Impact of mechanization on smallholder agricultural production

evidence from Ghana

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Motivation

Mechanization of agriculture in international development

- A key technology to boost productivity and release labour from agriculture sector?
- An inappropriate technology for SSA smallholders, creating unemployment or reducing off-farm income opportunities?

Political economy minefield

- Governments importing and promoting machinery without regard for smallholder needs?
- Government-sponsored mechanization failed in 1980s; who benefits from the current schemes (Cabral 2016)?

Questions

i. Is mechanization really reducing **labour use** in agricultural production?

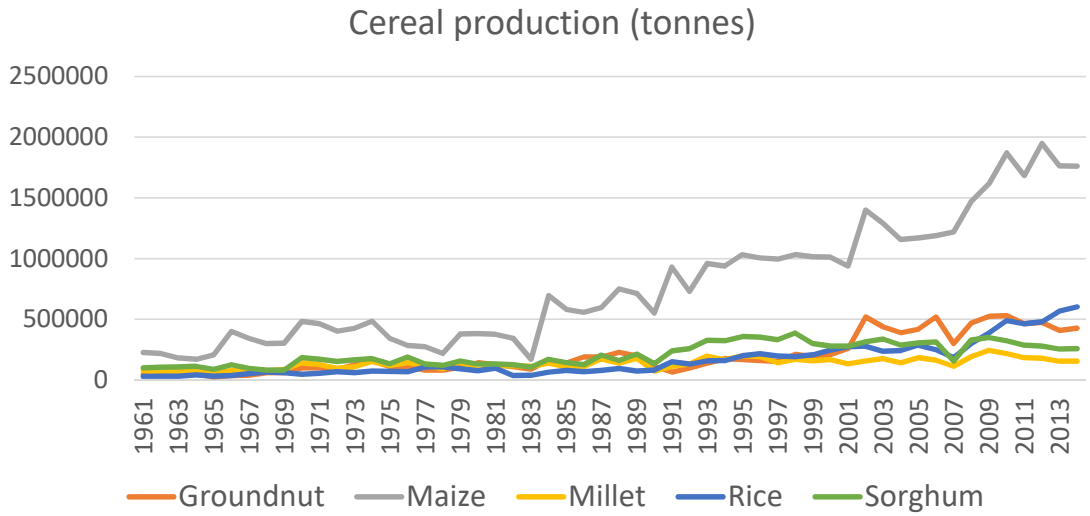
ii. In a low productivity system, can mechanization alone boost **productivity**?

iii. Without a land market, will mechanization ever happen? Do **scale** and mechanization go together?

iv. Will **gender disparities** just be exacerbated by introduction of capital-intensive machinery?

Methodology

Ghana context



Increased maize production in cereal-producing areas

Rising urbanization and economic growth

Tractor plowing associated with cereal production

Maize particularly requires early planting in the north

Most farmers access tractor plowing through service market, not ownership

Average hh farm size in northern region is 3.86ha

Percent of households using tractor plowing on at least one plot	
Northern savannah	93.37%
Transitional	6.26%
Forest	8.68%

Source: EGC/ISSER Socioeconomic Survey 2009

Empirical approach

To identify changes in agricultural production which can be attributed to use of tractor for land preparation:

- government scheme distributed agricultural machinery in Ghana over 2008-2010
  - 5-7 tractors per district
  - No other agricultural assistance attached to program
  - No systematic prioritization of district allocation
- government scheme simulates an exogenous positive shock to the supply of machinery services at the district level
- 2009-2010 EGC-ISSER Socioeconomic Panel Survey (round 1) is used to create pseudo treatment and control groups from those districts
  - single cross section covering 2009 main season.

