Fertilizer Import Bans, Agricultural Exports, and Welfare: Evidence from Sri Lanka[1]

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[1]The findings, interpretations, and conclusions expressed in this paper are entirely those of the authors and do not necessarily represent the views of the World Bank and its affiliated organizations, or those of the Executive Directors or the countries they represent. All errors are our responsibility.

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The Economist

A rush to farm organically has plunged Sri Lanka's economy into crisis

Oct 16, 2021

Preview of findings: After the fertilizer ban of May 2021

Our reduced form estimates reveal:

- Fertilizer imports $\downarrow$ 99%, driven by quantities, spike in prices
- Rice: Largest $\downarrow$ in yields in a decade $+ \uparrow$ in imports ($>$ 1000%)
- Exports: 33% $\downarrow$ fertilizer-intensive agro exports

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Our quantitative general equilibrium model reveals:

- Average welfare losses equivalent to a 1.5% decline in income
- Heterogeneity:
  - Landowners (tied to agriculture) suffered 4-8% losses
  - Workers (more sectorally mobile) suffered 0.01-3.2% losses
  - Regions specialized in relatively fertilizer-intensive crops affected more
- Defeating protectionist motive: The ban decreased fertilizer imports by \$11.5 million but agricultural exports by \$137.7 million

Contribution to literature

- **Effects of fertilizer on agricultural productivity using RCTs** (Carter et al., 2021; Beaman et al., 2013; Duflo et al., 2008, 2011)
- Hard to assess GE effects using small-scale experiments (Bergquist et al., 2022; Muralidharan and Niehaus, 2017)

  Contribution: Natural experiment removing fertilizer rather than subsidizing provision (depends on farmer take-up). Allows quantifying the GE value of fertilizer + welfare losses from fertilizer shortage in open economy

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- **Quantitative spatial models with a focus on agriculture** (Costinot et al., 2016; Aggarwal et al., 2022; Farrokhi and Pellegrina, 2022; Pellegrina, 2022; Sotelo, 2020)

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- **NTM and trade** (survey: Ederington and Ruta, 2016). Import prohibitions rarely studied (Atkin et al., 2022; Bernini and Garcia-Lembergman, 2022)

  Novel finding+newly digitized trade-policy data: NTM-driven decline in fertilizer imports reduces exports of larger value, jeopardizing the hidden forex-saving motivation of the NTM.

Data

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- Nationally representative Household Surveys (2016, 2019) for pre-ban wages, occupation distribution, and land distribution

Stylized facts on fertilizer imports, agricultural production, and exports

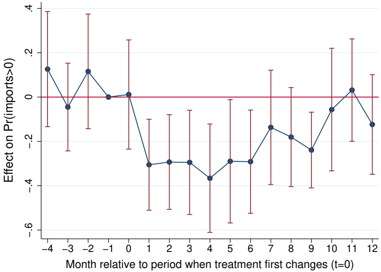
Imports:

De Chaisemartin and d'Haultfoeuille (2022) event study design to account for ban switching on and off Ban Timeline

$$y_{ct} = \sum_{\tau \neq -1} \beta_\tau \times ban_{ct}^{\tau} + \omega_t + \omega_c + \epsilon_{ct}$$

y_{ct}: log imports (intensive) or dummy for positive imports (extensive)
c : HS8 product, t: month-year, ban_{ct}^{τ}: dummy indicating whether an import ban on product c was first imposed τ periods before period t.

1. Fertilizer imports ↓ after the ban: Monthly event study



(a) Dynamic Ban Effects on Imports (Extensive Margin)

Notes: The treatment variable is a dummy indicating whether fertilizer product c had its imports banned in month t, and the not-yet-treated products serve as the control group, which includes non-banned fertilizers as well as other products.

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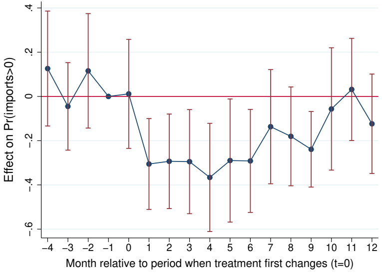

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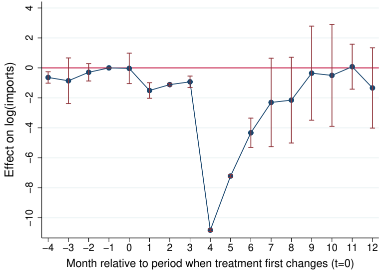

(b) Dynamic Ban Effects on Imports (Intensive Margin)

