Does Land Inequality Magnify Climate Change Effects? Evidence from France

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EPCI

The shift to Agro-ecology

- **Agro-ecology is to enhance agricultural production using biodiversity** and natural processes, reducing the use of polluting inputs.

- **Strong political support:** Part of the European Green Deal and central to the CAP reforms in 2018/2023 (e.g., Farm to Fork and biodiversity initiatives). Also a French State objective by law since 2014 (n° 2014-1170).

- **Large economic investment**: France Relance, 2.2 billion euros spent up to 2030. Ecophyto, half a billion euros spent on farm experimentation, subsidies, and farmer education.

- **Q:** Crop diversity can help to mitigate the causes of climate change, but what about its consequences?

Framing questions

- **Policy:** Can we use diversity to improve the resilience of our agricultural systems facing climate change?
- **Historical:** Have land-consolidation patterns affected resilience to climate change in modern agriculture?
- **Theoretical:** How can we model the productivity-diversity trade-off?

A story of crop diversity land concentration

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

Different levels of diversity

- **Within exploitation:** inter- or intra-species diversity, crop rotation, agroforestry.
- **Landscape diversity:** crop configuration, crop shares, parcel sizes, semi-natural elements.
- **Semi-natural vegetation** is often considered for conservation of biodiversity, yet rarely studied in interaction with agricultural production.

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

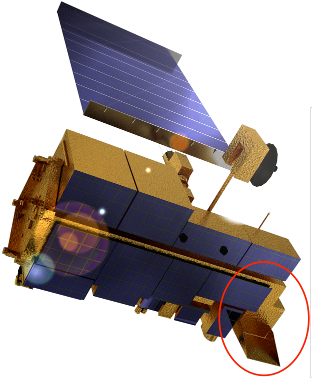
- Convergence towards higher farmland consolidation with development (due to increased labour productivity) (Eastwood, Lipton, and Newell, 2010; Frankema, 2010; Adamopoulos and Restuccia, 2014; Lowder, Sánchez, and Bertini, 2021). Explains most of cross-country differences in productivity levels, average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

Biology literature

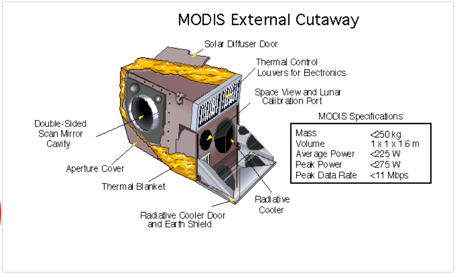
- Strong links and clear mechanisms between diversity and resilience in both natural and agricultural ecosystems (Cadotte, Cardinale, and Oakley, 2008; Kremen and Miles, 2012; Duffy, Godwin, and Cardinale, 2017; Renard and Tilman, 2019).

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

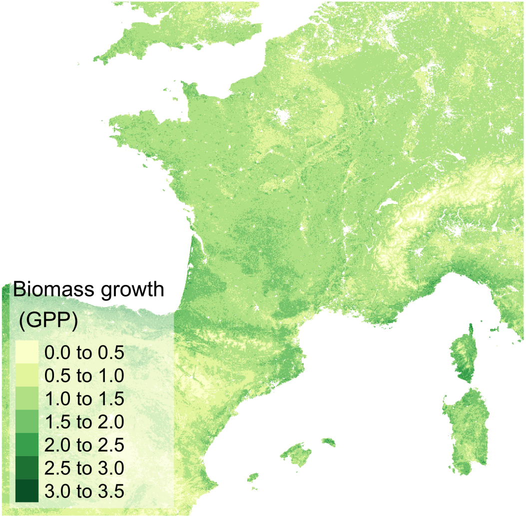


Figure: Cumulated 2021 GPP at 500m resolution

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)