Instrumental variable (2SLS) used to estimate Local Average Treatment Effect of mechanized plowing on outcome variables

- Effect is only estimated for farm household which were just-excluded from tractor service market.
- Short-term impact within season of using tractor plowing

Regression model

The model which would ideally be estimated is the following.

$$y_{ij} = \alpha + \beta T_{ij} + \gamma X_{ij} + \delta C_j + \epsilon_{ij} \quad (1)$$

The first stage regression, formulated as follows:

$$T_{ij} = \alpha + \beta Z_{ij} + \gamma X_{ij} + \delta C_j + \epsilon_{ij} \quad (2)$$

where:

y_{ij} : outcome variables for agricultural productivity, labour use, and the scale of production

T_{ij} : dummy variable taking the value 1 for households which used machine plowing on at least one plot

X_{ij} : set of variables capturing household characteristics such as quality of housing, assets, number of household members

C_j : set of district characteristics capturing population density, remoteness, welfare, election results, and length of growing period

Z_{ij} : dummy variable taking the value 1 for households in treated districts (received machine package before 2009 season), and 0 for households in control districts (received machine package after 2009 season).

Data

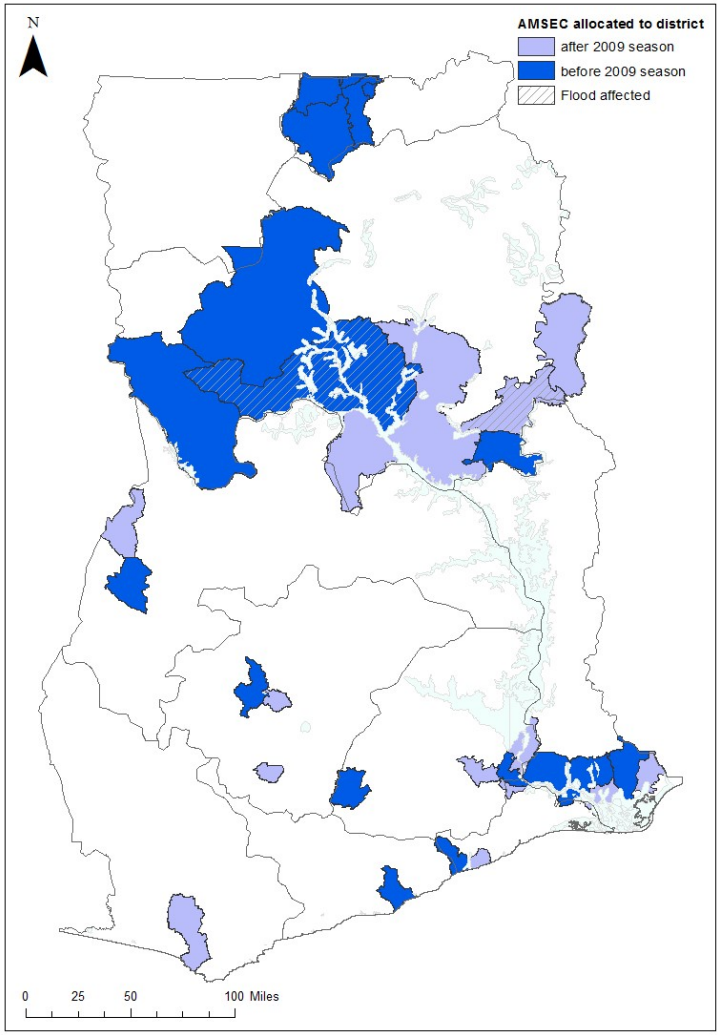


Table 1: Survey coverage, treatment and control groups

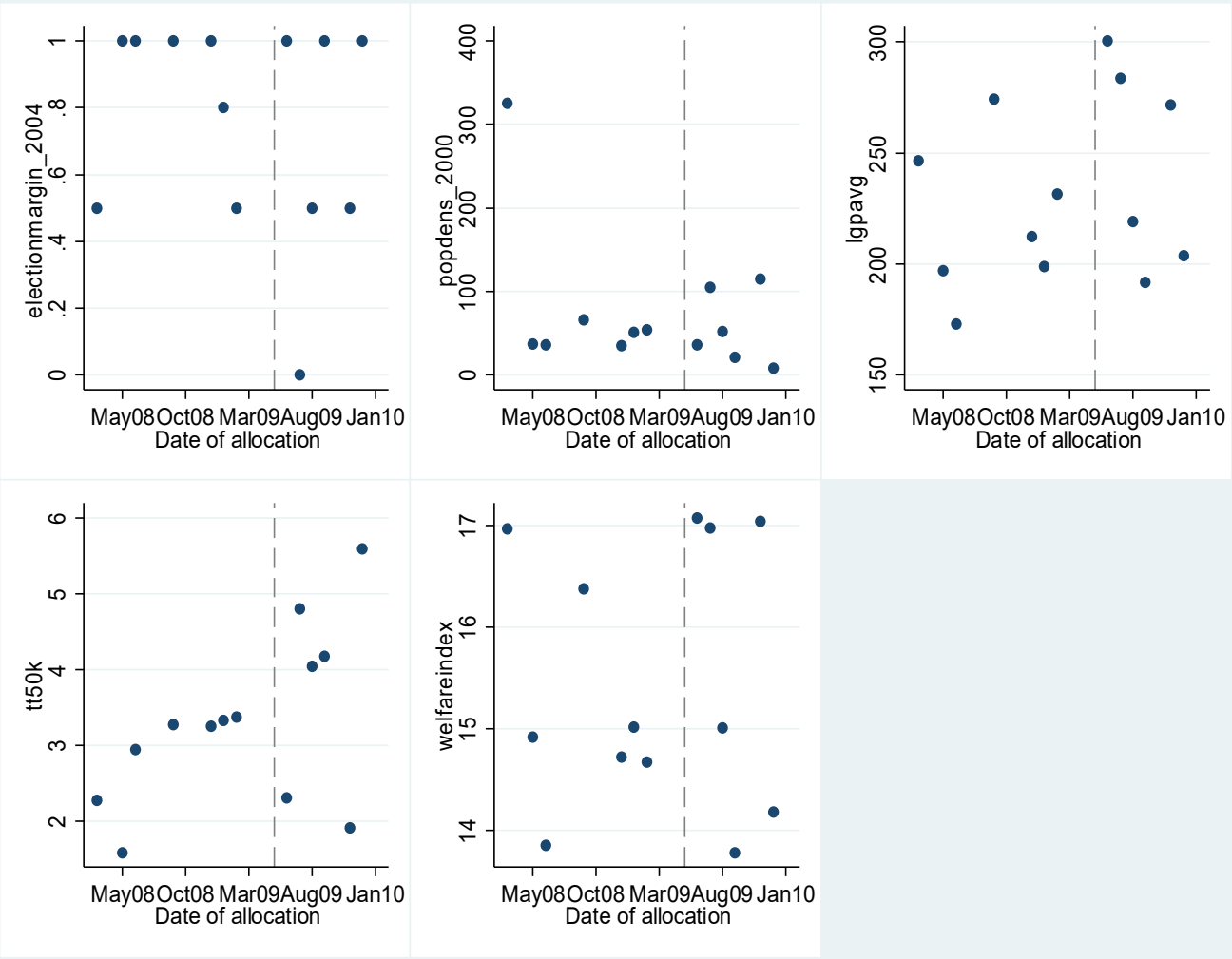
	No. of districts			No. of farm households		
Region	All survey	Treated	Control	All survey	Treated	Control
Western Region	10	0	1	465	0	23
Central Region	13	1	0	420	15	0
Greater Accra Region	4	1	1	585	20	7
Volta Region	14	1	2	495	36	76
Eastern Region	18	1	0	630	11	0
Ashanti Region	24	0	2	900	0	20
Brong Ahafo Region	19	3	1	510	32	15
Northern Region	18	3	4	584	74	118
Upper East Region	6	2	0	240	68	0
Upper West Region	5	4	0	180	147	0
	131	16	11	5009	403	259