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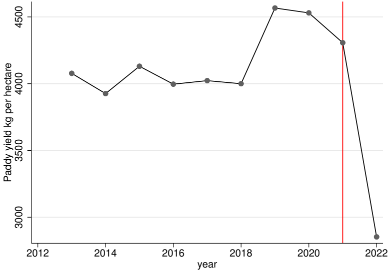
Decline driven by quantities of fertilizer imports while import prices spiked

Results

2. Rice production ↓ significantly after the ban on fertilizer imports



(a) Annual Maha yield

Notes: The left panel shows the Maha rice yield in 2012-2022. The Maha season is September-March of the following year. The right panel shows the monthly imports of rice. The first red line in May 2021 and the second red line in August 2021 marks the import ban's beginning and end.

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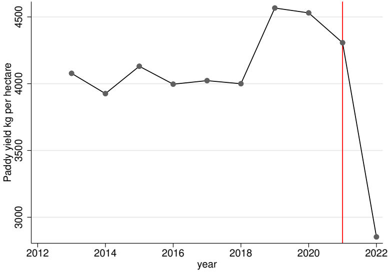

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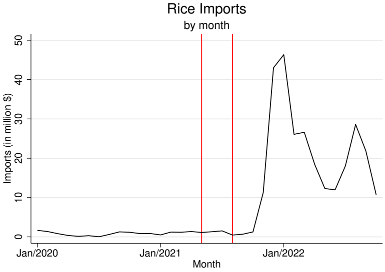

(b) Monthly rice imports

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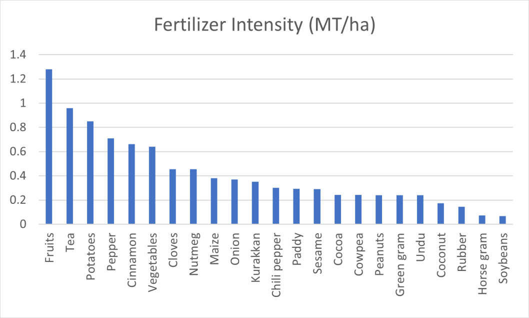
3. Fertilizer-intensive agro exports declined significantly after the ban on fertilizer imports

3A. Firm-quarter-level export regressions



- Define a firm's Fertilizer Usage: average fertilizer intensity of the crops exported by the firm (in 2017-19 data).

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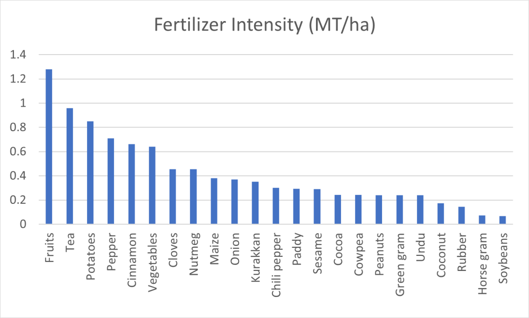

- Define a firm's Fertilizer Usage: average fertilizer intensity of the crops exported by the firm (in 2017-19 data).
- Define a Treated Firm: a firm above 75th pctile of Fertilizer Usage.

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3B. Product-quarter level export regressions

- Import-export data from all single-product firms in the 2017-2019 period to define input-output matrix (a_{cd}) at HS-8 level

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3B. Product-quarter level export regressions

- Import-export data from all single-product firms in the 2017-2019 period to define input-output matrix (a_{cd}) at HS-8 level
- Define the Input Ban Severity (IBS) faced by a product in a quarter: the fraction (weighted by a_{cd}) of the product's inputs that are banned in that quarter

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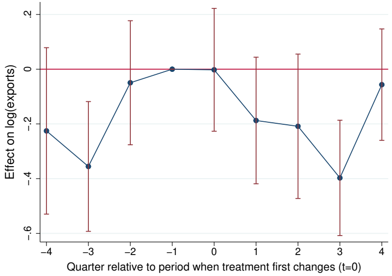

(a) Dynamic Ban Effects on Exports (Firm-level)

Notes: Treatment variable is a dummy indicating whether import bans on the fertilizer inputs required by product c in panel (a) or firm f exports in panel (b) in quarter t were above the $75th$ percentile of fertilizer requirement for all products/ firm exports.