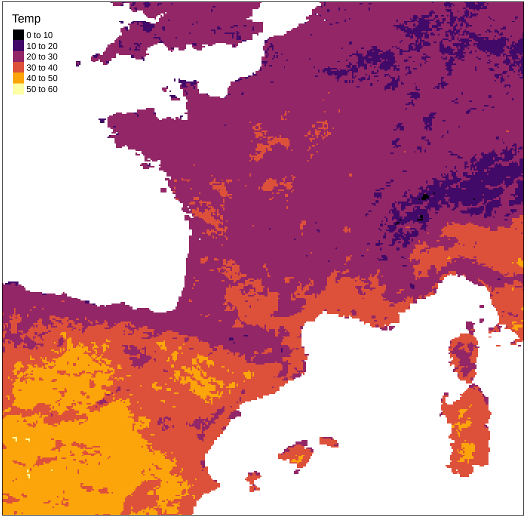


Figure: Monthly average temperature, at 5.6km resolution, summer 2021

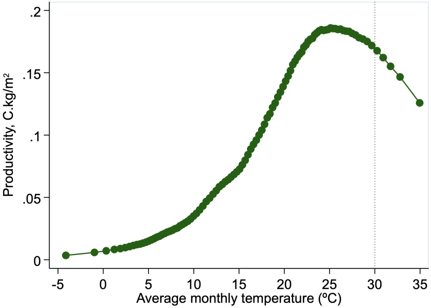
Temperature shocks

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

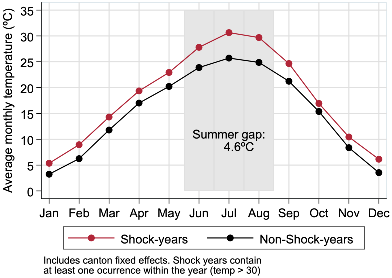
Figure: Monthly productivity vs. temperature (2000-2021)



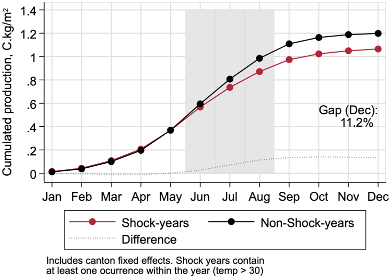
Notes. Binned scatter plot in centiles of observations, no controls. Using Running and Zhao, 2019, Wan, Hook, and Hulley, 2021, and French cantons

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

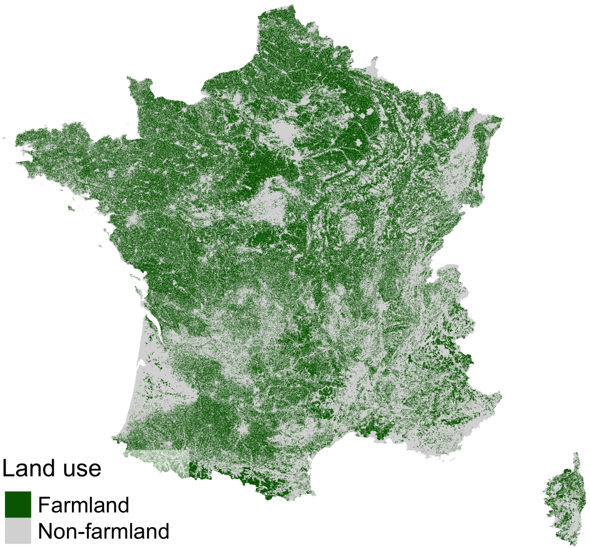
- **Critical temperature for treatment** in canton c for year t is

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

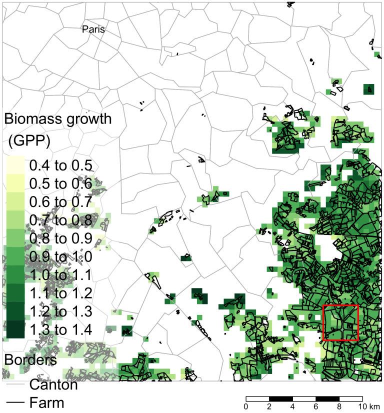
- The average critical temperature of crop i (T_i) weighted by its land share ($A_{i,c,t}$).

