Impacts of Mechanization on Agricultural Production and Intra-Household Labor Supply

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Abstract

Despite the potential for mechanization to boost agricultural productivity and reduce poverty, evidence on its impacts remains scarce—particularly in post-conflict settings, where farmers seeking to mechanize must overcome credit constraints stemming from equipment and collateral loss. We study the impacts of a mechanization intervention in post-conflict Côte d'Ivoire using the random allocation of matching grants for traction oxen among 2,580 farmers. We find positive impacts on households' agricultural production during the agricultural season overlapping with oxen delivery, and increases in land holdings and input use in the subsequent season. The intervention affected household members in different ways, with wives and daughters substantially reducing their work on the farm. In districts with more restrictive gender norms around handling oxen, introducing traction oxen resulted in women shifting to off-farm work.

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1 Introduction

Most rural households in lower-income countries rely on farming as their primary source of income, and on labor as the primary input to farming. Mechanization, including animal traction, has the potential to boost labor productivity, raise agricultural incomes, and facilitate the structural transformation of developing country economies. Previous research has identified which farming conditions—such as farming intensity, cropping system, and soil type—favor the adoption of animal traction. Yet observational studies on its potential benefits yield nuanced results, and there is a dearth of rigorous evidence on impacts. In addition to knowledge gaps around whether lack of access to credit is a binding constraint to adopting mechanization, and how mechanization economically affects agricultural households, we also know little about whether (and why) technology adoption has differential impacts within the household. In this paper, we show that labor-saving technology can have large economic benefits, but that examining intra-household impacts—including gendered impacts—is crucial to understanding longer-term ramifications.

In a two-year randomized phase-in trial conducted with 2,580 cotton farmers in rural Côte d'Ivoire, we test the impacts of a matching grant designed to ease credit constraints—exacerbated by recent civil wars—limiting farmer access to oxen by covering 50% of the cost and delivery of a pair of oxen. We find high take-up and use of the oxen, and positive impacts on agricultural production. In the first agricultural season, producers increased their cotton production and cotton revenues by 7%, despite only being notified about the program and receiving the oxen after planting decisions were made. Second season agricultural outcomes show that households increased their land area under cultivation by 6%, while also increasing spending on complementary non-labor inputs by about 15%. Moreover, household member time spent on plots decreased by about 1.5 hours per hectare or 7%, driven by decreased time spent on household plots by women and girls. We also find suggestive evidence of downstream impact on girls' health, but no robust evidence of impacts

on education. We show that, under conservative assumptions, investing in oxen is profitable, with the large estimated returns validating binding credit constraints to farmers investing in livestock. These results represent a lower-bound of the impacts of oxen, as the phase-in trial resulted in a non-trivial share of control households receiving the oxen in advance of the endline survey; the implied treatment-on-the-treated impacts, while large, are generally consistent with cross-sectional comparisons of hand-cultivated and traction-animal cultivated farms.

Why do time use impacts differ systematically by gender? One answer comes from community gender norms. Internationally, gendered social norms and assumptions have discouraged—or outright excluded—women from jobs that are perceived as relatively dangerous due to 'benevolent sexism' (Cuddy et al., 2015; Glick et al., 2000; Padavic and Reskin, 2002). In Côte d'Ivoire, for example, the employment law explicitly states that women cannot engage in activities 'beyond their strength' and should be assigned 'suitable jobs' (Code du Travail, Art. 23.13; Décret No. 2018-272). While employment law is not binding in informal agriculture, it is indicative of this pervasive custom. Within the agricultural space, tending to traction oxen is considered risky due to their large size and potentially erratic behavior (Alesina, Giuliano and Nunn, 2013) and women are generally considered less suited for the task—though there is substantial heterogeneity in adherence to this norm. Nationally-representative data shows that in districts where this norm is stronger (i.e., districts with relatively lower female involvement in oxen tasks), matrilineal ethnic groups are less prevalent and norms are more restrictive. In these communities, women shift to working off-farm once oxen are introduced. These empirical patterns align with predictions from our simple model of time allocation under social prescriptions.

Our paper makes three main contributions. First, we provide the first experimental evidence on the effects of agricultural mechanization in Sub-Saharan Africa—building on a rich literature that has examined the adoption and use of labor-saving agricultural technology in the region (Pingali, 2007; Owolabi et al., 2012; Guthiga, Karugia and Nyikal, 2007; Williams, 1997)—and the first ex-

perimental evidence on the impacts of animal traction as a whole. The existing non-experimental research lays out several key stylized facts about animal-traction mechanization, including minimal yield gains, an increase in land under cultivation and devotion of the expanded land to market crops, as well as a reduction in labor required during the land-preparation period (Pingali et al., 1987). More recently, studies of rice production in Côte d'Ivoire highlight how mechanizing land preparation can contribute to agricultural intensification, thereby raising productivity (Mano, Takahashi and Otsuka, 2020)—especially when mechanized land preparation is combined with increased use of agro-chemicals (Aihounton and Christiaensen, 2023). Even beyond Sub-Saharan Africa, there is very limited experimental evidence on the impact of mechanization. To our knowledge, only one other study, which took place in Karnataka, India, provides evidence of the causal impact of mechanization, demonstrating that subsidized access to rental equipment markets lowered labor demand across all farming stages, leading to an increase in non-agricultural income (Caunedo and Kala, 2021). In addition to the new context, our focus on matching grants eases potential frictions in rental markets, including equipment supply constraints for time-sensitive agricultural tasks.

Our second contribution is to examine how the time-use impacts of mechanization vary within the household, thereby expanding the existing literature on the intra-household consequences of technology adoption (Wodon and Blackden, 2006; Bryceson, 2019; Doss, 2013; Theis et al., 2018). This analysis is particularly important in contexts where the social norm discourages women's use of a particular technology—in our case, animal-traction mechanization (Fisher et al., 2017; Starkey, 1995; Wanjiku et al., 2007). Modern agricultural technologies can affect women's farm labor negatively (Afridi, Bishnu and Mahajan, 2020), facilitating shifts to new tasks or activities, or positively (Wilson, 2003; Bassett, 1988), depending on the context and the extent to which the technologies complement gender-specific tasks. Importantly, these shifts have the potential to drive structural transformation if they free up women's time for other market-based activities (Goldin and Sokoloff, 1984; Dinkelman and Ngai, 2022). This tension highlights that 'one norm does not fit all': sexist beliefs or practices limiting women's engagement in one economic domain

can spur women's engagement in other economic domains.

Lastly, our study also speaks to the literature on child labor, health, and education in rural economies. The education impacts of expanding child labor–intensive crops (such as cotton) will depend on two competing effects: On the one hand, growing these crops could increase the opportunity cost of children's time leading households to pull them from school while, on the other, higher incomes from the crops could lead households to increase their demand for education (Levy, 1985; Baker, 2015; Kazianga and Makamu, 2017; Cogneau and Jedwab, 2012). We build on the limited existing literature by examining the impacts of crop expansion driven by mechanization, which can also replace tasks done by young children, showing heterogeneous impacts by gender, while also demonstrating the downstream health benefits for children from decreasing on-farm work.

This paper proceeds as follows. In Section 2 we present a simple model of the links between gender norms and labor supply, which generates testable predictions for our empirical analysis. Section 3 provides information on the local context as well as the experimental design. We present the experimental results in Section 4, while Section 5 discusses the implication of our results and concludes.

2 Conceptual Framework: Rural Households Operating Under Social Prescriptions

Building on Akerlof and Kranton (2000) and Kevane and Wydick (2001), we develop a simple model to illustrate the links between traction power, gendered social prescriptions, and household members' labor supply.

In our simple framework, farm households maximize utility subject to income, production technology, time constraints, and social prescriptions. Men own farm capital K, including traction oxen, and female household members divide T units of work time between farm work, T_f, off-farm

work T_o, and domestic work T_d. The household has a farm production function $A(K,T_f)$, domestic production function $H(K,T_d)$, while off-farm production, T_o, is valued by the market at price p. Household utility also depends on whether household members' time use corresponds to social prescriptions, P. In our simple model, P represents the social prescription that women should not undertake risky work (specifically, tending to oxen). This yields an aggregate utility function:

$$A(K,T_f)+H(K,T_d)+p_o\cdot T_o+\overline{P}-\sum(\frac{1}{2}a_j\cdot T_j\cdot(K-\overline{K_j})^2) \tag{1}$$

where $j=f,o,d$ denotes the set of activities available to the woman. The benefit from her behavior conforming to social prescriptions is given by $\overline{P}$. The parameter a_j represents the intensity of social penalties for violating norms regarding risky work in each of the different activities. $\overline{K_j}$ is the mean intensity of oxen use in activity j for women in a particular community. Social penalties depend on the intensity parameter a_j, whether the woman performs relatively more tasks with oxen than women in her community (i.e., $K>\overline{K_j}$) and how much time she spends on these tasks (T_j). For simplicity and given our setting, we focus on social penalties related to farm work, setting $a_o=a_d=0$.[1]

This framework yields several predictions about women's time use and community social norms. In the absence of social prescriptions and associated penalties, an infusion of farm capital will generally increase returns to on-farm work and boost on-farm labor relative to off-farm work. However, in communities with stronger social prescriptions regarding women handling traction oxen, the social penalty from defying norms by working on newly mechanized farms exceeds the returns to on-farm labor and women will decrease their time on the farm and increase their off-farm work.

[1] Appendix A provides additional model details and the derivation of various comparative static results.

3 Experimental Design and Implementation

3.1 Experimental design

We conducted a randomized evaluation of a matching grant that subsidized the purchase of traction oxen for cotton farmers in northern Côte d'Ivoire.[2] The delivery and subsidy of traction material was implemented under the World Bank's Agricultural Support Program, which partnered with Intercoton—Côte d'Ivoire's cotton value-chain interprofessional organization—and its constituent cotton societies for this activity. The provision of equipment and oxen was subsidized with a non-repayable matching grant of 50% and a loan from cotton societies of 50% repayable in two annual installments by the beneficiary producer. This mechanism sought to help farmers overcome credit and collateral constraints that had become acute in the years following the almost decade-long conflict that ended in 2011, and the two oxen—which together had a market value of FCFA 480,000 (US$ 916) at the time of delivery—represented the bulk of the value of the matching grant. Beyond the treatment's monetary value, the oxen also represented a large productive asset transfer. Previous studies have found that an ox provides farm labor equivalent to five to eight men, and that traction oxen are at least twice as powerful as smaller bovines (Smil, 2004; Starkey and Faye, 1990).

