Resource Allocation, Technology Adoption, and Productivity: A Quantitative Analysis with Panel Farm-Level Data

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Motivation

- Agriculture essential in understanding the wide income disparity across nations (Gollin, Parente & Rogerson 2002; Restuccia, Yang & Zhu 2008).
- Factor misallocation across farms among leading potential explanations (Adamopoulos & Restuccia 2014).
- Misallocation may prevent technology adoption and diffusion (Ayerst 2025; Ayerst, Nguyen & Restuccia 2024).
- We examine factor misallocation and technology adoption in Canadian agriculture both empirically and in a quantitative model.

Why Canada?

- An advanced country in the process of structural transformation.
- Features substantial increase in agricultural productivity and average farm size.
- Unique longitudinal dataset of the universe of farms spanning 1986-2006.
- Period features widespread diffusion of new seeding technique “zero tillage" among Canadian farms, from zero percent of cultivated land in 1986 to 60 percent by 2006.
- Data allow to examine factor allocation and technology adoption on agricultural productivity and structural transformation.

What we do

- Examine empirically resource allocation, land consolidation, and adoption of zero-tillage technology on agricultural productivity using a panel of Canadian farms between 1986-2006.
- Develop a model of structural transformation with sectoral choice and farm operation and technology adoption decisions.
- Use the model to measure contribution of zero-tillage adoption on productivity and structural transformation.
- Examine the effect of farm-level distortions on technology adoption and aggregate outcomes.

What we find

Empirically:

- High allocative efficiency among Canadian farms (0.83-0.95), roughly constant over time.
- Substantial land consolidation and agricultural productivity growth, along with widespread diffusion of zero-tillage technology by the most productive farms.
- Significant positive effect of zero-tillage adoption on farm-level productivity.

Quantitatively:

- Zero-tillage adoption contributed to 35% of near doubling agricultural productivity and 45-70% of observed structural transformation.
- Same technology shock in distorted economy would dampen adoption rate to 5% and generate only one-sixth of agricultural growth.
- Technological progress can be a powerful driver of catch-up growth in developing economies with low correlated distortions.

Related literature

- Production heterogeneity and misallocation: Restuccia & Rogerson (2008); Guner, Ventura & Xu (2008); Hsieh & Klenow (2009).
- Misallocation in agriculture: Adamopoulos & Restuccia (2014, 2020); Adamopoulos et al. (2022); Chen et al. (2023), Ayerst et al. (2020).
- Technology adoption and productivity in agriculture: Yang & Zhu (2013); Caunedo & Keller (2020); Chen (2020); Ayerst et al. (2024).
- Link of misallocation with selection/technology: Pavcnik (2002), Bustos (2011), Kanderwal et al. (2013), Yang (2021), Majerowitz (2023), Ayerst (2025), Ayerst et al. (2025).

Outline

- Data and empirical evidence.
- Model.
- Calibration.
- Quantitative analysis.
- Conclusions.

Data and Empirical Evidence

Data

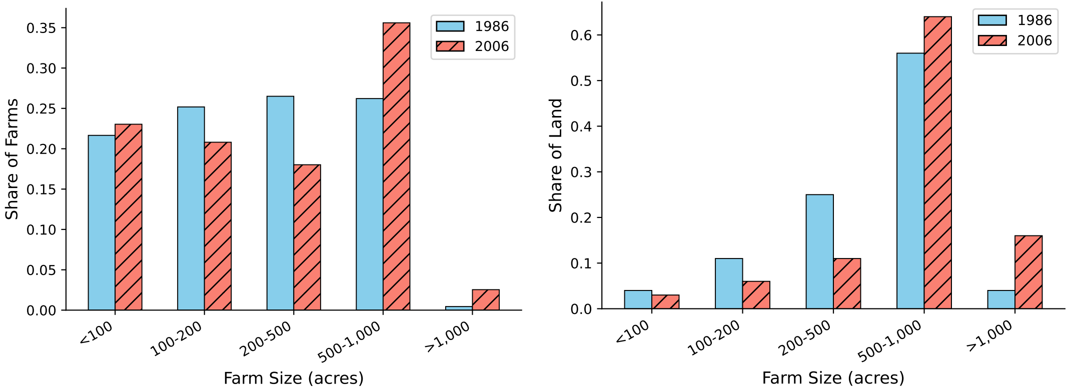
- Canadian Longitudinal Census of Agriculture (L-CEAG) from 1986 to 2006.
- Information on all operating farms every 5 years.
  - Real gross output (y)
  - Real capital stock (k)
  - Cultivated land (ℓ)
  - Cultivated land using zero-tillage technology.
  - Others: farm identifiers, farm location such as Census Consolidated Subdivision (CCS), characteristics of farm operators.
- Focus our analysis on crop farms.

