Temperature Shocks and Land Fragmentation: Evidence from Transaction and Property Registry Data

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Motivation

- Large share of population in developing countries employed in small, low productivity farms. (Restuccia et al., 2008; Adamopoulos and Restuccia, 2014; Gollin et al., 2014)
- Increasing average farm sizes could lead to substantial productivity gains. (Foster and Rosenzweig, 2022)
- Determinants of farm size are first-order concern. But literature usually abstracts away from role of land markets.
  - Farm size taken as given.
  - Little evidence on the prevalence of distress sales.
  - What prevents farmers from consolidating land into larger, more productive units?

This Paper

- **We study the effect of adverse temperature shocks on land sales and the size of farms in Colombia.**
- We use detailed, longitudinal data on land transactions and the farm size distribution for most of Colombia.
  - We quantify the large role of land sales after increases in shock intensity.
  - We show that shocks cause land *fragmentation*.
  - Consistent with a model of subsistence constraints + 'outside buyers' entering ag.
- In the event of an uninsured negative income shock:
  - Farmers may be forced to sell land to smooth consumption.
  - Increased supply may lower land prices $\rightarrow$ increase number of transactions.
  - Land transactions lead to changes in the equilibrium farm size distribution.

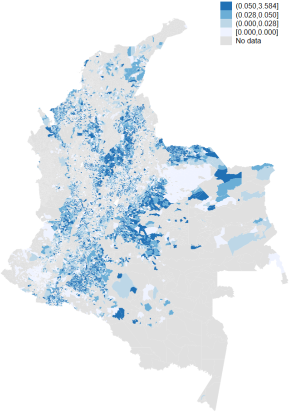
Context

- Low adoption of agricultural insurance.
  - Agricultural insurance coverage rate in Colombia: 1% (ENA, 2019-I)
- Thin rental markets.
  - Share of land plots in Colombia operated by:
    - Renter → 9%
    - Owner → 85% (ENA, 2019-I)
- Suggestive evidence of consumption-smoothing land sales (ELCA household survey, 2016)
  - 65% of households who report selling land did so in order to:
    - Pay for household expenses or cover outstanding debts (51%)
    - Pay for a medical treatment or education fees (14%)
- Land ownership ceilings on *some* land (Arteaga, 2023) → Not driving our results.

Data

1. **Land Sales** – Admin data on land transactions:
   - Transaction-level data for plots originally granted by the government
   - 550,000 land plots, $\approx$ 23 million hectares, $\approx$ 50% of private land
   - $\approx$ 150,000 distinct transactions, but, *i)* only formal; *ii)* potentially selected sample
2. **Farm size Distribution** – Admin data on rural land properties:
   - Municipal census of all rural properties; updated (roughly) every five years.
   - Panel at municipality level with number of plots and owners by area bins.
3. **Household** – Survey data focused on small landholders (ELCA):
   - 4,800 rural households interviewed in three rounds (2010, 2013, 2016).
4. **Temperature** – Satellite imagery data (ERA5):
   - Municipality-specific measure of atypical temperature days.

Land Sales



(a) Sales as fraction of Allocations

(b) Number of Transactions

Temperature Shocks

- ERA5 data set from the Copernicus Climate Change Service (C3S).
- Hourly info. with horizontal resolution of 0.25 x 0.25 degrees ($\approx$ 28 km^2)
- Construction of the shocks:
  1. Obtain daily average temperature of each pixel and aggregate at municipal level.
  2. Compute historical (1979-2016) distribution of daily average temperature for each municipality-quarter.
  3. Temperature of a day is *atypical* if below 20th or above 80th percentile of long run distribution.
  4. $TempShocks_{v,y} \equiv$ number of days of atypically temperature in years $y-1$ and $y-2$.

Map Shocks Alternative Definitions

Empirical Strategy

- Sample period 2000–2011.
- Estimate by OLS:

$$s_{v,y} = \beta_1 TempShocks_{v,y} + X_{v,y} + \eta_v + \theta_y + \varepsilon_{v,y}$$

  Where,
  - $s_{v,y}$: Land sales in municipality v in year y.
  - $X_{v,y}$: rainfall, # land allocations, cadastral update dummy, total farmland in registry.
  - η_v, θ_y: location and year fixed-effects.
  - $\varepsilon_{v,y}$ clustered at the municipality level.
- Identification: conditional on FE, shocks unrelated to factors affecting outcome.
  - Typical in literature on effects of weather shocks. (e.g, Dell et al., 2014)

Descriptive Stats.

Result 1: Shocks increase land sales and mortgages

$$NumTransactions_{v,y} = \beta_1 TempShocks_{v,y} + X_{v,y} + \eta_v + \theta_y + \varepsilon_{v,y}$$

	Municipality level panel			
	Total (1)	Full (2)	Partial (3)	Mortgage (4)
$TempShocks_{v,y}$	0.076***	0.088***	0.116***	0.104***
	(0.021)	(0.023)	(0.028)	(0.020)
Observations	10,392	10,392	10,392	10,392
R-Squared	0.912	0.903	0.710	0.793
Mean Dep. Var.	12.38	10.63	1.75	2.57

Result 2: Shocks reduce the average farm size

	Number of Farms (1)	Number of Owners (2)	Mean Farm Size (3)	Mean Area/Owner (4)	Median Farm Size (5)	Median Area/Owner (6)
$TempShocks_{v,y}$	0.0120**	0.0120***	-0.0120**	-0.0123***	-0.0164	-0.0126
	(0.0048)	(0.0045)	(0.0048)	(0.0046)	(0.0113)	(0.0089)
Observations	10,934	10,934	10,934	10,934	10,934	10,934
R-squared	0.9905	0.9920	0.9935	0.9947	0.9763	0.9881
mean.dep.var	2519	2516	30.50	29.36	15.22	12.88