Participant local cotton societies compiled the farmer sampling frame using their member lists and a mix of objective criteria (such as being married, having been a member of a cotton society for at least 3 years, and belonging to a single cotton society) and more subjective criteria determined by cotton society staff (being credit-worthy, trust-worthy, and able to increase their cotton farmland). Few farmers in the sampling frame owned traction oxen before the intervention, although many

[2] In practice, there are small variations in treatment across farmers. Households assigned to treatment could request either one or two oxen: while 96% of farmers requested two oxen, 4% instead requested one ox. Moreover, 7% of farmers in the treatment group requested and received a multicultivator, 6.4% a seed drill, 5.1% a plow, and less than 3.5% received tillers or carts. Appendix Table B1 provides a full list, and shows that households own an average of 2 pieces of equipment, irrespective of their treatment status.

owned other types of farm equipment (Appendix Table B1).

We used a randomized phase-in approach for our experiment: from an initial sample frame of 2,580 eligible farmers, we randomly assigned 1,273 producers to receive the oxen matching grant offer in the fall of 2016 (treatment group) and 1,307 to receive the offer starting in April 2018 (control group).[3] We measure impacts using detailed household surveys conducted in July and August 2018.[4]

As cotton cultivation is a key outcome in this experiment, Figure 1 presents the timing of oxen distribution (as reported by study participants) together with the key activities of Côte d'Ivoire's 2017 and 2018 cotton seasons. Delays compiling the lists of eligible farmers and procuring the oxen pushed the delivery of the oxen to April-November 2017, meaning that most treatment households received the oxen after the 2017 land-preparation and planting activities but before harvest. Given the project communication and oxen distribution process, it is unlikely that farmers would have been able to anticipate when they would receive their oxen, and thus likely could not have made their 2017 land preparation decisions based on treatment assignment. With the delivery timeline and survey timing in mind, we focus on agricultural outcomes that span two seasons: agricultural production for the 2017 season and agricultural inputs for the 2018 season.

3.2 Sample characteristics

At endline, we tracked and surveyed 88% of randomized farmers, resulting in a sample of 2,268 households. Within each household, we administered the main survey instrument to the household head and directed questions regarding the receipt and use of oxen to the cotton producer. In 94% of households, the household head and the cotton producer were the same individual. Moreover, we randomly selected and surveyed one girl and one boy in the household and administered age-

[3]We stratified the randomization by cotton zone, whether the cotton societies' administrative data indicated that they already owned any oxen, whether they requested one or two oxen, and whether they owned a cart.

[4]We only collected information on agricultural inputs use from a random half of the sample, due to budget constraints. The data are balanced across this split.

appropriate numeracy and literacy assessments. For our analysis, we focus on the 2,113 households who reported comprehensive agricultural production, sales, and time use data.[5] Appendix Table B2 shows that there was no differential attrition between the treatment and control groups for the full survey or the analysis sample.

Appendix Table B3 reports the socio-demographic characteristics production of the sample along with the administrative cotton production data, disaggregated by treatment status, demonstrating broad balance across the evaluation arms. Sample households are large with an average of over 8 members, including just under two children younger than 5 years old, and overwhelmingly (over 99%) male-headed, while 42.3% are polygamous. Educational attainment is low, with 81% of household heads having received no formal schooling. For 86% of sample cotton producers, we also have pre-program administrative data on cotton production from the cotton societies: farmers report cultivating cotton on an average of 3.65 ha, yielding 3770 kg. Together, these pre-program administrative data and the program eligibility criteria suggest that the sample comprises fairly successful farmers with significant land holdings, a large area devoted to a high-value cash crop, and the expressed ability to expand their land devoted to cotton.

Our survey data provide a detailed picture of household agricultural tasks and cotton production in Côte d'Ivoire. While cotton producers are almost exclusively men, both men and women in these farm households engage in cotton production. Contrary to conventional wisdom detailing stark gender divisions in the performance of agricultural tasks, with men being more responsible for physically-intensive tasks like plowing and land clearing and women more responsible for weeding and sowing, we find limited gender specialization in cotton-related tasks in our setting (Appendix Table B4). The starkest gender difference is that men are generally more involved than women in all tasks: over 80% of male producers perform each type of task and producers are over 10 percentage points more likely to conduct any given task than any other household member. Still,

[5]Of the 155 cotton producers dropped from the study, 137 reported partial agricultural output or sales data and 18 reported incomplete time use data.

women are broadly engaged in agricultural tasks: 74% of producers' spouses perform transport-related tasks, while 68% plow (though consistent with the social prescriptions outlined in Section 2, rates are higher for plowing without oxen). Similarly, while 55% of spouses sow and weed, 85% of male producers also perform these tasks. The only two tasks in which women are relatively less involved are land clearing (40% for spouses) and marketing (9% for spouses).

Several aspects of our data suggest the presence of gendered social prescriptions around oxen. First, cotton producers report systematically lower perceived skills handling oxen for women relative to men: over 85% of girls and women are reported to have no oxen skills, about 30 and 60 percentage points above the equivalent rates for boys and for the male producer, respectively (Appendix Figure B1). The sizable difference in skill rates between boys and girls persists even for children under 10 years old—though prior to puberty, boys and girls do not exhibit significant differences in physical strength. Second, we find significant district-level variation in the degree of female involvement in oxen tasks. In our survey data, women in less restrictive communities (in which women do a higher share of oxen tasks) perform about 26% more of their agricultural tasks with oxen than women in more restrictive communities.

While the likelihood that women work with oxen is potentially endogenous to treatment, we find that it is highly correlated with broader district-level descriptive norms regarding women's decision-making power. Specifically, we use Demographic and Health Survey (DHS) data on women's decision-making power—the extent to which women have decision-making power over their health care, large household purchases, and visits to family and relatives—to define a household-level decision-making index and associated district-level index, before classifying districts as high or low decision-making depending on whether they are above or below the median district. We find that districts with relatively lower female involvement in oxen tasks are also those where women have less overall decision-making power (correlation coefficient of 0.75).[6] Underlying these pat-

[6]The main assumption underlying this approach relates to the mapping of DHS villages to districts. As the DHS does not report districts, we assign villages to districts using the village GPS coordinates together with administrative

terns in women's decision-making is variation in kinship structure, particularly in matrilineal vs. patrilineal systems, which has been shown to be a predictor of modern-day gender norms (Lowes, 2022). According to DHS data, these less restrictive districts are 70% Gour (traditionally matrilineal) and 17% Mande (traditionally patrilineal), while more restrictive areas are 41% Gour and 38% Mande.

In Section 4.3, we build on our conceptual framework and this norms variation to explore gendered social prescriptions as a potential driver of whether introducing oxen shifts women away from agricultural work, concentrating farming among men.

3.3 Compliance

In line with the phase-in design, we find a low but significant difference of 9.1 percentage points in the likelihood that the treatment group received traction oxen by the endline survey.[7] This relatively small difference between the oxen distribution rates for the treatment and control groups stems from the adopted phase-in approach, as 46% of the control group had already received an ox by the time of the survey. However, as intended, the treatment group reports receiving their oxen earlier than the control group: the likelihood that the treatment group reports having received an oxen before September 2017 is 18.6 percentage points, or 77%, higher than in the control group. Moreover, the (unconditional) total number of oxen received is also 25% higher overall in the treatment group.

4 Analysis

We report intent-to-treat (ITT) estimates of the impacts of animal-traction mechanization. Treatment assignment of households was random within strata, so the impacts of the intervention on a

geo-coded boundaries. However, the DHS shifts these coordinates by up to 5km, with 1% of clusters shifted up to 10km: Our approach assumes that the GPS coordinates for villages still fall within the correct district boundaries.

[7] Table B5 summarizes self-reported compliance with the study design.

given outcome Y_i can be measured using the following regression:

$$Y_i = \alpha + \beta \times \text{Treat}_i + \gamma_i \times \mathbf{X}_i + \delta_{stratum} + \varepsilon_i$$

where Y_i represents outcome y for household i, Treat_i is an indicator variable equal to 1 if household i was assigned to receive oxen in the first wave, $\mathbf{X_i}$ is a vector of LASSO-selected baseline covariates (Belloni, Chernozhukov and Hansen, 2014), and $\delta_{stratum}$ is a series of strata fixed effects. For household-level outcomes, we report heteroskedasticity-robust standard errors as treatment was assigned at the producer level. For individual-level outcomes with more than one observation per household, such as children's education and health, and wives' initial labor outcomes, we cluster standard errors at the household level.

In addition, we examine impact heterogeneity by whether households live in districts with relatively higher or lower female involvement in oxen tasks. Specifically, we run the following regression:

$$Y_{ij} = \alpha + \beta \times \text{Treat}_i \times \text{High}_j + \gamma_i \times \mathbf{X}_i + \text{High}_j + \delta_{stratum} + \varepsilon_i$$

where High_j is an indicator variable equal to one for households living in districts where the share of oxen tasks conducted by women within the district exceeded the median across all districts. We restrict to control households for this calculation, since our goal is to get as close as we can to capturing baseline-level norms. As a robustness check, we run this analysis using pre-program Demographic and Health Survey (DHS) data to divide districts into ones that are more restrictive (below-median women's decision-making power over their health care, making large household purchases, and visiting family and friends) versus less restrictive, as described in Section 3.2.

