The Effects of Climate Change on Labor and Capital Reallocation: Evidence from Brazil

Christoph Albert[1], Paula Bustos[2] and Jacopo Ponticelli[3]

[1]Collegio Carlo Alberto

[2]CEMFI and CEPR

[3]Northwestern University, CEPR and NBER

Motivation

- Expected economic effects of climate change
  - $\uparrow$ frequency and intensity of extreme weather events [Hsiang and Kopp, 2018]

Motivation

- Expected economic effects of climate change
  - $\uparrow$ frequency and intensity of extreme weather events [Hsiang and Kopp, 2018]
- Developing economies particularly exposed
  - Larger agricultural employment share
  - Frictions to labor and capital reallocation

Motivation

- Expected economic effects of climate change
  - ↑ frequency and intensity of extreme weather events [Hsiang and Kopp, 2018]
- Developing economies particularly exposed
  - Larger agricultural employment share
  - Frictions to labor and capital reallocation
- Open questions
  - Existing evidence: effects on local economic activity, migration
  - Our focus: (i) labor and capital reallocation across sectors/regions
    (ii) spillover effects on destination regions

This paper

- Study effects of excess dryness:

This paper

- Study effects of excess dryness:
  1. Direct: local economy of affected regions (origin)

This paper

- Study effects of excess dryness:
  1. Direct: local economy of affected regions (origin)
  2. Indirect: economy of regions integrated with affected regions via:
     - Bank branch networks (capital)
     - Migrant networks (labor)

This paper

- Study effects of excess dryness:
  1. Direct: local economy of affected regions (origin)
  2. Indirect: economy of regions integrated with affected regions via:
     - Bank branch networks (capital)
     - Migrant networks (labor)
- Setting: Brazil 2000-2018
  - New data on natural disaster reports (droughts)
  - Meteorological measure of excess dryness relative to historical average (SPEI)

This paper

- Study effects of excess dryness:
  1. Direct: local economy of affected regions (origin)
  2. Indirect: economy of regions integrated with affected regions via:
     - Bank branch networks (capital)
     - Migrant networks (labor)
- Setting: Brazil 2000-2018
  - New data on natural disaster reports (droughts)
  - Meteorological measure of excess dryness relative to historical average (SPEI)
- Outcomes
  - Agricultural output (PAM)
  - K reallocation: Bank branch balance-sheet data (ESTBAN)
  - L reallocation: Census and employer-employee data (RAIS)

Main Findings

- A full decade of excess dryness relative to historical averages generates:

  1. Reallocation of capital and labor away from affected regions
     - Consistent with expected permanent reduction in agricultural productivity

Main Findings

- A full decade of excess dryness relative to historical averages generates:

1. Reallocation of capital and labor away from affected regions
   - Consistent with expected permanent reduction in agricultural productivity

2. Changes in the structure of the economy

$\rightarrow$ Labor reallocation away from agriculture and services in directly affected areas
- Within regions: $\rightarrow$ manufacturing

Main Findings

- A full decade of excess dryness relative to historical averages generates:

1. Reallocation of capital and labor away from affected regions
   - Consistent with expected permanent reduction in agricultural productivity

2. Changes in the structure of the economy

$\rightarrow$ Labor reallocation away from agriculture and services in directly affected areas
- Within regions: $\rightarrow$ manufacturing
- Across regions: $\rightarrow$ agriculture, services

Main Findings

- A full decade of excess dryness relative to historical averages generates:

1. Reallocation of capital and labor away from affected regions
   - Consistent with expected permanent reduction in agricultural productivity

2. Changes in the structure of the economy

→ Labor reallocation away from agriculture and services in directly affected areas
- Within regions: → manufacturing
- Across regions: → agriculture, services

→ Explore mechanisms using firm-level exposure to climate migrants

Main Findings

- A full decade of excess dryness relative to historical averages generates:

1. Reallocation of capital and labor away from affected regions
   - Consistent with expected permanent reduction in agricultural productivity

2. Changes in the structure of the economy

→ Labor reallocation away from agriculture and services in directly affected areas
- Within regions: → manufacturing
- Across regions: → agriculture, services

→ Explore mechanisms using firm-level exposure to climate migrants
- Manufacturing firms: (i) less connected to "drying" regions via migrant networks

Main Findings

- A full decade of excess dryness relative to historical averages generates:

1. Reallocation of capital and labor away from affected regions
   - Consistent with expected permanent reduction in agricultural productivity

2. Changes in the structure of the economy

→ Labor reallocation away from agriculture and services in directly affected areas
- Within regions: → manufacturing
- Across regions: → agriculture, services

→ Explore mechanisms using firm-level exposure to climate migrants
- Manufacturing firms: (i) less connected to "drying" regions via migrant networks
  (ii) if connected, respond less to climate-driven L supply ↑

Literature and Contribution

- Evidence on effects of weather shocks and long differences in temperature on local economic activity (agriculture) and migration

  [Jayachandran, 2006; Schlenker and Roberts 2006; Deschenes and Greenstone 2007; Dell et al. 2012; Hornbeck, 2012; Burke and Emerick, 2016; Henderson et al. 2017; Colmer, 2021; Mullins and Bharadwaj 2021]

- Quantitative trade and spatial models on effects of climate change on allocation of economic activity

  [Costinot et al. 2016; Balboni 2021; Conte et al. 2021.]

→ This paper:

(i) Direct local effects vs indirect spillover effects on connected regions

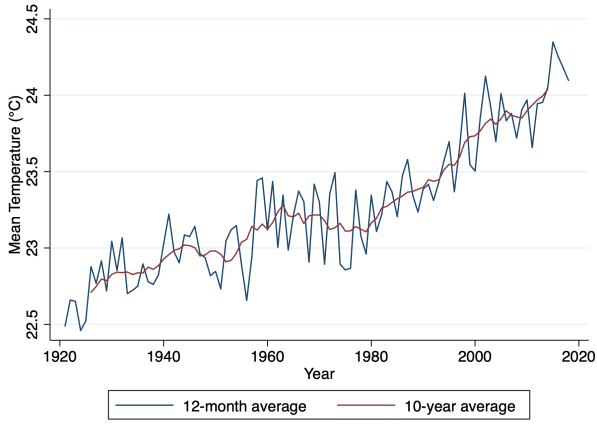
(ii) Evidence on capital reallocation

(iii) Bring analysis to firm-level

Background and Data

Background: Climate Change in Brazil

Figure: Average temperature in Brazil since 1920

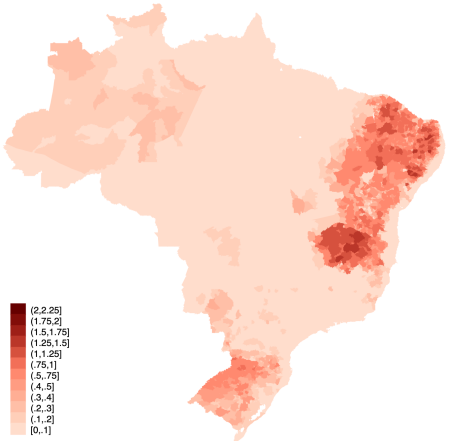


Notes: Data from Climatic Research Unit - University of East Anglia (`https://www.uea.ac.uk/groups-and-centres/climatic-research-unit`)

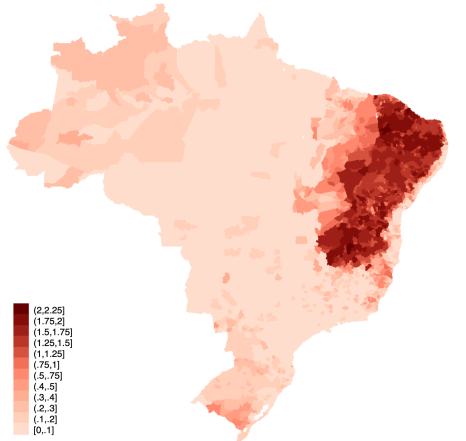
By macro-region

Reported Droughts

(a) 2000-2010

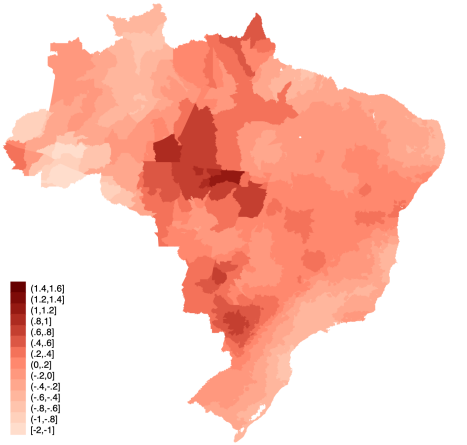


(b) 2011-2018

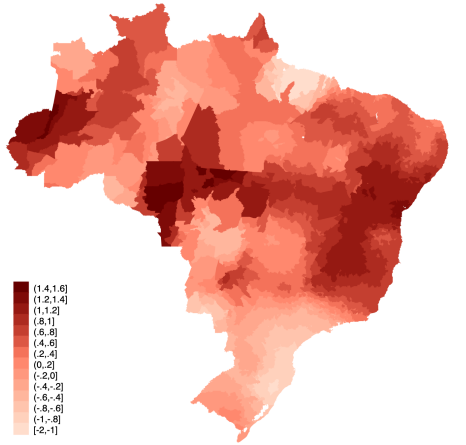


Dryness relative to historical average

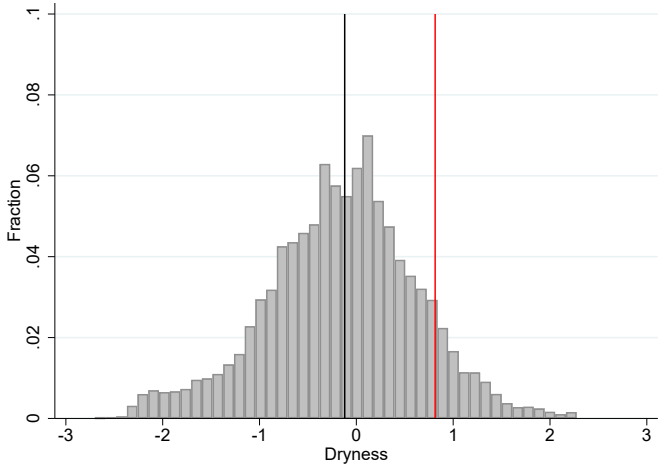
(a) 2000-2010 "normal" decade



(b) 2011-2018 "dry" decade

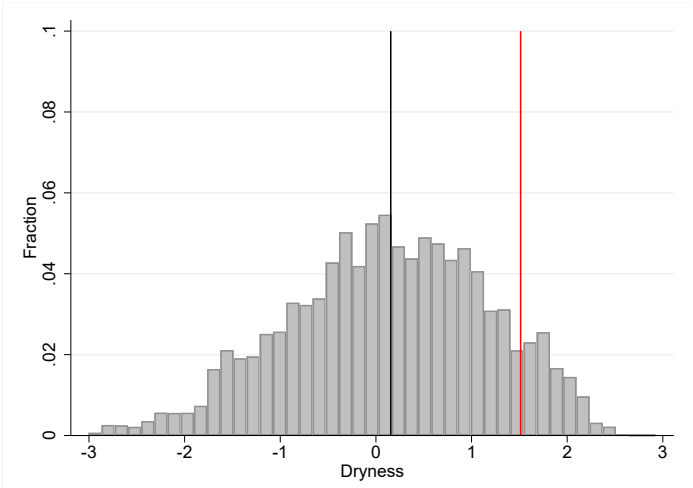


Distribution of Dryness: 2000 to 2010 ("normal" decade)



- municipality moving $50^{th} \rightarrow 90^{th}$ percentile of Dryness $\approx$ 1 St.Dev

Distribution of Dryness: 2011 to 2018 ("dry" decade)



- municipality moving $50^{th} \rightarrow 90^{th}$ percentile of Dryness $\approx$ 1.36 St.Dev First Stage

Balance test

	Number of reported droughts				
	1(# Droughts =0)	1(# Droughts > 0)	Difference		t-stat
share of rural population	0.387	0.536	0.148	***	7.50
log income per capita	4.719	4.309	-0.410	***	3.88
alphabetization rate	0.768	0.661	-0.107	***	3.13
soy soil suitability	0.271	0.334	0.064	***	2.86
maize soil suitability	0.859	1.132	0.272	***	4.31
	Dryness index				
	1(Dryness $\leq$ median)	1(Dryness > median)	Difference		t-stat
share of rural population	0.440	0.477	0.037		1.47
log income per capita	4.570	4.478	-0.092		0.93
alphabetization rate	0.734	0.700	-0.035		1.24
soy soil suitability	0.285	0.317	0.031		1.33
maize soil suitability	0.951	1.028	0.078		1.05

Notes: Observable characteristics observed in 1991 (pop census), except soy and maize productivity, which are theoretical soy and maize yields under low inputs as defined in Bustos, Caprettini and Ponticelli (2016).