Owners lags

Size lags

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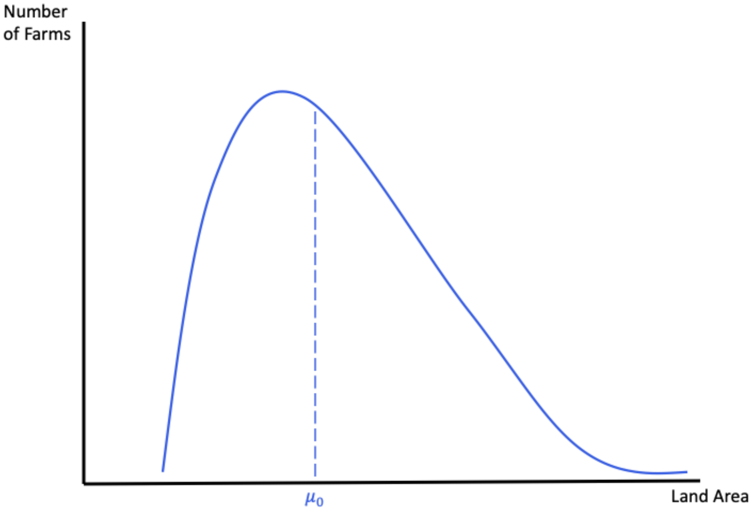
Owners lags

Size lags

- Not informative on *which* farms are becoming smaller...

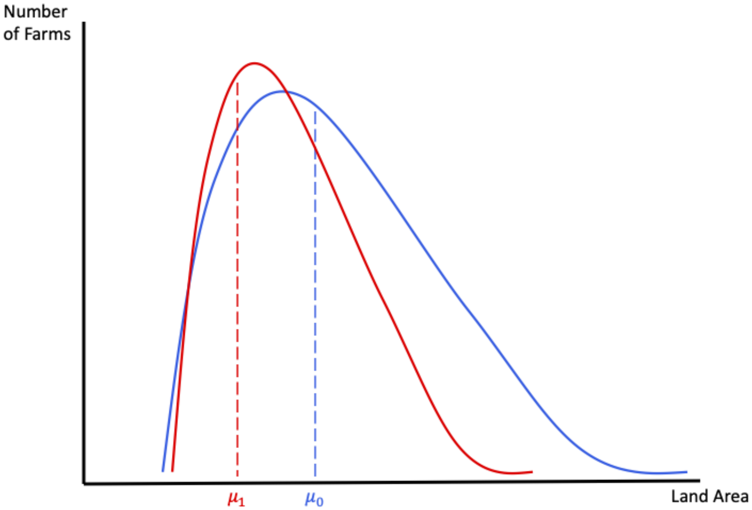
Change in number of owners by size bins

Drop in average farm size could be because...