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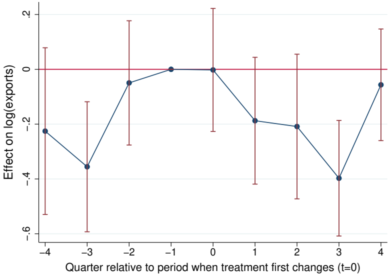

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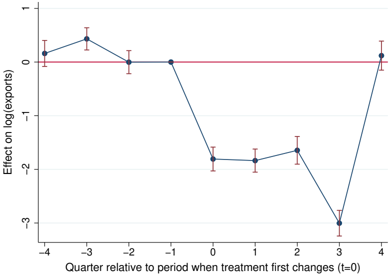

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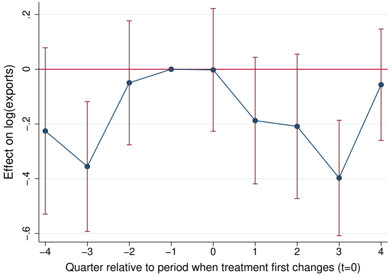

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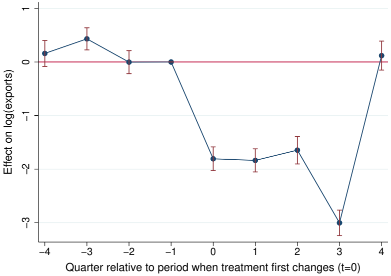

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DiD estimates the effect of fertilizer shortage on directly affected (treatment) relative to control products, missing economy-wide GE, including welfare effects

A quantitative spatial model of agricultural production and trade: Setting

- **Geography**: I domestic regions + 1 foreign (RoW).
  - Fixed population and land.
- **Sectors**:
  - Agriculture (**A**): K homogeneous crops.
  - Manufacturing (**M**): region-specific varieties (Armington).
  - Fertilizer (**f**): one homogeneous agro input.
- Consumer **preferences**: Preferences
  - Between **A** and **M**: non-homothetic (PIGL)

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- Consumer **preferences**: Preferences
  - Between **A** and **M**: non-homothetic (PIGL) $\rightarrow$ Food larger share of expenditure for poor households.
  - Within **A** + within **M**: nested CES
- Two types of consumers: **workers** and **landowners**:
  - **Land inequality:** Exogenous landholdings are log-normally distributed for each region. Land and Income

Model: Production and equilibrium

- Fertilizer is pure endowment (i.e. not produced). Fertilizer
  - Only RoW has positive endowment ⇒ LKA must import.
- Manufacturing production: CRS, linear in labor. Manufacturing
  - Regional differences in productivity.
- **Agro production: CRS, Cobb-Douglas in labor, land, fertilizer.**
  - Regional differences in crop-specific productivity. Agriculture
  - C-D fertilizer intensity parameters **vary across crops**.
  - Each region has a continuum of plots.
- **Perfect competition** and "iceberg" **trade costs** in all sectors.
  - Key variable: cost of importing fertilizer into LKA ($\tau^f_{i,RoW}$).
- **Equilibrium**: market clearing in fertilizer, crops, labor. Market clearing

Estimation

- **Demand side: Preference parameters**
  1. Non-homotheticity i.e. Engel elasticity: Co-movement of food expenditure shares with household income

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- **Supply side: Cobb-Douglas Production function parameters**
  1. Share of fertilizer expenditure in crop value (National Fertilizer Secretariat)

Parameter Values

Counterfactual results: Increase in fertilizer import costs

To replicate ban, increase international trade cost of fertilizer ($\tau^f_{i,RoW}$).

- Calibrate increase to match observed fertilizer price increase.
- Recompute equilibrium and compare to original equilibrium.

Counterfactual results: Increase in fertilizer import costs

Table: Country-level effects

Variable	Effect	% Effect
Fertilizer imports ($)	-$11.5 MM	-5.7%
Fertilizer imports (kg)	-322 MM kg	-49.5%
Fertilizer price ($/kg)	+$0.27/kg	+87.2%
Agro exports ($)	-$137.7 MM	-5.5%
Net Agro exports ($)	-$134.3 MM	-6.7%

- Stylized Fact: "1. Fertilizer imports declined after the import ban"
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- Trade deficit? -$11.5 MM +$137.7 MM = + $126.1 MM
  - Not effective in saving foreign exchange.

