Does Land Inequality Magnify Climate Change Effects? Evidence from France

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Harvesting the consequences of climate change

Note. *Heatwaves threaten global food security and price-stability.*
AI-generated image with Stable Diffusion

Framing questions

- **Historical:** Have land-consolidation patterns affected resilience to climate change in modern agriculture?

- **Policy:** Can we improve the resilience of our agricultural systems facing climate change?

A story of land inequality and crop diversity

Our contribution

- **We show** at canton level, in France
  - $+$ land inequality $\rightarrow$ - crop diversity
  - Heatwaves cause greater loss in more concentrated land
- **We uncover** a trade-off for farmers and policy makers
  - Concentrated systems: more productive but fragile
  - Diverse systems: less productive but resilient

Related literature (1/2)

Climate change on agricultural productivity

- Negative impacts on productivity: extreme weather events (Lobell and Field, 2007; Schlenker and Roberts, 2009). Compound shocks (Haqiqi et al., 2021). Overall production (Dell, Jones, and Olken, 2012)
- Positive impacts on productivity: the CO_2 fertilisation effect (Taylor and Schlenker, 2021)
- Long term predictions and technological adaptantions: Predictions (Mendelsohn, Nordhaus, and Shaw, 1994; Schlenker, Michael Hanemann, and Fisher, 2005; Burke and Emerick, 2016).
- Techonolgical adaptations (Moscona and Sastry, 2022)

Related literature (2/2)

Farms consolidation and productivity

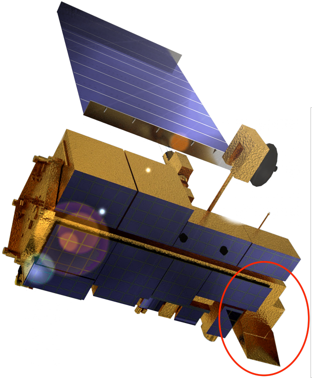
- Convergence towards higher farmland consolidation with development (due to increased labour productivity) (Eastwood, Lipton, and Newell, 2010; Frankema, 2010; Adamopoulos and Restuccia, 2014; Lowder, Sánchez, and Bertini, 2021). Explains most of cross-country differences in productivity levels, average farm sizes, and in farmland distributions.

Biology literature

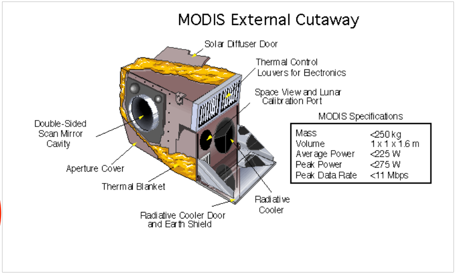
- Strong links and clear mechanisms between diversity and resilience in both natural and agricultural ecosystems (Cadotte, Cardinale, and Oakley, 2008; Kremen and Miles, 2012; Duffy, Godwin, and Cardinale, 2017; Renard and Tilman, 2019).

Data and definitions

Measurements from the sky: in orbit since 2000



(a) Terra spacecraft model



(b) MODIS sensor

Measurements from the sky: main variables

Gross Primary Productivity (GPP)

- Measures the growth of biomass every 8-days in $C.kg/m^2$
- Based on fluorescence from photosynthesis
- Resolution: 0.5km pixels
- Credits to Running and Zhao (2019)

Surface temperatures

- Monthly averages in ºC
- Resolution: 5.6km pixels
- Credits to Wan, Hook, and Hulley (2021)

Measurements from the sky: plant productivity

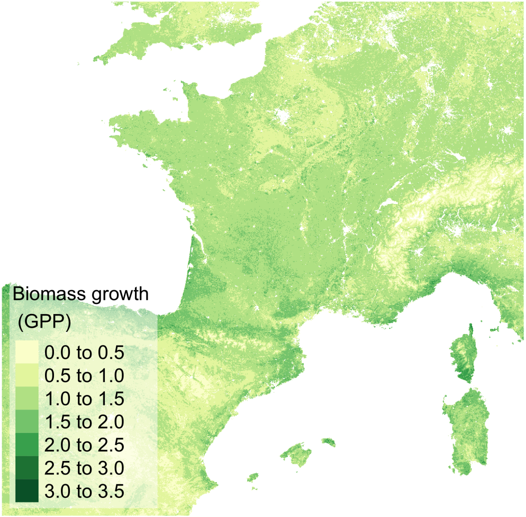


Figure: Cumulated 2021 GPP at 500m resolutuion

Measurements from the sky: plant productivity

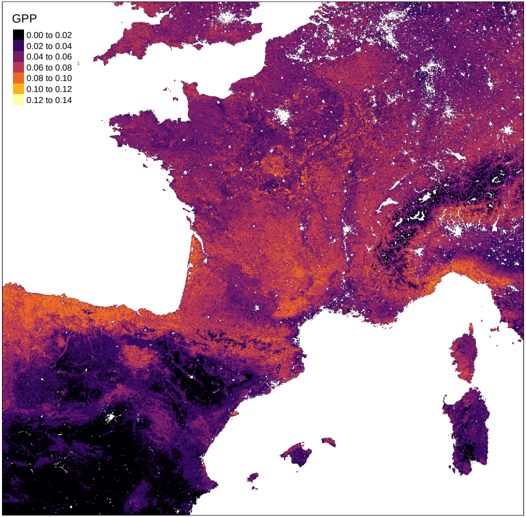


Figure: 8-days cumulative GPP at 500m resolution, mid-summer 2021

Can we convert GPP into yield?