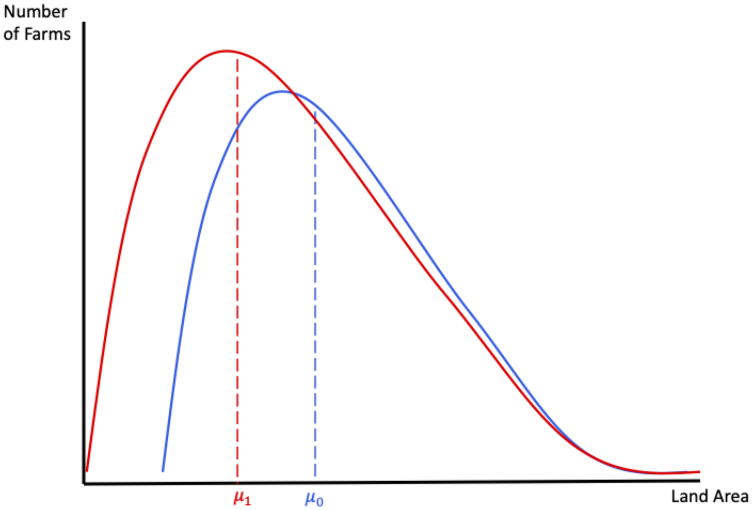
Change in number of owners by size bins

...larger farms split up,



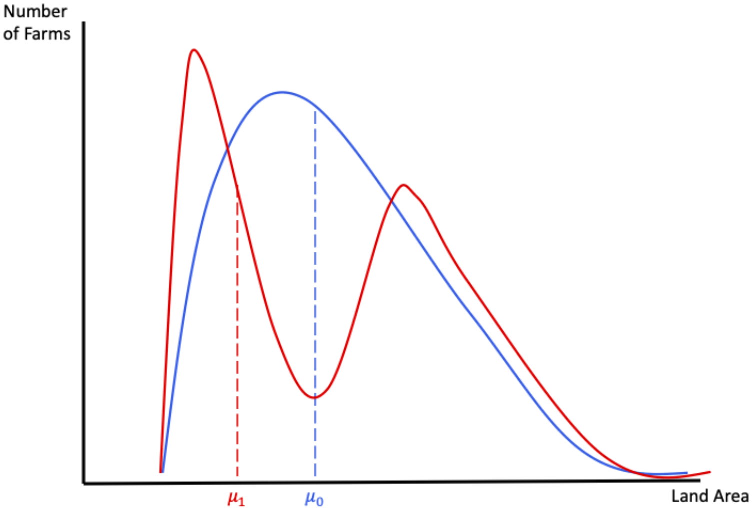
Change in number of owners by size bins

...smaller farms split up



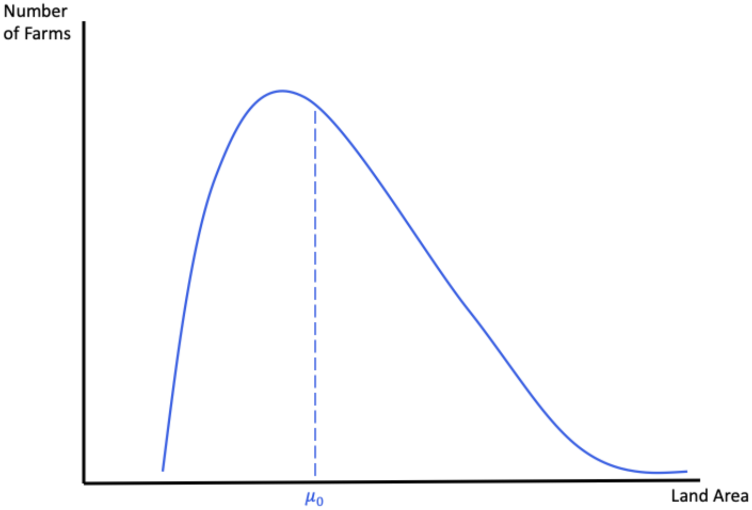
Change in number of owners by size bins

...or mid-sized farms split up



Change in number of owners by size bins

- We define land size bins according to the *initial* distribution in each location



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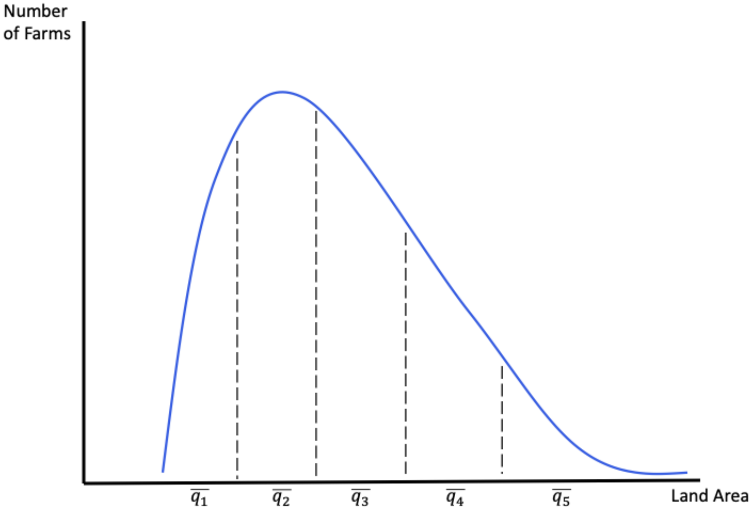
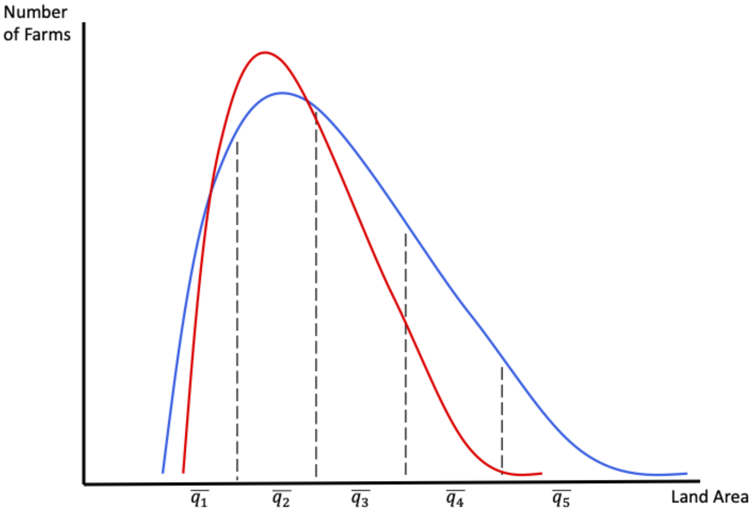


Change in number of owners by size bins

- and estimate the change in the number of owners in each fixed area bin



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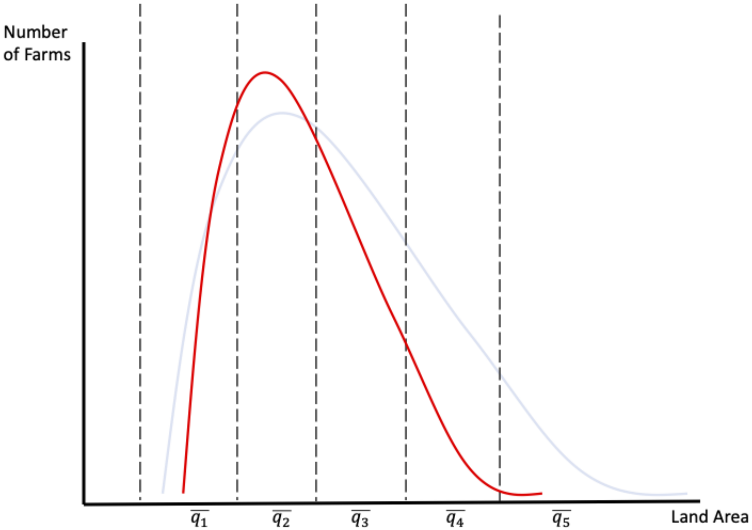
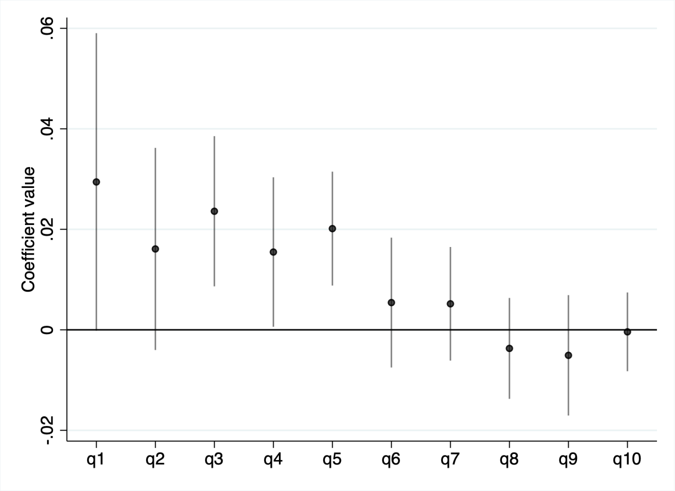