Table 2: Balance between groups on household variables

	Control districts		Treated districts			
	Mean	n	Mean	n	Difference in means	p-value for equality of means
Female hh head	0.21	259	0.19	402	-0.02	0.54
Age of hh head	50.1	259	51.06	402	0.96	0.46
Education level of hh head	20.47	103	20.36	120	-0.11	0.88
Size of hh	5.09	259	4.85	402	-0.24	0.28
Urban area	0.13	259	0.07	402	-0.06	0.01
HH owns a motorbike	0.08	259	0.12	402	0.04	0.19
Hh head in-migrated less than 5 years ago	0.02	259	0.01	402	-0.01	0.48
Main dwelling has cement floor	0.31	259	0.14	402	-0.17	0.00
Land owned by hh (ha)	2.63	254	2.48	400	-0.15	0.50
% of land described as heavy clay	0.08	259	0.06	402	-0.02	0.09
% of land described as less wet than local community	0.12	259	0.08	402	-0.04	0.07
Contact with agricultural extension agent in last 12 months	0.08	259	0.05	402	-0.03	0.25

Sources: Data from EGC/ISSER Socioeconomic Panel Survey 2009/10, except: Population density source from IPUMS using 2000 Population and Housing Census (Government of Ghana); length of growing period and travel time to 50k town are from IFPRI's HarvestChoice; and Welfare Index is from the Core Welfare Indicator Questionnaire survey conducted in 2003.

Figure 1: Scatter plots of district variables by date of government allocation



Sources: Population density source from IPUMS using 2000 Population and Housing Census (Government of Ghana); length of growing period and travel time to 50k town are from IFPRI's HarvestChoice; and Welfare Index is from the Core Welfare Indicator Questionnaire survey conducted in 2003. Marginal election result is a dummy which takes the value 1 if the winner got less than 60% of the vote share, and zero otherwise. N is the number of districts.

Table 4: First stage regression

Dependent variable: Dummy for tractor use by hh on at least one plot in major season

	(1) OLS	(2) OLS	(3) OLS	(4) Probit	(5) Probit	(6) Probit
treated district	-0.09***	0.10**	0.11**	-0.33*	0.76**	0.69**
	(0.03)	(0.05)	(0.06)	(0.18)	(0.31)	(0.33)
Population density (2000, district)	-0.00*	-0.00***	-0.00***	0	0	0
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Length of growing period (district median)	-0.01***	-0.01***	-0.01***	-0.02***	-0.08***	-0.09***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.02)	(0.02)
Travel time to nearest 50k town (district median)	-0.12***	-0.11***	-0.11***	-0.35***	-0.27*	-0.35**
	(0.02)	(0.02)	(0.02)	(0.08)	(0.16)	(0.16)
Welfare index (district mean)	-0.14***	-0.02	-0.02	-0.90***	-0.15	-0.15
	(0.02)	(0.03)	(0.03)	(0.20)	(0.28)	(0.29)
Marginal election result (2004, district)	-0.15***	-0.11*	-0.13*	-0.43*	0.2	0.16
	(0.05)	(0.07)	(0.07)	(0.23)	(0.36)	(0.39)
regional fixed effects	no	yes	yes	no	yes	yes
household controls	no	no	yes	no	no	yes
R2/pseudo-R2	0.67	0.69	0.69	0.62	0.60	0.63
N	422	422	422	422	387	387
F-stat/Wald	534.69	.	768.58	170.00	389.52	330.78

Note: Household controls are: owning a motorbike, migrating into the area in last 5 years, main dwelling has a cement floor, no. of household members, age of household head, female household head, proportion of land described as heavy clay, contact with an agricultural extension agent, and being in an urban enumeration area. Standard errors are robust. Model (6) is used for subsequent second stage regressions.