Possible in theory, but not enough information at our scale

Table: GPP to Yield conversion factors, examples

Crop	Factor
Alfalfa	0.55
Barley	0.42
Maize	0.44
Durum wheat	0.22
Peas	0.28
Spring wheat	0.24
Winter wheat	0.35

Notes. By He et al. (2018) for annual yield of staple crops in Montana, USA

Values are proportional to yield and we can control by composition

Measurements from the sky: temperatures (ºC)

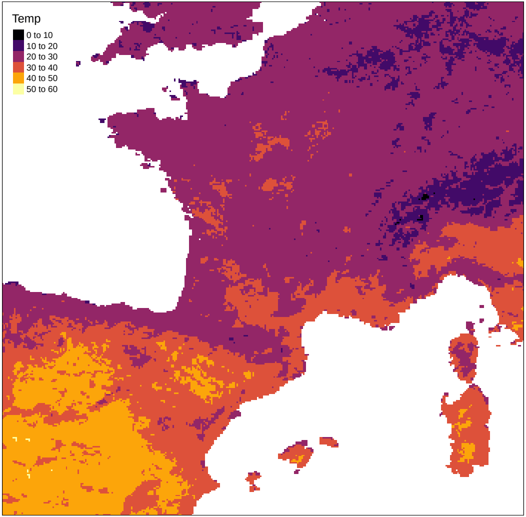


Figure: Monthly average temperature, at 5.6km resolution, summer 2021

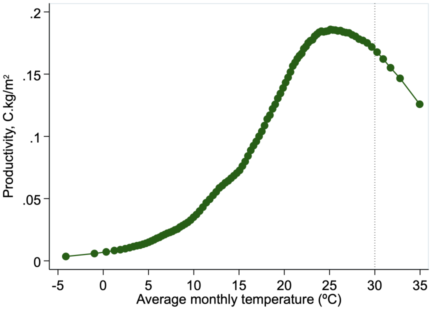
Temperature shocks

Temperature and productivity: non-linearity

- More light is beneficial for plants in normal times (photosynthesis), but there are limits
- Schlenker and Roberts, 2009 find a nonlinear relation with crop-dependent turning points: corn (29ºC), soybean (30ºC) and cotton (32ºC) in the US.

Temperature and productivity: France

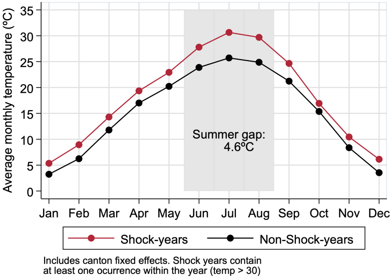
Figure: Monthly productivity vs. temperature (2000-2021)



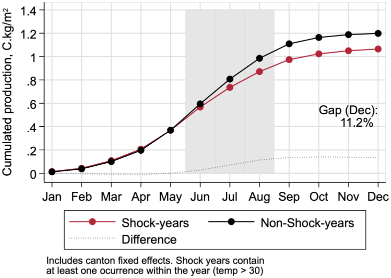
Notes. Binned scatter plot in centiles of observations, no controls. Using Running and Zhao, 2019, Wan, Hook, and Hulley, 2021, and French cantons

Year-long consequences of extreme heat

Figure: Agricultural production in normal vs. shock year, 2000-2021



(a) Warmer temperatures overall



(b) The summer slowdown

Heat tolerance is crop-cycle specific

Table: Critical temperatures by crop in spring/summer

Crop	Max. temp (ºC)	Land share	Cumulative	Reference
Winter wheat	32	34.5	34.5	Gammans et al. (2017)
Corn/Maize	32	17.4	51.9	Hawkins et al. (2013)
Winter barley	33	7.4	59.3	Gammans et al. (2017)
Rapeseed	27	6.1	65.4	Pollowick and Sawhney (1988)
Sunflower	35	4.3	69.8	Rondanini et al. (2003)
Grapevine	30	3.6	73.3	Imputed
Spring barley	32	3.3	76.6	Gammans et al. (2017)
Alfalfa	30	2.8	79.5	Murata et al. (1965)
Beetroot	30	2.6	82.1	Imputed
Potato	30	1.1	83.2	Imputed
Soybean	30	1.0	84.1	Schlenker and Roberts (2009)
Spring wheat	33	0.2	84.3	Gammans et al. (2017)
Other (<1%)	30	15.6	100.0	Imputed