Measurements from the land

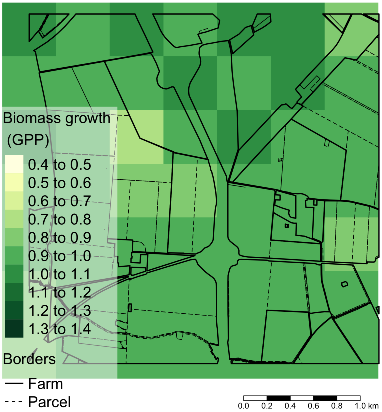
Exhaustive farm information



Overlapping cadastral data and GPP (Zoom-in)



(c) Farms near Paris



(d) High resolution

Measurements from the land: main variables

Cantonal crop diversity:

- Data on crop-mixes within farm borders
- Crop level, independent of ownership
- Broader categories (28) or detailed (150+)
- We build a Herdindahl-Hirschman index on concentration:

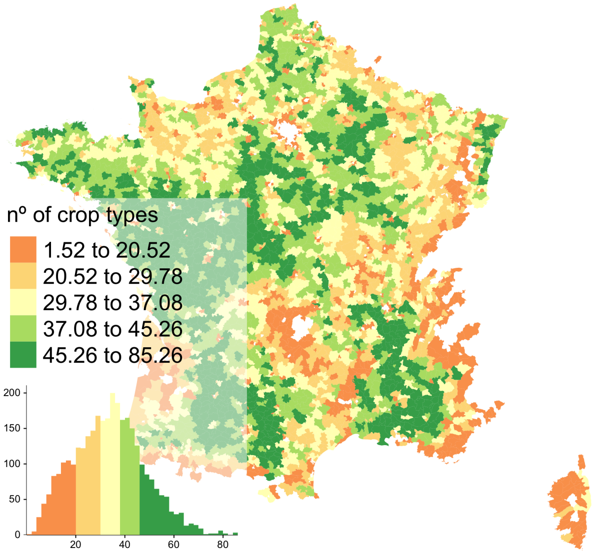
$$HHI = \sum_{c=1}^{N} s_i^2 \tag{1}$$

Where s_i^2 is the squared share of land taken by crop c **Cantonal**

Land Inequality:

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

Crop diversity (nº of species), latest year



Measuring shock-effects in the growing season

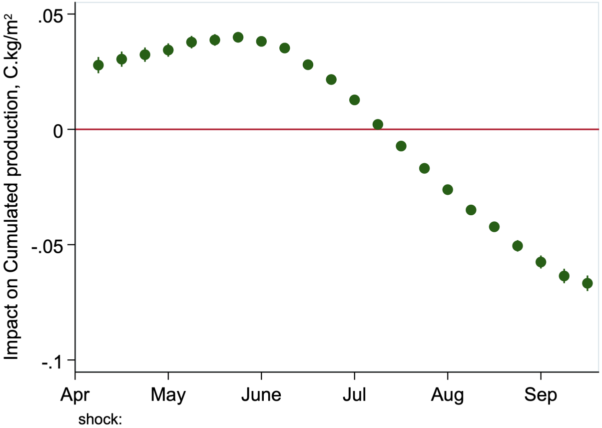
Basic heatshock specification

- Effect of extreme weather with canton and time fixed effects

$$CumulGPP_{c,t} = \sum_{w=1}^{22} \beta_w \times D_{c,y} + \gamma_c + \lambda_t + \epsilon_{c,t} \qquad (2)$$

- $D_{c,y} = 1$ if at least one heat-shock in canton c in year y
- β_w capture the effect on each of 22 pseudo-weeks (8 days)
- γ_c, λ_t canton and time fixed effects
- **Compare weekly-production in shock vs. non-shock years**