Canadian agriculture between 1986-2006

Year	Output	Farms	Land	Capital	TFP	Average Farm Size
1986	6.69	107,980	86.29	10.91	1.00	800
1991	7.72	90,685	79.44	10.75	1.15	876
1996	5.78	81,185	78.10	12.83	0.91	961
2001	7.35	69,670	71.94	13.74	1.23	1,033
2006	9.50	61,665	72.11	15.19	1.62	1,169
Ratio (06/86)	1.42	0.57	0.84	1.39	1.62	1.46

- Substantial decline in number of farms, along with farm reallocation: agricultural yield increased 70%, output per farm 149% (4.7% annual).

Farm and land size distribution



- Substantial process of land consolidation towards largest farms.

Misallocation framework

- Standard framework of heterogeneous production units and input allocation (Lucas 1978; Hopenhayn 1992; Adamopoulos and Restuccia 2014).

- M heterogeneous farms producing a single homogeneous good:

$$y_i = \text{TFP}_i \left(k_i^{\alpha} \ell_i^{1-\alpha}\right)^{\gamma}, \qquad \gamma \in (0,1).$$

- Efficient allocation (maximum output Y^e given total resources M, K and L)

$$k_i^e = \frac{\text{TFP}_i^{(1/1-\gamma)}}{\sum_{j=1}^{M} \text{TFP}_i^{(1/1-\gamma)}} K, \qquad \text{and} \qquad \ell_i^e = \frac{\text{TFP}_i^{(1/1-\gamma)}}{\sum_{j=1}^{M} \text{TFP}_i^{(1/1-\gamma)}} L.$$

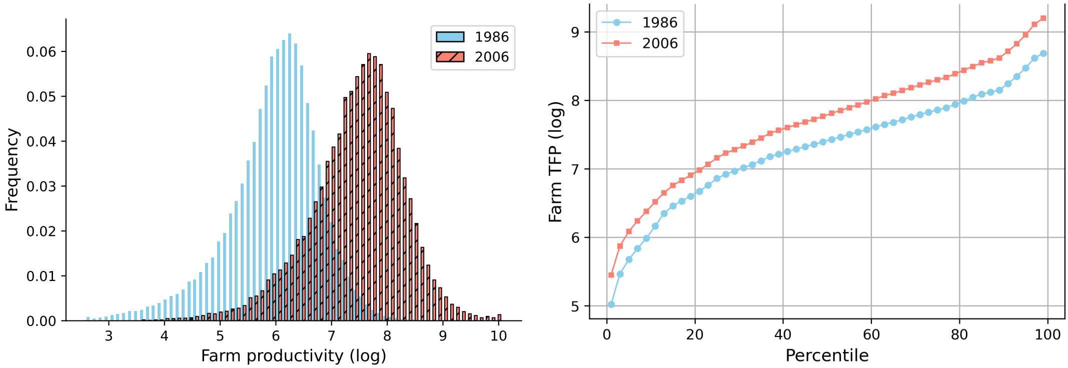
- Aggregate productivity cost of resource misallocation summarized by allocative efficiency,

$$\text{AE} = \frac{Y}{Y^e}.$$

Misallocation analysis

- Focus on the farm as unit of analysis.
- Data on farm outputs (revenue), capital and operated land.
- Measure farm TFP as residual from farm production function, measure farm distortions as output per unit of composite input $(y_i/(k_i^{\alpha}\ell_i^{1-\alpha}))$.
- Assume standard parameter values from literature (Valentinyi & Herrendorf 2008):
  - Span-of-control $\gamma = 0.54$.
  - Capital share $\alpha = 0.67$.

Farm-level TFP distribution over time



- Substantial increase in farm-level productivity from 1986 to 2006.
- Increased dispersion, stronger TFP growth at the top of the distribution (p90/p10 4.4-fold in 1986, 6.8-fold in 2006).