4.1 Household-level impacts

Table 1 presents intent-to-treat impacts on agricultural yields and area cultivated, showing that traction oxen increase yields and lead farmers to bring a larger area under cultivation.[8] Panel A of Table 1 focuses on treatment effects for first season agricultural outcomes, showing that assignment to the oxen treatment arm led to significant increases in agricultural output, even though the oxen were distributed mid-season and recipient producers were not notified that they would receive oxen before they made their planting decisions. Producers increased cotton production by 7%, yielding an equivalent increase in cotton revenues; the cotton society-dominated market structure yields little variation in the price farmers receive for their cotton, with the median reported sales prices within communities in the sample varying by less than 2%. Notably, the total market value of all crops did not increase, with the increase in cotton production partially offset by a negative but not statistically significant impact on other agricultural production.[9] We also find limited impact on total household income, which almost exclusively comprises agricultural sales. The fact that this increased cotton output stems from the early-season, unanticipated receipt of oxen after planting suggests that producers were able to increase output through higher productivity by using oxen for crop maintenance and harvesting.

Panel B of Table 1 presents the impacts on early second season agricultural outcomes. In contrast to the first season—when households received oxen unexpectedly and after several key input decisions had been made—households were able to take the oxen into account for planning and land preparation. This added flexibility led to large shifts in land holding and cultivation decisions: households assigned to receive traction oxen increased their total land holdings by 8%, land area under cultivation by 6%, and land cultivated with cotton by 10%.[10]

[8] As noted in Section 3.3, above, non-compliance within both the treatment and control groups suggests that our estimates represent a lower-bound for the treatment effects of the matching grant for the oxen.

[9] Appendix Table B6 presents impacts on the production of other crops. Farmers assigned to receive the traction oxen increased rice production by 9%. Rice is primarily produced for household-consumption with only 8% of the rice-producing households selling any amount.

[10] Appendix Table B7 demonstrates that this increased focus on cotton, an inedible cash crop, does not come at the

Table 2 shows that, for the random subsample of households asked about agricultural inputs, the oxen increased producers' use of traction power, increased their use of other non-labor inputs, and decreased plot household labor. Panel A shows that treatment households increased the likelihood that households used traction oxen by 10 percentage points and the number of plots on which they used the traction oxen by almost 30%, while also decreasing the likelihood of renting oxen, indicating that they are better able to meet their traction needs despite a larger area to manage.

Panel B focuses on non-labor inputs, showing that treatment households increased the share of plots on which they use organic fertilizer by almost 5 percentage points. There is little evidence that the oxen increased use of inorganic fertilizer or pesticides though extensive-margin use of these inputs was already high, with over 95% of households using at least one. Overall, households increase the value of non-labor inputs used by about 15%.[11] Finally, Panel C shows that households assigned to receive the oxen decreased their aggregate time spent on household plots over the last week without an accompanying increase in hired labor. Overall, household member time spent on plots decreased by about 1.5 hours per hectare or 7%.

Given the relatively low and time-varying impacts on likelihood of having an oxen noted in the Compliance section above, we benchmark the implied treatment-on-the-treated effect sizes for the key first- and second-season agricultural outcomes. Treatment producers were 19 percentage points more likely to have received the oxen by the end of the first agricultural season. Together with the point estimate on cotton production, this implies that receipt of the oxen boosted cotton production by slightly over 2,000 kg, or about 39%. While these gains are substantial, they are generally consistent with those possible under mechanization-facilitated high-density planting (Singh, Tanweer and Kalbhor, 20213). Similarly, our results imply treatment-on-the-treated impacts on land area cultivated of 48%. Although large, this increase is also reasonable, falling well below

expense of food security.

[11] Appendix Table B8 presents the estimated impacts of the treatment on the proportion of expenditures across six categories, finding that treatment households increased their spending on agricultural investments as a share of their overall spending.

the cross-sectional differences in land area cultivated between hand-cultivated and traction-animal cultivated farms, which average over 100% (Pingali et al., 1987).

4.2 Intra-household labor allocation

This section unpacks the intra-household composition of the observed reduction in agricultural labor provision as a result of the intervention and tests the predictions in Appendix A. We restrict attention to the 1,834 married producers with complete time-use data for spouses. Appendix C presents results equivalent to those presented above, showing that this sub-sample is balanced across socio-demographic characteristics and that the estimated impacts on household agricultural outcomes are consistent with those presented for the full sample, above, but less precisely estimated.

Table 3 shows that the oxen had different impacts for different household members, with time on household plots decreasing for women and girls. Columns 1 and 2 show that assignment to treatment had no significant impacts on the producer's time use. Columns 3-8 show that wives and girls in treatment households decreased the time spent on household plots by almost 6% and 9%, respectively. The large decrease in household plot activities for girls represents around two-thirds of a larger decrease in their total reported active time.[12] Due to the high prevalence of polygamy, we report results for both the first spouse and other spouses, when applicable. The impact of the treatment on time use, including household plot activities, is not statistically different between the first spouse (column 4) and other spouses (column 6). Results on other spouses being noisier but equivalent to results on first spouse, the rest of the paper averages outcomes across the producer's wives. Finally, boys in treatment households increased time spent on household chores by almost

[12]The omitted category in the time use questionnaire is passive rest time that is not spent on hobbies or socializing. A reduction likely indicates an increase in rest, but may also stem from the fact that the treatment shifts these individuals away from household plots, decreasing the observability of their time use to the producer. Appendix Table B9 presents equivalent results for average weekly hours spent on household agricultural plots over the prior year, showing a similar pattern of decreased time on plots by women and girls.

0.6 hours, representing an increase of over 30%. The low reported time spent on education for girls and boys is likely due to the timing of the survey, which took place during the summer school break.

Decreased time spent on agricultural plots has the potential to shift time in school and broader education outcomes, and to affect child health by decreasing their exposure to agricultural chemicals and zoonotic diseases. Broadly, we don't find robust evidence of short-term downstream impacts on education. We do find suggestive evidence of downstream impact on girls' health outcomes, consistent with larger reductions in household agricultural time for girls.[13]

4.3 Role of community norms in driving intra-household impacts

As discussed in Sections 2 and 3.2, restrictive social prescriptions around women working with oxen are likely to play a key role in determining the intra-household impacts of a mechanization intervention. If the community norm is low female involvement in oxen tasks, introducing oxen to agricultural work may shift women away from such work. This subsection builds on these theoretical considerations by examining treatment effect heterogeneity for households residing in districts where control-group women perform relatively more or relatively fewer oxen tasks.[14]

Table 4 presents heterogeneous impact estimates for second-season time use outcomes. Column 1 shows the estimated impact of delivering oxen to households residing in districts with relatively higher female involvement in oxen tasks. In these households, oxen treatment had relatively limited time-use impacts with none of the 12 coefficients being statistically significant. This contrasts with

[13] Appendix Table B10 examines impacts on overall school enrollment, school dropout, and literacy and numeracy assessments, with no robust evidence of short-term downstream impacts on education outcomes. Appendix Table B11 presents impacts of treatment on likelihood and duration of illness among the producers' spouse and children. While all six of the coefficients are negative, the impacts are only statistically significant for girls, for whom treatment decreases the likelihood of illness and duration of illness over the last month by about a quarter.

[14] Appendix Table B12 presents summary statistics comparing households residing in districts with relatively high and relatively low rates of female involvement in oxen tasks, showing significant differences across several household and production characteristics. The regressions include controls for LASSO-selected baseline covariates. Appendix Figure B2 presents the distribution of the share of oxen-tasks performed by control-group women, across communities.

the results presented in Columns 2-3, where we display the marginal impact of treatment within households in districts where women perform fewer oxen-related tasks (Column 2) as well as the p-value of the test comparing these impacts to those in districts where men dominate oxen work (Column 3). In these households, we find significant intra-household impacts of the oxen delivery. In particular, in districts with low female involvement in oxen tasks, we see a significant 1.78 hour/week increase in how much time the spouse spends on off-farm work. This matches qualitatively with the fact that the spouses' (and girls') reduction in time spent working on the producer's plots is concentrated in these same districts. This is consistent with our conceptual framework: the impacts of introducing traction oxen depend critically on how restrictive social prescriptions regarding oxen-work are for different household members. Taken together, these results show that gender norms around the suitability of working with oxen lead to a concentration of household plot activities under men in the household, with women shifting to non-agricultural work.

One concern with the above heterogeneity analysis is the potential endogeneity of women's involvement in oxen tasks. While we define this using endline data from control group households, the phase-in design means that many of these households also received the oxen and may have changed behaviors in response to treatment. With this in mind, we demonstrate the robustness of the heterogeneity results to using an alternative construction of gender norms: district-level differences in women's decision-making power calculated using pre-program DHS data.[15] Appendix Table B13 presents heterogeneity results splitting the sample as either more or less restrictive, with an equivalent pattern of results.

[15] Appendix Figure B3 presents the variation of more/less restrictive districts across the sample.

5 Conclusion and Discussion

In this paper, we provide experimental evidence on how easing credit constraints to mechanization positively impacts household production and intra-household labor allocation among cotton farmers in Côte d'Ivoire. We find positive impacts on cotton production—a male-dominated cash crop—and intensification of agriculture, along with an increase in the value of complementary agricultural inputs used. Though our results are short-term and we do not detect a significant increase in household income in our survey time-frame, second season outcomes indicate that households expand their overall agricultural cultivation and not merely cotton. Moreover, our data indicates that animal traction can lead to yield—not just production—improvements, as farmers were able to increase their cotton production after land cultivation decisions were made.

Our results shed additional light on four stylized facts related to agricultural mechanization identified in observational studies. First, earlier studies analyzed by Pingali et al. (1987) suggested minimal yield gains for animal traction farms relative to hand-hoe farms. The increased cotton and rice production we detect in the first season, together with the fact that the oxen were distributed after land cultivation decisions were made, suggest that the oxen increased yields through either task quality or efficiency improvements during crop maintenance, harvest, and/or crop transport. Second, Pingali et al. (1987) documented a relationship between animal traction use and a larger area under cultivation. Our estimates indicate that this relationship is causal, with households who gain access to traction oxen bringing new land under cultivation. Third, earlier findings have suggested that additional area brought under cultivation as a result of mechanization was concentrated among market crops including cotton, rice, and groundnuts (Pingali et al., 1987). We find impacts concentrated among both cotton and rice but caution against the market crop characterization: few farmers in this setting report selling rice, suggesting that the impacts may stem from specific traction oxen efficiencies of cultivating rice rather than a market crop designation. Finally, Pingali

et al. (1987) note that there is "general agreement that a transition [to animal traction] reduces the amount of labor required during the land-preparation period". We find evidence of broader labor savings from oxen: specifically, we document a reduction in household agricultural labor during crop maintenance, when households may have been expected to need more labor due to their increased land under cultivation. This is in line with results from Afridi, Bishnu and Mahajan (2020), who point to the fact that mechanization leads to higher-quality plowing, which in turn lowers the demand for weeding labor.