Shock vs non-shock years



Acceleration in warm springs, collapse during baking summers

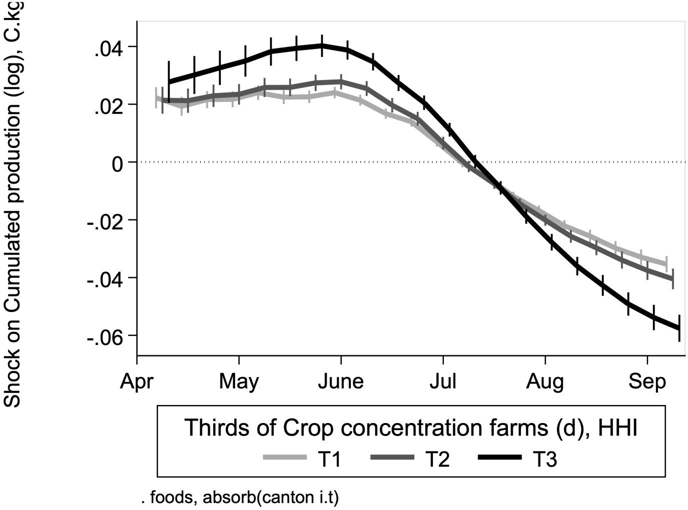
Heatshock across diversity levels

- Spreading effects across quantiles of diversity/concentration:

$$CumulGPP_{c,t} = \sum_{q=1}^{3} \sum_{w=1}^{22} \beta_{w,q} \times D_{c,y} \times Q_{c,q} + \gamma_c + \lambda_t + \epsilon_{c,t} \quad (3)$$

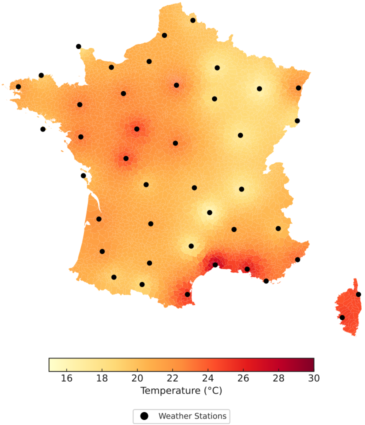
- $\beta_{w,q}$ capture the weekly-effect across quantiles of diversity ($Q_{c,q}$)
- **Compare weekly-production differentials within ranks of diversity**

More diverse land is more resilient (HHI index)



A closer look

Hourly temperature data (Météo France)



- We **interpolate** average afternoon temps using kriging techniques (considers latitudes, longitudes and altitude)
- We can ventilate temperatures at weekly level

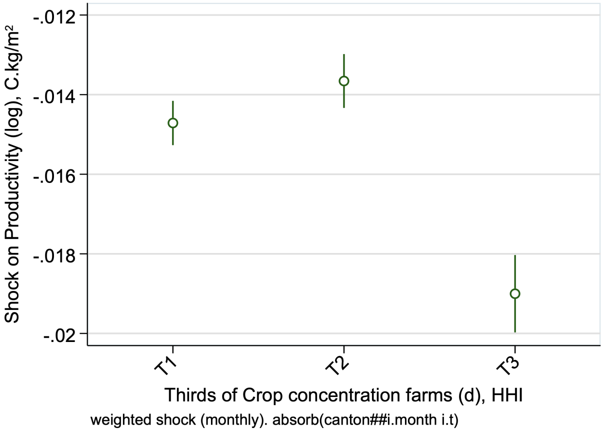
Static weekly heat-shock on flows

- Effect:

$$log(GPP_{ct}) = \sum_{q=1}^{3} \beta_q \times D_{c,t} + \mu_{c,t} + \epsilon_{c,t} \quad (4)$$

- $D_{c,t} = 1$ if canton c is shocked in period t
- β_q capture effects over quantiles
- $\mu_{c,t}$ captures two-way fixed effects plus the interaction of canton and time effects.
- **Compare weekly-flow capturing unique effects for each unit in each time period (detrending)**