Note. Compiled by the authors

Defining a threshold for heatwaves

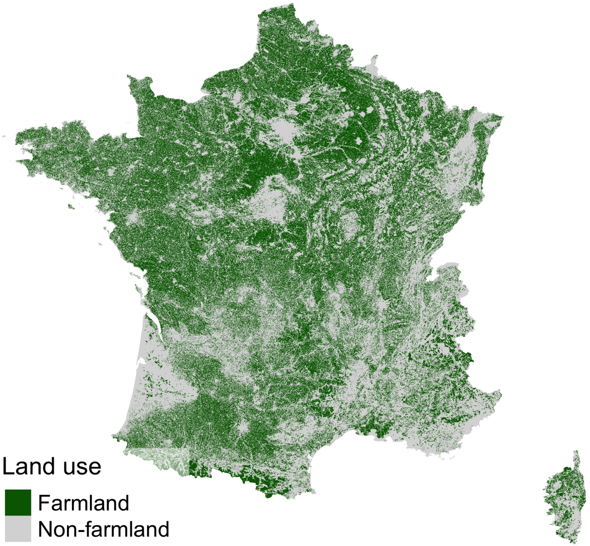
- **Critical temperature for treatment** in canton c for year t is

$$T_{c,t} = \sum_{i=1}^{N} T_i * A_{i,c,t}$$

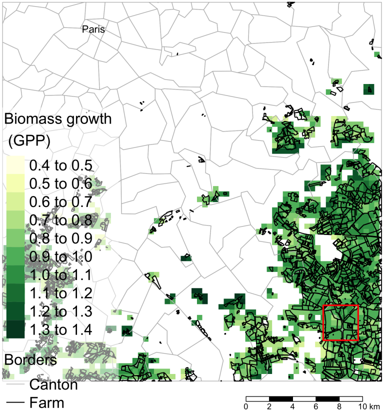
- The average critical temperature of crop i (T_i) weighted by its land share ($A_{i,c,t}$).

Measurements from the land

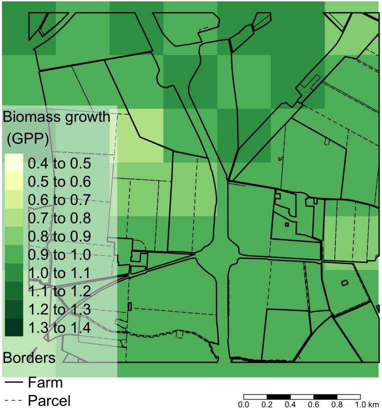
Exhaustive farm information



Overlapping cadastral data and GPP (Zoom-in)



(c) Farms near Paris



(d) High resolution

Measurements from the land: main variables

Cantonal Land Inequality:

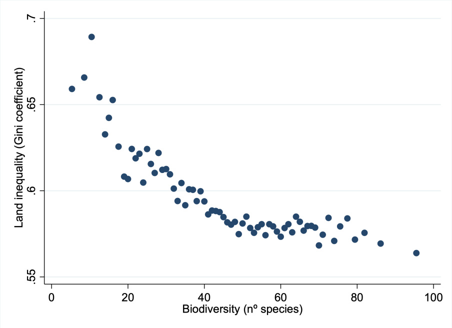
- Uses georeferenced information on farm borders
- Farm level $\neq$ owner level

Cantonal crop diversity:

- Data on crop-mixes within farm borders
- Crop level, independent of ownership
- Broader categories (28) or detailed (+150)

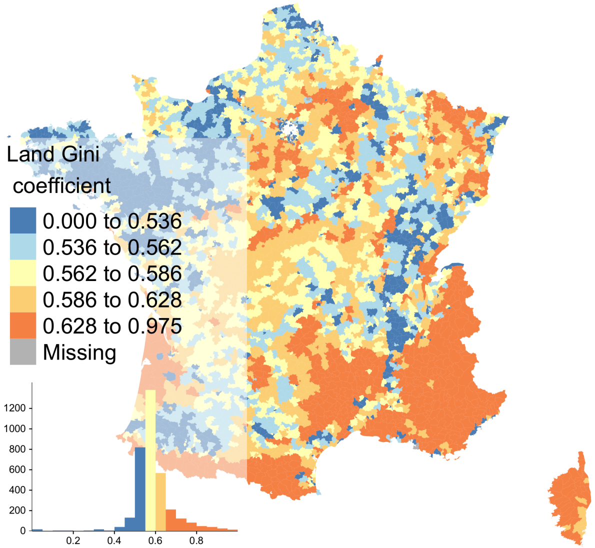
…which are highly correlated (-)

Figure: Diversity vs. Gini (Binned scatterplot)