Our findings show the broad labor-saving potential of animal traction beyond the land preparation period, but also how this labor-saving does not affect everyone in the household equally. Only wives and girls significantly reduce the time they spend working on household plots as a result of mechanization. Moreover, our analysis suggests that gender norms are tightly linked to mechanization impacts, with women in districts with more restrictive social prescriptions against women working with oxen shifting off-farm. Looking forward, it will be important to better understand how social norms influence household members' off-farm engagement when a new technology is introduced.

Our results also provide suggestive evidence that—even under fairly conservative assumptions—investing in oxen is profitable for farmers over the longer term. Specifically, while the short-term agricultural impact estimates alone would not yield a positive return on the the unsubsidized market cost of the oxen, they are typically sold for slaughter at the end of their working life, with farmers recouping in excess of 100% of the original oxen cost at sale (Okello et al., 2015; Takele, 2018; Kanu, 2000). As shown in Online Appendix D, at the mean estimated recovery rate of 107%, the pair of oxen yield an estimated return on investment of 39% over 7 years, or 4.9% compounded annually.

In terms of consequences for structural transformation, it is worth noting that gender norms related to technology and capital-intensive tasks affect many more domains than simply working with

oxen. Prescriptions regarding the acceptability of different types of work for women are not just relegated to informal norms, but are also enshrined in formal legislation. In 49 of 190 countries worldwide, women are not allowed to work in jobs deemed 'dangerous' in the same way as men (World Bank, 2023). Beyond examining the effects of legal and normative changes regarding what sectors it is acceptable for women to work in, future research should examine whether offering complementary gender-targeted programming alongside mechanization can strengthen women's economic empowerment, and more broadly continue unpacking the relationship between technology, labor and (gendered) power.

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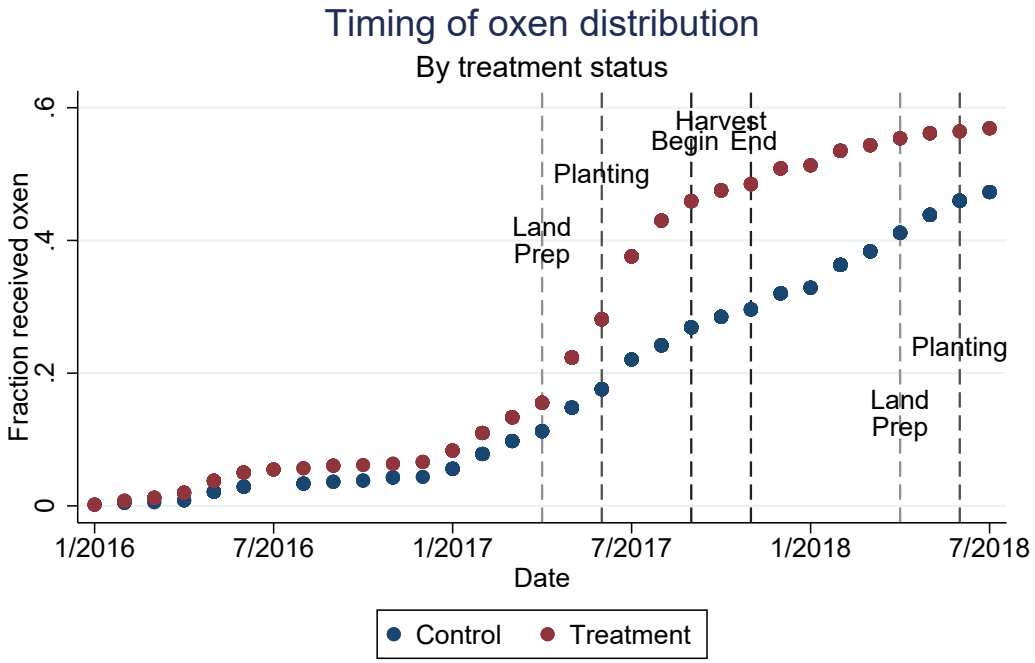
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Tables and Figures

Figure 1: Timeline of the experiment and of the 2017 and 2018 cotton seasons



Note: No date reported for 13% of the sample that received oxen. These households are assumed to receive the oxen at the mean delivery date within their given strata.

Table 1: Impacts on agricultural output and land cultivated

Outcome	Obs	Control Mean	Estimated Impact
Panel A: Prior season			
Total cotton production (kg)$^{\diamond}$	2113	5292.93	387.23**
			(179.58)
Value of cotton sold (USD)$^{\diamond}$	2113	2706.25	191.54*
			(105.70)
Value of non-cotton agric production (USD)$^{\diamond}$	2113	1115.50	-72.52
			(69.55)
Value of agricultural products sold (USD)$^{\diamond}$	2113	4263.35	45.79
			(175.86)
Total non-farm income (USD)$^{\diamond}$	2113	41.60	2.87
			(3.83)
Total household income (USD)$^{\diamond}$	2113	4342.99	56.53
			(177.99)
Panel B: Current season land holdings			
Household plots cultivated	2113	1.67	0.04
			(0.04)
Total land holdings (ha)$^{\diamond}$	2113	13.81	1.05***
			(0.36)
Total land cultivated (ha)$^{\diamond}$	2113	12.64	0.74**
			(0.31)
Total land cultivated w/ cotton (ha)$^{\diamond}$	2113	4.81	0.49***
			(0.14)

Note: *, **, and *** indicate significance at the 90, 95, and 99% confidence intervals, respectively. $\diamond$ indicates variables that have been winsorized at the 5% level. All regressions control for whether household head completed primary school, number of boys between 6 and 16 years old, and stratum fixed effects.

Table 2: Impacts on agricultural inputs

Outcome	Obs	Control Mean	Estimated Impact
Panel A: Traction ox use			
Household used traction oxen	947	0.56	0.10***
			(0.03)
Number of plots where traction oxen were used	947	0.91	0.27***
			(0.07)
Share of plots where traction oxen were used	947	0.53	0.11***
			(0.03)
Household rented oxen	947	0.16	-0.04
			(0.02)
Panel B: Non-labor inputs			
Share of household plots using organic fertilizer	947	0.82	0.05**
			(0.02)
Share of household plots using inorganic fert	947	0.95	-0.00
			(0.01)
Share of household plots using phytosanitary products	947	0.95	0.01
			(0.01)
Value of non-labor inputs for household plots (USD)$^{\diamond}$	947	1267.11	164.07**
			(77.72)
Panel C: Labor inputs			
Household hired labor	947	0.63	0.02
			(0.03)
Quantity of hired labor$^{\diamond}$	947	28.85	1.37
			(2.49)
Total household plot hours in last week$^{\diamond}$	2113	219.58	-8.46*
			(4.91)
Total household plot hours in last week/ha$^{\diamond}$	2113	21.21	-1.51**
			(0.58)

Note: *, **, and *** indicate significance at the 90, 95, and 99% confidence intervals, respectively. Agricultural input usage only collected for half the sample. $\diamond$ indicates variables that have been winsorized at the 5% level. All regressions control for whether household head completed primary school, number of boys between 6 and 16 years old, and stratum fixed effects.

Table 3: Impacts on household member time use

	Producer		*First Spouse*		*Other Spouses*		*Girls*		*Boys*	
Outcome	**Control Mean [1]**	**Estimated Impact [2]**	**Control Mean [3]**	**Estimated Impact [4]**	**Control Mean [5]**	**Estimated Impact [6]**	**Control Mean [7]**	**Estimated Impact [8]**	**Control Mean [9]**	**Estimated Impact [10]**
HH plot activities	43.11	-0.48	35.31	-2.14**	35.34	-1.50	26.68	-2.65**	34.54	-0.96
		(0.86)		(0.91)		(1.38)		(1.12)		(1.21)
Other agric work	1.32	-0.30	1.19	-0.06	1.12	-0.05	0.28	0.00	0.20	0.05
		(0.23)		(0.21)		(0.30)		(0.11)		(0.08)
Non-farm labor	11.38	-0.61	5.47	0.61	5.09	0.02	4.10	0.06	12.90	-1.20
		(0.85)		(0.59)		(0.82)		(0.56)		(0.95)
Household chores	1.62	0.19	28.52	-0.53	28.87	0.06	16.37	-0.02	1.79	0.55*
		(0.31)		(0.82)		(1.38)		(0.81)		(0.31)
Hobbies	9.26	-0.00	4.50	-0.02	5.63	-0.04	9.69	-0.63	9.47	-0.37
		(0.55)		(0.38)		(0.66)		(0.79)		(0.71)
Education	0.62	-0.02	0.19	-0.02	0.07	0.06	0.79	-0.19	0.69	-0.14
		(0.14)		(0.11)		(0.11)		(0.15)		(0.12)
Total inactive time	100.49	1.17	92.82	2.20	92.18	1.01	110.06	3.67**	108.38	2.23
		(1.47)		(1.46)		(2.26)		(1.74)		(1.69)
Observations	1836		1781		757		1199		1352	

Note: *, **, and *** indicate significance at the 90, 95, and 99 % confidence intervals, respectively. Regression reports impacts of treatment on weekly average household time use for given tasks: for households with multiple wives, daughters, or sons, the time use is averaged and regressions are reported at the household level. All regressions control for whether household head completed primary school, number of boys between 6 and 16 years old, and stratum fixed effects.

