegetable harvesting eliminated the need for workers to carry heavy loads of vegetables to trucks, and made the work accessible to more women and older workers, and less likely to cause back injuries (Huffman 2009).

[9]However, Ma et al. (2018) also acknowledge that their findings of the significant spread of smaller machines among women and female-headed households may be unique to China, where mechanization use might have spread more widely than some other Asian and African countries. For example, in Bangladesh, male-headed households are still more likely than female-headed households to use farm machines such as irrigation pumps, threshers, and power tillers (Mottaleb et al. 2016; Ma et al. 2018), including the use of machines through custom-hiring services (Ahmed & Takeshima 2020 p.246). In Nepal, male-headed households are more likely to own mini-tillers than female-headed households, despite the relative attractiveness of mini-tillers described earlier (Paudel et al. 2020b). In Tanzania, male household heads were more likely than women to own a 2WT due to better access to technical information from extension agents (Mrema et al. 2020).

[10]Importantly, Amanor & Iddrisu (2021) cautions that the extent of empowerment of women, including younger women through mechanization, can still be limited if access to plowing services is socially stratified in which women, especially younger smallholder farmers, are less favored to receive services, which is often the case in Ghana and elsewhere.

Similarly, small-scale rice flour processing mills introduced in Bangladesh have been found to be associated with greater empowerment and disposable incomes for females (e.g., Paris et al., 2011). The interventions that focused on applying draught powers to grain milling in the 80s had positive effects (though anecdotal) on reducing women's drudgery in pounding and/or traveling to the otherwise distant power mills, including prototype donkey-pulled mills in Senegal where women could bring their own donkeys or horses and complete griding of grains (Hoffman et al. 1989). In early Asia, when mechanical threshers reduced the arduousness of post-production tasks and lightened the intensity of tasks, the use of women and children's labor for threshing work increased to substitute for men (Ebron 1984; Pingali 2007). Pingali (2007) argues that, in these cases, the overall effects of mechanical threshers on household-level income (and indirectly for women) can be significant if released male labor be absorbed by off-farm employment. Vemireddy & Choudhary (2021) also cite Gulati et al. (2019) as indirect evidence that mechanical rice planting in India has been associated with the increased involvement of women in the decision-making process. In Bangladesh, where mechanical reaper-harvesters service for rice and wheat is emerging as an important business, women are more actively involved and benefit from such growth through managing and sometimes owning machines, contrary to the conventional wisdom that women are rather excluded (Theis et al. 2019).

Theis et al. (2019) also highlights in their study of mechanical reapers in Bangladesh that, as the use of mechanical reapers increases, women switch from serving wage laborers and meeting all their needs by cooking and serving them during harvest to supervising and assisting a machine operator. Similar effects are also observed in Eastern Africa, where mechanized land preparation would reduce the need for women to travel frequently to serve men with food in the fields (Baudron et al., 2019).

The spread of agricultural mechanization can also affect female labor use through the change in their child-birth and child-caring requirements. In Nepal, Bhandari & Ghimire (2013) provided scarce evidence using longitudinal panel data. They find empirically that the use of modern farm technologies, particularly the use of a tractor and other modern farm implements, reduce subsequent births in farm households because of the reduced demand for farm labor (including children) (Bhandari & Ghimire 2013). However, the implications of these effects can be more complex if the reduced demand for farm labor for girls also leads to underinvestment in girls. Carranza (2014) is one notable study that highlights this point; in India, the adoption of deep tillage (which often involves mechanization) is found to reduce the demand for tasks traditionally performed by women and girls, in areas where such deep tillage is a more suitable way for intensification given the soil textures. Cazzanza (2014) argues that the reduced economic value of children also tends to be disproportionately associated with girls than boys, significantly enough to contribute to deficit and underinvestment in female children.

Despite the potential for female empowerment, Fischer et al. (2018), as well as World Bank (2008) and van Eerdewijk & Danielsen (2015) reemphasize that mechanization also often entails a renegotiation of labor with unpredictable outcomes, in which women may mechanize their own tasks or transgress into male domains, or female jobs may be turned into male enterprises as soon as they become mechanized and profitable.

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