Table 3: Summary of tractor use and impact variables

	Obs	Mean	Std. Dev.	Min	Max
Tractor use (on at least one plot in main season)	422	0.61	0.49	0	1
Yield (maize only, in kg)	233	566.81	440.12	5.19	1976.80
Output per person day of labour (kg)	258	9.79	11.42	0	70.18
Value of output per ha (cedis)	418	116.22	286.41	0	1562.69
Value of output per person-day (cedis)	258	4.67	9.50	0	50.10
Area cultivated (ha)	407	2.54	2.70	0	24.28
Area cultivated - maize (%)	252	63.89	32.30	10	100.00
Area cultivated - female holder (%)	407	20.78	40.26	0	100.00
Herbicide use per ha (kg)	182	1.55	5.25	0	45.83
Insecticide use per ha (kg)	182	0.07	0.51	0	6.18
Fertilizer use per ha (inorganic, kg)	182	30.05	63.38	0	247.10
Labour use per ha (land preparation, days)	394	22.96	19.53	0	70.63
Labour use per ha (field management, days)	393	27.22	26.04	0	95.31
Labour use per ha (harvest, days)	383	19.18	15.92	0	55.60
Labour use per ha (post harvest, days)	398	6.87	6.75	0	24.30
Labour use per ha (all operations, hours)	393	85.48	62.60	3.99	243.39
Labour share: family and exchange	412	73.66	30.82	0	100
Family labour share: female	392	40.15	28.66	0	100
Labour share: hired	412	26.34	30.82	0	100
Hired labour share: female	296	17.67	28.66	0	100

Note: Above variables are derived from the EGC/ISSER Socioeconomic Panel Survey 2009-10. Productivity and area variables were winsorized for high values at 0.5%. Chemical and labour use per ha were trimmed for extreme high values, and then winsorized for high and low values at 5%.

Results

i. Is mechanization really reducing labour use in agricultural production?

Labour use by operation (person days)	Land preparation			Field management			Harvest			Post Harvest		
	(1) OLS	(2) IV (conventional SE)	(3) IV with flood control	(1) OLS	(2) IV (conventional SE)	(3) IV with flood control	(1) OLS	(2) IV (conventional SE)	(3) IV with flood control	(1) OLS	(2) IV (conventional SE)	(3) IV with flood control
Tractor use	-8.77**	-8.72	-6.35	-0.32	39.28**	43.42**	0.97	33.92**	36.18**	1.71	10.92**	11.61**
	(4.04)	(12.79)	(13.66)	(5.32)	(17.09)	(18.55)	(3.29)	(13.72)	(15.13)	(1.27)	(5.37)	(5.88)
flood district (dummy)			5.18			8.71			3.76			1.2
			(4.79)			(6.63)			(4.53)			(1.82)
N	394	387	387	393	391	391	383	376	376	398	391	391
R2 adjusted	0.07	0.07	0.07	0.15	-0.05	-0.09	0.13	-0.2	-0.25	0.07	-0.09	-0.12
F-stat	3.73	2.15	2.13	292.33	3.24	3.01	4.94	2.85	2.62	2.5	1.83	1.71
F-stat (first stage excluded instruments)		31.74	27.95		33.15	29.21		21.17	18.14		22.46	19.18
Pagan & Hall's heteroskedasticity test (p-value)		0.88	0.89		1.00	1.00		1.00	1.00		1	1
Anderson-Rubin weak instrument F test (p-value)		0.51	0.65		0.01	0.01		0.00	0.01		0.03	0.04

Note: Tractor use is instrumented using the predicted values of 'treatment' variable from probit regression of tractor use on treatment, hh assets, size, and urban EA variables, population density, length of growing period, travel time, marginal election result, and regional fixed effects (model 6 in Table 4). The p-value for Pagan and Hall's (1983) test of heteroskedasticity for instrumental variables (IV) estimation (null is homoscedasticity) is reported. For significance test of tractor use that is robust to a weak instrument in the first stage, the p-value for the Anderson-Rubin F statistic for the significance of the coefficient on tractor use is reported.