Counterfactual results: Increase in fertilizer import costs

Table: Crop-level effects

Crop	**Fertilizer intensity**	**Production** in MT	**in %**	**Gross Exports** **in $ MM**	**in %**
Potatoes	0.151	-4,988	-14.3%	-2.8	-10.7%
Rice	0.086	-402,865	-7.9%	-123.1	-5.9%
Cinnamon	0.053	-1,083	-4.7%	-7.7	-3.5%
Clove	0.043	-263	-3.9%	-1.1	-3.0%
Maize	0.042	-10,268	-3.3%	-2.2	-2.5%
Onions	0.024	-695	-2.0%	-0.5	-1.6%
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- Stylized Fact: "3. Rice production declined significantly after the ban on fertilizer imports (model explains 25%)"

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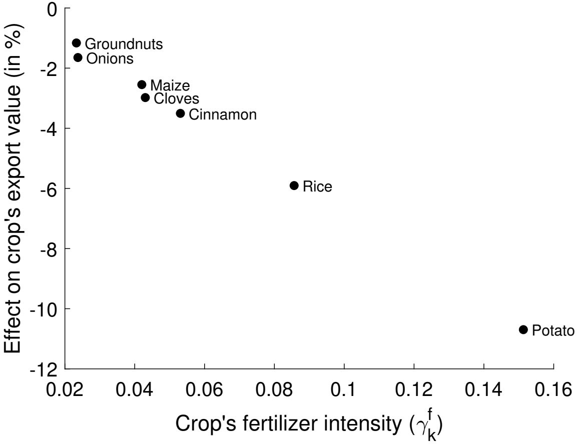


- Stylized Fact: "4. Fertilizer-intensive agro exports declined significantly after the ban on fertilizer imports"

Counterfactual results: Increase in fertilizer import costs

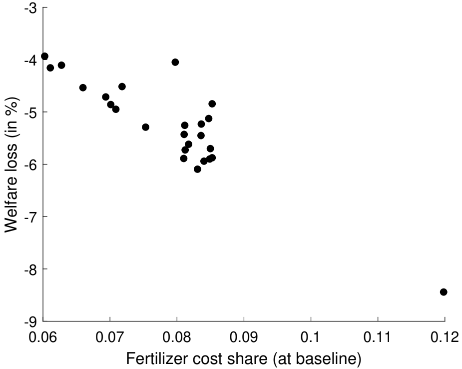
Table: Effect on welfare

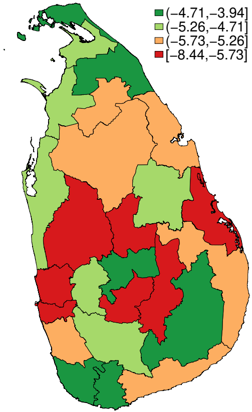
Agent type	**EV (Equivalent Variation)**
Worker	-0.76%
Repr. Landowner	-5.27%
Repr. Agent	-1.48%

- Landowner (whose income is attached to agriculture) suffers more.
- Worker (sectorally mobile) suffers less.

Counterfactual results: Increase in fertilizer import costs

Welfare effects across land-owners

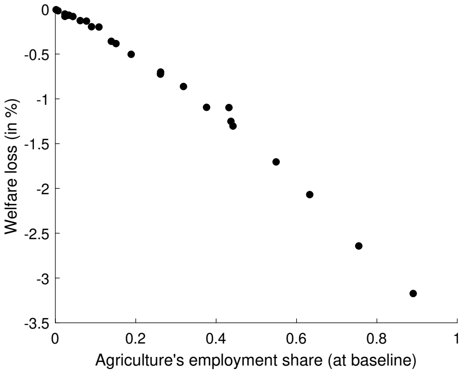


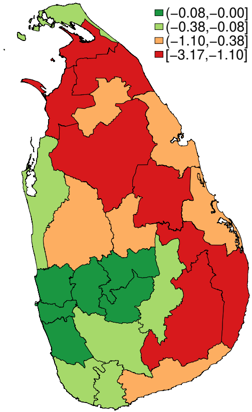


Geographic Heterogeneity #1: Worse effects in regions specialized in fertilizer-intensive crops ($\rho = -0.90$).

Counterfactual results: Increase in fertilizer import costs

Welfare effects across workers





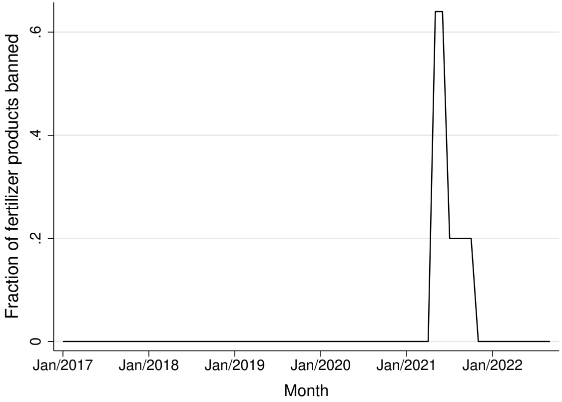
Geographic Heterogeneity #2: Worker suffers little if her region has large manufacturing employment "buffer" that can easily absorb her.