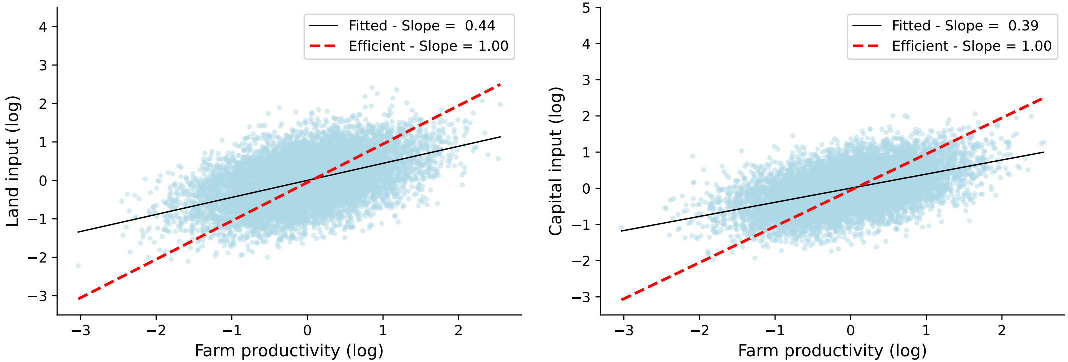
Misallocation among Canadian farms

- Allocative efficiency (AE) $\approx$ 83-85% nationwide ($\approx$ 87-88 within CCS), roughly constant over time.
- AE $\approx$ 0.95 (both nationwide and within CCS) when estimating farm fixed effects from the panel (Adamopoulos et. al. 2022).
- AE substantially higher in Canada than estimated in less developed countries:
  - Chen et al. (2023): 0.36 in Malawi.
  - Ayerst et al. (2020): 0.56 in Vietnam.
  - Adamopoulos et al. (2022): 0.35 in China.

Misallocation accounting for measurement error

	(1) Nationwide	(2) Within CCS
Standard deviation		
log TFP	0.33	0.26
log distortion	0.28	0.26
Elasticity		
Distortion wrt TFP	0.59	0.57
Land wrt TFP	0.96	1.04
Capital wrt TFP	0.85	0.87
Allocative Efficiency	0.95	0.95

Resource allocation by farm productivity



- Land and capital allocations across farms much more aligned to farm productivity in Canada compared to evidence for developing countries.

Zero-tillage technology

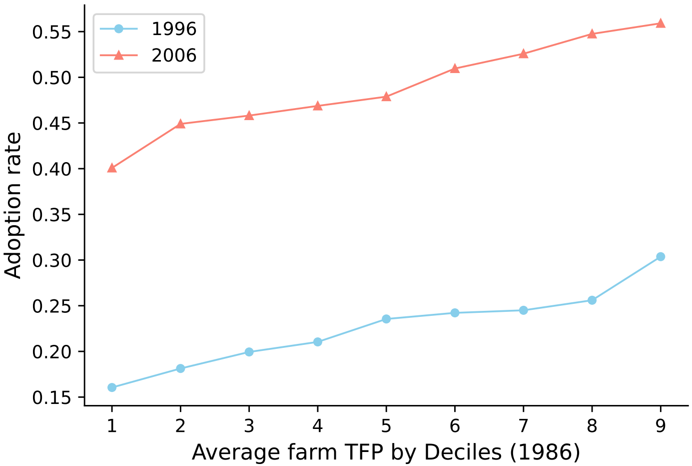
- Soil management practice where crops are grown without plowing or turning the soil.
- Unlike conventional tillage, seeds placed directly into the undisturbed soil using a zero-till seed drill (special drill that cuts through residue and places seed at the right depth).
- Previous crop residue acts as mulch, helping with moisture conservation and weed suppression.
- Empirical evidence shows this method reduces costs and increases yield for farmers.
- Massive adoption of zero-tillage technology in Canada, from 0% of cultivated farm land in 1986 to 60% in 2006.

Zero-tillage adoption and farm productivity

	$\Delta \log(\text{TFP})$
$ZTAdopt_{2006}$	0.24***
	(0.0087)
Controls	✓
Observations	18,275
Adj. R-squared	0.28

- 20-year changes in farm log(TFP) on dummy indicating whether the farm adopted the technology by 2006.
- Controls for initial productivity, changes in land shares by crop types (wheat, canola, barley, and rye), and location (CCS) fixed effects.

Adoption rate of zero-tillage by productivity deciles



- More productive farms adopted zero-tillage more intensively.