Result 3: Sales translate into increase in number of *small* farmers

$$NumOwners^{q^j}_{m,y} = \gamma TempShocks_{m,y} + X'_{m,y}\xi + \mu_m + \kappa_y + \omega_{v,y},$$



q=5 q=20

Supporting Evidence: Smallholder's Household Survey

	Household Migrated	Consumption per Capita	Household Has Land	Farm Size	Farm Size $\leq$ 3 ha	Work Outside Ag.	Work Off Farm
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$TempShock_{v,y}$	0.064***	-0.122***	-0.050***	-0.126	0.049***	0.077**	-0.010
	(0.019)	(0.026)	(0.016)	(0.088)	(0.019)	(0.034)	(0.023)
Observations	12,124	10,884	11,987	10,756	12,124	7,523	12,124
R-squared	0.555	0.729	0.678	0.779	0.717	0.767	0.537
Mean Dep. Var.	0.107	2.665	0.900	2.875	0.777	0.242	0.749

Summary of Results

- Temperature shocks cause *increases* in land sales and mortgages.
- Temperature shocks cause *reductions* in average farm size.
- Effects concentrated in left tail of the farm size distribution $\rightarrow$ large farmers don't buy smaller farms.
- At the household level, temperature shocks:
  - Make households more likely to migrate.
  - Causes drop in consumption.
  - Household less likely to own land.
  - More likely to work outside agriculture.

Mechanisms: Supply Side

- Strength of effects related to coping strategies available.
  - Fewer mortgages taken in isolated municipalities (poorer, more rural, lower access to markets).

	H_i: High Multipoverty Index		H_i: High Distance to Market		H_i: Low Population Density	
	(1) Sale	(2) Mortgage	(3) Sale	(4) Mortgage	(5) Sale	(6) Mortgage
$TempShocks_{v,y}$	0.0894***	0.169***	0.0727***	0.151***	0.0403	0.161***
	(3.66)	(6.82)	(2.96)	(6.29)	(1.56)	(6.52)
$TempShocks_{v,y} \times H_i$	-0.0184	-0.113***	0.00560	-0.0828***	0.0554**	-0.0898***
	(-0.77)	(-5.01)	(0.24)	(-3.77)	(2.28)	(-4.03)
Observations	9924	9924	10392	10392	10392	10392
R-Squared	0.913	0.794	0.912	0.794	0.912	0.794

Mechanisms: Demand Side

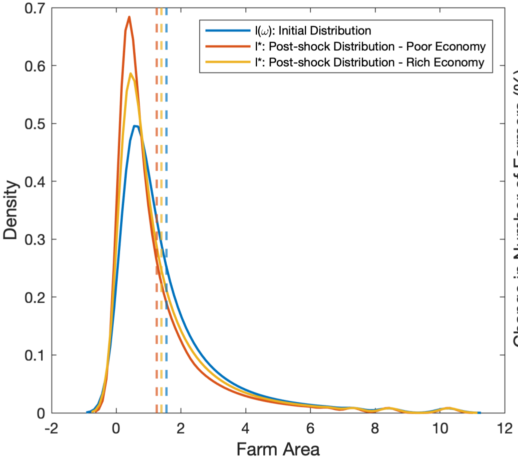
- Law 160 of 1994 forbids accumulation of government-allocated land
  → No evidence that this drives results Land Market Restrictions
- Frictions against consolidation due to non-contiguity of plots for sale? (e.g. Brooks and Lutz)
  → No evidence that this drives results Large Neighbor Prob.

How to explain these results?

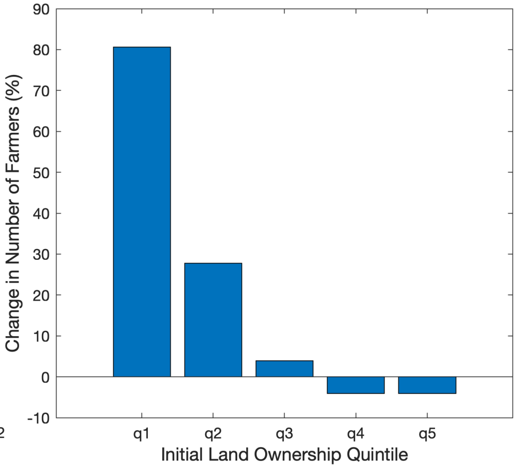
- Stilized Model:
  - Two-periods + heterogeneous agents that differ in initial endowments (land & ‘wealth’).
  - A shock is a change in (agricultural) TFP:
    1. Subsistence constraint binds → poorer farmers exit agriculture → land supply increases.
    2. Land price drops → landless agents unaffected by shock buy land.
- Key elements:
  - Subsistence-consumption constraints.
  - Sectoral shocks.

Model Structure Model Results

Stylized Model



(a) Shocks reduce average farm size



(b) Results come from left tail

Discussion & Next Steps

- Qualitatively results are consistent with subsistence constraints + ‘outside buyers’ entering ag when land prices drop.
  - Working on how to test this in the data.
- Currently working on a richer model.
  - Adding uncertainty.
  - Adding multiple periods.
  - Inspired by heterogeneous agent models in macro.
- Working to take the model to the data and evaluate two sets of counterfactuals:
  - Increased rates of agricultural insurance adoption.
  - Higher shock prevalence/intensity based on climate change projections.

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Thanks!