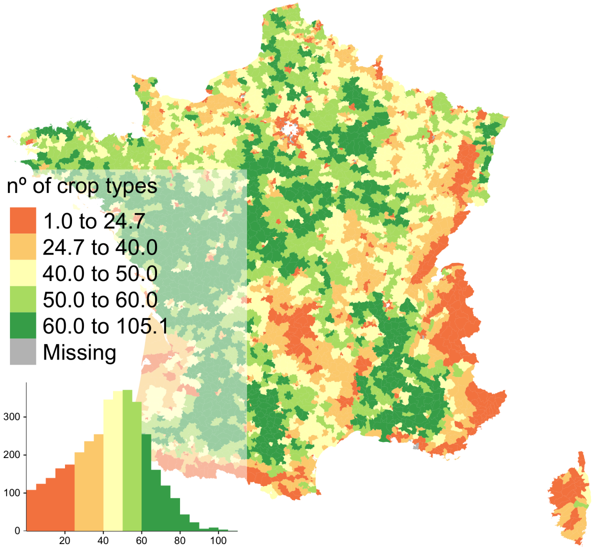


Notes. Own estimates based on French Cadastral data. Cantons with less than 10% of agricultural area are ignored

Map of Gini coefficients, latest year



Crop diversity (nº of species), latest year



Identification

Two faces of the same coin?

- Rational incentives towards specialisation and land consolidation
- Plants do not farm themselves: land distribution is the political economy of the problem
- Biodiversity has a well studied causal effect on resilience of natural and experimental ecosystems

Basic weather shock specification

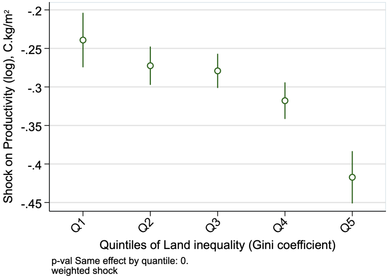
- Effect of extreme weather shock with leads and lags to account for correlation in temperatures over months

$$ln(GPP_{ct}) = \gamma_c + \lambda_t + \sum_{\tau=0}^{3} \beta_{-\tau} \times D_{c,t-\tau} + \sum_{\tau=1}^{3} \beta_{\tau} \times D_{s,t+\tau} + \epsilon_{c,t} \quad (1)$$

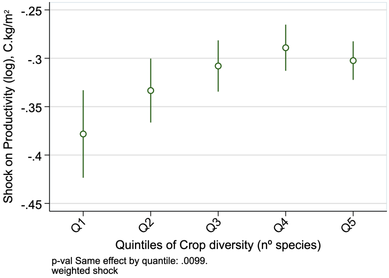
- $D_{c,t} = 1$ if there is a temperature shock in canton c in month t
- γ_c, λ_t canton and time fixed effects
- **Compare impact over quantiles of land Gini and crop diversity**

Stationary impact on monthly productivity-flows

Figure: What cantons suffer more losses?



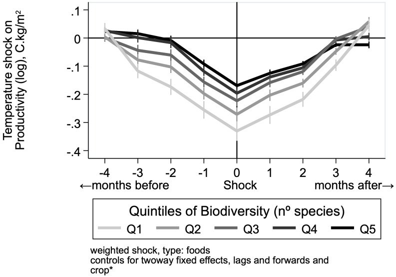
(a) Most unequal



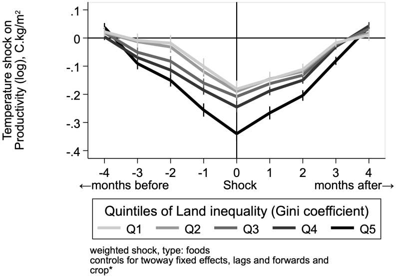
(b) Least diverse

Heterogeneous impacts on monthly productivity

Figure: What cantons suffer more losses?



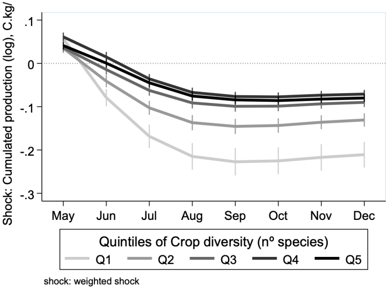
(a) Least diverse



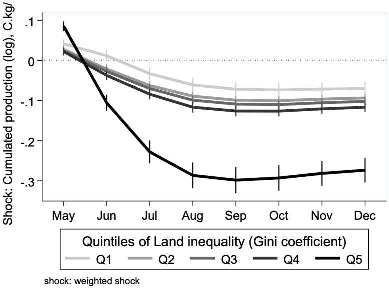
(b) Most unequal

.. what about yearly cumulative production?

Figure: What cantons perform better under heat shocks?



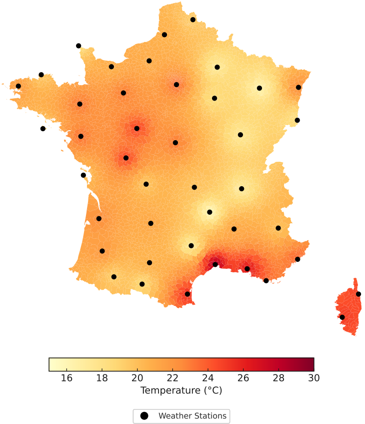
(a) More diverse crops



(b) ... and less unequal land

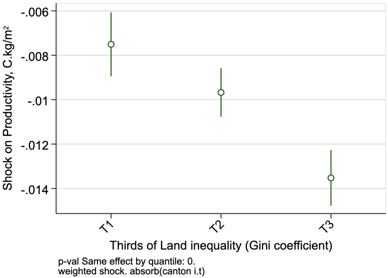
Can we de-trend estimates?