Empirical Results

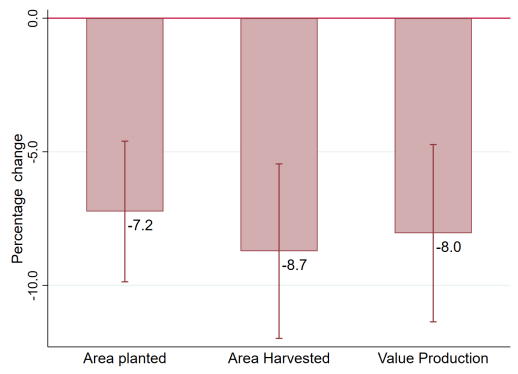
Empirical results

1. Agriculture
2. Capital
3. Labor

Agriculture

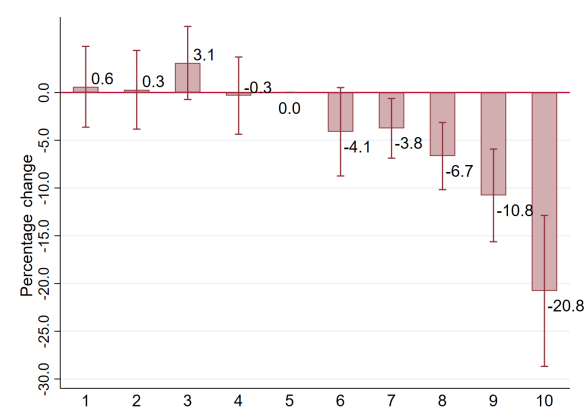
$$y_{mrt} = \alpha_m + \alpha_t + \alpha_{rt} + \beta Dryness_{mt} + \gamma X_{mrt} + u_{mrt}$$

m: municipality (4,248)
r: region (5)
t: time (2000-2018)



Notes: Effects for a municipality going from 50th→ 90th pct of *Dryness*.

Dryness and Value of Agricultural Production



Notes: Effects by decile of *Dryness* (wettest to driest), relative to 5th decile.

Temporary crops, by decile | Yields | All crops | Table

Capital: Specification

$$y_{mrt} = \alpha_m + \alpha_t + \alpha_{rt} + \beta_1 \underbrace{Dryness_{mt}}_{\text{Direct effect}} + \beta_2 \underbrace{ExposureDryness_{mt}}_{\text{Indirect effect}} + \gamma X_{mrt} + u_{mrt}$$

- Outcomes: local deposits, loans, capital outflows

Capital: Specification

$$y_{mrt} = \alpha_m + \alpha_t + \alpha_{rt} + \beta_1 \underbrace{Dryness_{mt}}_{\text{Direct effect}} + \beta_2 \underbrace{ExposureDryness_{mt}}_{\text{Indirect effect}} + \gamma X_{mrt} + u_{mrt}$$

- Outcomes: local deposits, loans, capital outflows
- Steps to compute *ExposureDryness*:
  1. $$BankExposure_{bt} = \sum_{o \in O_b} \omega_{bo} Dryness_{ot}$$

     O_b: set of origin municipalities o in which bank b was present at baseline
     ω_{bo}: share of deposits in bank b originating in municipality o

Capital: Specification

$$y_{mrt} = \alpha_m + \alpha_t + \alpha_{rt} + \beta_1 \underbrace{Dryness_{mt}}_{\text{Direct effect}} + \beta_2 \underbrace{ExposureDryness_{mt}}_{\text{Indirect effect}} + \gamma X_{mrt} + u_{mrt}$$

- Outcomes: local deposits, loans, capital outflows
- Steps to compute *ExposureDryness*:
  1. $$BankExposure_{bt} = \sum_{o \in O_b} \omega_{bo} Dryness_{ot}$$

     O_b: set of origin municipalities o in which bank b was present at baseline
     ω_{bo}: share of deposits in bank b originating in municipality o

  2. $$ExposureDryness_{mt} = \sum_{b \in B_m} w_{bm} BankExposure_{bt}$$

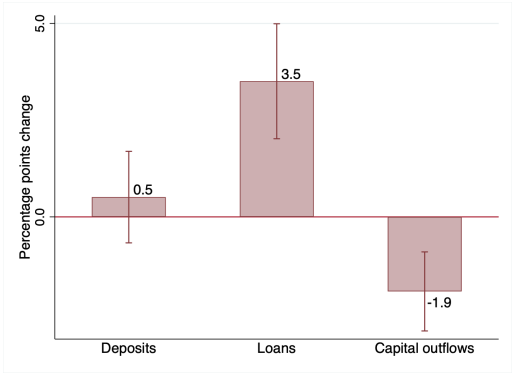
     B_m: set of banks operating in municipality m
     w_{bm}: market share of bank b in m

Year-to-year effect of Dryness on Capital Outcomes

$$y_{mrt} = \alpha_m + \alpha_t + \alpha_{rt} + \beta_1 \underbrace{Dryness_{mt}}_{\text{Direct effect}} + \beta_2 \underbrace{ExposureDryness_{mt}}_{\text{Indirect effect}} + \gamma X_{mrt} + u_{mrt}$$

(a) Direct effect

(b) Indirect effect



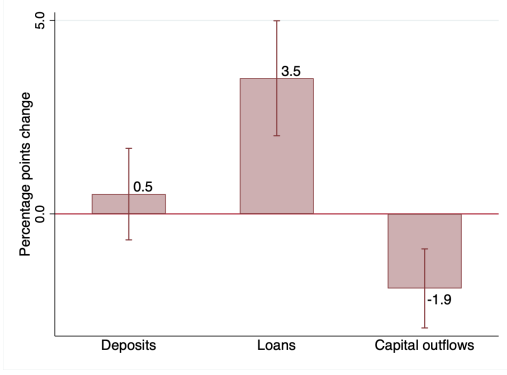
Notes: Effects for a municipality going from 50th→ 90th pct of *Dryness*, *ExposureDryness*.

Table

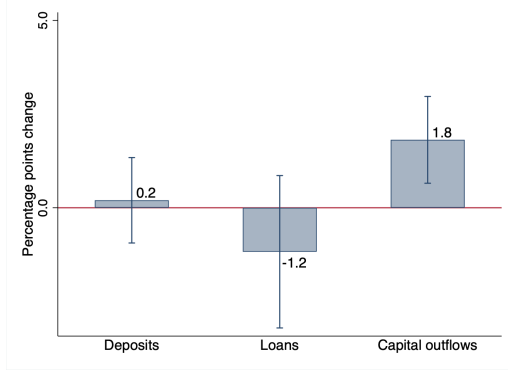
Year-to-year effect of Dryness on Capital Outcomes

$$y_{mrt} = \alpha_m + \alpha_t + \alpha_{rt} + \beta_1 \underbrace{Dryness_{mt}}_{\text{Direct effect}} + \beta_2 \underbrace{ExposureDryness_{mt}}_{\text{Indirect effect}} + \gamma X_{mrt} + u_{mrt}$$

(a) Direct effect



(b) Indirect effect



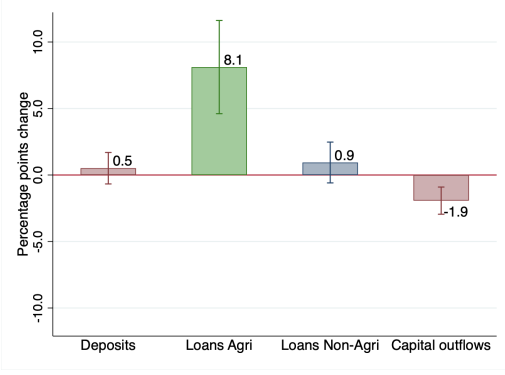
Notes: Effects for a municipality going from 50th→ 90th pct of *Dryness*, *ExposureDryness*.

Table

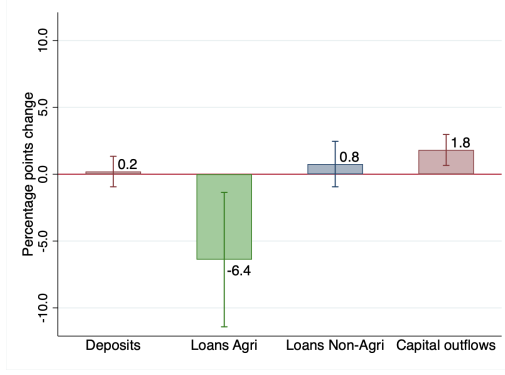
Year-to-year effect of Dryness on Capital Outcomes

$$y_{mrt} = \alpha_m + \alpha_t + \alpha_{rt} + \beta_1 \underbrace{Dryness_{mt}}_{\text{Direct effect}} + \beta_2 \underbrace{ExposureDryness_{mt}}_{\text{Indirect effect}} + \gamma X_{mrt} + u_{mrt}$$

(a) Direct effect



(b) Indirect effect



Notes: Effects for a municipality going from 50th→ 90th pct of *Dryness*, *ExposureDryness*.

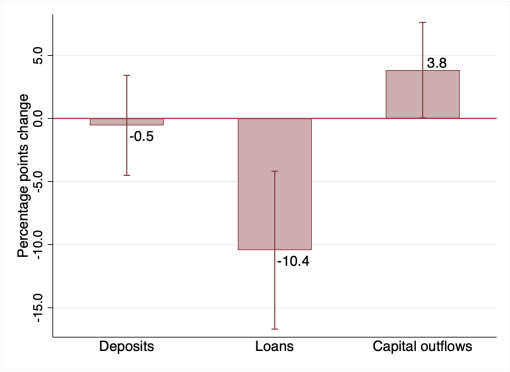
Table

Decadal effect of Dryness on Capital Outcomes

$$\Delta y_{mr,2000-2010} = \alpha_r + \beta_1 \underbrace{Dryness_{m,2001-2010}}_{\text{Direct effect}} + \beta_2 \underbrace{ExposureDryness_{m,2001-2010}}_{\text{Indirect effect}} + \gamma X_{mr} + u_{mr}$$

(a) Direct effect

(b) Indirect effect



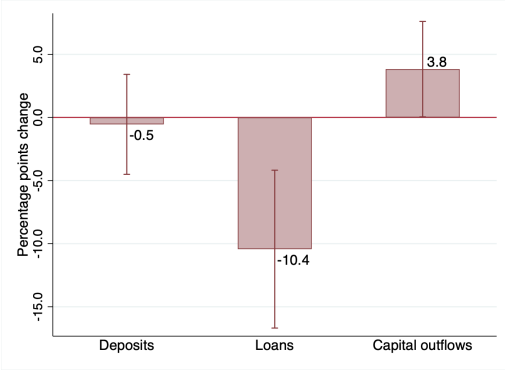
Notes: Effects for a municipality going from 50th→ 90th pct of *Dryness*, *ExposureDryness*.

Table Agri vs Non-agri

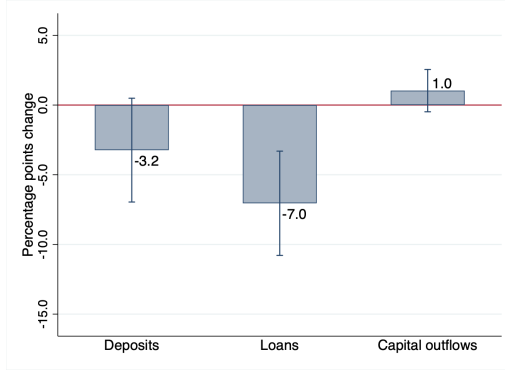
Decadal effect of Dryness on Capital Outcomes

$$\Delta y_{mr,2000-2010} = \alpha_r + \beta_1 \underbrace{Dryness_{m,2001-2010}}_{\text{Direct effect}} + \beta_2 \underbrace{ExposureDryness_{m,2001-2010}}_{\text{Indirect effect}} + \gamma X_{mr} + u_{mr}$$

(a) Direct effect



(b) Indirect effect



Notes: Effects for a municipality going from 50th→ 90th pct of *Dryness*, *ExposureDryness*.

