Gendering Technological Change: Evidence from Agricultural Mechanization

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- Increasing agricultural mechanization in India
  - Tractor penetration in India: 1 million in 1990, doubled to 2 million in 2000 and tripled to 6 million in 2011
  - Subsidies on machinery and agri credit

Research Question

- What are the labor impacts of technological change in agriculture?
- Does the gendered division of labor in agriculture lead to gender differentiated labor impacts?
- What is the role of economic structure, if any?

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- The estimates suggest that increased mechanized tilling led to a more than 22% fall in women's agricultural labor in India, with no accompanying increase in their non-farm sector employment, during 1999-2011.
- Results highlight the gendered impact of technological change in contexts where there is sex-specific specialization of labor.

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Gendered Division of Labor

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  - Physical labor intensive Stage 1 - land preparation, primary and secondary tilling
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  - Stage 3 - harvesting and threshing

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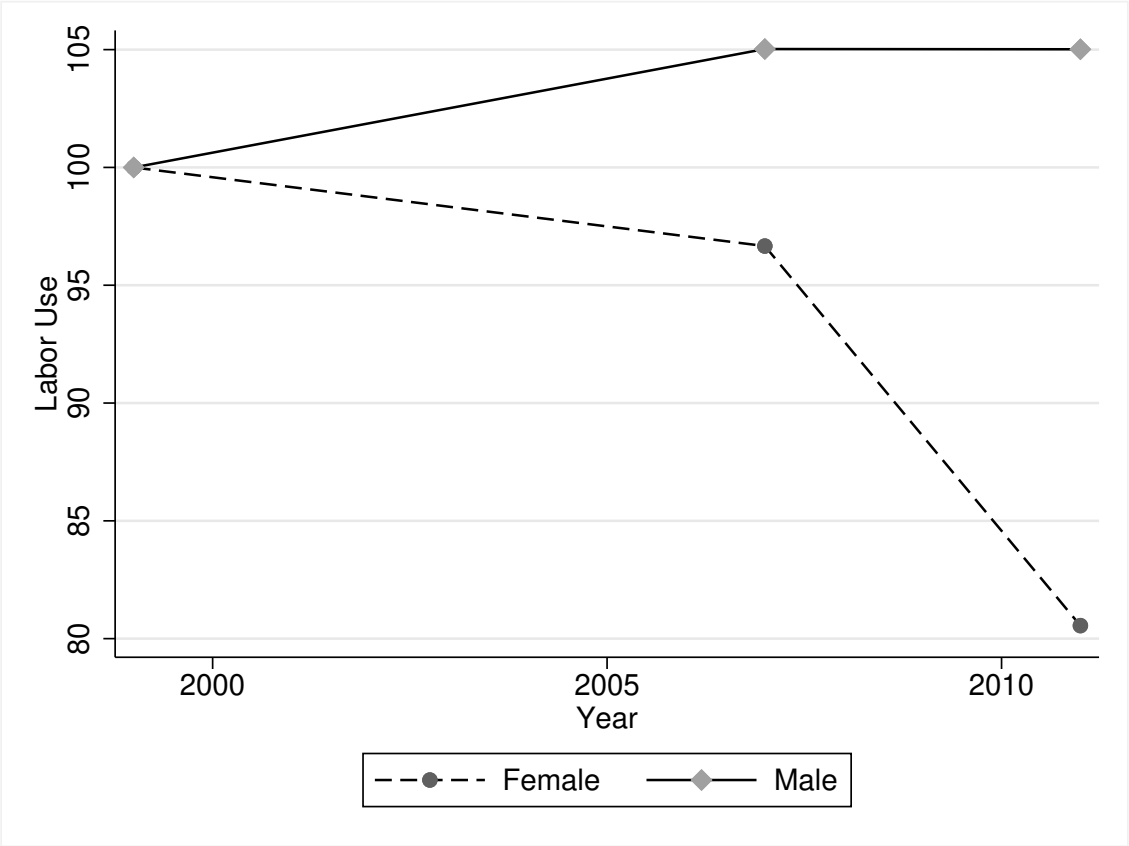
Table: Gender composition across tasks

	Tilling	Sowing	Weeding	Harvesting
Proportion Female Labor	9%	33%	38%	30%

Labor Use=Total employment in farm sector/Cultivated area



- Agricultural implements can be classified into:
  - Hand operated
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  - **Power operated** (diesel, electric etc)
    - Tractor or Power tiller driven
    - Self-propelled