Static effect with canton-month interaction and fixed effects



After detrending, shock-weeks still show heterogeneity

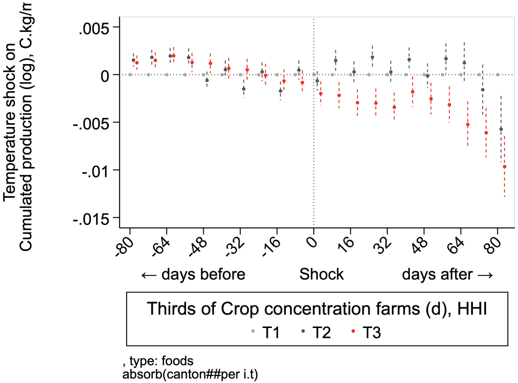
Lagged heat-shock specification

- De-trended effect of extreme weather

$$CumGPP_{c,t} = \sum_{q=1}^{3}\sum_{\tau=0}^{10}\beta_{-\tau,q}D_{c,q,t-\tau} + \sum_{q=1}^{3}\sum_{\tau=1}^{10}\beta_{\tau,q}D_{c,q,t+\tau} + \mu_{c,t} + \epsilon_{c,t} \tag{5}$$

- $D_{c,t} = 1$ if at least one heat-shock in canton c in year y
- $\beta_{-\tau,q}$ and $\beta_{\tau,q}$ capture lags and forwards for periods up to 80 days before and after the shock, for each quantile q
- **Compare ...**

De-trended impact on production stocks



- two months after the shock, accumulated production keeps diverging for many periods suggesting structural damages.

Potential mechanisms

- **Pollination:** heatwaves kill pollinators, indirectly reducing yield. Semi-natural areas host more of them, also providing refuge from extreme heat.

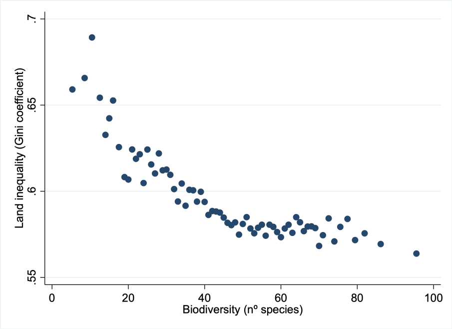
- **Water retention:** Semi-natural environments host below-ground diversity. Complex root systems, funghi and insects retain useful water to endure extreme weather.

- **Regulating bio-agressors:** Biodiversity effectively regulates pests (Barrier, pull or push strategies).

The political economy of diversity

Diversity and Land Inequality 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

Higher concentration corresponds to more mega-farms

Table: Land composition by farm class

Variable	Quantile	Small farm		Medium farm		Large farm		Very large farm	
		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

Robustness checks and discussion

What we have done:

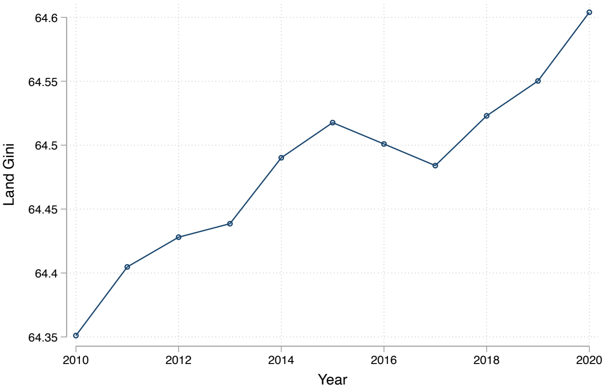
- Drop everything that is not food ($\approx$ 40% sample)
- Several shock-thresholds ($25, 27, 33$, and 35 Celsius)
- Other definitions of diversity (Hirschman-Herfindahl index) and inequality (coefficient of variation, s.d. of logs)
- Weighted shocks
- Finer temperature data
- Can inequality/diversity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