Conventional standard errors are reported. Robust standard errors, adjusted for small samples, and bootstrapped standard errors are also reported in the full paper and do not change the significance of the results.

ii. In a low productivity system, can mechanization alone boost productivity?

	Yield (maize, kg per ha)			Labour productivity (maize, kg per person day)			Output value per ha (all crops, cedis)			Output value per person day (all crops, cedis)		
	(1) OLS	(2) IV with area control	(3) IV with flood control	(1) OLS	(2) IV with area control	(3) IV with flood control	(1) OLS	(2) IV with area control	(3) IV with flood control	(1) OLS	(2) IV with area control	(3) IV with flood control
Tractor use	41.77	-190.2	-182.6	1.85	-8.94	-9.66	-27.11	207.97	169.55	1.07	9.44	10.15
	(116.01)	(256.83)	(271.11)	(2.46)	(9.08)	(9.30)	(44.58)	(176.39)	(184.22)	(2.03)	(7.48)	(7.68)
Area owned by hh (ha)		13.8			0.31			-14.37**			0.24	
		(10.83)			(0.27)			(5.59)			(0.22)	
flood district (dummy)			-78.32			-3.56			42.29			-0.67
			(115.92)			(2.82)			(64.18)			(2.33)
N	233	233	233	258	256	258	418	411	411	258	256	258
R2 adjusted	0.08	0.07	0.06	0.19	0.12	0.11	0.27	0.23	0.23	0.2	0.14	0.13
F-stat	2.03	1.98	1.92	3.92	3.49	3.49	7.87	7.59	7.36	4.13	3.78	3.71
F-stat (first stage excluded instruments)		48.85	44.64		18.52	17.96		26.94	24.81		18.52	17.96
Pagan & Hall's heteroskedasticity test (p-value)		1	1		0.75	0.97		0.01	0.21		0.98	1
Anderson-Rubin weak instrument F test (p-value)		0.48	0.52		0.33	0.3		0.24	0.36		0.21	0.19

iii. Do scale and mechanization go together?

	Area cultivated (total)			Area cultivated (maize)		
	(1) OLS	(2) IV (conventional SE)	(3) IV with flood control	(1) OLS	(2) IV (conventional SE)	(3) IV with flood control
Tractor use	0.53**	4.32**	4.94***	12.70***	9.78	16.82
	(0.23)	(1.70)	(1.89)	(4.37)	(20.78)	(21.82)
flood district (dummy)			1.17*			11.51*
			(0.62)			(6.06)
N	407	400	400	252	252	252
R2 adjusted	0.38	0.23	0.19	0.51	0.5	0.51
F-stat	13.23	10.46	9.47	37.1	13.57	13.22
F-stat (first stage excluded instruments)		25.95	22.38		16.96	15.14
Pagan & Hall's heteroskedasticity test (p-value)		1	1		1	1
Anderson-Rubin weak instrument F test (p-value)		0.01	0		0.66	0.47

iv. Will **gender disparities** just be exacerbated by introduction of capital-intensive machinery?

	Total labour hours - female			Total labour hours - male			Female labour as share of family labour		
	(1) OLS	(2) IV (conventional SE)	(3) IV with flood control	(1) OLS	(2) IV (conventional SE)	(3) IV with flood control	(1) OLS	(2) IV (conventional SE)	(3) IV with flood control
Tractor use	8.63	145.48**	168.27**	19.67	197.76	221.84	4.15	38.69**	42.29*
	(10.79)	(70.66)	(77.89)	(19.46)	(134.63)	(146.72)	(4.28)	(19.32)	(21.79)
flood district (dummy)			45.99*			48.62			5.83
			(26.97)			(50.80)			(6.94)
N	422	415	415	422	415	415	392	385	385
R2 adjusted	0.11	-0.02	-0.06	0.15	0.11	0.09	0.34	0.22	0.19
F-stat	6.05	3.29	3.07	7.41	4.60	4.32	7.32	8.81	8.13
F-stat (first stage excluded instruments)		28.71	24.75		28.71	24.75		21.07	17.24
Pagan & Hall's heteroskedasticity test (p-value)		1.00	1.00		0.00	0.00		0.93	0.98
Anderson-Rubin weak instrument F test (p-value)		0.03	0.02		0.14	0.13		0.03	0.04