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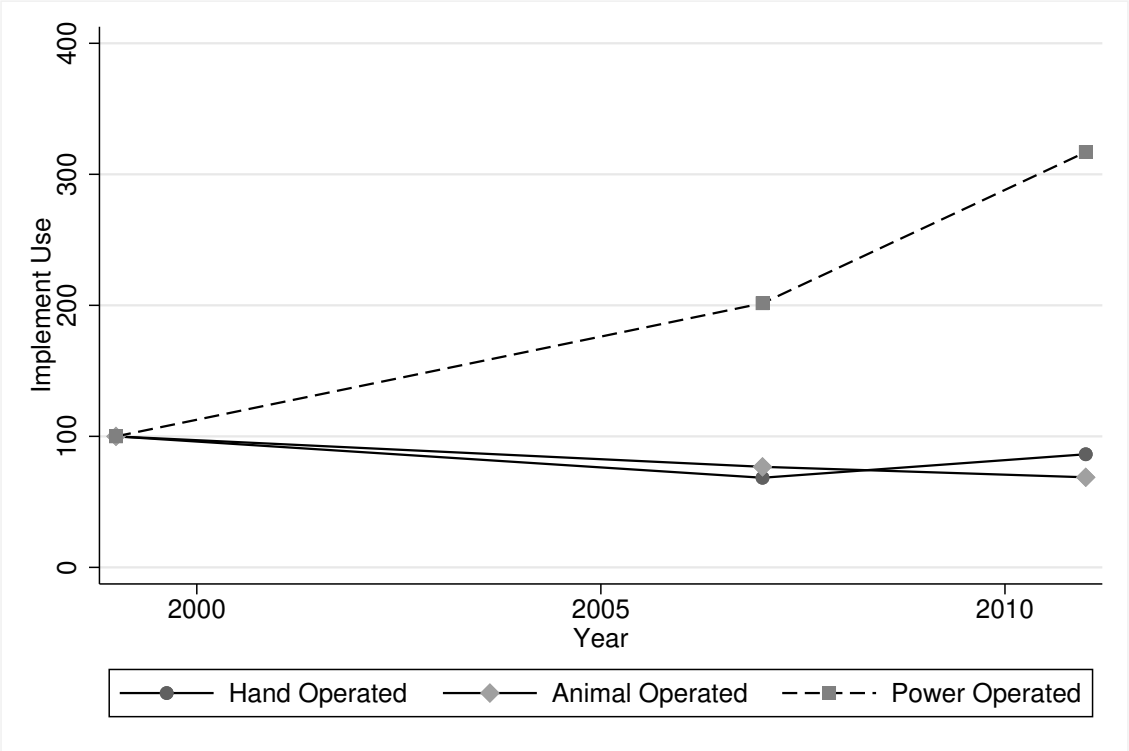
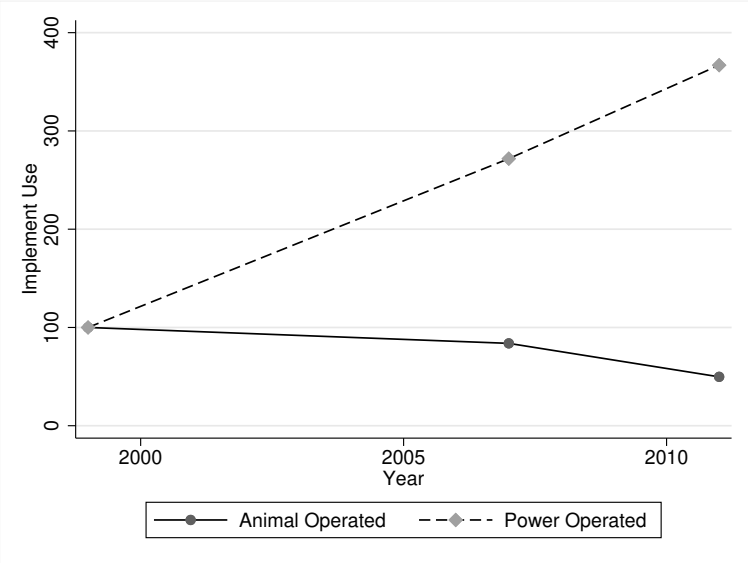
- Mechanization: Adoption of power operated implements