Table Agri vs Non-agri

Labor: Specification

- Data on migration flows and employment: Population Census 2000 and 2010

$$y_{mr,2000-2010} = \alpha_r + \beta_1 \underbrace{Dryness_{m,2001-2010}}_{\text{Direct effect}} + \beta_2 \underbrace{ExposureDryness_{m,2001-2010}}_{\text{Indirect effect}} + \gamma X_{mr} + \varepsilon_{mr},$$

Labor: Specification

- Data on migration flows and employment: Population Census 2000 and 2010

$$y_{mr,2000-2010} = \alpha_r + \beta_1 \underbrace{Dryness_{m,2001-2010}}_{\text{Direct effect}} + \beta_2 \underbrace{ExposureDryness_{m,2001-2010}}_{\text{Indirect effect}} + \gamma X_{mr} + \varepsilon_{mr},$$

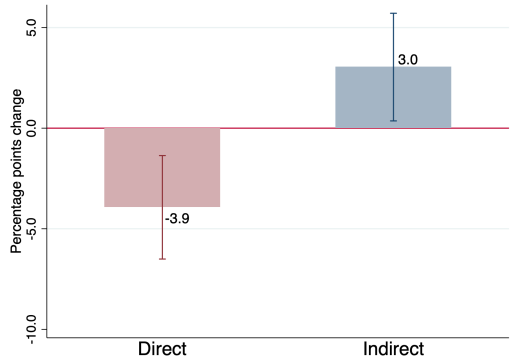
$$ExposureDryness_{m,2001-2010} = \sum_{o \neq m} \alpha_{om} Dryness_{o,2001-2010},$$

$$\alpha_{om} = \frac{\text{Migrants}_{o \to m}}{\text{Migrants}_{m}} \text{ in 2000 Census}$$

o: origin municipality, m: destination municipality

Employment

$$\Delta \log L_{mr,2000-2010} = \alpha_r + \beta_1 \underbrace{Dryness_{m,2001-2010}}_{\text{Direct effect}} + \beta_2 \underbrace{ExposureDryness_{m,2001-2010}}_{\text{Indirect effect}} + \gamma X_{mr} + \varepsilon_{mr},$$

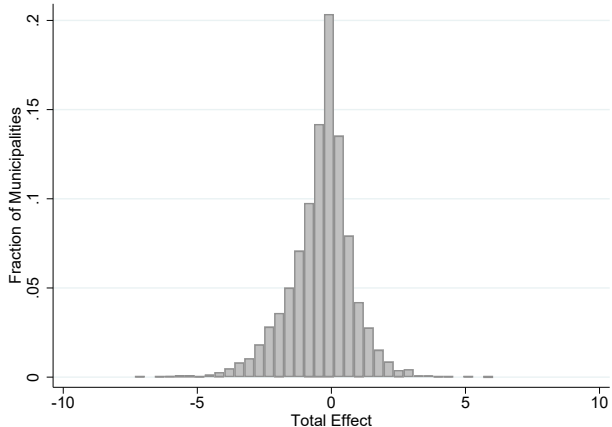


Notes: Effects for a municipality going from 50th→ 90th pct of *Dryness*, *ExposureDryness*.

Table | Table with distance | Population | Droughts

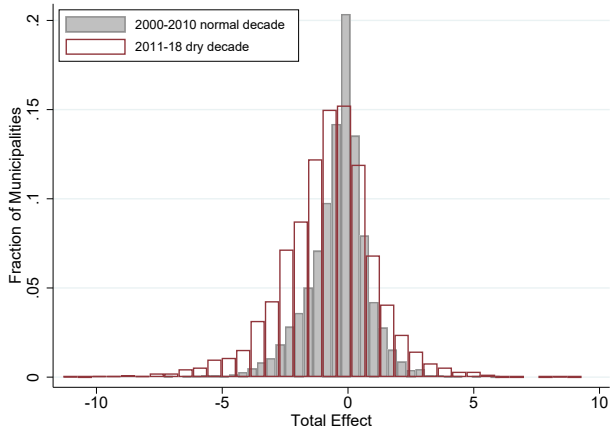
Total Effect on Employment = Direct + Indirect

$$TE_m = \hat{\beta}_1 Dryness_m + \hat{\beta}_2 ExposureDryness_m$$



Total Effect on Employment = Direct + Indirect

$$TE_m = \hat{\beta}_1 Dryness_m + \hat{\beta}_2 ExposureDryness_m$$

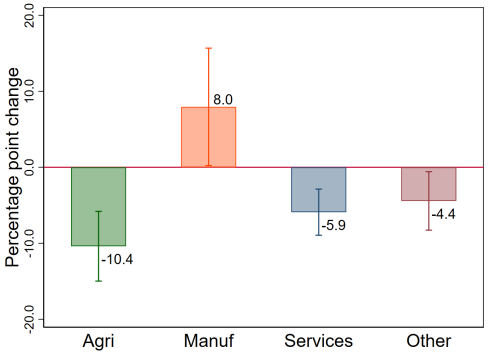


Sectoral structure of the economy

$$\Delta \log L^{sector}_{m,2000-2010} = \beta_1 \underbrace{Dryness_{m,2001-2010}}_{\text{Direct effect}} + \beta_2 \underbrace{ExposureDryness_{mr,2001-2010}}_{\text{Indirect effect}} + \alpha_r + \gamma X_{mr} + \varepsilon_{mr},$$

(a) Direct effect

(b) Indirect effect

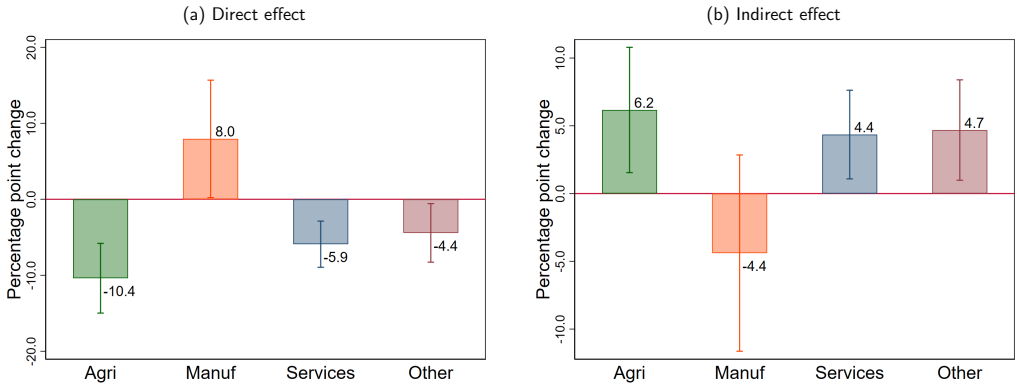


Notes: Effects for a municipality going from 50th→ 90th pct of *Dryness*, *ExposureDryness*.

Figure shares | Table | Droughts

Sectoral structure of the economy

$$\Delta \log L^{sector}_{m,2000-2010} = \beta_1 \underbrace{Dryness_{m,2001-2010}}_{\text{Direct effect}} + \beta_2 \underbrace{ExposureDryness_{mr,2001-2010}}_{\text{Indirect effect}} + \alpha_r + \gamma X_{mr} + \varepsilon_{mr},$$



Notes: Effects for a municipality going from 50th→ 90th pct of *Dryness*, *ExposureDryness*.

Figure shares | Table | Droughts

Margins of adjustment

- Effects for a municipality going from 50th→ 90th pct of *Dryness*

  → 3.7% of individuals aged 18-64 leave employment in agriculture and services.

  Of these:

  15% relocate locally to the manufacturing sector Table

  50% emigrate to other municipalities Migration

- No direct/indirect effects on average wages Wages
  - Suggestive evidence that migrants from dry areas earn less than average worker at destination Individual-level results

Effects on Destination Firms

- Analysis at firm level:
  1. Explore mechanisms:
     - Why lack of reallocation into manufacturing at destination?

Effects on Destination Firms

- Analysis at firm level:
  1. Explore mechanisms:
     - Why lack of reallocation into manufacturing at destination?
  2. Identification:
     - Municipalities more exposed to *Dryness* via migrant flows might also be more connected via other channels (e.g. trade links)

     $\rightarrow$ Exploit variation *within* destination regions

Effects on Destination Firms

- Analysis at firm level:
  1. Explore mechanisms:
     - Why lack of reallocation into manufacturing at destination?
  2. Identification:
     - Municipalities more exposed to *Dryness* via migrant flows might also be more connected via other channels (e.g. trade links)

     $\rightarrow$ Exploit variation *within* destination regions

To measure workers' flows across locations and firms we use data from RAIS:

- Employer-employee dataset, covering all formal workers

Firm exposure

- Firm exposure to past migration from municipality o:

$$\alpha_{oi(m)} = \frac{L_{i(m),o \to m}}{L_{i(m)}}$$

- Share of workers employed in firm i whose last move was $o \to m$

  (baseline year: 2005, reference period 1998 to 2005)

Firm exposure

- Firm exposure to past migration from municipality o:

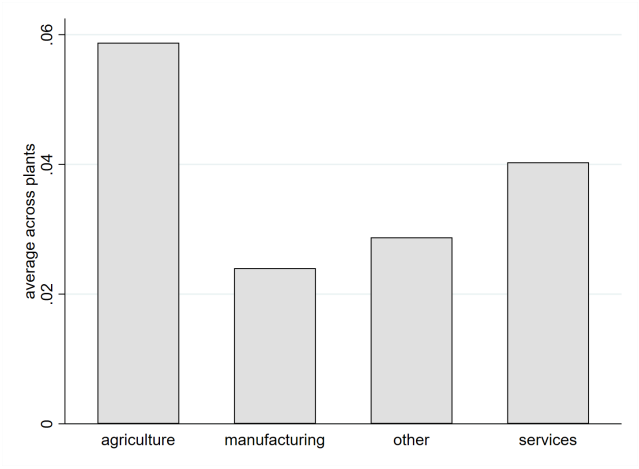
$$\alpha_{oi(m)} = \frac{L_{i(m),o \to m}}{L_{i(m)}}$$

- Share of workers employed in firm i whose last move was $o \to m$

  (baseline year: 2005, reference period 1998 to 2005)

$\to$ Rationale: migrant workers follow similar employment trajectories as previous migrants from same area (e.g. referrals)

Figure: Average firm-level initial connections to "very dry" municipalities



- Agriculture and services: more connected to dry regions via past migrant networks
- Manufacturing: least connected

Firm-origin level specification

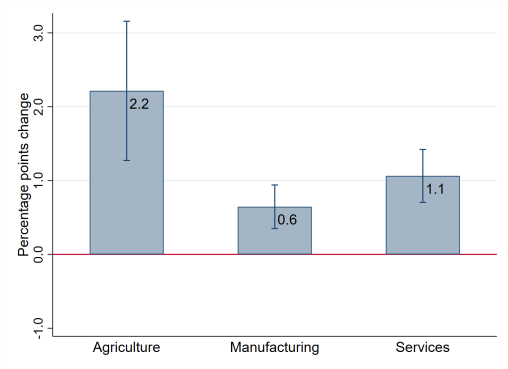
$$\underbrace{\frac{L_{oi(m),2006-2010}}{L_{i(m)}}}_{\substack{\text{worker flow}\\ \text{from origin } o\\ \text{to firm } i}} = \alpha_i + \beta_1 \alpha_{oi(m)} + \beta_2 \underbrace{\alpha_{oi(m)}}_{\substack{\text{firm initial}\\ \text{exposure to } o}} \times \underbrace{1(Dry)_o}_{\substack{=1 \text{ if } o\\ \text{top quartile}\\ \text{of } Dryness}} + \gamma 1(Dry)_o + \varepsilon_{oi(m)}$$

i: plant
m: destination municipality
o: origin municipality

Firm exposure and employment growth

- Effect for firms with average connection to areas with excess dryness, for 0.76 st.dev. ↑ *Dryness*

(a) by sector

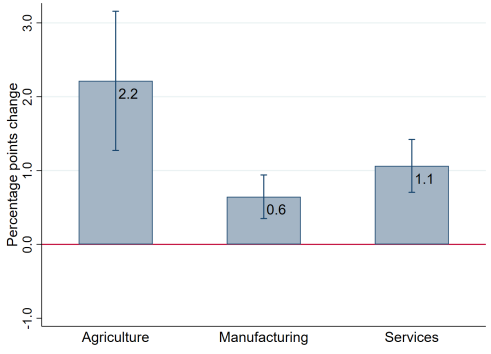


(b) by size

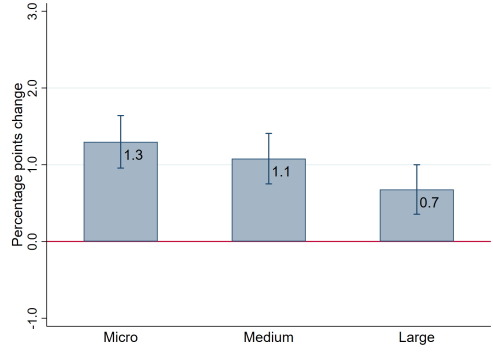
Firm exposure and employment growth

- Effect for firms with average connection to areas with excess dryness, for 0.76 st.dev. ↑ *Dryness*

(a) by sector



(b) by size



Concluding Remarks

- Evidence on effects of climate change on labor and capital reallocation
- A full decade of excess dryness relative to historical averages generates:

  1. Reallocation of capital and labor away from affected regions
  2. Changes in the structure of the economy

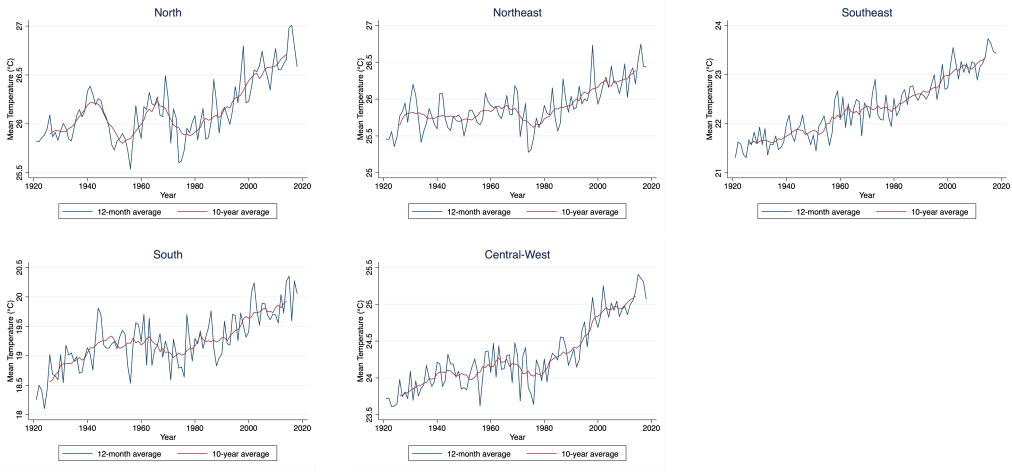
  $\rightarrow$ Labor reallocation away from agriculture and services in directly affected areas
  - within regions: $\rightarrow$ manufacturing
  - across regions: $\rightarrow$ agriculture, services

  $\rightarrow$ Key friction: spatial reallocation from agriculture to manufacturing

Thank you!