Determinants of zero-tillage adoption

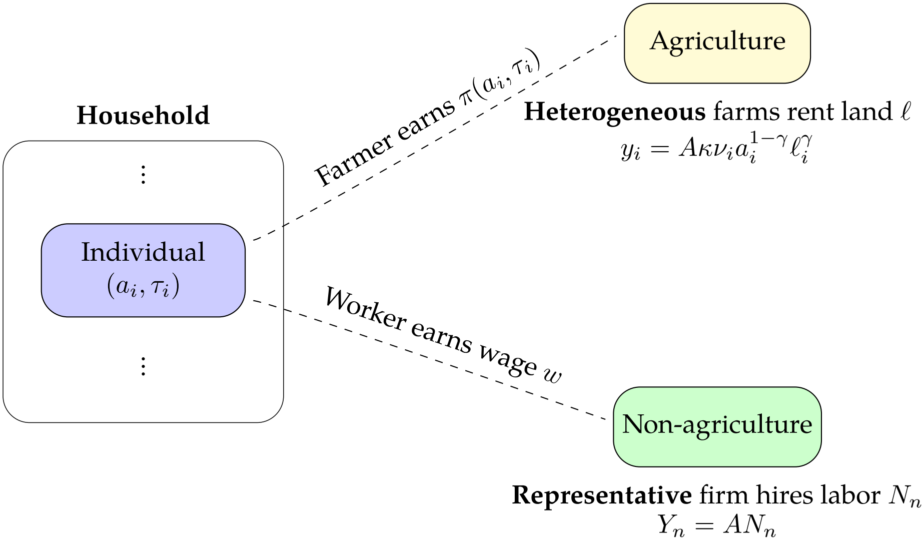
	(1) OLS $ZT\,Adopt_t$	(2) Logit $ZT\,Adopt_t$
$\log(\text{TFP}_{t-5})$	0.17***	1.13***
	(0.0045)	(0.0291)
$\log(distortion_{t-5})$	−0.11**	−0.68***
	(0.0046)	(0.0305)
Age of operators	−0.002***	−0.01***
	(0.0001)	(0.0008)
Controls	✓	✓
Observations	72,090	72,090
Adj. R-squared	0.12	

- Adoption positively related to productivity, negatively related to distortions and age of operators.

Model

Model

- Standard model of structural transformation with agriculture (a) and non-agriculture (n) (Restuccia, Yang, and Zhu 2008).
- Production heterogeneity in agriculture with distortions (Adamopoulos and Restuccia 2014) and occupational (sectoral) selection (Lucas 1978).
- Farms decide technology adoption facing standard convex cost (Ayerst. et al. 2024).
- Representative household comprises of individuals endowed with heterogeneous farming ability and distortions.
- Model is static.


Household
⋮
Individual
(a_i, τ_i)
⋮
Farmer earns π(a_i, τ_i)
Worker earns wage w
Agriculture
Heterogeneous farms rent land ℓ
y_i = Aκν_i a_i^{1−γ} ℓ_i^γ
Non-agriculture
Representative firm hires labor N_n
Y_n = AN_n

Technologies

- Homogeneous agricultural good produced by farms indexed by i

$$y_i = A\kappa\nu_i a_i^{1-\gamma}\ell^{\gamma}, \quad \gamma \in (0,1).$$

- Farming idiosyncratic productivity a_i is

$$\log(a_i) = \underbrace{\log(z_i)}_{\text{technology adoption}} + \underbrace{\log(s_i)}_{\text{farming ability}},$$

  where technology adoption faces convex cost ψz_i^{ϕ}.

- Non-agricultural technology linear in labor:

$$Y_n = AN_n,$$

  where A is economy-wide productivity.

Market structure and distortions

- Competitive economy where households, individuals, and firms/farms take prices as given.
- Price of agricultural output normalized to 1, denote relative price of non-agriculture by p_n and wage rate by w.
- Farms face idiosyncratic distortions, modeled as proportional tax τ_i on revenues and parameterized by:

$$\log(1-\tau_i) = (1-\gamma)[\underbrace{-\rho \log a_i}_{\text{correlated}} - \underbrace{\log \epsilon_i}_{\text{random}}],$$

where ϵ is log normal with normalized mean and standard deviation σ_ϵ.