Implement Use=Area under type of implement/Cultivated area

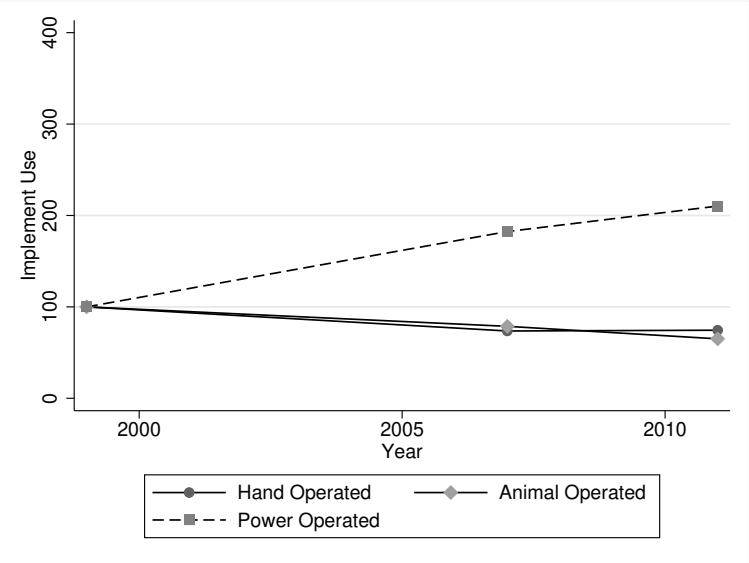


Background

Farm mechanization by operation: Stage 1



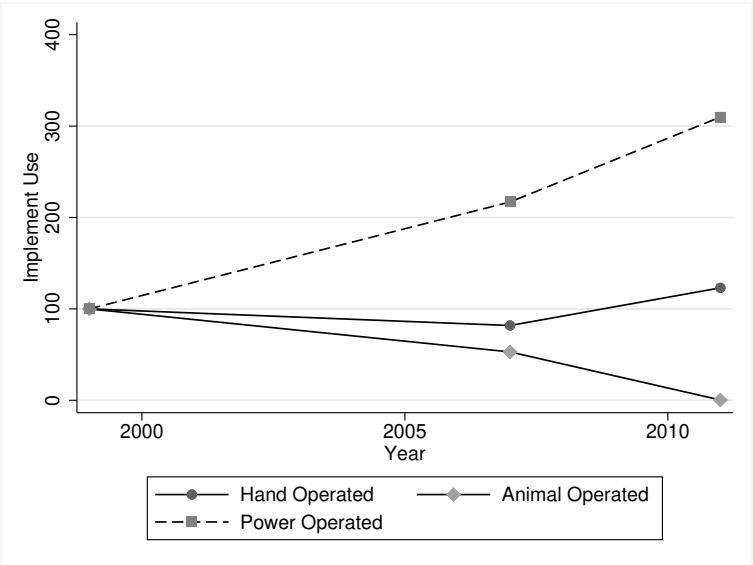
Stage 1: Primary Tilling



Stage 1: Secondary Tilling

Background

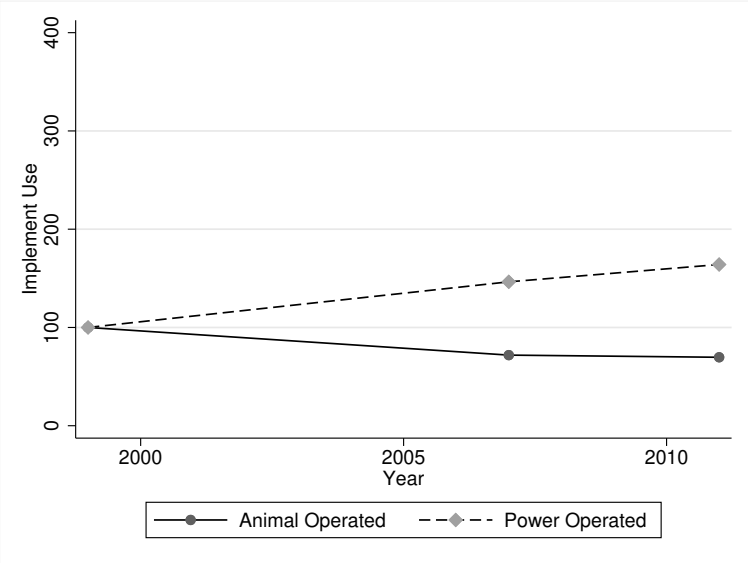
Farm mechanization by operation: Stage 3