Concluding remarks and questions

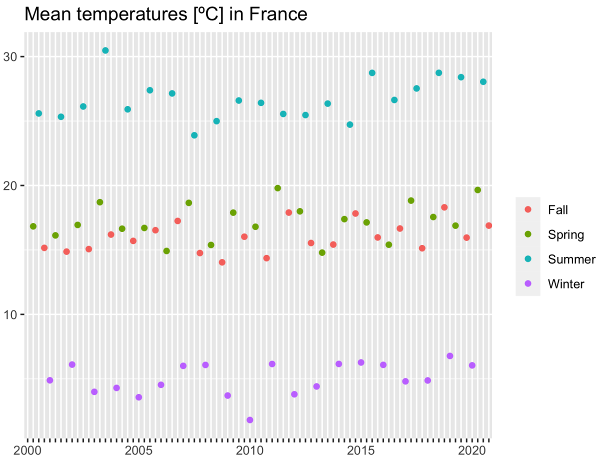
- Agricultural diversification is not random
- What particular crop-mixes perform better?
- Is this a portfolio effect or a symbiotic one?

Appendix

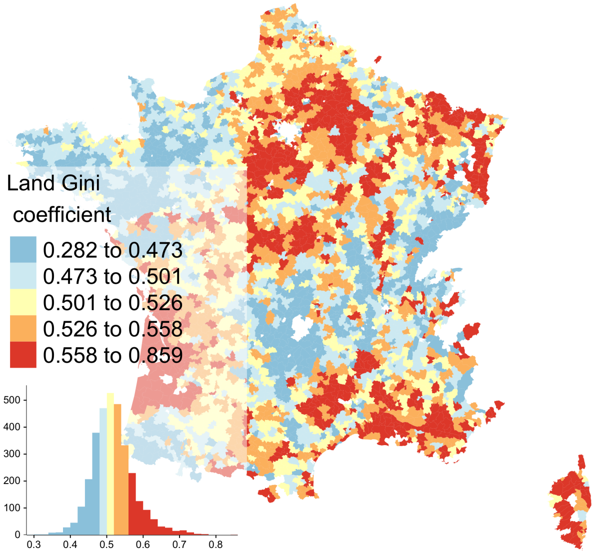
Appendix: Consistent trend with census



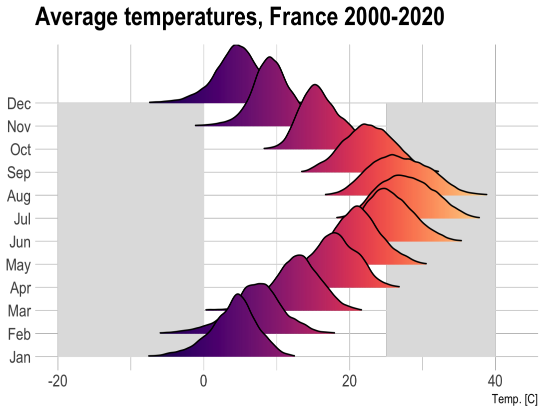
Appendix: Seasonal temperatures



Appendix: Map of Gini coefficients, latest year

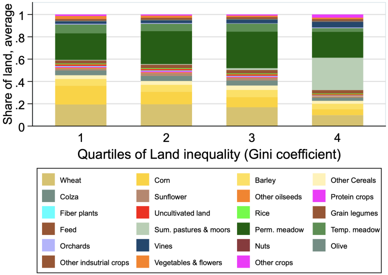


Appendix: Average monthly temperatures (ºC)