Hourly temperature data (Météo France)

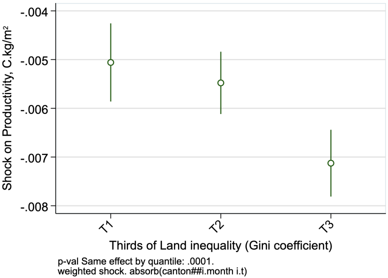


- We de-trend estimates using data from public weather stations
- We **interpolate** average afternoon temps with most simple function (inverse-distance weighting)

Ranking of magnitudes holds with new data on temps.

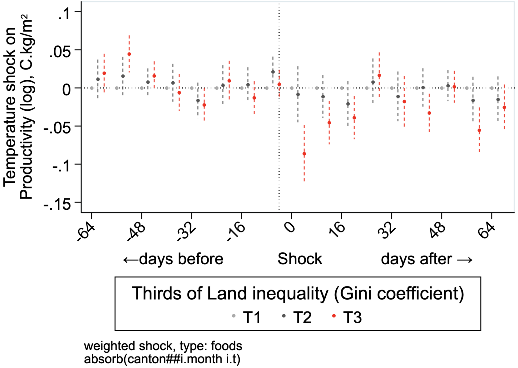


(c) Two-way FE



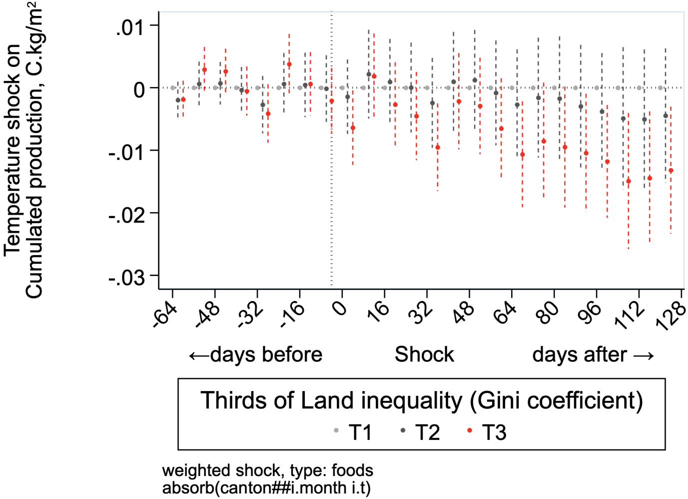
(d) Canton-month interaction

Dynamic impact on production flows, by Gini fractiles



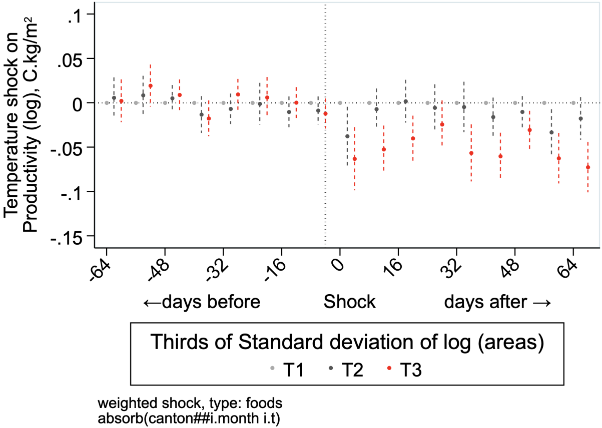
- After the shock, lower productivity is observed for many periods suggesting structural damages. Estimates are de-trended using canton-month interactions

Cumulative production (by Gini fractiles)



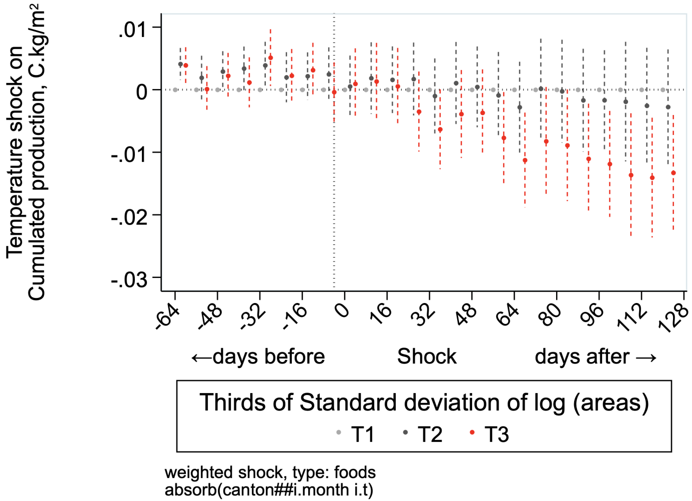
- The most unequal third of cantons suffer more with lasting consequences for yearly production (relative to 1st third)

Studying more granular flows (SD of logs)



- The standard deviation of logs provides an even cleaner identification, as an inequality index, it weights more transfers to the lower end of the distribution (Atkinson, 1970).