iv. Will **gender disparities** just be exacerbated by introduction of capital-intensive machinery?

	Area cultivated (female holder/cultivator, %)		
	(1)	(2)	(3)
	OLS	IV (conventional SE)	IV with flood control
Tractor use	2.16	26.76**	27.99**
	(1.55)	(11.97)	(13.03)
flood district (dummy)			2.31
			(4.29)
N	407	400	400
R2 adjusted	0.86	0.82	0.82
F-stat	631.15	93.65	87.77
F-stat (first stage excluded instruments)		25.95	22.38
Pagan & Hall's heteroskedasticity test (p-value)		0.05	0.08
Anderson-Rubin weak instrument F test (p-value)		0.02	0.02

Conclusions

Summary of the impacts of tractor plowing:

Labour	Labour use increases for operations other than land preparation ➢ Time constraint, rather than labour constraint, is motivating tractor use
Scale	Total area and proportion allocated to maize cultivation increases ➢ Time constraint is holding back the shift into maize cultivation
Productivity	No significant impact on land or labour productivity ➢ Either no effect, or measurement issues obscuring effect
Gender	Women increase their labour hours and control of a greater proportion of hh cultivated land ➢ Labour constraint more binding for women, tractor use increases their participation in agricultural production

Some implications of these results…

For smallholder farmers, machinery use is motivated by alleviating a **time constraint** for land preparation and planting, rather than a labour cost constraint.

→ weakness in the service market bears a cost for farmers

→ mechanization may be a response to increasing volatility of rainfall patterns, resulting from climate change

For women who may have **difficulty accessing labour** at peak times, mechanization has greater impact on they extent they farm, compared to men.

→Mechanization of land preparation may be improving women's engagement in agricultural production

Robustness checks

Table 1: Treatment Effect Regression Model (two-step control function method)

								Labour days per ha			
	Yield (kg/ha)	Labour productivity (kg/day)	Output per ha (USD)	Output per person day (USD)	Area cultivated (ha)	Area cultivated - maize (%)	Area cultivated - female (%)	land preparation	field management	harvest	post harvest
Tractor use	-229.43	-9.59	140.63	6.54	3.17**	1.2	19.83**	-11.39	25.80*	25.78**	11.66**
	(225.70)	(7.01)	(147.88)	(5.77)	(1.34)	(17.49)	(9.63)	(11.11)	(14.30)	(10.02)	(4.3(
λ (inverse Mill ratio)	193.56	7.13*	-98.99	-3.4	-1.55**	7	-10.35*	1.56	-15.54*	-14.44***	-5.79*
	(137.46)	(4.02)	(83.01)	(3.36)	(0.74)	(10.09)	(5.34)	(6.27)	(7.96)	(5.45)	(2.3(
N	233	258	418	258	407	252	407	394	393	383	39
Chi2 (joint significance) statistic	86.58	134.99	299.52	143.75	379.67	345.2	2497.74	159.79	201.71	181.6	165.6

	Total labour days				Chemicals (kg/ha)		
	Female	Male	female labour share of family labour	hired share of total labour	Herbicide	Insecticide	Inorganic fertilizer
Tractor use	99.97*	135.2	31.76**	8.38	8.74**	-0.71**	-8.58
	(58.60)	(124.58)	(15.33)	(17.01)	(3.67)	(0.35)	(42.59)
λ (inverse Mill ratio)	-53.80*	-68.05	-16.17*	-3.66	-6.44***	0.33	18.9
	(32.70)	(69.95)	(8.52)	(9.51)	(2.17)	(0.21)	(26.65)
N	422	422	392	412	182	182	182
Chi2 (joint significance) statistic	202.55	222.48	328.26	293.63	114.8	95.66	96.77