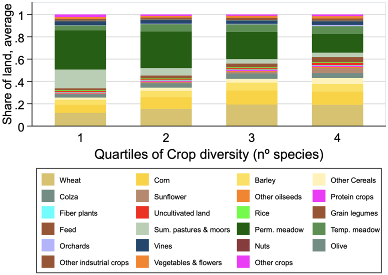


Appendix: Crop composition by fractile

Figure: Composition in farmland



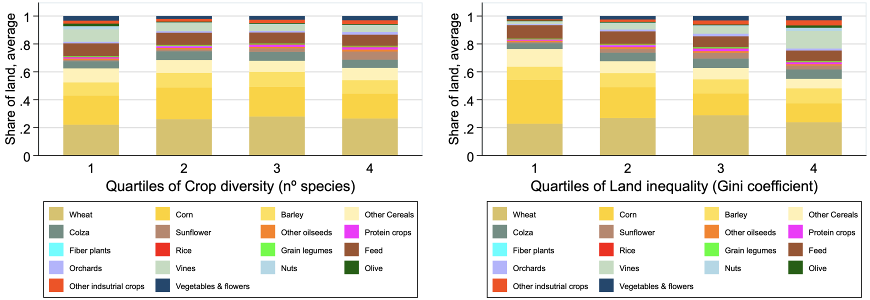
(a) Quintiles of Gini



(b) Quintiles of diversity

Appendix: Crop composition by fractile

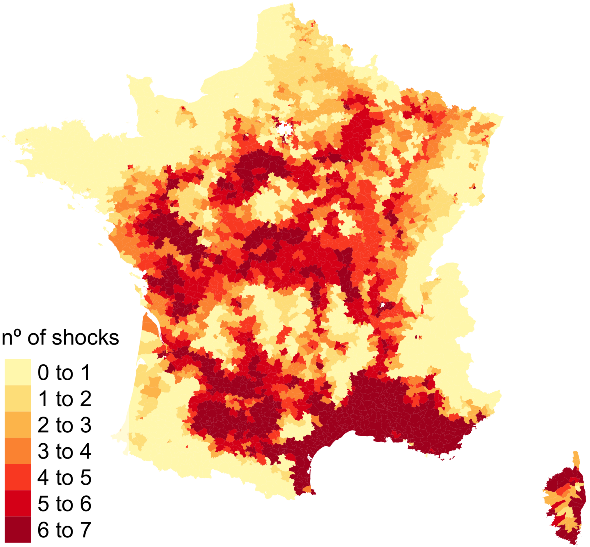
Figure: Composition in farmland (food only)