Cumulative production (SD of logs)



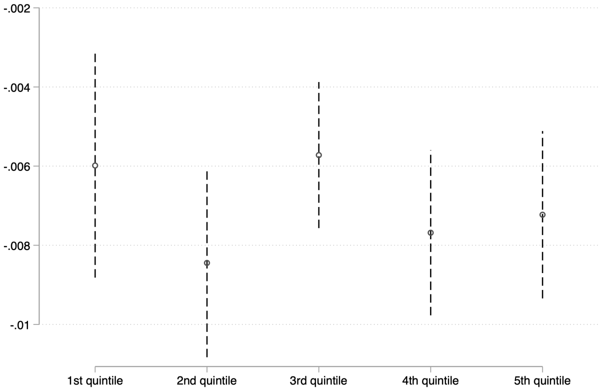
Higer inequality corresponds to more mega-farms

Table: Land composition by farm class

		Small farm		Medium farm		Large farm		Very large farm	
Variable	Quantile	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Crop count	1	12.5	(11.1)	70.8	(24.4)	5.9	(9.5)	10.8	(23.1)
	2	12.3	(10.2)	77.1	(17.7)	5.1	(6.1)	5.5	(14.6)
	3	11.4	(9.6)	81.3	(12.7)	4.8	(5.3)	2.5	(8.0)
	4	11.9	(9.5)	81.6	(11.4)	4.4	(5.1)	2.1	(6.5)
	5	11.4	(8.8)	82.4	(11.2)	4.2	(5.1)	2.0	(6.0)
Land Gini	1	12.9	(11.4)	85.5	(11.4)	1.4	(3.1)	0.2	(3.1)
	2	11.9	(9.9)	85.1	(9.0)	2.6	(3.4)	0.4	(2.2)
	3	11.9	(9.7)	83.7	(8.3)	3.9	(4.5)	0.6	(1.4)
	4	11.8	(9.2)	80.7	(8.8)	6.0	(6.4)	1.5	(3.4)
	5	11.1	(9.0)	57.7	(22.9)	10.6	(8.8)	20.5	(25.0)

Notes. Standard classification: small ($<$ 2ha), medium (2-50ha), large (50-100ha), and very large ($>$ 100ha). Farms

Inequality's effect disappears when we impose high crop diversity



Robustness checks and discussion

What we have done:

- Drop everything that is not food ($\approx$ 40% sample)
- Several shock-thresholds ($25, 27, 33$, and 35 Celsius)
- Other definitions of diversity (Hirschman-Herfindahl index) and inequality (coefficient of variation, s.d. of logs)
- Weighted shocks
- Finer temperature data
- Can inequality/diversity be endogenous? We restrict ranking as in initital periods.

Steps forward and further questions:

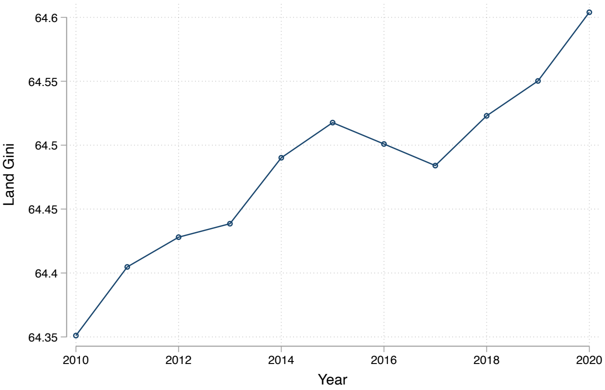
- What particular crop-mixes perform better?
- Is this a portfolio effect or a symbiotic one?

Concluding remarks

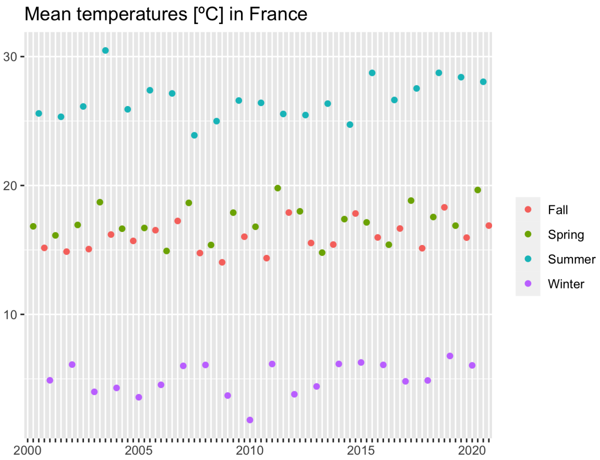
- Land concentration seems to matter for resilience to heatwaves
- The mechanism is likely related to crop diversity (policy oportunity?)
- Several questions remain open: Portfolio effects? Symbiotic effects? Behavioral?