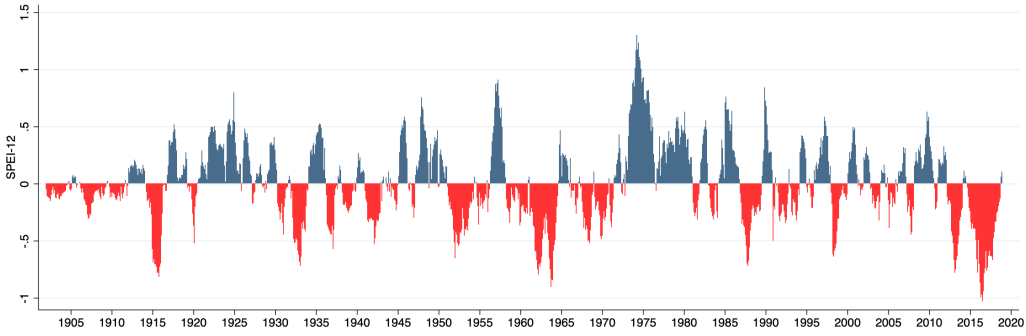
Background

Figure: Average temperature by macro-region since 1920



Measured dryness over time using SPEI

Figure: Average monthly SPEI for Brazil since 1902

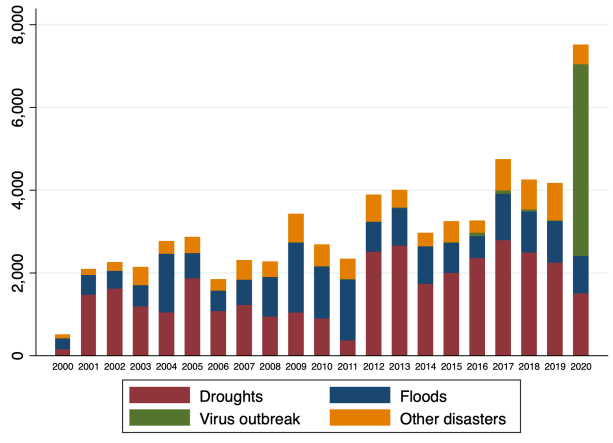


Source: Vicente-Serrano et al. (2010), available at `https://spei.csic.es/database.html`

By macro-region

Reported disasters over time

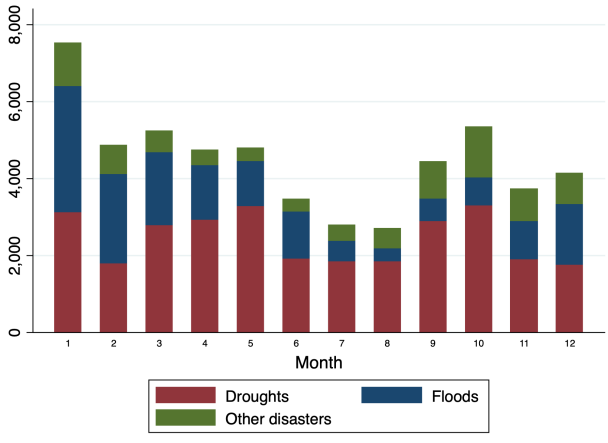
Figure: Disasters By Year - Relatorio: 2000-2020 (with virus category)



Back

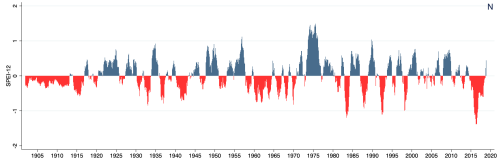
Reported disasters by calendar month

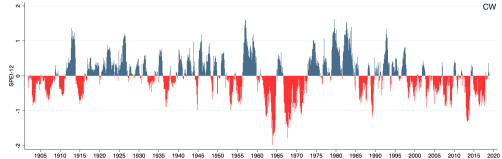
Figure: Disasters By Month - Relatorio

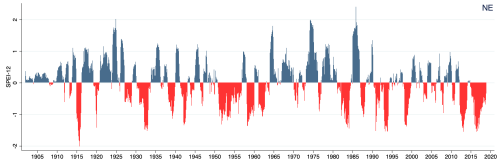


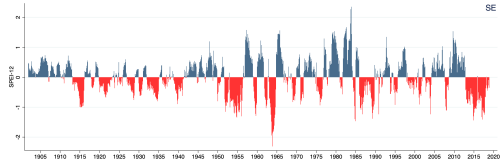
Back

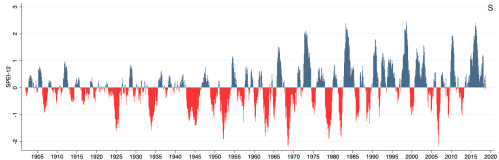
Measured dryness over time











Back

Self-Calibrating Palmer Drought Severity Index

- PDSI (Palmer, 1964)
  - Standard measure of *meteorological droughts*
  - Objective: "measure the cumulative departure in surface water balance"

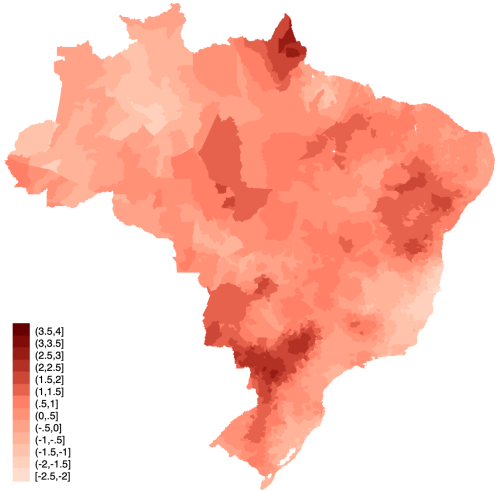
$$PDSI_i = 0.897 * PDSI_{i-1} + \frac{1}{3} * Z_i$$

  - where i month, $Z_i = dK$:
  - d: moisture departure, gap between actual precipitation (P) and the precipitation needed to maintain a normal soil moisture level ($\hat{P}$). $\hat{P}$ depends on: potential evapotranspiration, recharge, runoff, and loss
  - K: "climatic characteristics"
- sc-PDSI: (Wells et al. 2004)
  - PDSI uses model parameters from US data: not representative
  - Main innovations:
    1. compute constants used in K using data on local climate
    2. automatic calculation of duration factors (0.897 and 1/3)

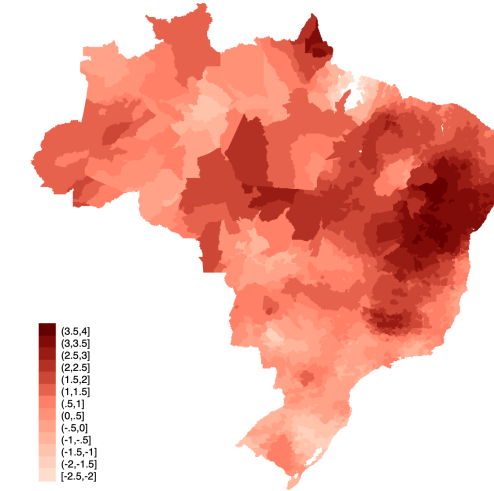
Back

Geographical Distribution of PDSI

(a) 2000-2010



(b) 2011-2018



Effects of contemporaneous weather shocks on agriculture

$$y_{ort} = \alpha_o + \alpha_t + \alpha_{rt} + \gamma Dryness_{ot} + \beta_2 Floods_{ot} + \Lambda Controls_o \times t + u_{ort}$$

Table: Effects of dryness on agricultural outcomes

	(1)	(2)	(3)	(4)	(5)	(6)
	log area planted	log area harvested	log value production	log area planted	log area harvested	log value production
VARIABLES	2000-2010	2000-2010	2000-2010	2011-2018	2011-2018	2011-2018
# Droughts	0.000702	-0.0411***	-0.0923***	-0.0593***	-0.0879***	-0.135***
	(0.00460)	(0.00597)	(0.00714)	(0.00637)	(0.00821)	(0.00917)
Observations	46,228	46,224	46,224	33,599	33,549	33,548
R-squared	0.960	0.949	0.943	0.952	0.937	0.943
Year and AMC FE	y	y	y	y	y	y
RuralShare1991 x year FE	y	y	y	y	y	y
Dist Coast x year FE	y	y	y	y	y	y

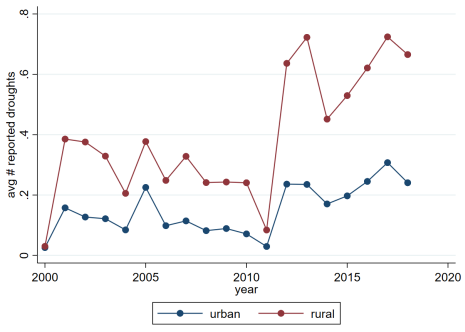
Notes: Standard errors are clustered at the AMC level. A control for the number of reported floods is included in all columns. Data are at the yearly level and range from 2000 to 2010.

Back

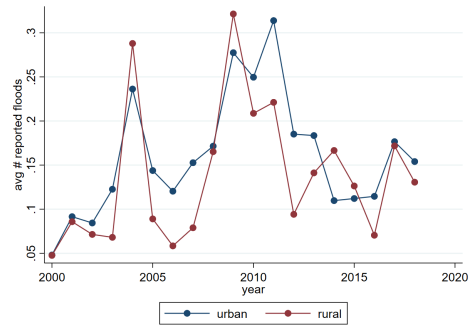
Natural Disasters Affecting Rural vs Urban Areas

- Droughts mostly affect rural areas, while floods similarly affect rural and urban areas

(a) Avg. yearly reported droughts



(b) Avg. yearly reported floods



Notes: Rural municipalities = share of rural adult population above median in 1991 Population Census (47%).

Back

Effects of droughts on agricultural outcomes

$$y_{ort} = \alpha_o + \alpha_t + \alpha_{rt} + \beta Dryness_{ort} + \Lambda Controls_{or} \times t + u_{ort}$$

where o: origin municipality, r: macroregion, t: year

Table: Effects of dryness on agricultural outcomes

VARIABLES	(1) log area planted 2011-2018	(2) log area harvested 2011-2018	(3) log value production 2011-2018
SPEI-12 ×(-1)	-0.0467*** (0.00304)	-0.0699*** (0.00354)	-0.0741*** (0.00358)
Observations	33,599	33,549	33,548
R-squared	0.952	0.937	0.943
Year and AMC FE	y	y	y
RuralShare1991 x year FE	y	y	y
Dist Coast x year FE	y	y	y

Notes: Standard errors are clustered at the AMC level. A control for the number of reported floods is included in all columns.

Back

Capital reallocation: Specification

$$Exposure_{dt} = \sum_{b \in B_d} w_{bd} BankExposure_{bt},$$

$$BankExposure_{bt} = \sum_{o \in O_b} \omega_{bo} \lambda_{TAo} Dryness_{ot}.$$

- w_{bd}: lending market share of bank b in destination municipality d
- ω_{bo}: share of national deposits of bank b from origin municipality o
- O_b: set of origin municipalities in which bank b was present at baseline
- λ_{TAo}: share of land employed by the agricultural sector in origin o

Back

Migration Flows between 2005-2010, from Population Census

- We construct 2005-2010 bilateral migration flows across municipalities based on reported municipality of residence 5 years ago.
- We obtain 2005-2010 municipality inflows and outflows by aggregating bilateral flows by destination and origin, respectively.
- The net migrant flow of a municipality is the difference between its inflows and outflows.
- Around 8% of the 18-64 population have migrated in 2005-2010.