Table 4: Heterogeneity for HHs in districts where women perform relatively few oxen tasks

Outcome	Obs	Control Mean	Impacts in Districts where Women Perform Relatively More Ox Tasks [1]	Few Ox Tasks [2]	p-value [1]=[2]
Total land cultivated (ha)$^{\diamond}$	1718	12.64	0.76*	0.40	0.60
			(0.45)	(0.51)	
Producer total active time	1718	69.95	-0.85	-2.96	0.48
			(2.28)	(1.95)	
Producer household plot labor supply	1718	43.36	0.61	-1.66	0.20
			(1.27)	(1.22)	
Spouse total active time	1718	76.61	-1.90	-1.77	0.96
			(1.99)	(1.99)	
Spouse household plot labor supply	1717	37.73	-1.64	-2.77**	0.53
			(1.29)	(1.24)	
Spouse other agric work	1718	1.02	0.16	-0.06	0.55
			(0.28)	(0.26)	
Spouse non-farm labor	1716	5.55	-0.53	1.78**	0.04
			(0.76)	(0.81)	
Spouse household chores	1714	28.12	-0.36	-0.28	0.96
			(1.11)	(1.24)	
Spouse hobbies	1713	4.29	0.19	-0.35	0.47
			(0.50)	(0.58)	
Boys' total active time	1264	61.99	0.01	-3.46	0.33
			(2.45)	(2.56)	
Boys' household plot labor supply	1263	36.61	1.02	-1.72	0.29
			(1.67)	(1.98)	
Girls' total active time	1124	59.76	-2.46	-3.62	0.75
			(2.44)	(2.69)	
Girls' household plot labor supply	1124	29.61	-1.80	-3.04*	0.60
			(1.63)	(1.71)	

Note: Robust standard errors reported in parenthesis. *, **, and *** indicate significance at the 90, 95, and 99% confidence intervals, respectively. † indicates hours in last week. Spouse outcomes are averaged across wives in polygamous households. All regressions include controls for household composition, household-head education, and stratum fixed effects.

Online Appendix

Appendix A: Rural Households Operating Under Social Prescriptions

Our context is that of households in an agriculture-based rural economy, in which members maximize their utility over consumption and leisure. Households' utility depends, inter alia, on how their members conform (or do not conform) to behaviors that are considered socially appropriate. The purpose of the framework is to i) illustrate the links between traction power, agricultural production and labor supply in this setting, and ii) predict what happens to household members' labor supply in the face of gendered social prescriptions related to traction power.

A1 Setup

Our framework incorporates Akerlof and Kranton (2000)'s formalization of the insight that identity–including gender identity and the social prescriptions that accompany it–is a motivation for behavior, and draws on Kevane and Wydick (2001)'s model of time allocation under social norms.

In our simple setup, farm households maximize utility U subject to income, production technology and time constraints. Men own farm capital K, including traction oxen, and female household members divide T units of work time between farm work, T_f, off-farm work T_o, and domestic work T_d. The household has a production function $A(K,T_f)$ that corresponds to output on the husband's farm, and a function $H(K,T_d)$ that corresponds to domestic production, the value of which also depends on the household's farm capital. Off-farm production, T_o, is valued by the market at price p. We assume that $A_{TT}<0$, $A_{KK}<0$, and $A_{TK}>0$, and similarly for $H()$.[16] The labor supply of the husband is assumed inelastic and its allocation is fixed across activities for the purposes of this simplified model, where we are interested in examining female household members' labor supply.

As in Akerlof and Kranton (2000), an individual's utility is a function of their social category and the extent to which their own and others' actions correspond to behavior indicated by social prescriptions P. In our rural setting of northern Côte d'Ivoire, one example of such a 'benevolently sexist' social prescription is that women should not undertake activities perceived as risky, including handling large livestock (as discussed in Section 1). Since this social prescription does not regard women's farm work overall, but specifically farm work when oxen are used (K=1), we modify Kevane and Wydick (2001)'s formalization of this norm's impact on behavior by focusing on women's deviation from average oxen use by other women in their community:

$$\overline{P}-\sum(\frac{1}{2}a_j\cdot T_j\cdot(K-\overline{K_j})^2) \tag{2}$$

[16] While an expansion of farm capital such as traction oxen increases the productivity of domestic production, e.g., through easing water/fuel transport, this impact may be offset by increased chore responsibilities such as animal care. We thus assume that H_{TK}, though positive, is close to zero.

where $j = f, o, d$ denotes the set of activities available to the woman. The benefit from her behavior conforming to social prescriptions is given by $\overline{P}$. The parameter a_j represents the intensity of social penalties for violating norms regarding risky work in each of the different activities. $\overline{K_j}$ is the mean intensity of oxen use in activity j for women in a particular community. Social penalties depend on the intensity parameter a_j, whether the woman performs relatively more tasks with oxen than women in her community (i.e., $K > \overline{K_j}$),[17] and how much time she spends on these tasks (T_j). For simplicity and given our setting, we focus on social penalties related to farm work, setting $a_o = a_d = 0$.[18]

The household allocates the woman's labor to maximize:

$$\max A(K, T_f) + H(K, T_d) + p_o \cdot T_o + \overline{P} - \frac{1}{2} a_f \cdot T_f \cdot (K - \overline{K})^2 \tag{3}$$

subject to the time constraint:

$$T = T_f + T_o + T_d \tag{4}$$

This setup yields a set of tractable comparative statics for the relationship between a change in capital (oxen) and labor across the different categories.

This can be represented as:

$$\max A(K, T_f) + H(K, T_d) + p_o \cdot T_o + \overline{P} - \frac{1}{2} a_f \cdot T_f \cdot (K - \overline{K})^2 \tag{5}$$

subject to the time constraint:

$$T = T_f + T_o + T_d \tag{6}$$

The associated Lagrangian yields the following first order optimality conditions:

$$\frac{\partial \mathscr{L}}{\partial T_f} = \frac{\partial A}{\partial T_f} - \frac{1}{2} a_f \cdot (K - \overline{K})^2 - \lambda = 0 \tag{7}$$

$$\frac{\partial \mathscr{L}}{\partial T_d} = \frac{\partial H}{\partial T_d} - \lambda = 0 \tag{8}$$

$$\frac{\partial \mathscr{L}}{\partial T_o} = p_o - \lambda = 0 \tag{9}$$

$$0 = T - T_f - T_d - T_o \tag{10}$$

[17] In our context, there are no penalties for women who are less involved in risky activities than the norm, so we do not consider the case of $K < \overline{K_j}$.

[18] In line with the focus on farm norms and for simplicity, we drop the sector subscript for the mean intensity of on-farm oxen use, so that $\overline{K_j} = \overline{K}$.

where λ is the Lagrange multiplier on the time constraint. As detailed in the body of the paper, we set $a_o = a_d = 0$ for ease of exposition. From the first order conditions, we derive a set of reduced form equations for the allocation of time into each of the three activities. Time in each activity will depend on the level of household capital, the price of the market product, the extent of conformity to social norms, and intensity of penalties from deviating or rewards for conforming.

Following Kevane and Wydick (2001), we examine whether the task-induced and capital-dependent social norms influence the time allocation of women using comparative statics showing how time allocation varies with changes in animal traction K. Dropping the subscripts, the matrix of totally differentiated first order conditions is:

$$\begin{bmatrix} A_{TT} & 0 & 0 & -1 \\ 0 & H_{TT} & 0 & -1 \\ 0 & 0 & 0 & -1 \\ -1 & -1 & -1 & 0 \end{bmatrix} \begin{bmatrix} \frac{\partial T_f}{\partial K} \\ \frac{\partial T_d}{\partial K} \\ \frac{\partial T_o}{\partial K} \\ \frac{\partial}{\partial K} \end{bmatrix} = \begin{bmatrix} -A_{TK} + a_f \cdot (K - \overline{K}) \\ -H_{TK} \\ 0 \\ 0 \end{bmatrix}$$

The Hessian determinant is:

$$|H| = -H_{TT} \cdot A_{TT} < 0 \tag{11}$$

While Cramer's rule yields the desired partial derivatives:

$$\frac{\partial T_f}{\partial K} = \frac{\begin{vmatrix} -A_{TK} + a_f \cdot (K - \overline{K}) & 0 & 0 & -1 \\ -H_{TK} & H_{TT} & 0 & -1 \\ 0 & 0 & 0 & -1 \\ 0 & -1 & -1 & 0 \end{vmatrix}}{|H|} = \frac{(A_{TK} H_{TT} - a_f \cdot (K - \overline{K}) H_{TT})}{|H|} \tag{12}$$

$$\frac{\partial T_d}{\partial K} = \frac{\begin{vmatrix} A_{TT} & -A_{TK} + a_f \cdot (K - \overline{K}) & 0 & -1 \\ 0 & -H_{TK} & 0 & -1 \\ 0 & 0 & 0 & -1 \\ -1 & 0 & -1 & 0 \end{vmatrix}}{|H|} = \frac{A_{TT} \cdot H_{TK}}{|H|} > 0 \tag{13}$$

$$(14)\quad \frac{\partial T_o}{\partial K} = \frac{\begin{vmatrix} A_{TT} & 0 & -A_{TK} + a_f \cdot (K - \overline{K}) & -1 \\ 0 & H_{TT} & -H_{TK} & -1 \\ 0 & 0 & 0 & -1 \\ -1 & -1 & 0 & 0 \end{vmatrix}}{|H|} = \frac{(a_f \cdot (K - \overline{K}) - A_{TK}) \cdot H_{TT} - A_{TT} \cdot H_{TK}}{|H|}$$

To summarize, this process yields the following comparative statics:

$$(15)\quad \frac{\partial T_f}{\partial K} = \frac{A_{TK}H_{TT} - a_f(K - \overline{K})H_{TT}}{|H|}$$

$$(16)\quad \frac{\partial T_d}{\partial K} = \frac{A_{TT}H_{TK}}{|H|}$$

$$(17)\quad \frac{\partial T_o}{\partial K} = \frac{(a_f(K - \overline{K}) - A_{TK})H_{TT} - A_{TT}H_{TK}}{|H|}$$

A2 Predictions

We start with the first equation. The marginal effect of capital (in our context, introducing traction oxen) on women's farm work will depend on the sign of $A_{TK}H_{TT} - a_f(K - \overline{K})H_{TT}$, since $|H|$ is negative as shown in Appendix A. Recall that A_{TK} is positive by assumption, while H_{TT} is negative by assumption. This implies that if $a_f(K - \overline{K}) > A_{TK}$—that is, the social penalty she incurs from spending time on-farm with oxen is greater than the return of her labor to farm production when capital increases marginally—then the introduction of oxen will decrease the time she spends on the farm.