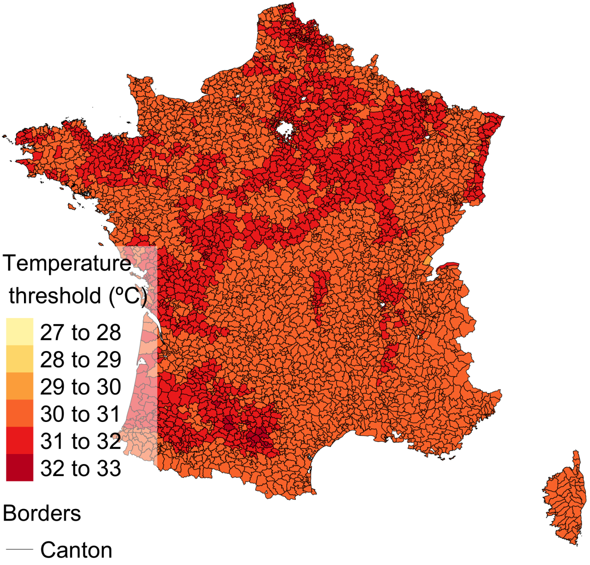
(a) Quintiles of Gini

(b) Quintiles of diversity

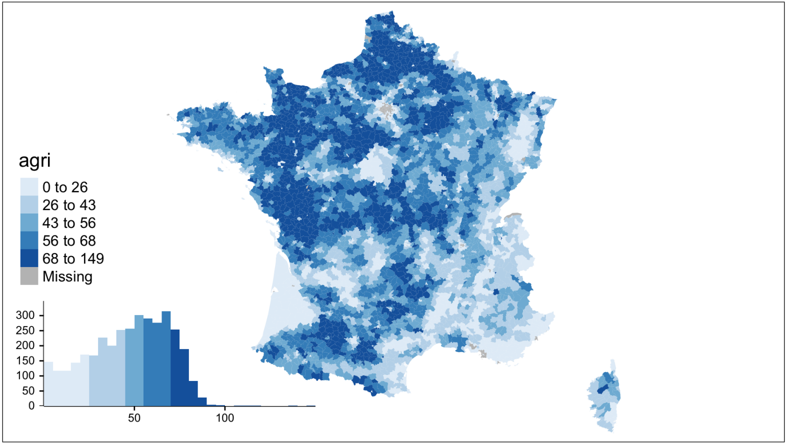
Appendix: Map of shocks



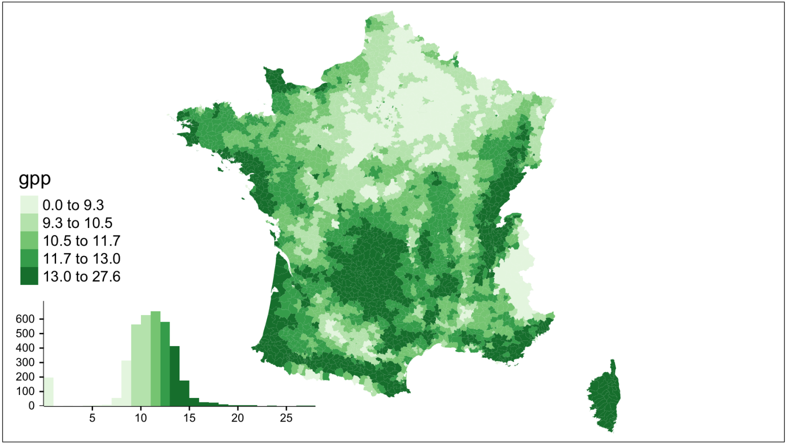
Appendix: Temperature thresholds



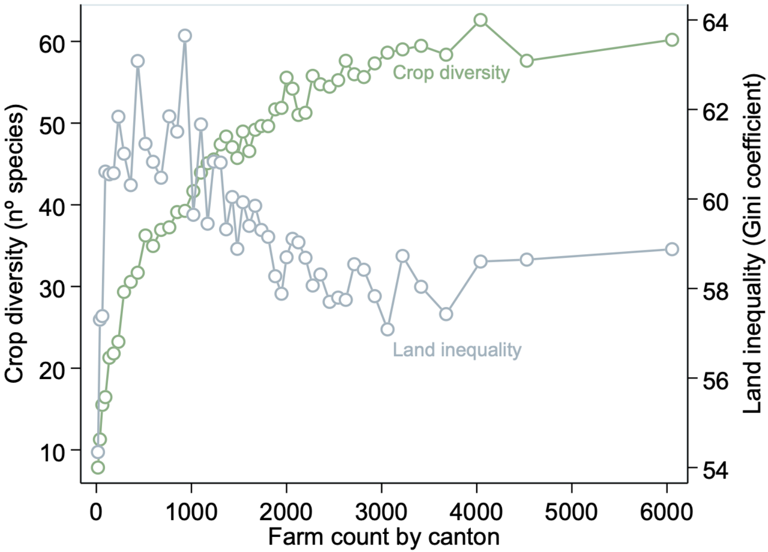
Appendix: Agricultural area by canton (%)



Appendix: Cumulated GPP in 2020

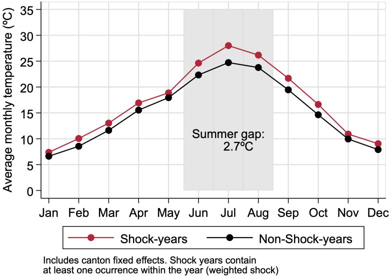


Appendix: Gini and diversity over farm count

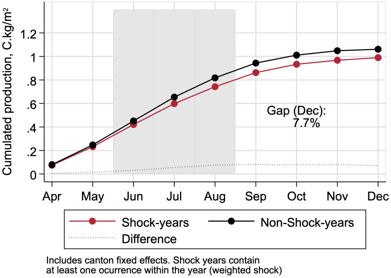


Year-long consequences of extreme heat (food crops)

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