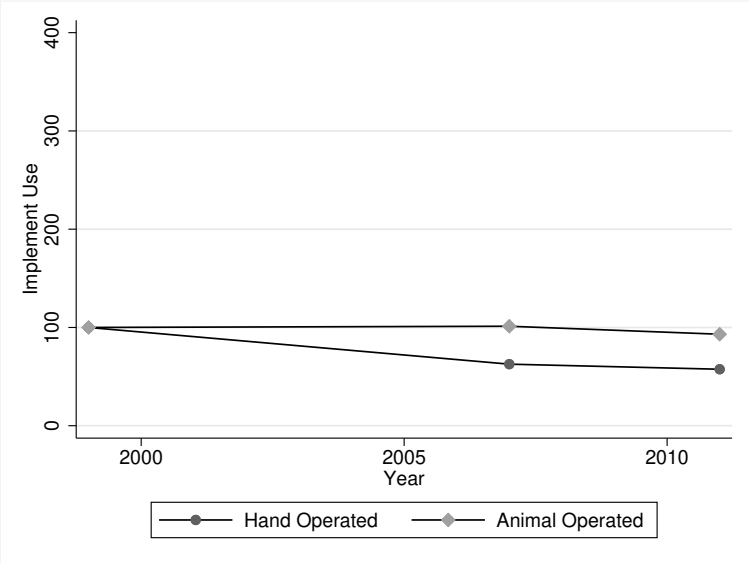
Stage 3: Harvesting

Background

Farm mechanization by operation: Stage 2



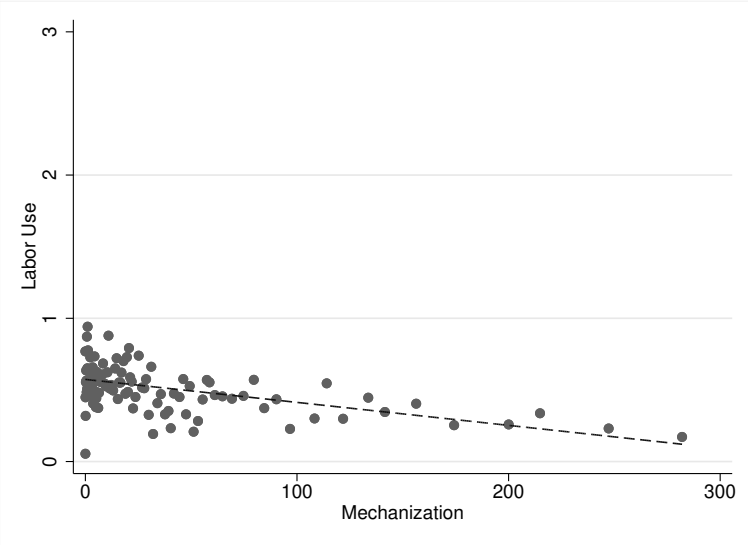
Stage 2: Sowing



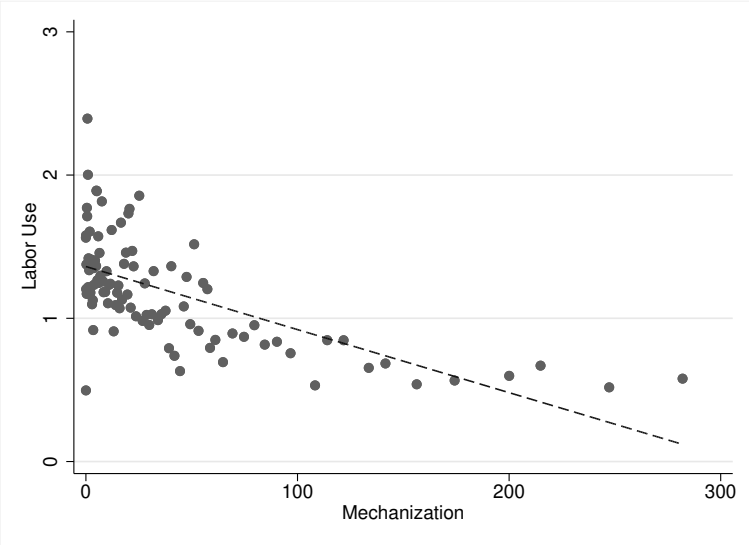
Stage 2: Weeding

- Mechanization in Stage 1 (primary and secondary tilling machines driven by tractor or power tiller)
  - Primary tilling machines
  - Secondary tilling machines

Mechanization (Stage 1) and Farm Labor Use



Female Labor



Male Labor

Literature

- Homogeneous agri labor (Pingali 2007)
  - 22 of the 24 studies reviewed reported lower total labor use per hectare of crop production for tractor farms compared to draft animal farms
  - 12 studies reported reductions in labor use of 50% or more.
  - Reduction in labor use for land preparation followed by weeding

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  - 22 of the 24 studies reviewed reported lower total labor use per hectare of crop production for tractor farms compared to draft animal farms
  - 12 studies reported reductions in labor use of 50% or more.
  - Reduction in labor use for land preparation followed by weeding
- Gender differentiated impacts have been ignored in the literature
  - Mechanization unlikely to affect male and female labor equally, since men and women are not only imperfect substitutes but their degree of complementarity with machinery also differs

Theoretical Model

- Technological change unlikely to affect male and female labor equally when they are imperfect substitutes in the production process

Theoretical Model

Final good production

- Final good (Y_a) is produced using two inputs:labor (L_a) and land (T_a), CES Production function

$$Y_a(L_a, T_a) = A_a[\theta(A_L L_a)^{\frac{(\sigma-1)}{\sigma}} + (1-\theta)(A_K T_a)^{\frac{(\sigma-1)}{\sigma}}]^{\frac{\sigma}{(\sigma-1)}}. \quad (1)$$

A_a: Hicks-neutral technological change
A_L: labor-augmenting technological change
A_K: land-augmenting technological change
$\sigma > 0$: elasticity of substitution b/w labor and land
$\theta \in (0, 1)$: relative importance of these two factors of production

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- Assumption: $\sigma < 1$ (labor and land are complementary)

- Decompose total labor L_a: female labor (F_a) and male labor (M_a)

$$L_a(F_a, M_a) = [\alpha F_a^{\frac{(\epsilon-1)}{\epsilon}} + (1-\alpha) M_a^{\frac{(\epsilon-1)}{\epsilon}}]^{\frac{\epsilon}{(\epsilon-1)}}. \quad (2)$$

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$\epsilon > 0$: elasticity of substitution b/w female and male labor
$\alpha \in (0, 1)$: relative weight of male and female labor

Theoretical Model

Optimization

- Optimization: Farmer maximizes profit

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- First order condition:

$$P_a \frac{\partial Y_a}{\partial F_a} = w_F \tag{3}$$

$$P_a \frac{\partial Y_a}{\partial M_a} = w_M \tag{4}$$

$$P_a \frac{\partial Y_a}{\partial T_a} = R \tag{5}$$

where:

- w_F and w_M: equilibrium wages of female and male labor
- R: factor price of land
- P_a: Price of final good

Theoretical Model

Assumptions

- Hicks neutral productivity change due to mechanization: increase productivity of both land and labor

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- Hicks neutral productivity change due to mechanization: increase productivity of both land and labor
- Gender difference in wage rates and weights (empirically validated)
  - $w_m > w_f$
  - $(1 - \alpha) > 0.5$