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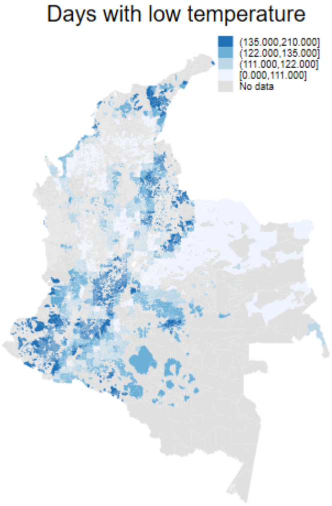
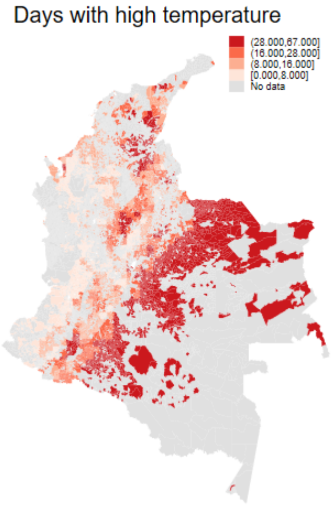
Appendix

Appendix: Temperature Shocks, 2000





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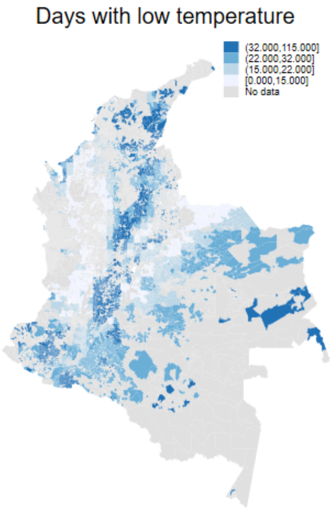
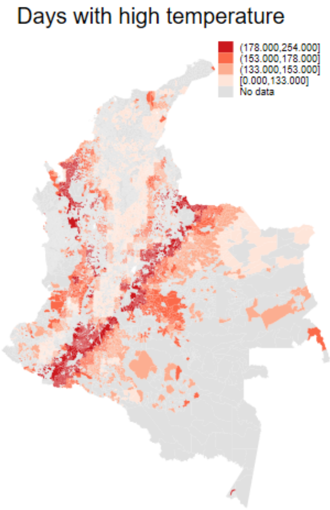
Appendix: Temperature Shocks, 2010





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Appendix: Descriptive Statistics

	Panel A: SNR - Vereda (N = 12,472)			
	Mean	Std. Dev.	Min	Max
Total number of sales	0.55	2.07	0	133
Number of full sales	0.47	1.80	0	132
Number of partial sales	0.07	0.64	0	61
Number of Mortgages	0.11	0.56	0	29
Days of atypical temperature	281.38	55.18	96	560
Days of atypical high temperature	158.42	93.46	0	508
Days of atypical low temperature	122.96	87.65	4	560
Number of total allocations	18.56	55.36	0	2,376
Accumulated precipitation	3,272.2	2,370.8	374.6	33,533
	Panel B: SNR - Municipality (N = 866)			
Total number of sales	12.38	24.56	0	292
Number of full sales	10.63	21.46	0	281
Number of partial sales	1.75	5.98	0	133
Number of Mortgages	2.57	7.48	0	172
Days of atypical temperature	277.24	56.38	96	566
Days of atypical high temperature	157.52	93.52	0	496
Days of atypical low temperature	119.72	90.29	0	564
Number of total allocations	436.52	675.85	0	6,550
Accumulated precipitation	3,539.9	2,836.1	372.2	42,287
	Panel C: Land Registry - Municipality (N = 927)			
Number of owners	2,516.2	2,151.27	18	18,768
Number of plots	2,518.6	2,347.8	17	21,482
Average farm size (ha.)	29.4	94.5	0.65	1,543.5
=1 if land registry update	0.07	0.25	0	1
Registered area (1000 ha.)	39,273.7	84,443.3	170.8	1,465,761
Days of atypical temperature	277.14	56.16	96	566
Days of atypical high temperature	157.68	93.43	0	496
Days of atypical low temperature	119.46	89.67	4	564
Accumulated precipitation	3,488.3	2,804.3	372.2	42,287
	Panel D: ELCA - Household N = 3200			
=1 if HH migrated	0.13	0.33	0	1
=1 if HH has land	0.89	0.31	0	1
=1 if farm size < 3 ha	0.78	0.41	0	1
Farm size (ha.)	2.49	5.54	0	118
Days of atypical high temperature	436.93	165.09	163	816
Days of atypical low temperature	67.03	62.45	0	254
Accumulated precipitation	3792.29	2625.24	720.06	21969.01

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Robustness

- Shocks as realizations outside $[10pct, 90pct]$ of temperature distribution.
- Shocks as realizations outside $[5pct; 95pct]$ of temperature distribution.
- Shocks as realizations outside $[\mu - 1.5sd; \mu + 1.5sd]$ of temperature distribution.
- Shocks as realizations outside $[\mu - 2sd; \mu + 2sd]$ of temperature distribution.
- Shocks defined as days above/below fixed temperature thresholds.
- Exclusion of additional controls.