Appendix

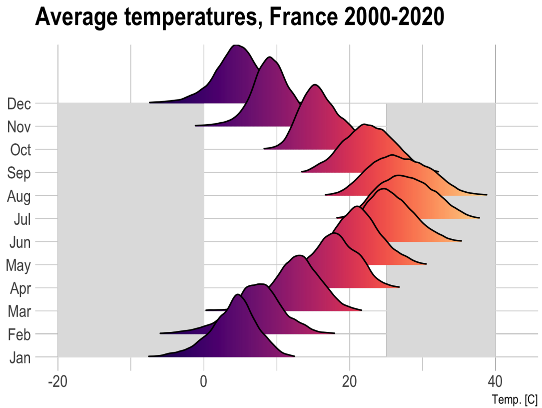
Appendix: Consistent trend with census



Appendix: Seasonal temperatures

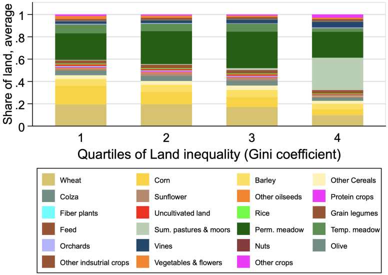


Appendix: Average monthly temperatures (ºC)

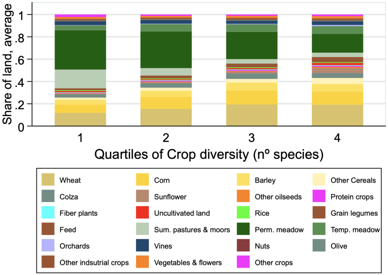


Appendix: Crop composition by fractile

Figure: Composition in farmland



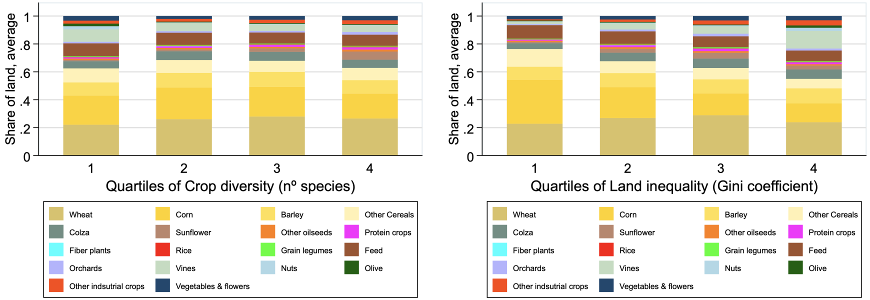
(a) Quintiles of Gini



(b) Quintiles of diversity

Appendix: Crop composition by fractile

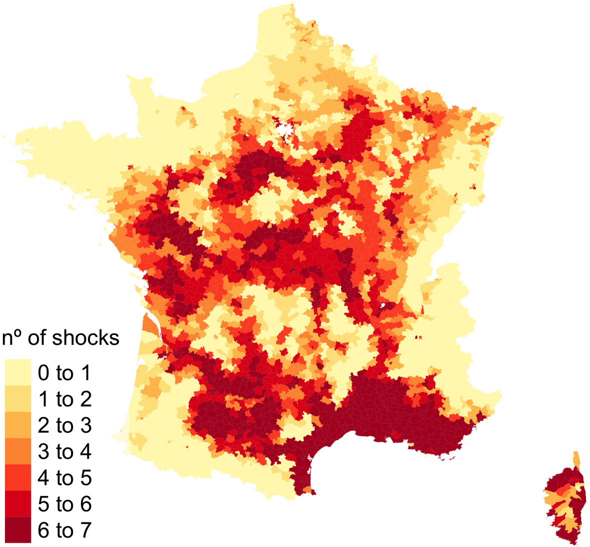
Figure: Composition in farmland (food only)