Conclusion

- Leverage unprecedented natural experiment (sudden fertilizer import ban) to quantify fertilizer value for a developing economy.
- To assess GE effects and welfare, propose and estimate quantitative model of agro trade reflecting key features of Sri Lankan economy:
  - Ban's welfare effects (or the value from loss of fertilizer) were equivalent to a 1.5% income reduction on average, with losses disproportionately concentrated on landowners and on regions specialized in fertilizer-intensive crops.
- Novel data and state-of-the-art event study design show dramatic declines in fertilizer imports, rice yields and fertilizer-intensive agro exports.
- Our estimates help inform fertilizer-related policies (e.g., subsidies) and public debate on costs and benefits of environmental regulation.

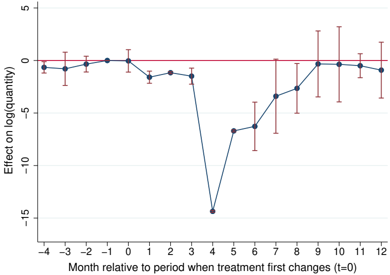
Thank You

Ban timeline



Back Fraction of banned fertilizers (out of 25): 64% in May 2021, 20% in July 2021, then down to 0 in November 2021.

2. Decline driven by quantities of fertilizer imports while import prices spiked



(a) Quantity

Notes: Control group includes all goods that were never banned (both fertilizers and non-fertilizers). The treatment group is fertilizers which were banned. The treatment variable is a dummy ban_{ct} indicating whether product c was banned in month t, and the not-yet-treated products serve as the control group

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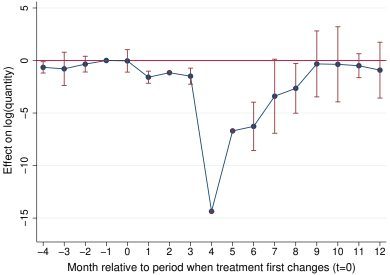
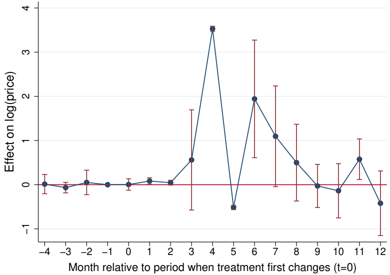


(a) Quantity



(b) Price

Notes: Control group includes all goods that were never banned (both fertilizers and non-fertilizers). The treatment group is fertilizers which were banned. The treatment variable is a dummy ban_{ct} indicating whether product c was banned in month t, and the not-yet-treated products serve as the control group

Results: Seasonality (1/4)

- **Concern**: seasonality as a potential confounder.
  - Already addressed by month-year/time-year fixed effects?
- Extra check: **deseasonalize** outcome variables. Example:
  - For each product p and month $m = \{1, ..., 12\}$, compute average $ imports during 2017-2019.
  - Then subtract this average from import variable M_{pt} wherever t corresponds to month m.
  - Then use the new, transformed import variable to run the regressions.
- Analogous procedure for extensive margin.
  - Outcome variable in this case is dummy for positive imports.
- Analogous procedures for:
  - Regressions at quarterly (not monthly) level.
  - Regressions at firm (not product) level.

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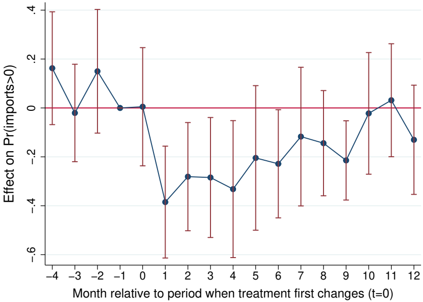
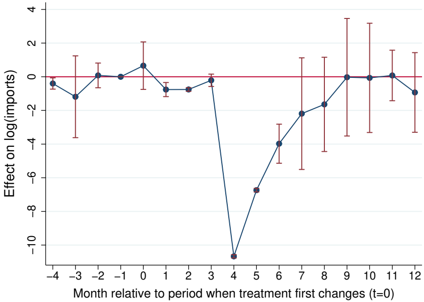
Results: Seasonality (2/4)