Technology adoption in agriculture

- Farmers choose whether to adopt new technology:
  - If adopt, farmer chooses technology level z to maximize farm's value:

$$V^{adopt}(s_i, \tau_i) = \max_{z \geq 0} \quad \pi(z s_i, \tau_i) - p_n \psi z^{\phi}.$$

  - If not adopt, there is no technology improvement $(z = 1)$:

$$V^{no\ adopt}(s_i, \tau_i) = \pi(s_i, \tau_i).$$

  - Optimal technology adoption maximizes farm's value:

$$V(s_i, \tau_i) = \max \left\{ V^{adopt}(s_i, \tau_i), V^{no\ adopt}(s_i, \tau_i) \right\}.$$

- We model technological progress as an exogenous change in cost (ψ): New technology not available/adopted when cost is large $(\psi = \infty)$.

Occupational choice

- Individuals are endowed with farming ability $s_i \sim F(s)$ and idiosyncratic distortion $\epsilon_i \sim G(\epsilon)$.
- Farmers can earn income $V(s_i, \tau(\epsilon_i))$ by operating a farm or earning a wage w in non-agricultural sector.
- Denote $o(s_i, \epsilon_i)$ as the individual's choice to be a farm operator:

$$o(s_i, \epsilon_i) = \begin{cases} 1 & \text{if} \quad V(s_i, \tau(\epsilon_i)) \geq w, \\ 0 & \text{otherwise.} \end{cases}$$

Household

- The representative household comprises of a mass one of individuals and endowed with L units of land.

- The household has Stone-Geary preferences over consumption of agricultural (c_a) and non-agricultural (c_n) goods:

$$U(c_a, c_n) = a \log(c_a - \bar{a}) + (1 - a) \log(c_n).$$

- The household chooses a consumption bundle to

$$\max_{c_a, c_n} \quad U(c_a, c_n)$$

$$\text{s.t.} \quad c_a + p_n c_n = \int_\epsilon \int_s \max\{V(s_i, \tau(\epsilon_i)), w\} \, dF(s) dG(\epsilon) + qL + T.$$

Competitive equilibrium

A competitive equilibrium comprises prices (p_n, w, q); decision functions for farms: land demand $\ell(a,\tau)$, output $y(a,\nu,\tau)$, expected profits $\pi(a,\tau)$, technology adoption $z(s,\epsilon)$, net value of farm $V(s,\epsilon)$, farm operating decision $o(s,\epsilon)$; mass of non-agricultural workers N_m; household's consumption (c_a, c_n), income I, and lump-sump transfer T such that:

(i) Given prices, household's income I and transfer T, the allocation (c_a, c_n) solves the household's problem.

(ii) Given w and q, decision function $\ell(a,\tau)$ solves the incumbent farm's problem, determining expected farms' profit $\pi(a,\tau)$ and realized output $y(a,\nu,\tau)$.

(iii) Given w and q, farms choose technology adoption $z(s,\epsilon)$ to maximize the value of the farm $V(s,\epsilon)$.

(iv) Given w and q, farm operating decision $o(s,\epsilon)$ solves the individual occupational choice problem.

(v) Government's budget is balanced.

(vi) All markets clear.

Calibration

Calibration

- Strategy: calibrate distorted benchmark economy in two periods, before and after technology adoption to match data for Canada in 1986 and 2006.
- A set of five parameters are normalized or assigned values from outside evidence: span-of-control $\gamma = 0.65$, curvature investment cost function $\phi = 2$, cost of adoption $\psi_0 = \infty$ (no zero-tillage), $A_0, \kappa_0 = 1$ (normalization).
- A set of 7 parameters $(\rho, \sigma_\epsilon, \sigma_s, \sigma_\nu, \bar{a}, L_0, a)$ jointly calibrated to 6 moments of 1986 Canadian data (initial period) and assumed long-run share of employment in agriculture of 1.5%:
  - (1) elasticity of distortions, (2) sd log distortions, (3) sd log land, (4) sd log TFP, (5) agricultural employment share, (6) average farm size.

Benchmark economy in 1986

Parameter	Value	Targeted moments	Model	Data
ρ	0.27	Elasticity of distortions	0.76	0.76
σ_ϵ	2.20	sd log distortions	0.53	0.54
σ_s	4.10	sd log land	0.94	0.93
σ_ν	4.10	sd log TFP	0.56	0.55
$\bar{a}$	19.10	Agricultural employment share	0.04	0.04
L_0	31.96	Average farm size	800	800
a	0.10	Long-run agricultural emp. share	0.015	0.015

- Calibrated $\rho = 0.27$ implies measured elasticity of distortions 0.76.
- Gap between model parameter and measured elasticity due to strong operation selection of farms.