Back

Change in Population: 2000-2010

Table: Change in Population: 2000-2010

	(1)	(2)	(3)	(4)	(5)
	Δ log Pop				
VARIABLES	all	all	all	rural	urban
# Droughts	-0.0401***	-0.0135*	-0.0391***	-0.0171	-0.0688***
	(0.00629)	(0.00698)	(0.0110)	(0.0140)	(0.0176)
Indirect exposure to droughts			0.0599***	0.0148	0.156***
			(0.0194)	(0.0243)	(0.0325)
Observations	4,254	4,249	4,248	2,126	2,122
R-squared	0.110	0.176	0.178	0.220	0.147
mean Y	.159	.159	.159	.145	.173
Macro-region FE	y	y	y	y	y
Controls	n	y	y	y	y

Notes: Robust standard errors are reported in parenthesis. The set of additional controls at the municipality level includes the share of population living in rural areas, log income per capita, literacy rate, population density and changes in soy and maize potential yields.

Back

Change in Employment: 2000-2010

Table: Change in Log Employment: 2000-2010

VARIABLES	(1) Δ log L all	(2) agriculture	(3) manufacturing	(4) services	(5) other
SPEI-12 $\times(-1)$	-0.0885***	-0.247***	0.188**	-0.130***	-0.100***
	(0.0236)	(0.0427)	(0.0794)	(0.0328)	(0.0334)
Indirect exposure to SPEI-12 $\times(-1)$	0.0894***	0.193***	-0.120	0.122***	0.140***
	(0.0334)	(0.0594)	(0.116)	(0.0466)	(0.0466)
Observations	4,248	4,248	4,241	4,248	4,248
R-squared	0.130	0.070	0.083	0.080	0.044
mean Y	.185	.003	.247	.293	.302
Macro-region FE	y	y	y	y	y
Controls	y	y	y	y	y

Notes: Robust standard errors are reported in parenthesis. The set of additional controls at the municipality level includes the share of population living in rural areas, log income per capita, literacy rate, population density and changes in soy and maize potential yields.

Back

Employment Regressions - Sector employment shares

Table: Change in Employment Shares (cols 2-5): 2000-2010

VARIABLES	(1) $\Delta \log L$	(2) $\Delta(L_{agri}/L)$	(3) $\Delta(L_{manuf}/L)$	(4) $\Delta(L_{serv}/L)$	(5) $\Delta(L_{other}/L)$
Dryness	-0.0885**	-0.0311**	0.0449***	-0.0120	-0.00189
	(0.0349)	(0.0132)	(0.0125)	(0.00773)	(0.00626)
Indirect exposure to Dryness via migrants	0.0894*	0.0124	-0.0342**	0.0117	0.00896
	(0.0475)	(0.0180)	(0.0142)	(0.0122)	(0.00829)
Observations	4,248	4,248	4,248	4,248	4,248
R-squared	0.130	0.098	0.128	0.116	0.056
Macro-region FE	y	y	y	y	y
Controls	y	y	y	y	y

Notes: Robust standard errors are reported in parenthesis. The set of additional controls at the municipality level includes the share of population living in rural areas, log income per capita, literacy rate, population density and changes in soy and maize potential yields.

Back

Employment Regressions - Baseline from paper, share of Pop

Table: Change in Employment 2000-2010 as a share of initial Population

VARIABLES	(1) $\Delta L/P$ all	(2) $\Delta L_i/P$ agri	(3) $\Delta L_i/P$ manuf	(4) $\Delta L_i/P$ serv	(5) $\Delta L_i/P$ other
Dryness	-0.0748***	-0.0325***	0.0125**	-0.0404***	-0.00934***
	(0.0173)	(0.00967)	(0.00545)	(0.00806)	(0.00362)
Indirect exposure to SPEI-12 $\times(-1)$	0.0771***	0.0183	-0.0105	0.0459***	0.0161***
	(0.0239)	(0.0142)	(0.00747)	(0.0110)	(0.00508)
Observations	4,248	4,248	4,248	4,248	4,248
R-squared	0.152	0.064	0.180	0.158	0.081
Macro-region FE	y	y	y	y	y
Controls	y	y	y	y	y

Notes: Robust standard errors are reported in parenthesis. The set of additional controls at the municipality level includes the share of population living in rural areas, log income per capita, literacy rate, population density and changes in soy and maize potential yields.

Back

Migration Flows between 2005-2010, from Population Census

Table: Migration Flows between 2005-2010

VARIABLES	(1) Net all	(2) In all	(3) Out all	(4) Net rural	(5) Net urban
# Droughts	-0.0253***	-0.0226***	0.00274	-0.0123**	-0.0406***
	(0.00420)	(0.00288)	(0.00307)	(0.00502)	(0.00747)
Indirect exposure to droughts	0.0186**	0.0125**	-0.00612	0.0210**	0.0284**
	(0.00792)	(0.00571)	(0.00582)	(0.00976)	(0.0139)
Observations	4,248	4,248	4,248	2,128	2,120
R-squared	0.212	0.290	0.166	0.210	0.148
Macro-region FE	y	y	y	y	y
Controls	y	y	y	y	y

Notes: Robust standard errors are reported in parenthesis. The set of additional controls at the municipality level includes the share of population living in rural areas, log income per capita, literacy rate, population density and changes in soy and maize potential yields.

Back

Migration Flows between 2005-2010, from Population Census

VARIABLES	(1) HS grad	(2) Empl	(3) log Income	(4) HS grad	(5) Empl	(6) log Income
Migrant	0.0483***	0.0119***	0.193***	0.0234***	0.0168***	0.192***
	(0.00278)	(0.00261)	(0.00865)	(0.00776)	(0.00342)	(0.0227)
Migrant × # Droughts	-0.181***	0.0689***	-0.274***	0.0257**	0.182***	0.418***
	(0.0211)	(0.00477)	(0.0379)	(0.0118)	(0.00981)	(0.0167)
Observations	5,243,677	6,273,292	4,607,486	5,243,677	6,273,292	4,607,486
R-squared	0.095	0.103	0.255	0.095	0.099	0.249
Fixed effects	destin.	destin.	destin.	origin	origin	origin

Notes: Data come from the Brazilian Census 2010 and include male individuals aged 18-64. *Migrant* is an indicator for having resided in a different municipality in 2005. *Droughts* and *SPEI-12*×(−1) refer to the origin municipality of migrants. Standard errors clustered at destination municipality are reported in parenthesis.

Back

Firm exposure and employment growth

Table: Workers' Flows to Firms Exposed to Climate Change, 2006-2010

VARIABLES	(1) $\frac{L_{oi(d)2006-2010}}{Lavg_i}$ all	(2) all	(3) all	(4) agri	(5) manuf	(6) services	(7) micro	(8) medium	(9) large
firm connection to origin × 1(#droughts> p75)		0.257***	0.388***	0.638***	0.466***	0.226***	0.714***	0.463***	0.315***
		(0.0395)	(0.0527)	(0.0763)	(0.0781)	(0.0686)	(0.0297)	(0.0307)	(0.0646)
firm connection to origin	0.642***	0.397***	0.462***	0.476***	0.406***	0.446***	0.319***	0.418***	0.492***
	(0.0149)	(0.0154)	(0.0144)	(0.0449)	(0.0210)	(0.0171)	(0.00981)	(0.0101)	(0.0177)
Observations	1,415,758	1,415,758	1,415,758	67,756	248,742	983,990	477,882	711,412	223,762
R-squared	0.267	0.393	0.683	0.649	0.673	0.708	0.627	0.647	0.696
mean Y	.13	.13	.13	.13	.13	.13	.13	.13	.13
destination AMC FE	y	y	y	y	y	y	y	y	y
origin FE	y	y	y	y	y	y	y	y	y
firm FE	n	n	y	y	y	y	y	y	y

Notes: Standard errors clustered at destination municipality reported in parenthesis.

Back

Firm exposure and employment growth

Table: Workers' Flows to Firms Exposed to Climate Change, 2011-2017

VARIABLES	(1) $\frac{L_{oi(d)2006-2010}}{Lavg_i}$ all	(2) all	(3) all	(4) agri	(5) manuf	(6) services	(7) micro	(8) medium	(9) large
firm connection to origin × 1(SPEI-12 < p25)		0.305***	0.474***	0.522***	0.610***	0.481***	0.684***	0.552***	0.399***
		(0.0340)	(0.0426)	(0.0853)	(0.0645)	(0.0486)	(0.0508)	(0.0462)	(0.0458)
firm connection to origin	0.712***	0.480***	0.592***	0.636***	0.456***	0.617***	0.489***	0.610***	0.620***
	(0.0110)	(0.0177)	(0.0275)	(0.0464)	(0.0186)	(0.0378)	(0.0253)	(0.0250)	(0.0297)
Observations	2,265,438	2,265,438	2,265,438	103,258	331,586	1,654,030	863,902	1,106,626	290,564
R-squared	0.276	0.358	0.663	0.641	0.674	0.666	0.548	0.607	0.689
mean Y	.158	.158	.158	.158	.158	.158	.158	.158	.158
destination AMC FE	y	y	y	y	y	y	y	y	y
origin FE	y	y	y	y	y	y	y	y	y
firm FE	n	n	y	y	y	y	y	y	y

Notes: Standard errors clustered at destination municipality reported in parenthesis.

Back

Change in employment - Pop Census - Weighted Regressions

VARIABLES	(1) Δ log L agri	(2) Δ log L manuf	(3) Δ log L serv	(4) Δ log L other
SPEI-12 $\times(-1)$	-0.297***	0.111	-0.0723***	-0.0240
	(0.0879)	(0.0690)	(0.0243)	(0.0422)
Indirect exposure to SPEI-12 $\times(-1)$	0.292**	-0.164	0.0250	0.00609
	(0.141)	(0.107)	(0.0400)	(0.0662)
Observations	4,248	4,241	4,248	4,248
R-squared	0.279	0.112	0.175	0.095
Macro-region FE	y	y	y	y
Controls	y	y	y	y

Notes: Robust standard errors reported in parenthesis.

Change in employment shares - Pop Census - Weighted Regressions

VARIABLES	(1) Δ L share agri	(2) Δ L share manuf	(3) Δ L share serv	(4) Δ L share other
SPEI-12 $\times(-1)$	-0.00597	0.0301***	-0.0263***	0.00254
	(0.00471)	(0.00586)	(0.00749)	(0.00391)
Indirect exposure to SPEI-12 $\times(-1)$	-0.0190**	-0.0253***	0.0364***	0.00646
	(0.00749)	(0.00933)	(0.0119)	(0.00585)
Observations	4,248	4,248	4,248	4,248
R-squared	0.370	0.187	0.199	0.128
Macro-region FE	y	y	y	y
Controls	y	y	y	y

Notes: Robust standard errors reported in parenthesis.

Change in employment shares - Pop Census - Unweighted Regressions

VARIABLES	(1) Δ L share agri	(2) Δ L share manuf	(3) Δ L share serv	(4) Δ L share other
SPEI-12 $\times(-1)$	-0.0311***	0.0449***	-0.0120*	-0.00189
	(0.00913)	(0.00650)	(0.00672)	(0.00507)
Indirect exposure to SPEI-12 $\times(-1)$	0.0124	-0.0342***	0.0117	0.00896
	(0.0134)	(0.00899)	(0.00968)	(0.00717)
Observations	4,248	4,248	4,248	4,248
R-squared	0.098	0.128	0.116	0.056
Macro-region FE	y	y	y	y
Controls	y	y	y	y

Notes: Robust standard errors reported in parenthesis.

Migration Flows between 2005-2010, from Population Census

Table: Migration Flows between 2005-2010

VARIABLES	(1) Net all	(2) In all	(3) Out all	(4) Net rural	(5) Net urban
SPEI-12 $\times(-1)$	-0.0405***	-0.0182***	0.0222***	-0.0410***	-0.0445***
	(0.00731)	(0.00618)	(0.00464)	(0.00868)	(0.0120)
Indirect exposure to SPEI-12 $\times(-1)$	0.0223**	0.0342***	0.0119*	0.0110	0.0357**
	(0.0103)	(0.00854)	(0.00676)	(0.0115)	(0.0181)
Observations	4,248	4,248	4,248	2,128	2,120
R-squared	0.221	0.285	0.207	0.234	0.150
Macro-region FE	y	y	y	y	y
Controls	y	y	y	y	y

Notes: Robust standard errors are reported in parenthesis. The set of additional controls at the municipality level includes the share of population living in rural areas, log income per capita, literacy rate, population density and changes in soy and maize potential yields.