Figure: Dynamic Ban Effects: Deseasonalized Imports



(a) Extensive Margin



(b) Intensive Margin

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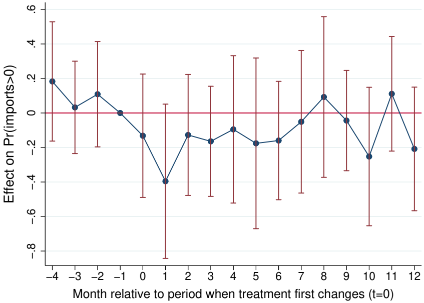
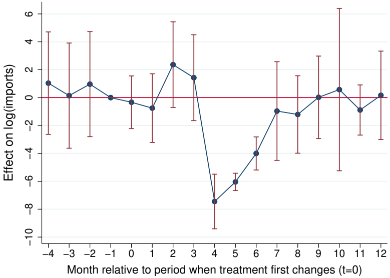
Results: Seasonality (3/4)

Figure: Dynamic Ban Effects: Deseasonalized Imports (fertilizer-only sample)



(a) Extensive Margin



(b) Intensive Margin

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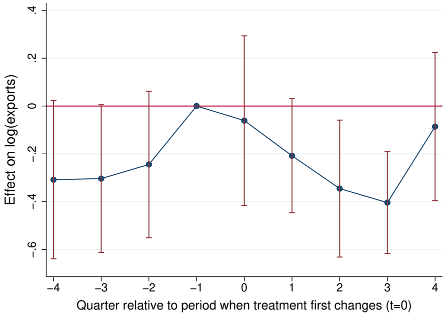
Results: Seasonality (4/4)

Figure: Dynamic Ban Effects: Firms' Deseasonalized Agro Exports (High vs Low Fertilizer Intensity)



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Results: Covid confounder (1/3)

- **Concern**: import bans happened during Covid pandemic.
- Could our estimated ban effects actually be Covid effects in disguise?
  - Covid shouldn't bias our estimates of import effects unless it affects banned fertilizers more than non-banned products/fertilizers.
- Extra check: when Covid arrived in March/2020, did imports of **"futurely banned"** fertilizers fall **disproportionately**?
  - Loosely similar in spirit to a "placebo test".
- **Results**: estimated Covid "effects" on "futurely banned" fertilizer imports are either zero or *positive*.
  - If anything, Covid biases estimates to make ban effects look milder.

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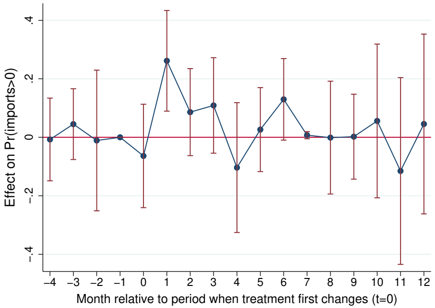
Results: Covid confounder (2/3)

Figure: Imports and the Arrival of Covid in March 2020



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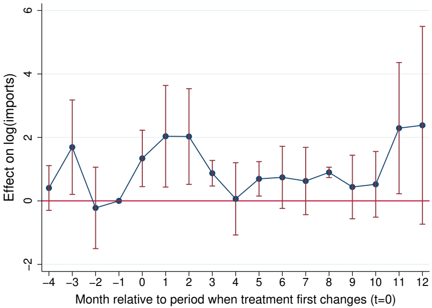

(b) Intensive Margin

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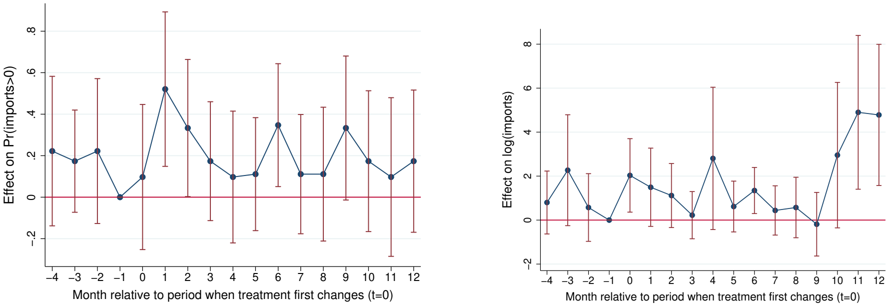
Results: Covid confounder (3/3)

Figure: Imports and the Arrival of Covid in March 2020 (fertilizer-only sample)



(a) Extensive Margin

(b) Intensive Margin

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Model: Income Sources

- Two types of agents in region i: **workers** and **landowners**
  - N_i^W workers provide labor, earn wage w_i
  - N_i^{LO} landowners rent out land, earn rent
- RoW also gets income from selling fertilizer (F_{RoW}).
- Aggregate income E_i in region i is:

$$E_i = w_i N_i^W + \overbrace{\sum_k \gamma_k^l p_{ik} Q_{ik}}^{\text{land rent } (R_i)} + p_i^f F_i \tag{1}$$

- Aggregate land rent distributed in proportion to landholding size.
  - Land size distribution assumed log-normal(μ_i, σ_{Li}^2).