Theoretical Model

Conditions

- Derive condition on ϵ, such that the below hold
  - The female-land labor intensity $\left(\frac{F_a}{T_a}\right)$ decreases when A_a increases
  - The male-land labor intensity $\left(\frac{M_a}{T_a}\right)$ decreases when A_a increases
  - The male-female labor intensity $\left(\frac{M_a}{F_a}\right)$ increases when A_a increases

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- Set of ϵ: lower bound $\leq$ (but not zero); upper bound $>$ than 1 but finite
- Male and female labor should be **Imperfect Substitutes**

Data

- District level data from multiple sources:
  - Mechanization: Agricultural Input Censuses (1997-99, 2006-07 and 2011-12)
  - Employment: National Sample Survey (1999, 2007, 2011)
  - Soil characteristics: digitize soil maps of India to get information on soil texture, pH, depth, slope
  - Other agri characteristics: Crop composition, rainfall, temperature, irrigation, landholding size, urban population (land use, APY statistics, Census of India)
  - Demographics, agri inputs, economic development (NSS, Census of India, input census, fertilizer association of India, DMSP)

Soil Maps

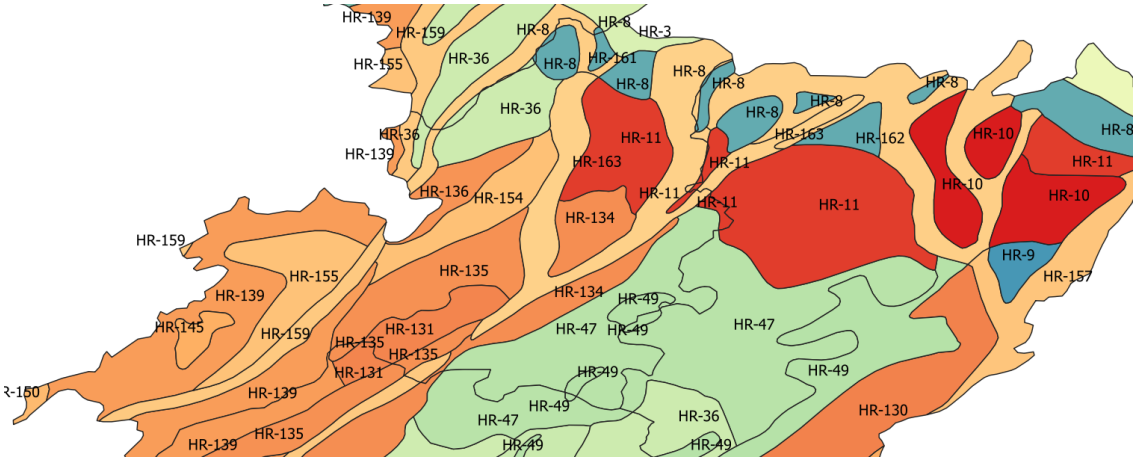

Figure: Haryana Map (1)

Source: National Bureau of Soil Survey (1995-98) Maps

Soil (surface texture): District level variation

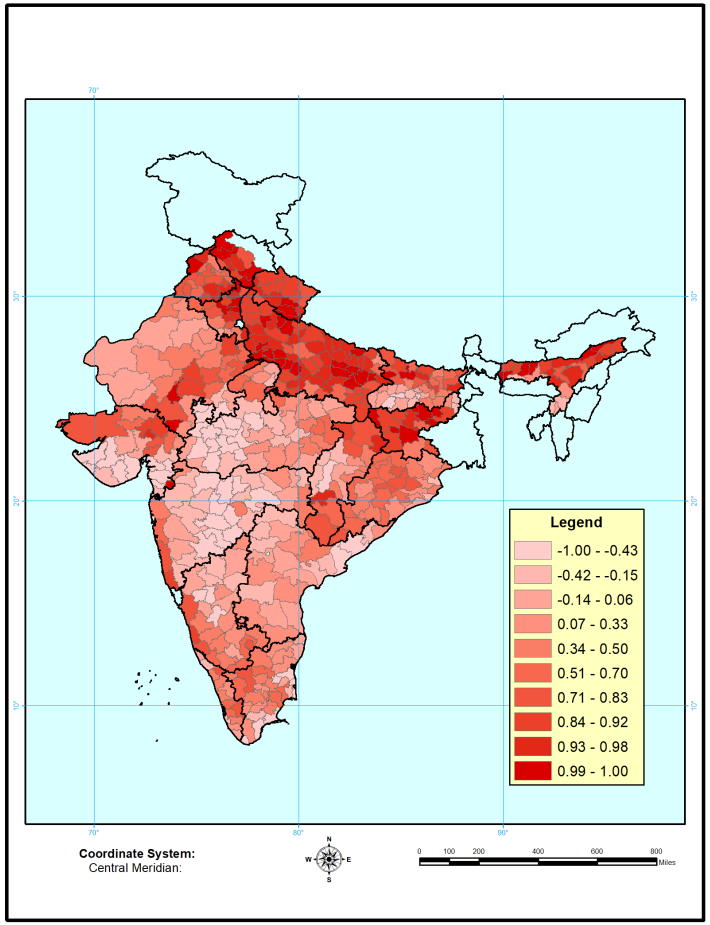

Figure: (%Loamy-%Clayey)

Source: Digitized by authors from National Bureau of Soil Survey (1995-98) Maps

Data: Mechanization

- Input census: area cultivated under each of the implements in that agricultural year