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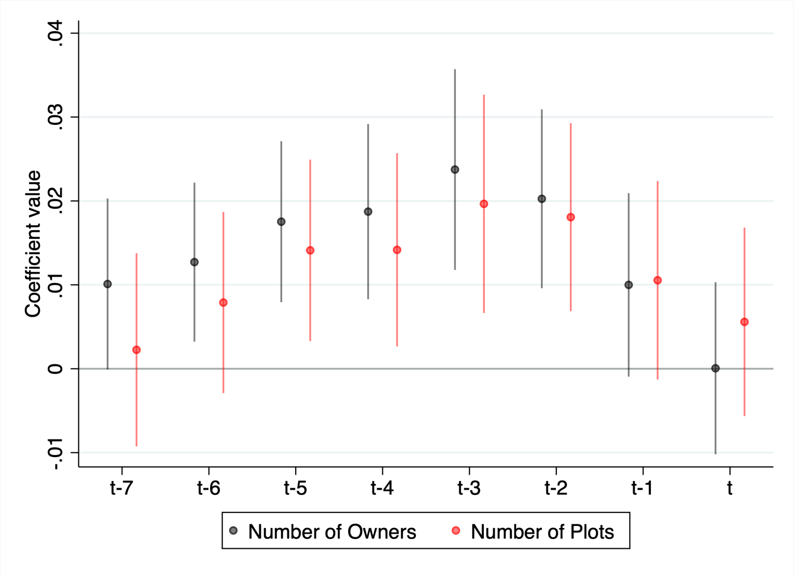
Appendix: Effect on Number of Owners, Lags of Shocks



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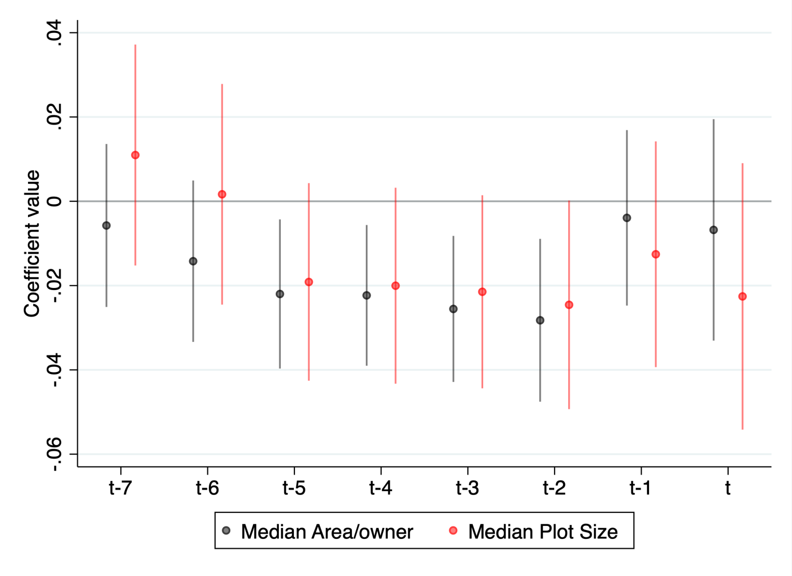
Appendix: Effect on Farm Size, Lags of Shocks



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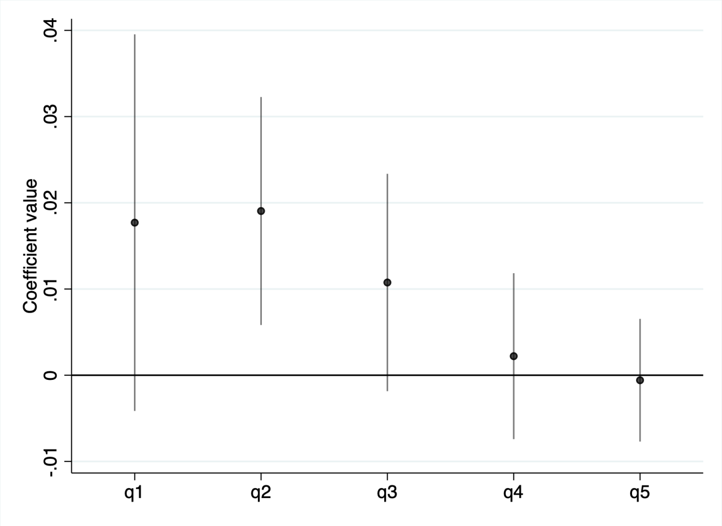
Appendix: Sales translate into increase in number of *small* farmers



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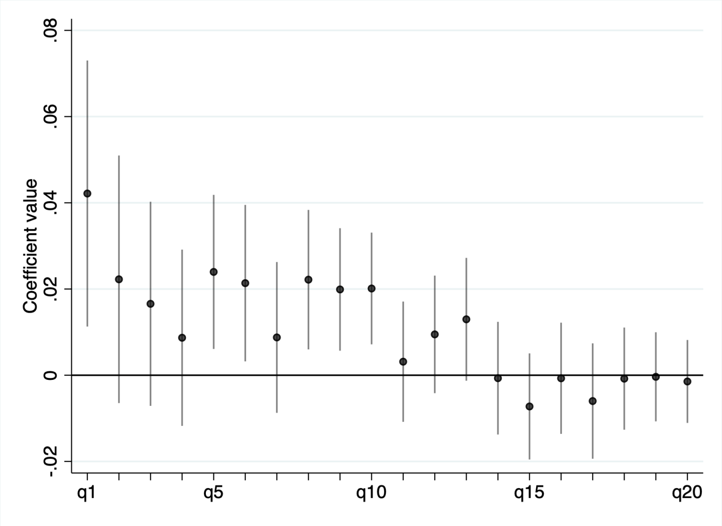

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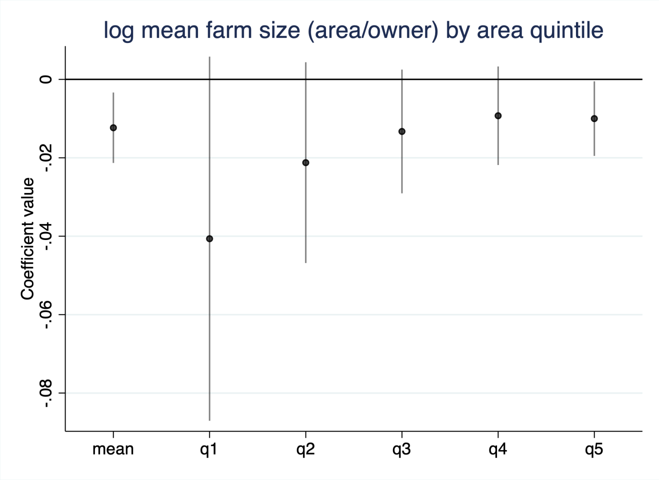
Appendix: Effect of shocks on farm size percentiles



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Mechanisms: Land Market Restrictinos

- Law 160 of 1994 forbids accumulation of land of the public allocation program.
  - Large owners cannot accumulate land.
  - If law explains results, effects concentrated in municipalities with more land allocation.