    $\Rightarrow$ Land rent distribution is log-normal($\mu_i + \ln(\frac{R_n}{L_n})$, σ_{Li}^2)

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Model: Consumer Demand (1/3)

- PIGL (price-independent generalized linear) preferences:
  - Non-homothetic, defined by indirect utility function V:

$$V(y, P^A, P^M) = \frac{1}{\eta}\left(\frac{y}{(P^A)^{\phi}(P^M)^{1-\phi}}\right)^{\eta} - \nu \ln\left(\frac{P^A}{P^M}\right) \qquad (2)$$

y: income; (P^A, P^M): agro/manufacturing price

- Agro's expenditure share ξ^A then given by:

$$\xi^A(y, P^A, P^M) = \phi + \nu\left(\frac{y}{(P^A)^{\phi}(P^M)^{1-\phi}}\right)^{-\eta} \qquad (3)$$

- Aggregate individual expenditures to get regional expenditure:

$$X_n^A = \phi E_n + \nu((P_n^A)^{\phi}(P_n^M)^{1-\phi})^{\eta}(N_n^W w_n^{1-\eta} + (N_n^{LO})^{\eta} R_n^{1-\eta} e^{-\eta(1-\eta)\frac{\sigma_{Ln}^2}{2}})$$

$$X_n^M = E_n - X_n^A$$

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Model: Consumer Demand (2/3)

- Within agriculture, CES preferences across crops:

$$\beta_{nk}^{A} = b_k (P_{nk}/P_n^A)^{1-\sigma_A}, \text{ for } k \in \{1, ..., K\} \tag{4}$$

$$P_n^A = (\sum_k b_k P_{nk}^{1-\sigma_A})^{\frac{1}{1-\sigma_A}}$$

- Within a crop, CES preferences across origins:

$$\beta_{ni,k}^{A} = b_{i,k} (p_{ik} \tau_{ni,k}^{A} / P_{nk})^{1-\sigma_K} \tag{5}$$

$$P_{nk} = (\sum_i b_{i,k} (p_{ik} \tau_{ni,k}^{A})^{1-\sigma_K})^{\frac{1}{1-\sigma_K}} \tag{6}$$

  - (β_n^s, β_{nk}): expenditure shares
  - (P_n^A, P_{nk}): price indices
  - $(b_k, b_{i,k})$: exogenous taste shifters
  - (p_{ik}): crop prices

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Model: Consumer Demand (3/3)

- Within manufacturing, CES preferences across origins:

$$\beta_{ni}^{M} = (p_{ni}^{M} / P_{n}^{M})^{1-\sigma_M} \tag{7}$$

$$P_{n}^{M} = (\sum_{i} (p_{ni}^{M})^{1-\sigma_M})^{\frac{1}{1-\sigma_M}}$$

  - β_{ni}^{M}: expenditure share (within manufacturing) on origin i
  - p_{ni}^{M}: price in n of the variety from i

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Model: Fertilizer Production

- Fertilizer is not produced, but simply given as an endowment:

$$Q_i^f = F_i \tag{8}$$

  - Q_i^f is fertilizer production in region i.
  - F_i is fertilizer endowment in region i.
  - We assume only RoW produces fertilizer: $F_i = 0$ for $i \neq RoW$.

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Model: Manufacturing Production

- Manufacturing production function in region i is given by:

$$q_i^M = T_i^M n_i^M \tag{9}$$

  - n is labor input.
  - T_i^M is manufacturing productivity.

- Combined with CES demand, these assumptions imply:

$$\beta_{ni}^M = \frac{(w_i \tau_{ni}^M / T_i^M)^{1-\sigma_M}}{\sum_j (w_j \tau_{nj}^M / T_j^M)^{1-\sigma_M}} \tag{10}$$

  - β_{ni}^M: expenditure share (within manufacturing) on goods from region i
  - w_i: wages in region i

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Model: Agricultural Production (1/2)

- Region i has L_{ik} hectares of land suitable for growing crop k.
- Cobb-Douglas production function of crop k in plot ω of region i:

$$q_{ik}(\omega) = T_{ik}^{A}(n_{ik}(\omega))^{\gamma_k^n}(f_{ik}(\omega))^{\gamma_k^f}(l_{ik}(\omega))^{\gamma_k^l} \tag{11}$$

  - n is labor; f is fertilizer; l is land.
  - γ_k^s are exogenous parameters, with $\gamma_k^n + \gamma_k^f + \gamma_k^l = 1$ (CRS).
  - T_{ik}^{A} is productivity parameter.