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- Input census: area cultivated under each of the implements in that agricultural year
- Classify them by operation:
  - Primary Tillage: tractor driven mould board plough, rotavator, cultivator
  - Secondary Tillage: tractor driven disc harrow, leveller, cagewheel

Data: Summary statistics

Variable	1999		2007		2011	
	Mean	SD	Mean	SD	Mean	SD
Total number of females in farm cultivation aged 15-65/cultivated area:						
Female labor per hectare	0.563	0.423	0.544	0.384	0.454	0.350
Total number of males in farm cultivation aged 15-65/cultivated area:						
Male labor per hectare	1.15	.635	1.21	0.674	1.21	0.727
Area operated under power operated machines/cultivated area						
Mechanization (Primary +Secondary Tilling)	18.6	36.8	40.3	51.9	50.4	62.9
Primary Tilling	7.25	14.3	19.7	25.0	26.6	34.8
Secondary Tilling	11.3	23.9	20.6	28.7	23.8	30.6

Empirical Strategy: 2SLS Estimation

$$L^g_{dst} = \beta^g_0 + \beta^g_1 MC_{dst} + X^g_{dst}\beta^g_2 + X_{dst}\beta^g_3 + D_s + D_t + \epsilon^g_{dst} \quad (6)$$

- Here, d refers to district, in state s at time t and for gender $g \in (F, M)$.
- Time: 1999, 2007, 2011
- Dependent variable: labor employed per unit of cultivated land (L) (inverse hyperbolic sine transformation).
- MC: Area under primary and secondary tilling implements/cultivated area.
- X_{dst}: other district controls,
- D_s are state fixed effects and D_t are time fixed effects.
- Since MC is likely to be endogenous, we instrument for it using the difference in loamy and clayey composition of the soil.

Empirical Strategy: 2SLS Estimation (First Stage)

$$MC_{dst} = \pi_0^g + \pi_1^g Loaminess_{ds} + X_{dst}^g \pi_2^g + X_{dst} \pi_3^g + D_s + D_t + e_{dst}^g \quad (7)$$

Here, *Soil Texture* is defined as the difference in the proportion of loamy and clayey soils in district d, in state s. Since this is an initially given endowment, it does not vary over time.

Instrumental Variable: Mechanization in Stage 1

- Extent of machine uptake in tilling: depth of required tillage
  - Primary or deep tilling (at least 45 cm of soil turned over), power intensive
  - Followed by secondary tillage or sowing
- Primary tilling: more amenable in loamy than clayey content of soil (Muller and Schindler (1999); Wildman (1981); Basant (1987))
- Higher loamy soil content, more likely to use deep tilling/ploughing implements
- Once tractors adopted for primary tillage, shallow tilling can be mechanized too (tractor driven implements)

IV Validity

(1)	(2) Loaminess	(3) Observations	(4) R-Squared
Panel A: Labor use per hectare			
Male labor per hectare	0.01	411	0.63
	(0.042)		
Female labor per hectare	-0.048	411	0.45
	(0.043)		
Panel B: Wage rate and income			
Wage Rate - Female	-0.02	363	0.5
	(0.044)		
Wage Rate - Male	-0.054	397	0.58
	(0.034)		
MPCE	-0.0031	411	0.47
	(0.026)		
Panel C: Cropping pattern and yields			
Ratio of Cropped area : Wheat by Rice	-10.25	388	0.21
	(5.581)		
Wheat Yield	0.052	330	0.79
	(0.054)		
Rice Yield	0.048	388	0.73
	(0.061)		

Note: All outcomes measured pre 1999. Each row shows the coefficient on loaminess i.e. the difference in loamy and clayey soil texture in a district, when the outcome variable (col 1) is regressed on loaminess, state fixed effects and other soil characteristics like pH, slope and depth of the soil. Robust standard errors in parentheses

IV Validity

- Soil texture may have direct effects on employment
  - soil texture affects soil fertility - concern alleviated in results for yields/wages/expenditure above
  - historically women are more disadvantaged in areas requiring more primary tilling (Carranza 2014) - check for rice/wheat ratio (Alesina, Giuliano and Nunn 2013) and also control for it; check for labor use in 1993 and also control for it
  - norms around women's labor - check for it but still control labor use in 1993

Other Controls

- *Initial Employment*: Labor use by gender in 1993
- *Agriculture*: Crop composition, rainfall, temperature, % urban, average land size, %Irrigated area
- *Lagged Input*: Fertilizer
- *Development*: Approach road and nightlights

Effect of Mechanization on Farm Labor Use: OLS Estimates

	(1)	(2)	(3)	(4)
Panel A: Female labor per hectare				
Mechanization	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	1077	1077	1077	1073
R-squared	0.524	0.538	0.545	0.557
Panel B: Male labor per hectare				
Mechanization	-0.000**	-0.000**	-0.000**	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	1077	1077	1077	1073
R-squared	0.712	0.721	0.724	0.749
Controls				
Agriculture	✓	✓	✓	✓
Demographic		✓	✓	✓
Development			✓	✓
Lagged Agri Input				✓

Note: All specification have State and Year Fixed Effects and initial employment; Robust standard errors clustered at the district level in parentheses