- Direct excess dryness $\rightarrow$ decline in net migration rate (lower inflows, higher outflows)
- Indirect excess dryness in connected areas $\rightarrow$ increase in net migration rate, mostly via inflows

Details mig flows | Reported droughts | Back

Individual Level Effects

Individual Level Regressions: Specification

- Objective: study selection and labor market outcomes of "climate" migrants vs
  - other migrants
  - non-migrants
- Data: male workers aged 18-64 in 2010 Census
- Specification:

$$y_{iod,2010} = \beta_d + \beta_1 Migrant_{iod} + \beta_2 Migrant_{iod} \times Dryness_{io,2001-2010} + \Lambda Age_{iod} + u_{iod},$$

i: individual
o: municipality of residence in 2005
d: municipality of residence in 2010
$Migrant_{iod}$: dummy indicating $o \neq d$
$Dryness_{io,2001-2010}$: average SPEI in o between 2001 and 2010
Estimate both with β_d and with β_o

Individual Level Regressions: Results

$$y_{iod,2010} = \beta_d + \beta_1 Migrant_{iod} + \beta_2 Migrant_{iod} \times Dryness_{io,2001-2010} + \Lambda Age_{iod} + u_{iod},$$

VARIABLES	(1) High-school grad	(2) Employed	(3) log Income
Migrant	0.00132	0.0307***	0.123***
	(0.00601)	(0.00250)	(0.00910)
Migrant × SPEI-12 ×(−1)	-0.0943***	0.0397***	-0.139***
	(0.0126)	(0.00445)	(0.0261)
Observations	5,243,677	6,273,292	4,607,486
R-squared	0.094	0.103	0.254
Fixed effects	destin.	destin.	destin.

Notes: Standard errors clustered at destination municipality are reported in parenthesis.

- Reference group: workers in the same destination municipality of migrants
- "climate" migrants:
  - negatively selected in terms of education
  - higher probability of employment
  - lower income than other migrants

Reported droughts

Individual Level Regressions: Results

$$y_{iod,2010} = \beta_o + \beta_1 Migrant_{iod} + \beta_2 Migrant_{iod} \times Dryness_{io,2001-2010} + \Lambda Age_{iod} + u_{iod},$$

VARIABLES	(1) High-school grad	(2) Employed	(3) log Income
Migrant	0.0292***	0.0591***	0.289***
	(0.00655)	(0.00435)	(0.0226)
Migrant × SPEI-12 ×(−1)	0.0101	0.0754***	0.178***
	(0.0105)	(0.00640)	(0.0189)
Observations	5,243,677	6,273,292	4,607,486
R-squared	0.095	0.098	0.248
Fixed effects	origin	origin	origin

Notes: Standard errors clustered at destination municipality are reported in parenthesis.

- Reference group: workers in municipality of origin of migrants
- "climate" migrants:
  - positively selected in terms of education (at origin)
  - higher probability of employment
  - higher income than other migrants / non migrants

Reported droughts Back

Excess Dryness and Agriculture

- One solution here is to use average SPEI over whole period 2001-2018. Works well in the data and makes sense conceptually

VARIABLES	(1) log area planted 2018 minus 2000	(2) log area harvested 2018 minus 2000	(3) log value production 2018 minus 2000
Avg SPEI(-1) 2001-2018	-0.0531	-0.208***	-0.168***
	(0.0441)	(0.0464)	(0.0468)
Observations	4,207	4,207	4,207
R-squared	0.224	0.206	0.220
Region FE	y	y	y
Controls	y	y	y

Notes: Robust standard errors reported in parenthesis. Controls: share of population living in rural areas, log income per capita, literacy rate, population density, distance to coast, changes in soy and maize potential yields.

Excess Dryness and Agriculture

- This uses decadal average SPEI (same variation as Census). No effects on agri value prod!

	(1)	(2)	(3)
	log area planted	log area harvested	log value production
VARIABLES	2010 minus 2000	2010 minus 2000	2010 minus 2000
Avg SPEI(-1) 2001-2010	0.189***	0.0639*	0.0319
	(0.0325)	(0.0344)	(0.0368)
Observations	4,205	4,205	4,205
R-squared	0.115	0.092	0.074
Region FE	y	y	y
Controls	y	y	y

	(1)	(2)	(3)
	log area planted	log area harvested	log value production
VARIABLES	2018 minus 2000	2018 minus 2000	2018 minus 2000
Avg SPEI(-1) 2011-2018	-0.112***	-0.130***	-0.132***
	(0.0216)	(0.0227)	(0.0228)
Observations	4,198	4,198	4,198
R-squared	0.198	0.210	0.229
Region FE	y	y	y
Controls	y	y	y

Notes: Robust standard errors reported in parenthesis. Controls: share of population living in rural areas, log income per capita, literacy rate, population density, distance to coast, changes in soy and maize potential yields.

Excess Dryness and Agriculture

- This uses long differences in decadal average SPEI relative to 1991-2000 decade

VARIABLES	(1) log area planted 2010 minus 2000	(2) log area harvested 2010 minus 2000	(3) log value production 2010 minus 2000
Avg SPEI(-1) 2001-2010 - Avg SPEI(-1) 1991-2000	0.0972***	-0.0380	-0.191***
	(0.0341)	(0.0365)	(0.0404)
Observations	4,205	4,205	4,205
R-squared	0.109	0.091	0.079
Region FE	y	y	y
Controls	y	y	y

VARIABLES	(1) log area planted 2018 minus 2000	(2) log area harvested 2018 minus 2000	(3) log value production 2018 minus 2000
Avg SPEI(-1) 2011-2018 - Avg SPEI(-1) 1991-2000	-0.397***	-0.498***	-0.404***
	(0.0396)	(0.0414)	(0.0415)
Observations	4,207	4,207	4,207
R-squared	0.247	0.235	0.238
Region FE	y	y	y
Controls	y	y	y

Notes: Robust standard errors reported in parenthesis. Controls: share of population living in rural areas, log income per capita, literacy rate, population density, distance to coast, changes in soy and maize potential yields.

Excess Dryness and Agriculture

- This uses long differences in decadal average SPEI relative to 1902-2000 decade

VARIABLES	(1) log area planted 2010 minus baseline	(2) log area harvested 2010 minus baseline	(3) log value production 2010 minus baseline
Avg SPEI(-1) 2001-2010 - Avg SPEI(-1) 1902-2000	0.134***	0.0233	0.00962
	(0.0281)	(0.0298)	(0.0318)
Observations	4,205	4,205	4,205
R-squared	0.113	0.091	0.074
Region FE	y	y	y
Controls	y	y	y

VARIABLES	(1) log area planted 2018 minus baseline	(2) log area harvested 2018 minus baseline	(3) log value production 2018 minus baseline
Avg SPEI(-1) 2011-2018 - Avg SPEI(-1) 1902-2000	-0.204***	-0.289***	-0.207***
	(0.0294)	(0.0306)	(0.0308)
Observations	4,207	4,207	4,207
R-squared	0.235	0.222	0.227
Region FE	y	y	y
Controls	y	y	y

Notes: Robust standard errors reported in parenthesis. Controls: share of population living in rural areas, log income per capita, literacy rate, population density, distance to coast, changes in soy and maize potential yields.

Using SPEI to predict reported droughts

Table: Reported droughts and excess dryness index (SPEI $\times -1$), 2000 to 2010

VARIABLES	(1) # droughts	(2) # droughts	(3) # droughts	(4) # droughts
Dryness	0.0678***			
	(0.00333)			
# months with SPEI-12<=-1		0.0118***		
		(0.000922)		
# months with SPEI-12<=-1.5			0.0145***	
			(0.00139)	
# months with SPEI-12<=-2				0.0234***
				(0.00224)
Observations	46,739	46,739	46,739	46,739
R-squared	0.507	0.504	0.503	0.503
First Stage F-stat	513	224	124	124

Notes: First stage F-stat is the Kleibergen-Paap rk Wald F statistic. Standard errors are clustered at the AMC level. A control for the number of reported floods is included in all columns..

A one standard deviation higher SPEI $\times -1$ increases:

- the average number of droughts per year by 0.07
- the probability of having at least one drought by 6 percentage points.
- similar magnitudes for the 2011-2018 period.

Dryness and Municipality observable characteristics

Balance based on number of reported droughts

VARIABLES	(1) rural pop share	(2) income per capita	(3) alphabetization rate	(4) soil suitability soy	(5) soil suitability maize
1(# Droughts =0)	0.387	4.719	0.768	0.271	0.859
1(# Droughts > 0)	0.536	4.309	0.661	0.334	1.132
Difference	.148	-.41	-.107	.064	.272
t-stat	7.5	3.88	3.13	2.86	4.31

Balance based on *Dryness*

VARIABLES	(1) rural pop share	(2) income per capita	(3) alphabetization rate	(4) soil suitability soy	(5) soil suitability maize
1(Dryness $\leq$ median)	0.440	4.570	0.734	0.285	0.951
1(Dryness > median)	0.477	4.478	0.700	0.317	1.028
Difference	.037	-.092	-.035	.031	.078
t-stat	1.47	.93	1.24	1.33	1.05

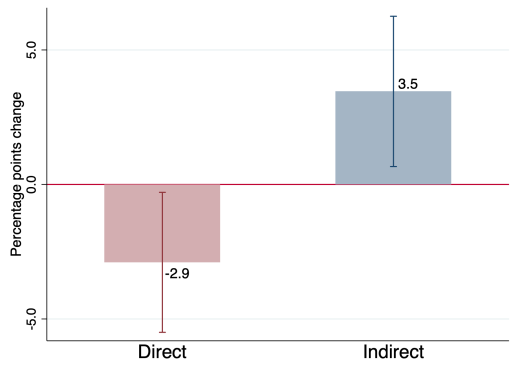
Notes: Observable characteristics observed in 1991 (pop census), except soy and maize productivity which are theoretical soy and maize yields under low inputs as defined in Bustos, Caprettini and Ponticelli (2016).

Back

Effect on Employment

$$y_{mr,2000-2010} = \beta_1 \underbrace{Droughts_{mr,2001-2010}}_{\text{Direct effect}} + \beta_2 \underbrace{ExposureDroughts_{mr,2001-2010}}_{\text{Indirect effect}} + \alpha_r + \gamma X_{mr} + \varepsilon_{mr},$$

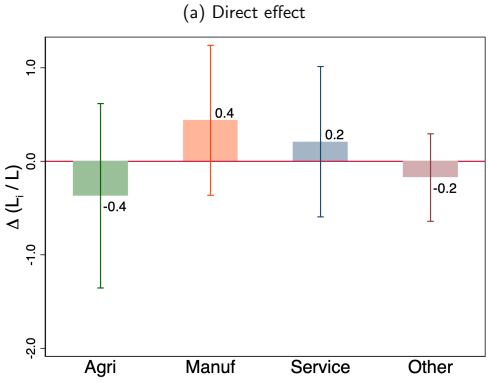
- Effects for a municipality going from 50th$\rightarrow$ 90th pct of *Droughts*, *ExposureDroughts*

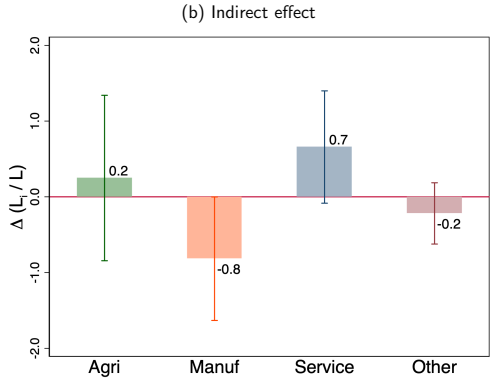


Back

Sectoral structure of the economy

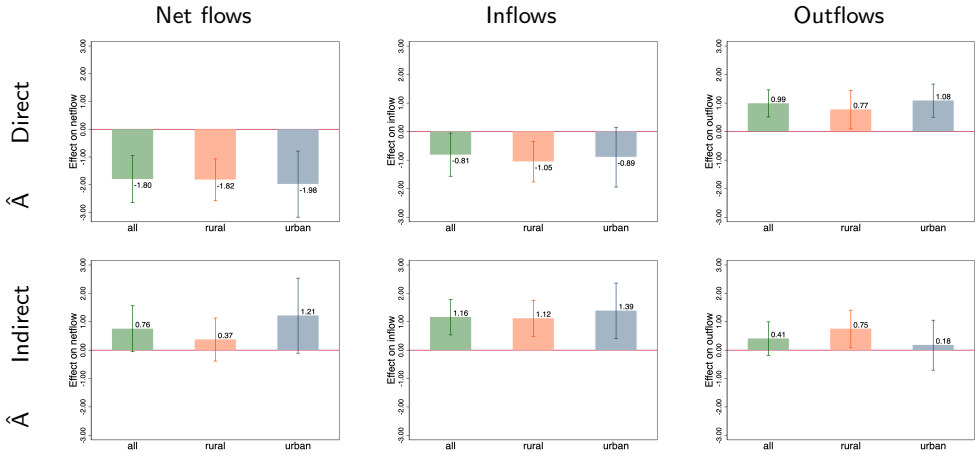
- Effects for a municipality going from 50th→ 90th pct of *Droughts*, *ExposureDroughts*