In the presence of social prescriptions that it is unsuitable for women to handle traction oxen, $a_f(K - \overline{K})$ is large and positive such that:

$$(18)\quad \frac{\partial T_f}{\partial K} < 0$$

Note that for lower values of the social penalty in less restrictive communities, where the norm is for women to already be relatively more involved in handling oxen, introducing oxen will naturally have a smaller negative effect on women's time spent on farm work.

Turning to domestic work, as explained above, we assume that H_{TK} is positive but only weakly so. Since A_{TT} is negative and $|H|$ is negative, this implies that the marginal effect of capital on domestic work is positive but close to zero:

$$(19)\quad \frac{\partial T_d}{\partial K} \gtrapprox 0$$

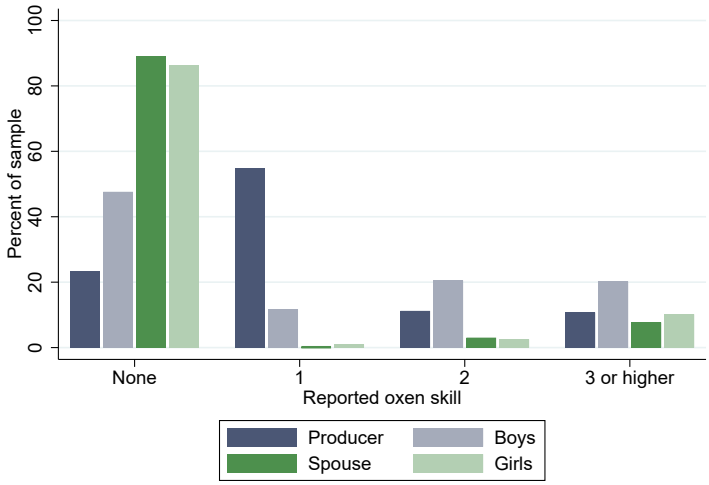
Lastly, we turn to the case of women's off-farm work. Since H_{TK} is near-zero, and H_{TT} is negative, the sign will again depend on the relative size of $a_f(K-\overline{K})$ and A_{TK}. If $a_f(K-\overline{K}) > A_{TK}$ as above, then the first term of the numerator will be negative. Since we know that the second term of the numerator is positive and close to zero, this implies that in households where women would go against the norm by working with oxen on-farm and thus face a social penalty, *ceteris paribus*:

$$\frac{\partial T_o}{\partial K} > 0 \tag{20}$$

Another way to see this result is that $\frac{\partial T_o}{\partial K}$ is merely $\frac{\partial T_d}{\partial K}$ subtracted from the inverse of $\frac{\partial T_f}{\partial K}$. Note also that as the social penalty shrinks, the increase in women's off-farm work resulting from an increase in capital will also get smaller.

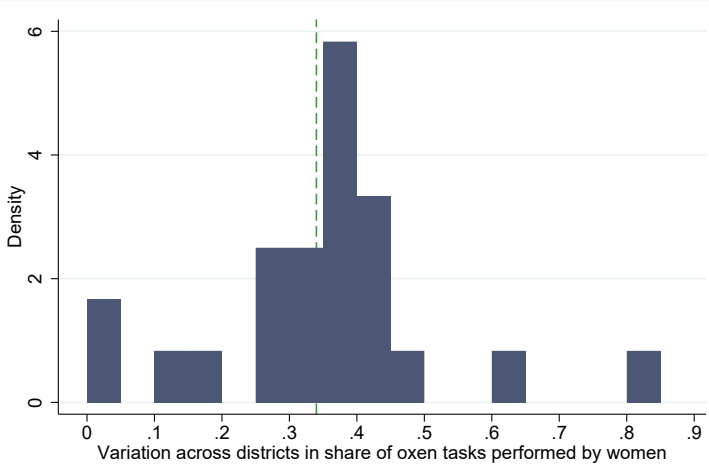
Appendix B: Supplemental Figures and Tables

Figure B1: Distribution of perceived oxen skill level for main household members



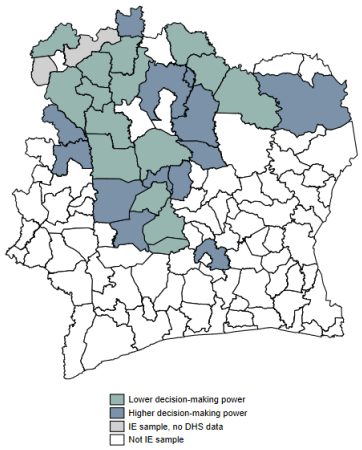
Note: Oxen skill reported by the household head for all household members on a 0-10 scale.

Figure B2: Distribution of share of oxen-tasks performed by women across sample communities



Note: Figure presents the distribution of the share of oxen tasks performed by women across districts. High women's oxen task defined as above sample median of 34%, which is indicated by the dashed vertical line.

Figure B3: Pattern of Gender Attitudes by Sample District



Note: Author computations using 2011-12 Cote d'Ivoire Demographic and Health Survey (DHS) data conducted under DHS Phase VI, within districts in the impact evaluation sample. Less (respectively more) stringent gender norms districts are those where the median women's decision-making index is above (respectively below) the median district's index. The decision-making index includes decision-making questions around women's health care, large household purchases, and visits to family and relatives.

Table B1: Other Inputs

Outcome	Obs	Control Mean	Estimated Impact
Inputs Owned			
Household has plough	2111	0.43	0.02
			(0.02)
Household has multicultivator	2106	0.52	0.01
			(0.02)
Household has multi tiller	2103	0.35	0.01
			(0.02)
Household has seed drill	2109	0.35	0.02
			(0.02)
Household has cart	2111	0.46	0.02
			(0.02)
Input equipment types owned	2113	2.11	0.08
			(0.06)
PSAC Inputs Received			
Household received plough	2113	0.04	0.01
			(0.01)
Household received multicultivator	2113	0.06	0.01
			(0.01)
Household received multi tiller	2113	0.03	0.01
			(0.01)
Household received seed drill	2113	0.05	0.02
			(0.01)
Household received cart	2113	0.04	-0.01
			(0.01)

Note: *, **, and *** indicate significance at the 90, 95, and 99% confidence intervals, respectively. All regressions control for whether household head completed primary school, number of boys between 6 and 16 years old, and stratum fixed effects.

Table B2: Impact of treatment on attrition

	(1)	(2)
	Attrition from	
	Endline survey	**Analysis sample**
Treatment	0.018	0.007
	(0.013)	(0.015)
Constant	0.87***	0.812***
	(0.009)	(0.011)
Observations	2580	2580

Note: *, **, and *** indicate significance at the 90, 95, and 99% confidence intervals, respectively. All regressions control for stratum fixed effects.

Table B3: Balance between treatment and control groups

Outcome	Obs	Control Group Mean	Treatment Difference
Household head: age	2104	42.09	-0.25
			(0.48)
Household head: no education	2113	0.81	-0.01
			(0.02)
Household head: some primary education	2113	0.10	-0.01
			(0.01)
Household head: completed at least primary school	2113	0.09	0.03*
			(0.01)
Household head: female	2113	0.01	0.00
			(0.00)
Household head: producer	2113	0.94	0.00
			(0.01)
Polygamous household	2113	0.42	-0.01
			(0.02)
Number of spouses	2113	1.46	-0.03
			(0.03)
Age of first spouse	1790	35.17	-0.64
			(0.49)
First wife: no education	1983	0.94	-0.02
			(0.01)
Men in household	2113	1.76	-0.05
			(0.05)
Women in household	2113	1.72	-0.01
			(0.05)
Boys aged 6-16	2113	1.55	-0.17**
			(0.06)
Girls aged 6-16	2113	1.21	-0.02
			(0.06)
Children under 5 years old	2113	1.83	-0.05
			(0.07)
Number of shocks in last year	2113	1.86	-0.12*
			(0.06)
Household assets (PCA)	2113	6.16	0.07
			(0.11)
Pre-program cotton area (ha)	1804	3.65	0.03
			(0.09)
Pre-program cotton production (kg)	1804	3769.34	10.27
			(133.96)

Note: Robust standard errors reported in parenthesis. *, **, and *** indicate significance at the 90, 95, and 99% confidence intervals. Pre-program cotton area and production come from cotton producer database.

Table B4: Share of Household Members Performing Agricultural Tasks

Household	Land Clearing	Plowing	Sow/Weed	Transport	Harvest	Marketing
Producer	0.85	0.88	0.85	0.90	0.81	0.86
Spouse	0.40	0.68	0.55	0.74	0.45	0.09
Other men	0.52	0.71	0.65	0.69	0.59	0.25
Other women	0.26	0.50	0.37	0.49	0.27	0.05
Boys	0.34	0.50	0.40	0.51	0.38	0.05
Girls	0.18	0.39	0.26	0.40	0.21	0.03

Note: Variable equal to 1 if the individual performed the agricultural task over the prior year. Sample restricted to control group.

Table B5: Treatment compliance

Outcome	Obs	Control Mean	Estimated Impact
Received traction oxen	2113	0.46	0.09***
			(0.02)
Received traction oxen before season 1 harvest	2113	0.24	0.19***
			(0.02)
Received traction oxen before season 2 land preparations	2113	0.38	0.16***
			(0.02)
Number of traction oxen received$^{\diamond}$	1811	0.93	0.23***
			(0.04)

Note: *, **, and *** indicate significance at the 90, 95, and 99% confidence intervals, respectively. $\diamond$ indicates variables that have been winsorized at the 5% level. All regressions include controls for whether household head completed primary school, number of boys between 6 and 16 years old, and stratum fixed effects.