Effect of Soil Texture on Tilling Mechanization: First Stage

	(1)	(2)	(3)
	Primary Tilling	Secondary Tilling	Mechanization (Total)
Loaminess	6.363***	5.773***	12.14***
	(1.939)	(1.770)	(3.373)
Constant	29.51	-29.29	0.219
	(44.05)	(40.32)	(77.53)
F-Stat	10.76	10.64	12.94
N	1073	1073	1073

Note: All specification have State and Year Fixed Effects and initial employment; Controls for agriculture, demographic, agricultural inputs and development. Robust standard errors clustered at the district level in parentheses

The measure of mechanization: power operated implement adoption in Primary and Secondary tillage

Effect of Mechanization on Farm Labor Use: 2SLS Estimates

	(1)	(2)	(3)	(4)
Panel A: Female labor per hectare				
Mechanization	-0.007*	-0.008**	-0.008**	-0.007**
	(0.004)	(0.004)	(0.004)	(0.003)
Observations	1077	1077	1077	1073
FS F-Stat	7.744	9.728	9.471	12.941
Panel B: Male labor per hectare				
Mechanization	-0.001	-0.001	-0.001	-0.001
	(0.003)	(0.003)	(0.003)	(0.002)
Observations	1077	1077	1077	1073
FS F-Stat	7.890	9.486	9.262	12.950
Test of Equality[p-value] Female=Male	0.113	0.068	0.090	0.079
Controls				
Agriculture	✓	✓	✓	✓
Demographic		✓	✓	✓
Development			✓	✓
Lagged Agri Input				✓

Note: All specification have State and Year Fixed Effects and initial employment; Robust standard errors clustered at the district level in parentheses

Effect of Mechanization on Farm Labor Use (Robustness)

	(1)	(2)	(3)	(4)
	Female labor per hectare		*Male labor per hectare*	
Mechanization	-0.006**	-0.005**	-0.001	0.000
	(0.003)	(0.002)	(0.002)	(0.002)
Observations	1073	1073	1073	1073
FS F-Stat	13.12	17.56	13.37	18.41
Controls				
Agriculture	✓	✓	✓	✓
Demographic	✓	✓	✓	✓
Development	✓	✓	✓	✓
Lagged Agri Input	✓	✓	✓	✓
Additional Controls				
Initial District Employment × Time	✓	✓	✓	✓
State × Time		✓		✓

Note: All specification have State and Year Fixed Effects and initial employment; Robust standard errors clustered at the district level in parentheses

Effect of Mechanization on Female Farm Labor Use: By operation

	(1)	(2)	(3)	(4)
	Tilling	Sowing	Weeding	Harvesting
Panel A: Female labor per hectare				
Mechanization	-0.000	-0.001	-0.009**	0.001
	(0.001)	(0.002)	(0.004)	(0.003)
Observations	1073	1073	1073	1073
FS F-Stat	12.941	12.941	12.941	12.941
Test of Equality [p-value] Col(3)=Col(1)/(2)/(4)	0.031	0.048	.	0.043
Controls				
Agriculture	✓	✓	✓	✓
Demographic	✓	✓	✓	✓
Development	✓	✓	✓	✓
Lagged Agri Input	✓	✓	✓	✓

Note: All specification have State and Year Fixed Effects and initial employment; Robust standard errors clustered at the district level in parentheses

Effect of Mechanization on Male Farm Labor Use: By operation

	(1)	(2)	(3)	(4)
	Tilling	Sowing	Weeding	Harvesting
Panel B: Male labor per hectare				
Mechanization	-0.001	-0.001	-0.001	-0.001
	(0.003)	(0.003)	(0.003)	(0.002)
Constant	0.491	0.669	0.729	0.797
	(0.891)	(0.949)	(0.961)	(0.813)
Observations	1077	1077	1077	1073
FS F-Stat	7.890	9.486	9.262	12.950
Test of Equality[p-value] Female=Male	0.113	0.068	0.090	0.079
Controls				
Agriculture	✓	✓	✓	✓
Demographic	✓	✓	✓	✓
Development	✓	✓	✓	✓
Lagged Agri Input	✓	✓	✓	✓

Note: All specification have State and Year Fixed Effects and initial employment; Robust standard errors clustered at the district level in parentheses

Ruling out other channels

- Rise in incomes
- Non-farm sector growth

Effect of Mechanization on Female Labor Use: By Type

	(1)	(2)	(3)	(4)
	Tilling	Sowing	Weeding	Harvesting
Panel A: Female labor per hectare				
Family Labor	-0.000	-0.001	-0.005**	-0.001
	(0.001)	(0.001)	(0.003)	(0.003)
Test of Equality [p-value] Col(3)=Col(1)/(2)/(4)	0.054	0.099	.	0.134
Hired Labor	-0.000	0.000	-0.004*	0.001
	(0.000)	(0.001)	(0.002)	(0.002)
Test of Equality [p-value] Col(3)=Col(1)/(2)/(4)	0.077	0.078	.	0.063
Observations	1073	1073	1073	1073
Controls				
Agriculture	✓	✓	✓	✓
Demographic	✓	✓	✓	✓
Development	✓	✓	✓	✓
Lagged Agri Input	✓	✓	✓	✓