	Control: Share Allocated				H_i: Share Allocated			
	Number of Farms	Number of Owners	Mean Farm Size	Mean Area/Owner	Number of Farms	Number of Owners	Mean Farm Size	Mean Area/Owner
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$TempShocks_{v,y}$	0.0113**	0.0112**	-0.0113**	-0.0115**	0.0134***	0.0116**	-0.0134***	-0.0119**
	(0.0049)	(0.0046)	(0.0049)	(0.0047)	(0.0048)	(0.0046)	(0.0048)	(0.0046)
$TempShocks_{v,y} \times H_i$					-0.0068	-0.0013	0.0068	0.0012
					(0.0092)	(0.0080)	(0.0092)	(0.0080)
Observations	10,934	10,934	10,934	10,934	10,935	10,935	10,935	10,935
R-squared	0.9905	0.9920	0.9935	0.9947	0.9905	0.9921	0.9935	0.9948
mean.dep.var	2519	2516	30.50	29.36	2518	2516	30.49	29.36
Share alloc.	Yes	Yes	Yes	Yes	No	No	No	No

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Mechanisms: Demand Side

Heterogeneity by probability of large-small plot contiguity

	Number of Plots	Numbers of Owners	Mean Plot Size	Mean Area/Owner
	(1)	(2)	(3)	(4)
	Panel A: Land Registry Map - Contiguous Plots			
$TempShocks_{v,y}$	0.011**	0.010*	-0.011**	-0.010**
	(0.006)	(0.005)	(0.006)	(0.005)
$TempShocks_{v,y} \times High$	-0.005	-0.004	0.005	0.004
	(0.006)	(0.005)	(0.006)	(0.005)
Observations	10,413	10,413	10,413	10,413
R-squared	0.990	0.992	0.994	0.995
Mean Dep. Var	2,576.47	2,582.51	30.41	29.16

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Mechanisms: Demand Side

Heterogeneity by probability of large-small plot contiguity

	Number of Plots	Numbers of Owners	Mean Plot Size	Mean Area/Owner
	(1)	(2)	(3)	(4)
	Panel B: Agricultural Census - Overlapping Buffers			
$TempShocks_{v,y}$	0.016***	0.016***	-0.016***	-0.017***
	(0.006)	(0.006)	(0.006)	(0.006)
$TempShocks_{v,y} \times High$	-0.006	-0.003	0.006	0.003
	(0.006)	(0.005)	(0.006)	(0.005)
Observations	9,402	9,402	9,402	9,402
R-squared	0.990	0.992	0.993	0.995
Mean Dep. Var	2,552.60	2,548.64	29.27	28.23

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Appendix: Model Structure

- Endowments, Occupation, Technology:
  - Agents are endowed with some land (l_0) or wealth (m_0)
  - Occupation is a discrete choice: agents who choose to hold land can't be wage workers
    - Decision depends on which occupation yields highest utility
  - All agents who choose to hold land have same skill and use the same CRS technology:

$$y(l) = al$$

  - A 'shock' is a change in TFP: $a = a_L$ in t_1, $a = a_H$ in t_2; $a_L < a_H$
  - Agents who choose to work in non-farm sector earn a fixed wage w
  - Both farmers and workers can hold 'wealth' asset which has a fixed, exogenous, return each period r_1, r_2

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Appendix: Model Structure

- Timing:
  - t_0: Agents are endowed with asset (m_0), or land (l_0)
  - t_1: Agents decide how much land and asset to hold $\{m_1^*, l_1^*\}$, and consumption (c_1)
  - t_2: Agents consume (c_2) according to their asset and land choices in t_1.

An equilibrium is a land price p_1 and a vector of land and wealth demands $\{l^*, m^*\}$ such that i) each agent is maximizing utility and ii) land markets clear

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Appendix: Model Structure

- Preferences:

$$U = \log(c_1 - c_S) + \log(c_2 - c_S)$$

- Budget constraints:
  - For farmers:

$$a_L(l_0 + l_1) - p_1 l_1 + r_1 m_0 - m_1 = c_1$$
$$a_H(l_0 + l_1) + r_2 m1 = c_2$$

  - For workers:

$$w + p_1 l_0 + r_1 m_0 - m_1 = c_1$$
$$w + r_2 m_1 = c_2$$

  - Farmers choose how much land to buy or sell (l_1), and how much wealth to keep for next period (m_1)
  - Workers sell all of their endowed land $(-l_0)$, choose wealth (m_1) and earn wage (w)

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Appendix: Individual solution

Solution to the individual maximization problem yields:

- For Farmers:

$$l^*_{1,F} = \frac{(2a_L - p_1)}{2(p_1 - a_L)}\left(l_0 + \frac{r_1}{a_L}m_0\right) + \frac{(p_1 - a_L - a_H)}{2a_H(p_1 - a_L)}c_S$$
$$m^*_{1,F} = 0$$
$$U^*_F = \log\left(a_L l_0 + r_1 m_0 - (p_1 - a_L) l^*_1 - c_S\right) + \log\left(a_H (l_0 + l^*_1) - c_S\right)$$