Table B6: Crop harvest, value sold, and area planted

Outcome	Obs	Control Mean	Estimated Impact
First Season			
Total cashews production (kg)$^{\diamond}$	2113	800.91	-63.47
			(61.53)
Total peanut production (kg)$^{\diamond}$	2113	580.74	54.61
			(39.04)
Total cotton production (kg)$^{\diamond}$	2113	5292.93	387.23**
			(179.58)
Total yam production (kg)$^{\diamond}$	2113	125.95	6.93
			(18.32)
Total maize production (kg)$^{\diamond}$	2113	2897.56	30.36
			(151.10)
Total rice production (kg)$^{\diamond}$	2113	1410.76	130.82*
			(75.04)
Value of crop sold: cashews (USD)$^{\diamond}$	2113	636.71	-45.93
			(47.68)
Value of crop sold: peanut (USD)$^{\diamond}$	2113	26.93	0.82
			(2.30)
Value of crop sold: cotton (USD)$^{\diamond}$	2113	2706.25	191.54*
			(105.70)
Value of crop sold: yam (USD)	2113	1.57	-1.10
			(0.84)
Value of crop sold: maize (USD)$^{\diamond}$	2113	218.46	-0.49
			(15.44)
Value of crop sold: rice (USD)	2113	7.99	2.52
			(2.41)
Second Season			
Total land cultivated w/ cashews (ha)$^{\diamond}$	2113	2.64	0.03
			(0.17)
Total land cultivated w/ peanut (ha)$^{\diamond}$	2113	0.57	0.00
			(0.03)
Total land cultivated w/ cotton (ha)$^{\diamond}$	2113	4.81	0.49***
			(0.14)
Total land cultivated w/ yam (ha)$^{\diamond}$	2113	0.07	0.01
			(0.01)
Total land cultivated w/ maize (ha)$^{\diamond}$	2113	2.40	0.03
			(0.08)
Total land cultivated w/ rice (ha)$^{\diamond}$	2113	1.44	0.11**
			(0.05)

Note: Robust standard errors reported in parenthesis. *, **, and *** indicate significance at the 90, 95, and 99% confidence intervals, respectively. $\diamond$ indicates variables that have been winsorized at the 5% level. All regressions include controls for number of boys 6-16 years old and stratum fixed effects.

Table B7: Food Security Impacts

Outcome	Obs	Control Mean	Estimated Impact
Food Security			
Food groups eaten in last 7 days	2113	7.302	-0.054
			(0.081)
Food groups eaten in last 24 hours	2113	5.534	0.061
			(0.082)
Meals skipped in last 7 days	2109	0.379	-0.012
			(0.057)

Note: Robust standard errors reported in parenthesis. *, **, and *** indicate significance at the 90, 95, and 99% confidence intervals, respectively.All regressions include controls for number of boys 6-16 years old and stratum fixed effects.

Table B8: Proportional Expenses Impacts

Outcome	Obs	Control Mean	Estimated Impact
Percentage of expenses: food	2070	0.210	-0.002
			(0.006)
Percentage of expenses: education	2070	0.100	-0.001
			(0.004)
Percentage of expenses: health	2070	0.153	-0.004
			(0.005)
Percentage of expenses: agricultural investments	2070	0.353	0.015**
			(0.007)
Percentage of expenses: other investments	2070	0.051	-0.007*
			(0.004)
Percentage of expenses: other categories	2070	0.133	-0.001
			(0.006)

Note: Robust standard errors reported in parenthesis. *, **, and *** indicate significance at the 90, 95, and 99% confidence intervals, respectively.All regressions include controls for number of boys 6-16 years old and stratum fixed effects.

Table B9: Time spent on household agricultural plots: Average Hours over Last Year

Outcome	Obs	Control Mean	Estimated Impact
Producer	1798	42.35	-0.49
			(0.60)
First spouse	1736	32.72	-1.87***
			(0.61)
Other spouse	745	32.32	-1.66*
			(0.89)
Other adults	1021	37.32	-1.06
			(0.91)
Boys	1332	30.89	-0.10
			(1.02)
Girls	1192	24.44	-1.94*
			(0.97)

Note: *, **, and *** indicate significance at the 90, 95, and 99% confidence intervals, respectively. All regressions control for whether household head completed primary school, number of boys between 6 and 16 years old, and stratum fixed effects.

Table B10: Household Member Education

	All Children		*Girls*		*Boys*	
Outcome	**Control Mean**	**Estimated Impact**	**Control Mean**	**Estimated Impact**	**Control Mean**	**Estimated Impact**
Panel A: Households with children 6-16 years old						
Children currently attending school	0.48	0.02	0.52	0.02	0.47	0.02
		(0.02)		(0.02)		(0.02)
Education assessment score	-0.01	0.05	-0.00	0.01	0.01	0.06
		(0.04)		(0.06)		(0.05)
Panel B: Households with children who have attended school						
Students dropped out of school	0.10	-0.02	0.09	-0.00	0.11	-0.03*
		(0.01)		(0.02)		(0.02)
Education assessment score	0.44	0.06	0.41	-0.02	0.47	0.07
		(0.06)		(0.08)		(0.08)

Note: *, **, and *** indicate significance at the 90, 95, and 99% confidence intervals, respectively. ⋄ indicates variables that have been winsorized at the 5% level. All regressions control for whether household head completed primary school, number of boys between 6 and 16 years old, and stratum fixed effects.

Table B11: Household Member Health

	Spouse		*Girls*		*Boys*	
Outcome	**Control Mean**	**Estimated Impact**	**Control Mean**	**Estimated Impact**	**Control Mean**	**Estimated Impact**
Sick in last 30 days	0.27	-0.01	0.15	-0.04**	0.13	-0.02
		(0.02)		(0.02)		(0.01)
Days sick in last 30 days$^{\diamond}$	2.24	-0.03	0.61	-0.14*	0.60	-0.09
		(0.20)		(0.07)		(0.07)
Observations	1988		1284		1451	

Note: *, **, and *** indicate significance at the 90, 95, and 99% confidence intervals, respectively. $\diamond$ indicates variables that have been winsorized at the 5% level. All regressions control for whether household head completed primary school, number of boys between 6 and 16 years old, and stratum fixed effects.

Table B12: Comparison of households in districts where women perform relatively more and relatively fewer oxen tasks

		Households in districts where	
Outcome	**Obs**	**women perform more oxen tasks**	**women perform fewer oxen tasks**
Household head: age	1836	42.34	-1.37
			(1.01)
Household head: no education	1836	0.80	-0.05
			(0.04)
Household head: some primary education	1836	0.10	-0.02
			(0.03)
Household head: completed at least primary school	1836	0.10	0.07**
			(0.03)
Household head: producer	1836	0.94	0.01
			(0.02)
Polygamous household	1836	0.46	-0.04
			(0.04)
Number of spouses	1836	1.57	-0.10*
			(0.06)
Age of first spouse	1781	35.43	-0.98
			(0.91)
Spouse has no education	1806	0.94	0.01
			(0.02)
Spouse completed primary school	1806	0.02	-0.01
			(0.02)
Men in household	1836	1.79	-0.20**
			(0.09)
Women in household	1836	1.99	-0.27**
			(0.12)
Boys aged 6-16	1836	1.64	-0.24*
			(0.14)
Girls aged 6-16	1836	1.32	-0.27**
			(0.12)
Number of elderly individuals over age 65	1836	0.11	-0.00
			(0.03)
Children under 5 years old	1836	1.96	-0.27*
			(0.15)
Total cotton production (kg)$^{\diamond}$	1836	5619.96	800.37**
			(362.86)
Total market value of production (USD)$^{\diamond}$	1836	3754.49	632.59**
			(280.01)
Value of agricultural products sold (USD)$^{\diamond}$	1836	4042.98	985.18**
			(413.11)
Total household income (USD)$^{\diamond}$	1836	4128.64	938.75**
			(419.38)
Household plots cultivated	1836	1.88	-0.13
			(0.10)
Total land holdings (ha)$^{\diamond}$	1836	13.97	0.38
			(0.82)
Total land cultivated (ha)$^{\diamond}$	1836	12.84	1.22
			(0.74)
Wife all or mostly responsible for food preparation	1576	0.95	-0.01
			(0.02)
Wife all or mostly responsible for laundry	1576	0.97	-0.02
			(0.03)
Wife all or mostly responsible for childcare	1576	0.63	0.07
			(0.05)
Violence justified if food burnt	1576	0.04	-0.01
			(0.02)
Violence justified if neglects children	1576	0.17	0.00
			(0.04)
Spouse hypothetical maximum income potential	1773	1790.15	177.58
			(255.30)

Note: Robust standard errors reported in parenthesis. *, **, and *** indicate significance at the 90, 95, and 99% confidence intervals.

Table B13: Heterogeneity for HHs in high women's decision-making districts

Outcome	Obs	Control Mean	Impacts in Districts where Women's Decision-making Power is Higher [1]	Lower [2]	p-value [1]=[2]
Total land cultivated (ha)$^{\diamond}$	1667	12.27	0.83	0.87*	0.96
			(0.50)	(0.44)	
Producer total active time	1667	69.88	-3.03	-0.77	0.48
			(2.62)	(1.82)	
Producer household plot labor supply	1667	43.09	-0.03	-1.06	0.56
			(1.28)	(1.21)	
Spouse total active time	1661	73.86	-1.27	-2.62	0.64
			(2.22)	(1.86)	
Spouse household plot labor supply	1660	38.05	-2.67**	-2.13*	0.76
			(1.32)	(1.23)	
Spouse other agric work	1662	0.85	0.01	0.02	0.97
			(0.27)	(0.26)	
Spouse non-farm labor	1662	6.07	-0.73	1.45**	0.06
			(0.94)	(0.69)	
Spouse household chores	1660	25.18	1.96	-1.97*	0.02
			(1.19)	(1.14)	
Spouse hobbies	1658	3.78	-0.06	0.09	0.83
			(0.51)	(0.53)	
Boys' total active time	1220	62.90	-0.80	-4.13*	0.36
			(2.79)	(2.35)	
Boys' household plot labor supply	1219	37.21	0.23	-2.03	0.37
			(1.71)	(1.83)	
Girls' total active time	1081	60.02	-1.44	-4.66*	0.39
			(2.73)	(2.51)	
Girls' household plot labor supply	1081	29.79	-0.79	-3.22*	0.32
			(1.76)	(1.67)	

Note: Robust standard errors reported in parenthesis. *, **, and *** indicate significance at the 90, 95, and 99% confidence intervals, respectively. † indicates hours in last week. All regressions include controls for household composition, household-head education, and stratum fixed effects.