Note: All specification have State and Year Fixed Effects and initial employment; Robust standard errors clustered at the district level in parentheses

Effect of Mechanization on Male Labor Use: By Type

	(1)	(2)	(3)	(4)
	Tilling	Sowing	Weeding	Harvesting
Panel B: Male labor per hectare				
Family Labor	0.001	0.001	-0.005	-0.004
	(0.003)	(0.003)	(0.004)	(0.004)
Test of Equality [p-value] Col(3)=Col(1)/(2)/(4)	0.189	0.256	.	0.798
Hired Labor	0.007**	0.004	-0.001	0.002
	(0.003)	(0.002)	(0.002)	(0.004)
Test of Equality [p-value] Col(3)=Col(1)/(2)/(4)	0.037	0.133	.	0.429
Observations	1073	1073	1073	1073
Controls				
Agriculture	✓	✓	✓	✓
Demographic	✓	✓	✓	✓
Development	✓	✓	✓	✓
Lagged Agri Input	✓	✓	✓	✓

Note: All specification have State and Year Fixed Effects and initial employment; Robust standard errors clustered at the district level in parentheses

Effect of Mechanization on Male Employment: Other sectors

	(1)	(2)	(3)	(4)	(5)	(6)
	Rural			*Rural & Urban*		
	Manu	Cons	Serv	Manu	Cons	Serv
Mechanization	-0.000	0.001	-0.000	-0.001	0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	1073	1073	1073	1073	1073	1073
FS F-Stat	12.950	12.950	12.950	12.950	12.950	12.950
Controls						
Agriculture	✓	✓	✓	✓	✓	✓
Demographic	✓	✓	✓	✓	✓	✓
Development	✓	✓	✓	✓	✓	✓
Lagged Agri Input	✓	✓	✓	✓	✓	✓

Note: All specification have State and Year Fixed Effects and initial employment; Robust standard errors clustered at the district level in parentheses

Effect of Mechanization on Female Employment: Other sectors

	(1)	(2)	(3)	(4)	(5)	(6)
	Rural			*Rural & Urban*		
	Manu	Cons	Serv	Manu	Cons	Serv
Mechanization	0.000	0.000	0.001	0.000	0.000	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	1073	1073	1073	1073	1073	1073
FS F-Stat	12.941	12.941	12.941	12.941	12.941	12.941
Controls						
Agriculture	✓	✓	✓	✓	✓	✓
Demographic	✓	✓	✓	✓	✓	✓
Development	✓	✓	✓	✓	✓	✓
Lagged Agri Input	✓	✓	✓	✓	✓	✓

Note: All specification have State and Year Fixed Effects and initial employment; Robust standard errors clustered at the district level in parentheses

Other effects of Mechanization

- Farm Productivity
- Total Labor Use
- Wages and earnings

Effect of Mechanization on Farm Productivity

	(1)	(2)	(3)	(4)
	log(Yield)			*Cropping Intensity*
	Rice	Wheat	Coarse Cereals	: GSA/NSA
Mechanization	0.001	0.010*	0.006	0.058
	(0.004)	(0.006)	(0.004)	(0.303)
Observations	980	803	956	1073
FS F-Stat	12.01	3.26	12.22	14.20
Controls				
Agriculture	✓	✓	✓	✓
Demographic	✓	✓	✓	✓
Development	✓	✓	✓	✓
Lagged Agri Input	✓	✓	✓	✓

Note: All specification have State and Year Fixed Effects and initial employment; Robust standard errors clustered at the district level in parentheses

Effect of Mechanization on Total Labor Use

	(1)	(2)
	Female Labor	*Male Labor*
Mechanization	-0.030*	0.008*
	(0.016)	(0.004)
Observations	1073	1073
FS F-Stat	14.157	13.527
Test of Equality [p-value]		
Female=Male	[0.025]	
Controls		
Agriculture	✓	✓
Demographic	✓	✓
Development	✓	✓
Lagged Agri Input	✓	✓

Note: All specification have State and Year Fixed Effects and initial employment; Robust standard errors clustered at the district level in parentheses

Effect of Mechanization on Wage and Earnings

	(1)	(2)
	log(Wage Rate)	*log(Wage Earnings)*
	Panel A: Females	
Mechanization	0.006*	0.010
	(0.003)	(0.010)
Observations	804	804
FS F Stat	9.156	7.093
	Panel B: Males	
Mechanization	0.005*	0.035**
	(0.003)	(0.015)
Observations	969	969
FS F-Stat	10.448	10.248
Test of Equality [p-value]		
Female=Male	[0.720]	[0.125]
Controls		
Agriculture	✓	✓
Demographic	✓	✓
Development	✓	✓
Lagged Agri Input	✓	✓

Note: All specification have State and Year Fixed Effects and Initial values of dependent variables; Robust standard errors clustered at the district level in parentheses

Conclusions

- 32 percentage point increase in mechanization during 1999-2011 led to more than 22% overall reduction in women's labor use in agriculture
- Technological change can reduce labor use, but it can have a differential impact by gender when men and women are imperfect substitutes in the production process
- Limited alternative job opportunities for women - skills and mobility
- Implications for income inequality by gender