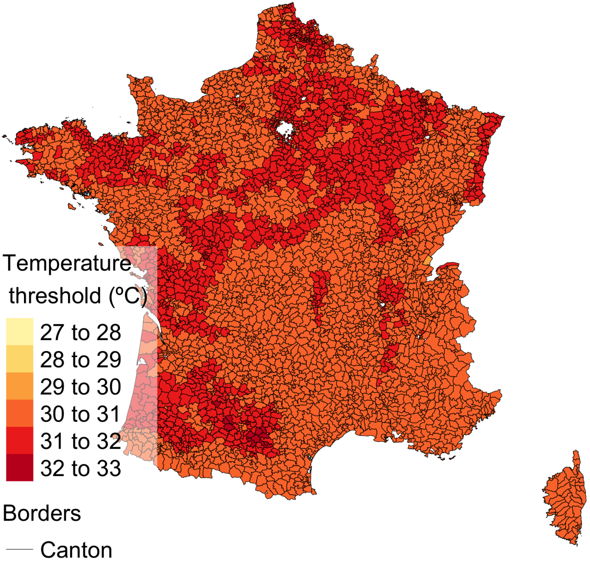
(a) Quintiles of Gini

(b) Quintiles of diversity

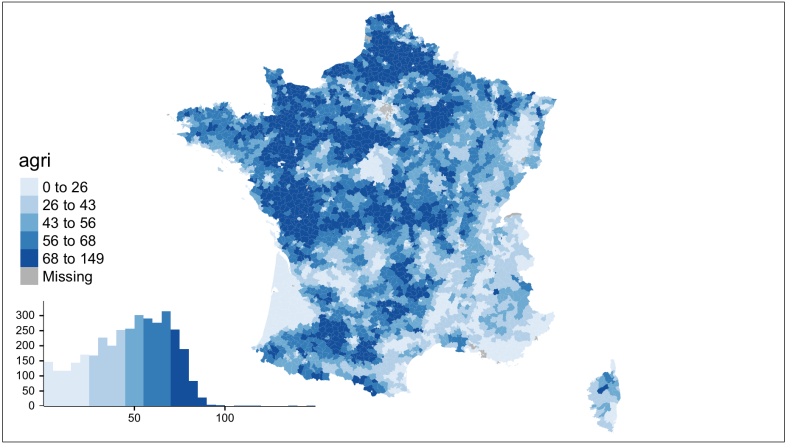
Appendix: Map of shocks



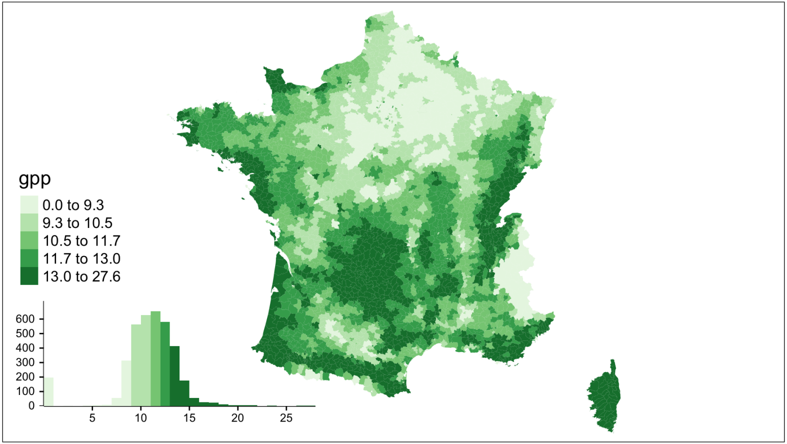
Appendix: Temperature thresholds



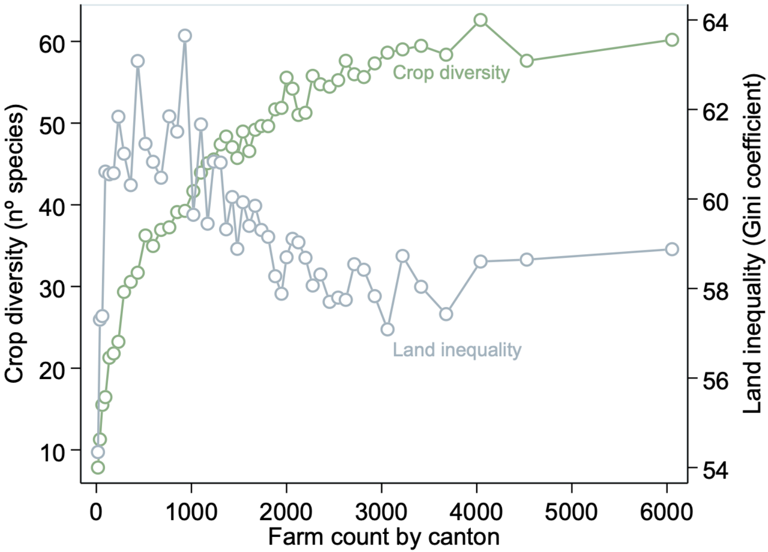
Appendix: Agricultural area by canton (%)



Appendix: Cumulated GPP in 2020

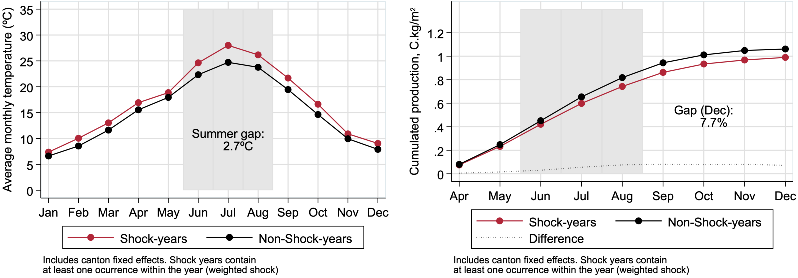


Appendix: Gini and diversity over farm count



Year-long consequences of extreme heat (food crops)

Figure: Agricultural production in normal vs. weighted shock year, 2015-2021



(a) Warmer temperatures overall

(b) The summer slowdown

Crop diversity ranks shock magnitudes but non-significantly