Note: Where the estimated coefficient on λ is significantly different from zero, there is evidence of endogeneity therefore OLS estimates are inconsistent and these endogenous treatment effects should be used. Stata program etregress with two-step option used which estimates the first stage using probit model. See Wooldridge, (2010, sec. 21.4.2) for details on the method used for estimation.

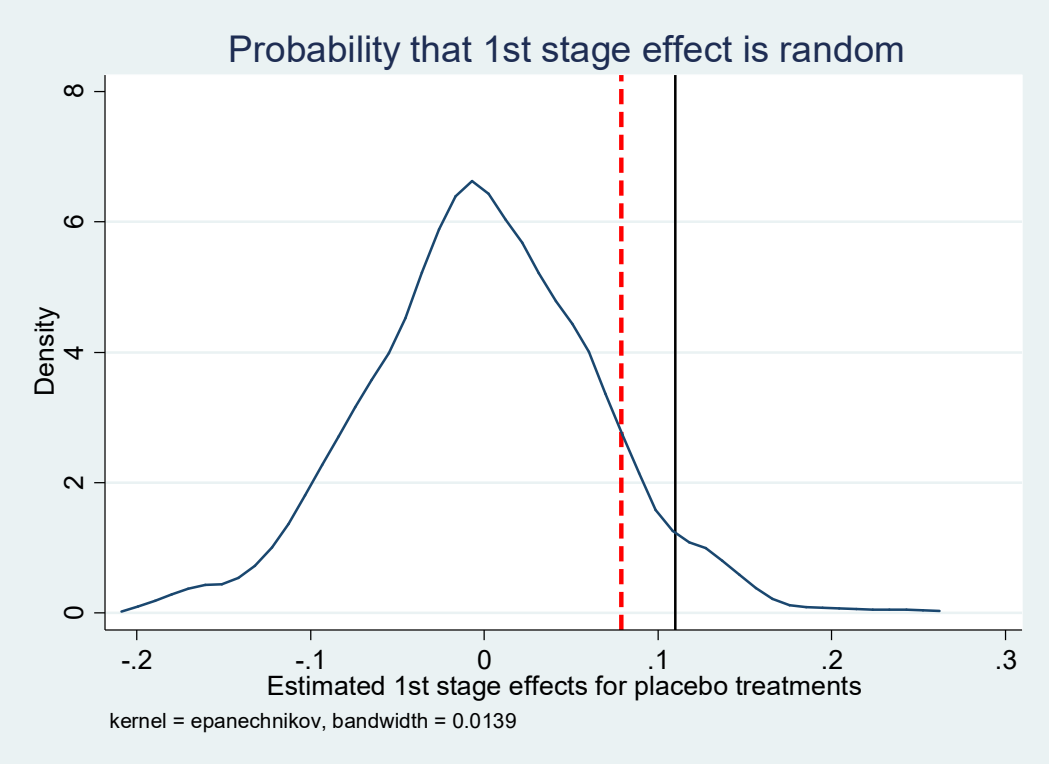


Figure A 1: First stage regression using placebo treatment and control groups

Notes: Placebo treatment is created by generating a random variable between (0,1), then assigning districts with random number greater than 0.5 to a placebo treatment group. 1,000 random draws were used to estimate the coefficient of treatment dummy from the first stage regression (same as model (3) from table 4). This was done for the same 28 districts as in the main sample. These first stage effects are plotted as a density function. The red dashed line indicates the 90^{th} percentiles of the distribution. The solid black line is 0.11 which is the estimated effect from table 4 (model 3).

Thank you

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