- Note:
  - Importance of fertilizer (γ_k^f) can vary across crops (k).
  - Productivity parameter (T_{ik}^{A}) captures suitability of land in region i for growing crop k.

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Model: Agricultural Production (2/2)

- In plot ω growing crop k, unit cost minimization is:

$$c_{ik}(\omega) \equiv \min_{q,n,l,m} w_i n + r_{ik}(\omega) l + p_i^f f, \text{ such that: } q(n, l, f, T_{ik}^A) \geq 1$$

$$\Rightarrow c_{ik}(\omega) = \kappa_k w_i^{\gamma_k^n} (r_{ik}(\omega))^{\gamma_k^l} (p_i^f)^{\gamma_k^f} (T_{ik}^A)^{-1}$$

  - $r_{ik}(\omega)$: land rent; p_i^f: fertilizer price

- Price equals marginal cost ($c_{ik}(\omega) = p_{ik}$) due to PC, so we get:

$$r_{ik}(\omega) = (T_{ik}^A)^{\frac{1}{\gamma_k^l}} \underbrace{(p_{ik})^{\frac{1}{\gamma_k^l}} (w_i)^{\frac{-\gamma_k^n}{\gamma_k^l}} (p_i^f)^{\frac{-\gamma_k^f}{\gamma_k^l}} (\kappa_k)^{\frac{-1}{\gamma_k^l}}}_{\equiv h_{ik}} \tag{12}$$

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Market Clearing (1/3): Fertilizer

- Worldwide market clearing in fertilizer is:

$$\underbrace{F_{RoW}}_{\text{fert supply}} = \sum_i \frac{\tau^f_{i,RoW}}{p^f_i} \underbrace{\sum_k \frac{\gamma^f_k}{S_k} p_{ik} Q_{ik}}_{\text{fertilizer expenditure in } i} \tag{13}$$

with fertilizer price given by: $p^f_i = p^f_{RoW} \tau^f_{i,RoW}$.

  - $\tau^f_{i,RoW}$ is "iceberg" trade cost from RoW to region i.
  - One way to represent the fertilizer import ban is as a large increase in $\tau^f_{i,RoW}$.

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Market Clearing (2/3): Agro Crops

- Crop k market clearing in i is:

$$\underbrace{Q_{ik}}_{\text{local production of } k} = \sum_n \frac{\tau^A_{ni,k}}{p_{ni,k}} \underbrace{X^A_n \beta^A_{nk} \beta^A_{ni,k}}_{\text{exports of } k \text{ to region } n} \tag{14}$$

with crop prices satisfying bilateral pricing for all n:

$$p_{ni,k} = \tau^A_{ni,k} p_{ik} \tag{15}$$

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Market Clearing (3/3): Labor

- Labor market clearing in each region i is:

$$\underbrace{N_i^W}_{\text{labor force (supply)}} = \frac{1}{w_i}\Big(\sum_k \underbrace{\frac{\gamma_k^n}{S_k} p_{ik} Q_{ik}}_{\text{wage bill of crop-}k\text{ farms}} + \underbrace{\sum_n X_n^M \beta_{ni}^M}_{\text{manufacturing revenue}}\Big)$$

- Note:
  - Labor demand comes from both agriculture and manufacturing.
  - Manufacturing only uses labor as input, so full revenue is paid to labor in the form of wages.

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Parameter Values

Parameter	Value	SE	Description
ϕ	0.0105	.	Asymptotic agro share
ν	0.12	.	PIGL parameter
η	0.656	0.13	Engel elasticity
σ_A	1.71	0.15	EoS across crops
σ_K	3.63	1.81	EoS across origins (within crop)
σ_M	2.53	.	EoS across origins (manufacturing)
K	7	.	Number of crops
I	25	.	Number Sri Lankan regions (districts)
$\tau^A_{ni,k}$, τ^M_{ni}	1	.	Agro/manufacturing trade costs

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Parameter Values (cont.)

Table: Estimated Parameters: Agro Production Functions

	Cobb-Douglas Coefficients		
Crop (k)	Fertilizer (γ_k^f)	Labor (γ_k^n)	Land (γ_k^l)
Cinnamon	0.053	0.419	0.528
Cloves	0.043	0.424	0.533
Groundnuts	0.023	0.433	0.544
Maize	0.042	0.425	0.533
Onions	0.024	0.433	0.543
Potatoes	0.151	0.384	0.465
Rice	0.086	0.481	0.433

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