Back

Effect of Excess Dryness on Migration Flows

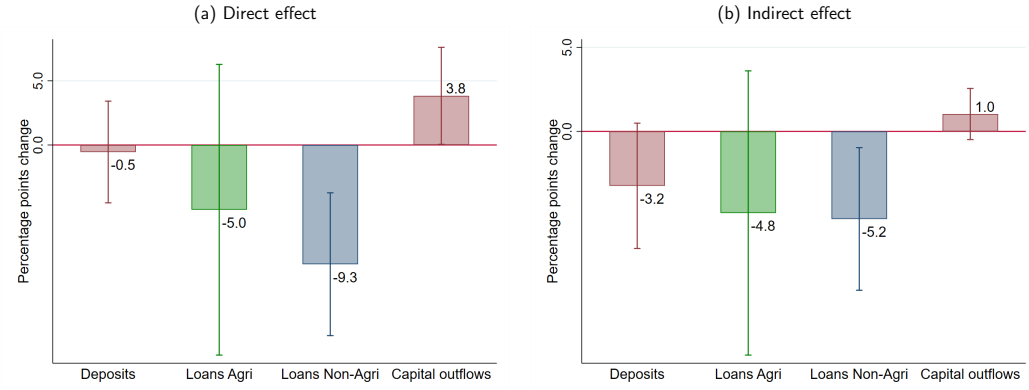


- Direct effects: percentage point change for a municipality $50^{th} \rightarrow 90^{th}$ pct of excess dryness
- Indirect effects: percentage points change when 10% of migrants come from municipalities that moved $50^{th} \rightarrow 90^{th}$ pct of excess dryness

Table - Details

Decadal effect of Dryness on Capital Outcomes

$$\Delta y_{mr,2000-2010} = \alpha_r + \beta_1 \underbrace{Dryness_{m,2001-2010}}_{\text{Direct effect}} + \beta_2 \underbrace{ExposureDryness_{m,2001-2010}}_{\text{Indirect effect}} + \gamma X_{mr} + u_{mr}$$

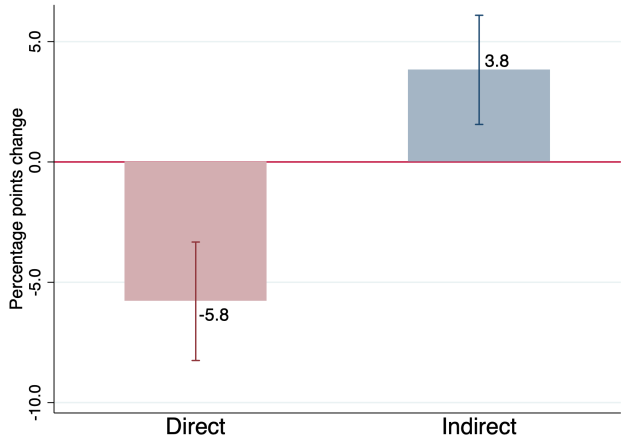


Notes: Effects for a municipality going from 50th→ 90th pct of *Dryness*, *ExposureDryness*.

Back

Effect on Population: 2000-2010

- Effects for a municipality going from 50th→ 90th pct of *Dryness*, *ExposureDryness*



Back

Controlling for distance weighted exposure to Dryness

VARIABLES	(1) $\Delta \log L$	(2) $\Delta \log L$	(3) $\Delta \log L$
Dryness	-0.0885***	-0.0880***	-0.0888***
	(0.0236)	(0.0241)	(0.0245)
Indirect exposure to Dryness via migrant networks	0.0894***	0.0898***	0.0892***
	(0.0334)	(0.0335)	(0.0334)
Indirect exposure to Dryness via distance		-0.0148	
		(0.104)	
Indirect exposure to Dryness via roads			0.00605
			(0.0936)
Observations	4,248	4,248	4,248
R-squared	0.130	0.130	0.130
Macro-region FE	y	y	y
Controls	y	y	y

Notes: Robust standard errors reported in parenthesis. Controls: share of population living in rural areas, log income per capita, literacy rate, population density, changes in soy and maize potential yields. Correlation between indirect exposure via migrants and indirect exposure via roads (51%) and via geographical distance (45%).

Back

Firm exposure and employment growth

VARIABLES	(1) $\frac{L_{oi(d)2006-2010}}{Lavg_i}$ agri	(2) manuf	(3) services	(4) micro	(5) medium	(6) large
firm connection to origin × 1(SPEI-12 < p25)	0.486***	0.369***	0.350***	0.657***	0.444***	0.255***
	(0.0798)	(0.0738)	(0.0484)	(0.0494)	(0.0351)	(0.0545)
firm connection to origin	0.561***	0.436***	0.502***	0.388***	0.479***	0.529***
	(0.0470)	(0.0213)	(0.0285)	(0.0174)	(0.0167)	(0.0224)
Observations	67,756	248,742	983,990	478,006	711,306	223,730
R-squared	0.612	0.662	0.675	0.561	0.610	0.683
mean Y	.13	.13	.13	.13	.13	.13
destination AMC FE	y	y	y	y	y	y
origin FE	y	y	y	y	y	y
firm FE	n	n	y	y	y	y

Notes: Standard errors clustered at destination municipality reported in parenthesis.

Effect for firms with average connection to areas with excess dryness, for 0.76 st.dev. ↑ in SPEI:

- Larger for Agriculture: 2.2% larger worker flow vs 0.7% for Manufacturing, 0.8% for Services
- Larger for Small/Medium firms: 1.3-1.1% vs 0.7% for large firms

Reported droughts 2011-2017

Year-to-year effect of Dryness on Capital Outcomes

$$y_{mrt} = \alpha_m + \alpha_t + \alpha_{rt} + \beta_1 \underbrace{Dryness_{mrt}}_{\text{Direct effect}} + \beta_2 \underbrace{ExposureDryness_{mrt}}_{\text{Indirect effect}} + \Lambda Controls_{mr} \times t + u_{mrt}$$

VARIABLES	(1) log deposits	(2) log deposits	(3) log loans	(4) log loans	(5) K outflows	(6) K outflows
Dryness	0.00499*	0.00437	0.0263***	0.0300***	-0.0108***	-0.0165***
	(0.00291)	(0.00295)	(0.00550)	(0.00564)	(0.00347)	(0.00356)
Exposure to Dryness via bank networks		0.00452		-0.0265*		0.0410***
		(0.00690)		(0.0141)		(0.00755)
Observations	58,124	58,124	58,124	58,124	58,124	58,124
R-squared	0.979	0.979	0.960	0.960	0.641	0.642
Year and AMC FE	y	y	y	y	y	y
Regions x year FE	y	y	y	y	y	y
Controls x year FE	y	y	y	y	y	y

Notes: Standard errors clustered at municipality level. Standard errors are clustered at the AMC level. Controls: share of population living in rural areas, log income per capita, literacy rate, population density, changes in soy and maize potential yields.

back

Decadal effect of Dryness on Capital Outcomes

$$\Delta y_{m,2000-2010} = \beta_1 \underbrace{Dryness_{m,2001-2010}}_{\text{Direct effect}} + \beta_2 \underbrace{ExposureDryness_{m,2001-2010}}_{\text{Indirect effect}} + \Lambda Controls_{m,2000} + u_m$$

VARIABLES	(1) Δ log deposits 2010-2000	(2) Δ log deposits 2010-2000	(3) Δ log loans 2010-2000	(4) Δ log loans 2010-2000	(5) K outflows 2010-2000	(6) K outflows 2010-2000
Avg SPEI(-1) 2001-2010	-0.0368	-0.0122	-0.287***	-0.233***	0.0933***	0.0854***
	(0.0321)	(0.0310)	(0.0576)	(0.0566)	(0.0306)	(0.0313)
Exposure to Dryness via bank networks		-0.480***		-1.046***		0.154*
		(0.105)		(0.171)		(0.0786)
Observations	2,795	2,795	2,795	2,795	2,795	2,795
R-squared	0.179	0.193	0.153	0.175	0.061	0.062
Macro FE	y	y	y	y	y	y
Controls	y	y	y	y	y	y

Notes: Robust standard errors reported in parenthesis. Controls: share of population living in rural areas, log income per capita, literacy rate, population density, changes in soy and maize potential yields.

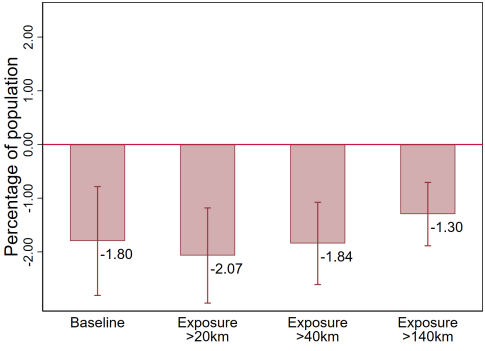
Back

Migration: 2005-2010

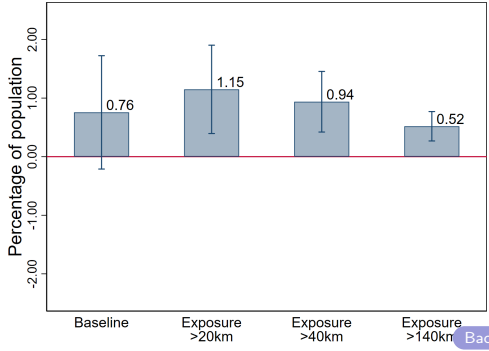
$$netflow_{mr,2005-2010} = \beta_1 \underbrace{Dryness_{mr,2001-2010}}_{\text{Direct effect}} + \beta_2 \underbrace{ExposureDryness_{mr,2001-2010}}_{\text{Indirect effect}} + \alpha_r + \gamma X_{mr} + \varepsilon_{mr},$$

- *ExposureDryness* excluding municipalities within: 20km radius (10th pct migration)
  40km radius (25th pct migration)
  140km radius (50th pct migration)

(a) Direct effect



(b) Indirect effect



Back

Interpretation of diff-in-diff estimates

1. Estimates do not capture GE effects if there are spillovers across regions

2. They do capture differential effects across regions with heterogeneous D and IE
   - useful to identify key theoretical mechanisms and frictions at play in the response of factor allocation to climate change

3. GE effects in recent quantitative economic geography models
   - Donaldson and Hornbeck (2016):
     IE capture spillovers across regions and permits to estimate GE effects
   - Adão, Arkolakis and Esposito (2021):
     framework where indirect effects capture all geographical spillovers
     (GE effects well approximated by DE+IE reduced-form estimates)

Back

Agriculture

- Year-to-year effect of excess dryness on agricultural outcomes
- Temporary crops, 2000-2018

$$y_{mrt} = \alpha_m + \alpha_t + \alpha_{rt} + \beta Dryness_{mrt} + \Lambda Controls_{mr} \times t + u_{mrt}$$

where m: municipality, r: macroregion, t: year

	(1)	(2)	(3)
VARIABLES	log area planted	log area harvested	log value production
Dryness	-0.0618***	-0.0745***	-0.0688***
	(0.0136)	(0.0168)	(0.0171)
Observations	79,441	79,323	79,319
R-squared	0.929	0.910	0.911

Notes: Standard errors are clustered at the AMC level. Controls: share of population living in rural areas, log income per capita, alphabetization rate, population density, changes in soy and maize potential yields, and distance to the cast interacted with year dummies.