Benchmark economy in 2006

- Calibrate to Canadian data in 2006 (later period 1): Zero-tillage technology becomes available ($\psi_1 < \infty$).
- Jointly calibrate 4 parameters $(A_1, \kappa_1, \psi_1, L_1)$ to match 4 moments in 2006: (1) growth in non-agricultural productivity, (2) agricultural employment share, (3) fraction of land with zero-tillage technology, (4) average farm size.

Parameter	Value	Targeted moments	Model	Data
A_1	1.30	Non-agr labor productivity 2006/1986	1.30	1.30
κ_1	2.08	Agricultural employment share	0.02	0.02
ψ_1	1.85	Fraction of land adopting zero-tillage	0.60	0.60
L_1	23.38	Average farm size	1,169	1,169

Model validation untargeted moments

Untargeted moments	Model	Data
Allocative efficiency in 1986	0.83	0.83
Agricultural TFP growth 1986-2006	94%	94%
Regression $\Delta \log(\text{farm TFP})$ on farm adoption dummy	0.36	0.24

QUANTITATIVE ANALYSIS

Impact of zero-tillage technology 1986-2006

	Agricultural Emp. Share (%)	Agricultural TFP	Average Farm Size (acres)
Benchmark economy:			
1986 $(A_0, \kappa_0, \psi_0, L_0)$	4.0	1.00	800
2006 $(A_1, \kappa_1, \psi_1, L_1)$	2.0	1.94	1,132
Experiments:			
(1) $(A_0, \kappa_0, \psi_1, L_0)$	2.6	1.26	1,294
Contribution (%)	*70*	*35*	–
(2) $(A_0, \kappa_0, \psi_1, L_1)$	3.1	1.26	791
Contribution (%)	*45*	*35*	–

- Adoption of zero-tillage technology accounts for 45-70% of structural transformation and 35% of growth in agricultural productivity.

Distortions and technology adoption

	Adoption Rate (%)	Agricultural TFP	Agr. Share of Emp. (%)	Average Farm Size
Benchmark $\rho = 0.27$				
1986 $(A_0, \kappa_0, \psi_0, L_0)$	0.0	1.00	4.0	800
2006 $(A_0, \kappa_0, \psi_1, L_0)$	63.0	1.30	2.5	1,294
Change (%)	–	*30*	$-$*38*	*62*
Experiment $\rho = 0.80$				
1986 $(A_0, \kappa_0, \psi_0, L_0)$	0.0	0.39	29.0	111
2006 $(A_0, \kappa_0, \psi_1, L_0)$	5.0	0.41	25.0	130
Change (%)	–	*5*	$-$*14*	*17*

- Distortions substantially dampen the adoption of technology, productivity growth, and structural transformation.

Technological Progress in Developing Economies

	Agr. Share of Emp. (%)	Adoption Rate (%)	Agricultural TFP	Average Farm Size
Counterfactual 1: $\rho = 0.80$				
$(A = 0.30, \kappa = 2.92)$				
Initial $\psi_0 = \infty$	70	0.0	0.28	46
Later $\psi_1 = 1.85$	48	7.6	0.32	66
Change (%)	*−22*	–	*14*	*43*
Counterfactual 2: $\rho = 0.27$				
$(A = 0.30, \kappa = 1.98)$				
Initial $\psi_0 = \infty$	70	0.0	0.28	45
Later $\psi_1 = 1.85$	8	60.2	0.62	395
Change (%)	*−62*	–	*121*	*778*

- Technological progress can be a powerful driver of catch-up growth in developing economies with low correlated distortions.

Conclusions

- The adoption of zero-tillage technology among Canadian farms (1986-2006) contributed to substantial agricultural productivity gains, structural transformation, and land consolidation.
- Rapid adoption facilitated by strong institutional environment of high allocative efficiency (low misallocation).
- Our counterfactual experiments show:
  - Correlated distortions as in developing countries substantially dampen the rate of technology adoption, productivity growth, and structural transformation.
  - Technological progress can be a powerful driver of catch-up growth in developing economies with low correlated distortions.