- For Workers:

$$l^*_{1,W} = -l_0$$
$$m^*_{1,W} = \frac{1}{1 + r_2}\left\{c_S(1 - r_2) - w(1 - r_2) + r_2 r_1 m_0 + r_2 p_1 l_0\right\}$$
$$U^*_W = \log\left(a_L l_0 + r_1 m_0 + w - m^*_1 - c_S\right) + \log\left(w + r_2 m^*_1 - c_S\right)$$

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Appendix: General Equilibrium

- For any given land price (p_1) each agent:
  - Computes $\{l^*_{1,F}, m^*_{1,F}, U^*_F\}$; $\{l^*_{1,W}, m^*_{1,W}, U^*_W\}$
  - Chooses to be a farmer if $U^*_F \geq U^*_W$
  - demands l^*_1 at price p_1.
- In GE:
  - Aggregate land demand has to equal aggregate land supply

$$\int_{\omega \in \Omega^\ell_F} l^*(\omega)\, dF(\omega) = \int_{\omega \in \Omega^\ell_W} l^*(\omega)\, dF(\omega)$$

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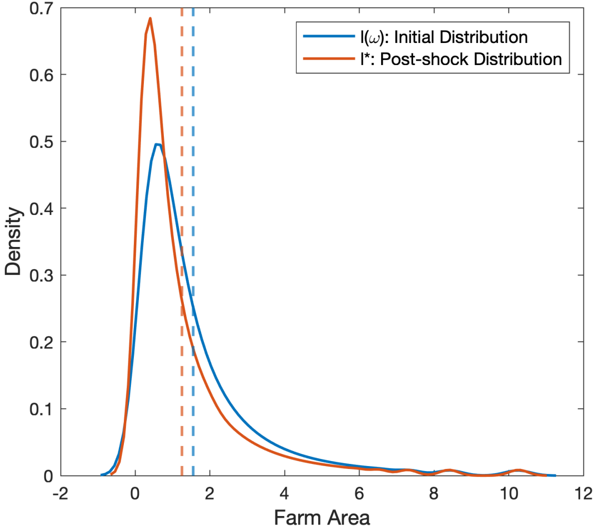
Appendix: Model Results

- $\downarrow$ productivity $\Rightarrow \downarrow$ average farm size, $\uparrow$ number of farmers



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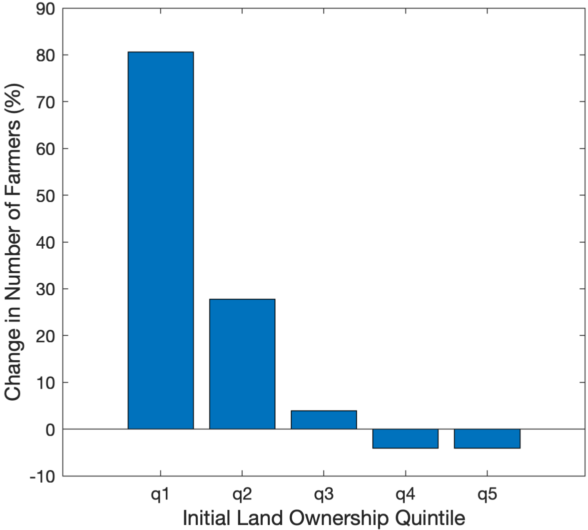
Appendix: Model Results

- $\downarrow$ productivity $\Rightarrow$ results come from left tail



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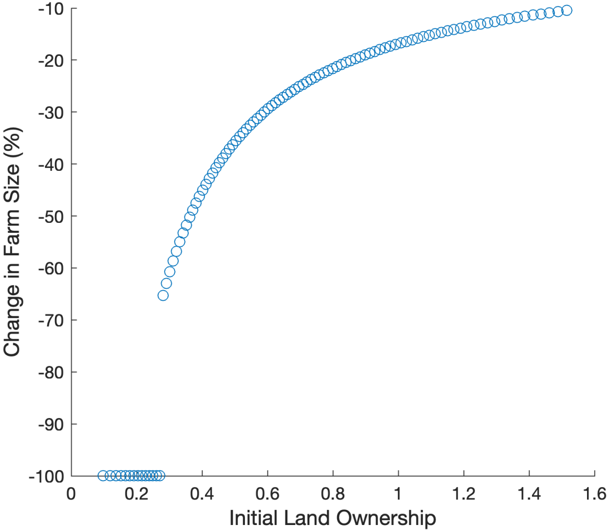
Appendix: Model Results

- $\downarrow$ productivity $\Rightarrow$ farmers leave agriculture



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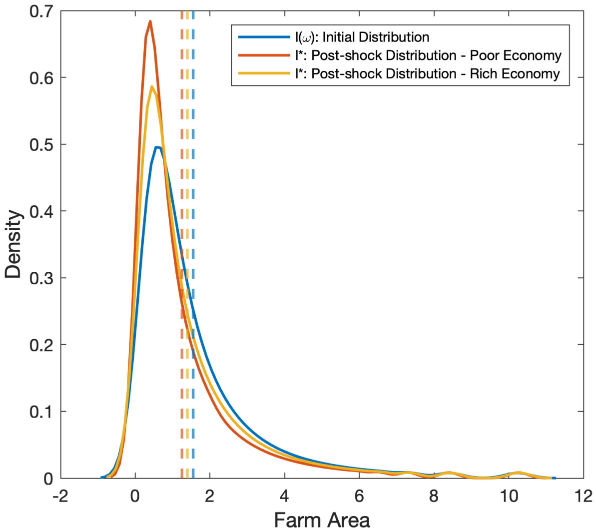
Appendix: Model Results

- $\downarrow$ productivity $\Rightarrow$ Results stronger if region is poorer/less connected to markets:



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