Appendix C: Supplemental Time-Use Sample Tables

Table C1: Balance between treatment and control groups

Outcome	Obs	Control Group Mean	Treatment Difference
Household head: age	1836	42.53	-0.80
			(0.50)
Household head: no education	1836	0.80	-0.01
			(0.02)
Household head: some primary education	1836	0.11	-0.02
			(0.01)
Household head: completed at least primary school	1836	0.09	0.03**
			(0.01)
Household head: female	1836	0.00	0.00
			(.)
Household head: producer	1836	0.94	0.01
			(0.01)
Polygamous household	1836	0.45	-0.02
			(0.02)
Number of spouses	1836	1.56	-0.05
			(0.03)
Age of first spouse	1781	35.33	-0.77
			(0.48)
First wife: no education	1806	0.94	-0.02*
			(0.01)
Men in household	1836	1.82	-0.07
			(0.05)
Women in household	1836	1.94	-0.03
			(0.06)
Boys aged 6-16	1836	1.68	-0.21***
			(0.07)
Girls aged 6-16	1836	1.32	-0.04
			(0.06)
Children under 5 years old	1836	1.95	-0.07
			(0.07)
Pre-program cotton area (ha)	1568	3.66	0.04
			(0.10)
Pre-program cotton production (kg)	1568	3791.90	33.05
			(143.62)
Number of shocks in last year	1836	1.87	-0.10
			(0.07)
Household assets (PCA)	1836	6.29	-0.00
			(0.12)
Pre-program cotton area (ha)	1568	3.66	0.04
			(0.10)
Pre-program cotton production (kg)	1568	3791.90	33.05
			(143.62)

Note: Robust standard errors reported in parenthesis. *, **, and *** indicate significance at the 90, 95, and 99% confidence intervals. Pre-program cotton area and production come from cotton producer database.

Table C2: Impacts on agricultural output and land cultivated

Outcome	Obs	Control Mean	Estimated Impact
Prior Season			
Total cotton production (kg)$^{\diamond}$	1836	5407.10	352.94*
			(192.87)
Average cotton sale price (USD)	1724	1.79	-0.88
			(0.89)
Value of cotton sold (USD)$^{\diamond}$	1836	2786.18	165.76
			(115.54)
Market value of cotton production (USD)$^{\diamond}$	1836	2416.25	140.58
			(90.69)
Total market value of production (USD)$^{\diamond}$	1836	4007.60	53.08
			(137.28)
Value of non-cotton agric production (USD)$^{\diamond}$	1836	1174.46	-112.77
			(76.22)
Value of agricultural products sold (USD)$^{\diamond}$	1836	4450.69	-49.61
			(194.52)
Total non-farm income (USD)$^{\diamond}$	1836	42.29	5.93
			(4.17)
Total household income (USD)$^{\diamond}$	1836	4518.62	-28.74
			(196.40)
Total rice production (kg)$^{\diamond}$	1836	1485.24	127.61
			(82.57)
Total cashews production (kg)$^{\diamond}$	1836	871.71	-102.61
			(68.16)
Total maize production (kg)$^{\diamond}$	1836	2856.87	17.74
			(161.75)
Total yam production (kg)$^{\diamond}$	1836	131.12	5.48
			(20.17)
Current Season			
Household plots cultivated	1836	1.71	0.03
			(0.05)
Total land holdings (ha)$^{\diamond}$	1836	14.06	0.94**
			(0.39)
Total land cultivated (ha)$^{\diamond}$	1836	12.95	0.57*
			(0.34)
Total land cultivated w/ cotton (ha)$^{\diamond}$	1836	4.86	0.49***
			(0.15)

Note: *, **, and *** indicate significance at the 90, 95, and 99% confidence intervals, respectively. $\diamond$ indicates variables that have been winsorized at the 5% level. All regressions control for whether household head completed primary school, number of boys between 6 and 16 years old, and stratum fixed effects.

Table C3: Impacts on agricultural inputs

Outcome	Obs	Control Mean	Estimated Impact
Traction ox use			
Household used traction oxen	839	0.56	0.13***
			(0.03)
Number of plots where traction oxen were used	839	0.93	0.32***
			(0.08)
Share of plots where traction oxen were used	839	0.53	0.14***
			(0.03)
Household rented oxen	839	0.16	-0.03
			(0.02)
Non-labor inputs			
Share of household plots using organic fertilizer	839	0.82	0.05*
			(0.02)
Share of household plots using manure	839	0.59	-0.00
			(0.03)
Share of household plots using inorganic fert	839	0.94	0.00
			(0.01)
Share of household plots using phytosanitary products	839	0.95	0.01
			(0.01)
Cost of non-labor inputs for household plots (USD)$^{\diamond}$	839	1320.93	198.56**
			(85.78)
Labor inputs			
Total household plot hours in last week$^{\diamond}$	1836	234.82	-9.88*
			(5.38)
Total household plot hours in last week/ha$^{\diamond}$	1836	22.25	-1.64**
			(0.63)
Household hired labor	839	0.61	0.04
			(0.03)
Quantity of hired labor$^{\diamond}$	839	29.47	1.95
			(2.73)

Note: *, **, and *** indicate significance at the 90, 95, and 99% confidence intervals, respectively. Agricultural input usage only collected for half the sample. $\diamond$ indicates variables that have been winsorized at the 5% level. All regressions control for whether household head completed primary school, number of boys between 6 and 16 years old, and stratum fixed effects.

Appendix D: Return on Investment

This section details the assumptions underlying our return on investment calculations.

Benefits

The oxen yield two main benefits to farmers. First, they provide increase returns to agricultural production. Second, they provide a lump sum at the end of their working life when they are sold for slaughter.

In terms of agricultural production, we assume that the short-term impacts reflect new equilibrium farming outcomes and farmers have constant returns to scale. The point estimates suggest that the oxen increase household returns per hectare to $348.06/ha ((4342.99+56.53)/12.64). In the subsequent season, the increased returns combine with the increased land under cultivation (13.38ha) to yield aggregate household income of $4,657.09, or $314.09 more than the control group.

In addition to the increased agricultural returns, the oxen yield a lump sum at the end of their working life. The existing literature suggests a trade-off, with weight and associated sale price increasing during the first few years working and potentially trailing off as they age. Estimates suggest that farmers recoup between 55%-160% of the original oxen cost at sale (Okello et al., 2015; Takele, 2018; Kanu, 2000), with a mean recovery rate of 107%. Post-project discussions with non-sample farmers in the region suggested that most farmers would purchase a 3-year old oxen, keep it for 7 years, and expect to sell it for 130% of the original purchase price. They also noted that oxen would generally only be sold before 7 years or at a lower price due to a household shock.

We apply an annual discount rate of 5% to future benefits.

Costs

As with the benefits, there are two main costs: the purchase price of the oxen and ongoing care and maintenance. Unsubsidized, the pair of oxen cost US$916. We assume both a 5% interest rate and a 5% discount rate, yielding a total present value of US$916. Care and management cost estimates for a pair of oxen range from $86-$335 per year (Okello et al., 2015; Takele, 2018; Kanu, 2000), and we use the median annual maintenance costs of $214 for the total duration of ownership.

Return on investment

We assume that the annual oxen care and maintenance costs are paid from the increased agricultural production value, yielding $100 per year post-care but before repaying the oxen loan. We also assume a discount rate of 5% on costs and benefits.

Table D1 calculates the ROI for the pair of oxen under varying assumptions. Assuming no value at the end of a 7-year productive life, the oxen yield a present discounted value of US$579 at a cost of

US$916 for an ROI of -37%. With a working life of 7 years, oxen are profitable for any investment recovery rate greater than 52% while, with a working life of 5 years, they are profitable with a recovery rate greater than 67%. At the mean estimated recovery rate of 107%, the oxen yield an estimated return on investment of 39% over 7 years, or about 4.9% compounded annually. At the farmer reported recovery rate of 130% after 7 years, the oxen yield 6.5% compounded annually. At the subsidized price provided under the project, the oxen yield annualized rates of 15.8%-17.6%.

Table D1: Return on Investment

	Working years	**Interest rate**	**Recovery rate**	**Cost of 2 oxen**	**Net gain from investment**	**ROI**
	[1]	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**
Unsubsidized	5	5%	0%	$916	$433	-53%
	7	5%	0%	$916	$579	-37%
	5	5%	55%	$916	$828	-10%
	7	5%	55%	$916	$937	2%
	5	5%	107%	$916	$1,201	31%
	7	5%	107%	$916	$1,275	39%
	5	5%	130%	$916	$1,366	49%
	7	5%	130%	$916	$1,425	56%
	5	5%	160%	$916	$1,581	73%
	7	5%	160%	$916	$1,620	77%
Subsidized	5	5%	0%	$458	$433	-5%
	7	5%	0%	$458	$579	26%
	5	5%	55%	$458	$828	81%
	7	5%	55%	$458	$937	105%
	5	5%	107%	$458	$1,201	162%
	7	5%	107%	$458	$1,275	178%
	5	5%	130%	$458	$1,366	198%
	7	5%	130%	$458	$1,425	211%
	5	5%	160%	$458	$1,581	245%
	7	5%	160%	$458	$1,620	254%

Note: Column 5 reports net present value of benefits assuming an annual discount rate of 5%.