Back

Agriculture

- Year-to-year effect of excess dryness on agricultural outcomes
- Temporary crops, 2000-2018

$$y_{mrt} = \alpha_m + \alpha_t + \alpha_{rt} + \beta Dryness_{mrt} + \Lambda Controls_{mr} \times t + u_{mrt}$$

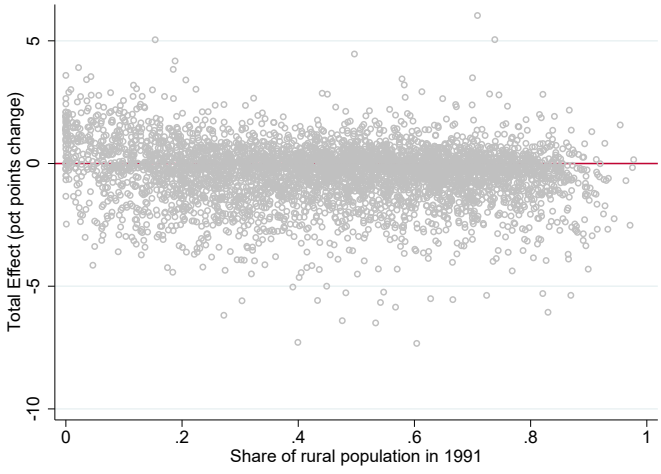
where m: municipality, r: macroregion, t: year

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	log area planted	log area planted	log area harvested	log area harvested	log value production	log value production
Dryness		-0.0632***		-0.0813***		-0.0921***
		(0.0107)		(0.0122)		(0.0120)
Precip.	0.0557***	-0.0123	0.0534***	-0.0342**	0.0281	-0.0710***
	(0.0138)	(0.0138)	(0.0164)	(0.0171)	(0.0180)	(0.0171)
Temp.	-0.296***	-0.128	-0.376***	-0.160	0.0447	0.289**
	(0.0996)	(0.102)	(0.121)	(0.124)	(0.134)	(0.136)
Observations	79,441	79,441	79,323	79,323	79,319	79,319
R-squared	0.928	0.929	0.910	0.910	0.911	0.911

Notes: Standard errors are clustered at the AMC level. Controls: share of population living in rural areas, log income per capita, alphabetization rate, population density, changes in soy and maize potential yields.

Back

Total effect on employment in rural vs urban areas



Notes: raw data.

Back

Example of Report on Drought

Municipality of Maravilha (state of Santa Catarina) reported a drought in February 2014

- Reported losses: 30% corn, 40% soy, 15% milk.
- Farmers unable to cover planting investments

Back

Using SPEI to predict reported droughts

$$y_{mrt} = \alpha_m + \alpha_t + \alpha_{rt} + \beta Dryness_{mrt} + \Lambda Controls_{mr} \times t + u_{mrt}$$

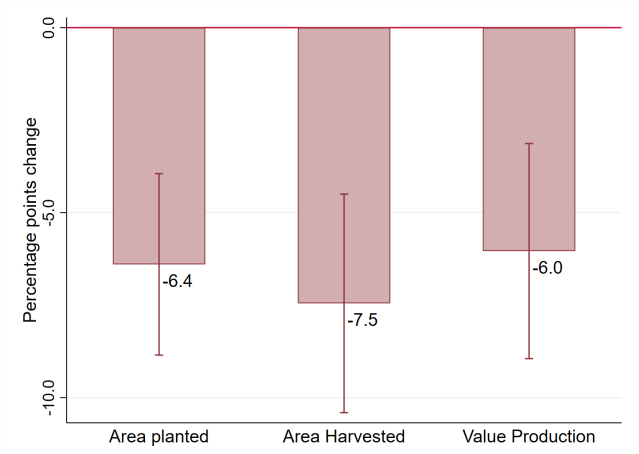
where m: municipality (4,248), r: region (5), t: year

VARIABLES	(1) # droughts	(2) # droughts	(3) # droughts	(4) # droughts
Dryness	0.0678***			
	(0.00333)			
# months with SPEI-12<=-1		0.0118***		
		(0.000922)		
# months with SPEI-12<=-1.5			0.0145***	
			(0.00139)	
# months with SPEI-12<=-2				0.0234***
				(0.00224)
Observations	46,739	46,739	46,739	46,739
R-squared	0.507	0.504	0.503	0.503
First Stage F-stat	513	224	124	124

Notes: First stage F-stat is the Kleibergen-Paap rk Wald F statistic. Standard errors are clustered at the AMC level. Controls: share of population living in rural areas, log income per capita, alphabetization rate, population density, changes in soy and maize potential yields.

Back

Temporary and Permanent Crops

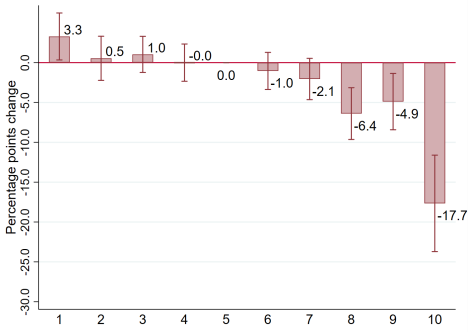


Notes: Effects for a municipality going from 50th→ 90th pct of *Dryness*.

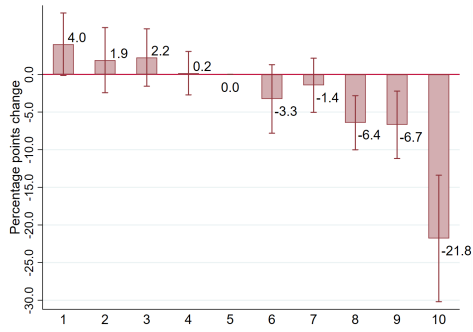
Back

Additional Agricultural Outcomes

(a) Area Planted



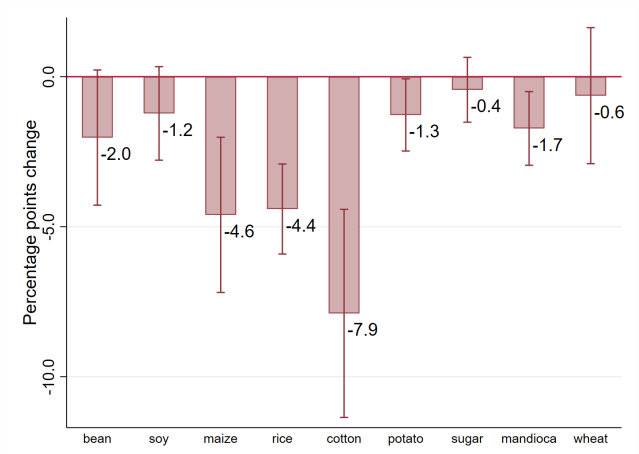
(b) Area Harvested



Notes: Effects by decile of *Dryness* (wettest to driest), relative to 5th decile.

Back

Yields of Main Temporary Crops

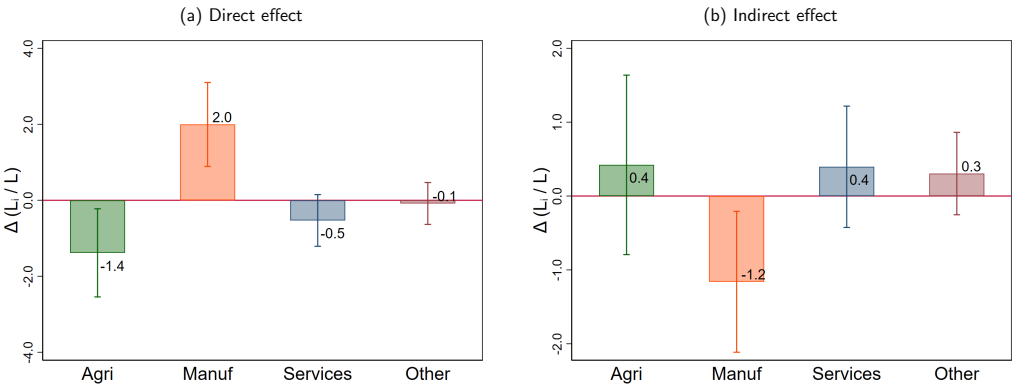


Notes: Effects for a municipality going from 50th→ 90th pct of *Dryness*.

Back

Sectoral structure of the economy

$$\Delta\left(\frac{L^{sector}}{L}\right)_{m,2000-2010} = \beta_1 \underbrace{Dryness_{m,2001-2010}}_{\text{Direct effect}} + \beta_2 \underbrace{ExposureDryness_{mr,2001-2010}}_{\text{Indirect effect}} + \alpha_r + \gamma X_{mr} + \varepsilon_{mr},$$



Notes: Effects for a municipality going from 50th→ 90th pct of *Dryness*, *ExposureDryness*.

Back

Wages: No adjustment

VARIABLES	(1) Δ log w all	(2) Δ log w all	(3) Δ log w agri	(4) Δ log w manuf	(5) Δ log w serv	(6) Δ log w all	(7) Δ log w all	(8) Δ log w agri	(9) Δ log w manuf	(10) Δ log w serv
Dryness	0.0415**	-0.0276	0.0314	-0.0451	-0.0172					
	(0.0199)	(0.0340)	(0.0539)	(0.0674)	(0.0498)					
Indirect exposure to Dryness		0.110**	0.121*	0.171*	0.0743					
		(0.0424)	(0.0722)	(0.101)	(0.0621)					
# Droughts						-0.0441**	-0.0402**	-0.118***	-0.0131	-0.0397
						(0.0190)	(0.0185)	(0.0331)	(0.0405)	(0.0289)
Indirect exposure to droughts							-0.00988	0.0272	0.0235	-0.0524
							(0.0455)	(0.0665)	(0.0819)	(0.0568)
Observations	4,249	4,248	4,248	4,241	4,248	4,249	4,248	4,248	4,241	4,248
R-squared	0.163	0.165	0.087	0.023	0.048	0.163	0.163	0.085	0.020	0.050
Macro-region FE	y	y	y	y	y	y	y	y	y	y
Controls	y	y	y	y	y	y	y	y	y	y

Notes: Standard errors are clustered at meso region level level. Controls: share of population living in rural areas, log income per capita, alphabetization rate, population density, changes in soy and maize potential yields.

Mincerian Adjusted Wages

Mincerian adjustment:

- Focus on male workers only
- Estimate regression of log hourly wage at individual level on AMC fixed effects and a vector of individual characteristics, which includes dummies for sector, skill group, age group, race, and all the interactions between these variables.

VARIABLES	(1) Δ log w all	(2) Δ log w all	(3) Δ log w agri	(4) Δ log w manuf	(5) Δ log w serv	(6) Δ log w all	(7) Δ log w all	(8) Δ log w agri	(9) Δ log w manuf	(10) Δ log w serv
Dryness	0.0590***	0.0323	0.0497	0.0765*	0.0269					
	(0.0163)	(0.0276)	(0.0355)	(0.0411)	(0.0305)					
Indirect exposure to Dryness		0.0425	0.0461	0.0102	0.0217					
		(0.0312)	(0.0460)	(0.0595)	(0.0370)					
# Droughts						-0.0421***	-0.00944	-0.0147	0.00815	-0.0129
						(0.0157)	(0.0155)	(0.0227)	(0.0262)	(0.0202)
Indirect exposure to droughts							-0.0766**	-0.0950**	-0.0461	-0.0594
							(0.0311)	(0.0417)	(0.0514)	(0.0377)
Observations	4,249	4,248	4,241	3,967	4,247	4,249	4,248	4,241	3,967	4,247
R-squared	0.161	0.161	0.165	0.031	0.083	0.154	0.156	0.161	0.026	0.083
Macro-region FE	y	y	y	y	y	y	y	y	y	y
Controls	y	y	y	y	y	y	y	y	y	y

Notes: Standard errors are clustered at meso region level level. Controls: share of population living in rural areas, log income per capita, alphabetization rate, population density, changes in soy and maize potential yields.

Average Wages

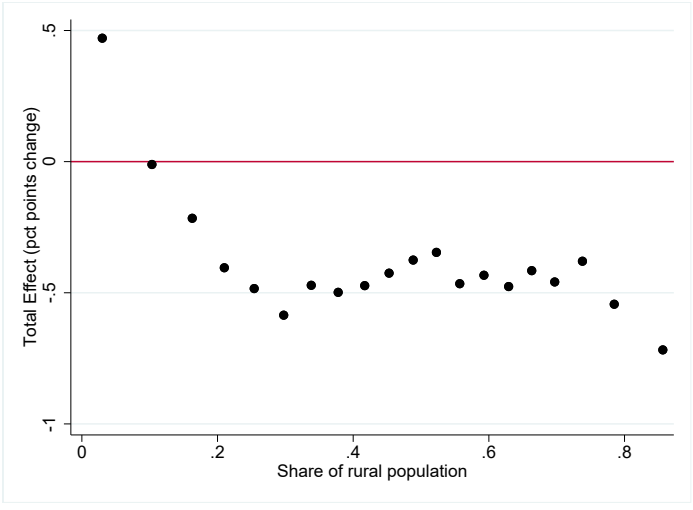
- Compute mincerian adjusted wages using male workers and controlling for dummies for sector, skill group, age group, race, and all the interactions between them

VARIABLES	(1) Δ log avg wage all	(2) Δ log avg wage all
Dryness	0.0323	
	(0.0276)	
Indirect exposure to Dryness	0.0425	
	(0.0312)	
# Droughts		-0.00944
		(0.0155)
Indirect exposure to droughts		-0.0766**
		(0.0311)
Observations	4,248	4,248
R-squared	0.161	0.156
Macro-region FE	y	y
Controls	y	y

Notes: Standard errors are clustered at meso region level level. Controls: share of population living in rural areas, log income per capita, alphabetization rate, population density, changes in soy and maize potential yields.

Back

Total effect on employment in rural vs urban areas



Notes: binned scatterplot, 20 equal-sized bins of municipalities.

raw data