Does Land Inequality Magnify Climate Change Effects? Evidence from France

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Harvesting the consequences of climate change

Note. *Farmer holding his head on overheated field.*
No farmers were harmed. AI-image from Stable Diffusion

- Heatwaves threaten global food security and price-stability

The bigger question

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
  - Low crop diversity <u>causes</u> lower resilience to heat shocks
- **We uncover** a trade-off for farmers and policy makers
  - Concentrated systems: more productive but fragile
  - Diverse systems: less productive but resilient

A story of land inequality and crop diversity

Our contribution (continued)

- **We model** agricultural production partially
  - Demonstrating rational incentives to land consolidation in a supply function with economies of scale and crop-specific costs
  - In reality, concentration increases in many countries
- **Take away** resilience can be improved
  - Resiliency is not a deterministic effect of land distribution, but its byproduct, given current industrial organization.
  - Resiliency can be improved by farmers individually by diversifying their production.

Related literature

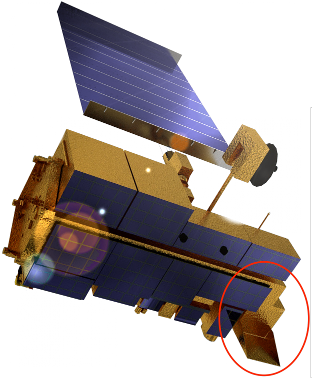
Climate change on agriculture

- 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)

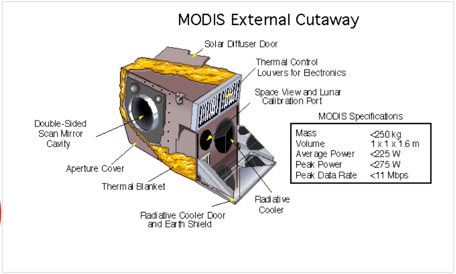
Others on Inequality/Biodiversity and productivity

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

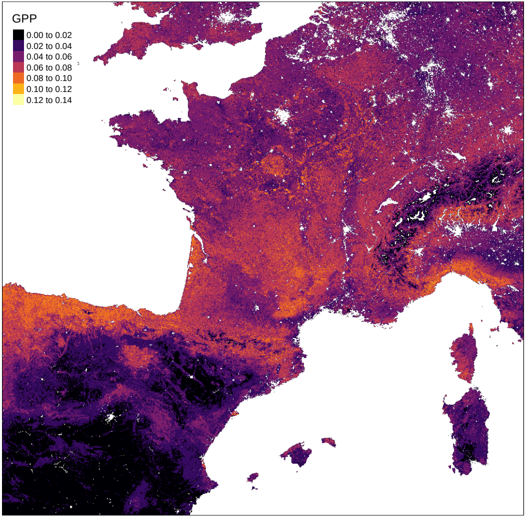


Figure: 8-days cumulative GPP at 500m resolution, mid-summer 2021

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)

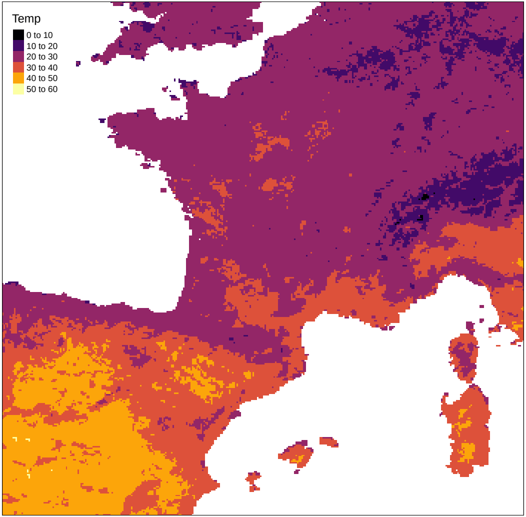


Figure: Monthly average temperature, at 5.6km resolution, summer 2021

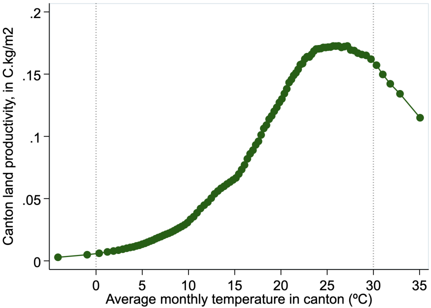
Temperature shocks

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

Defining a threshold for shocks

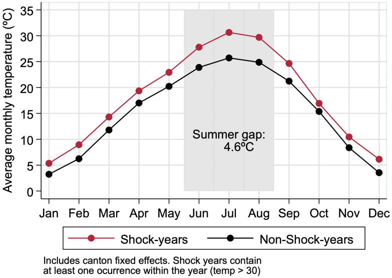
- We would ideally use crop-specific thresholds.
- For now, we define a single value where average productivity sharply decreases
- We define shocks as

$$t > 30^\circ C$$

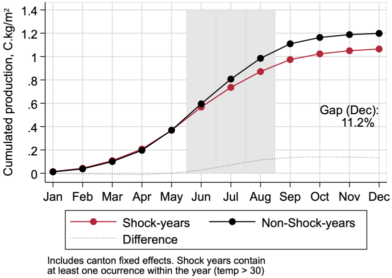
- 7.1% of observations (avg. 0.85 times per year)

Year-long consequences of temperature shocks

Figure: Normal vs. shock years (2000-2021)



(a) Warmer temperatures overall

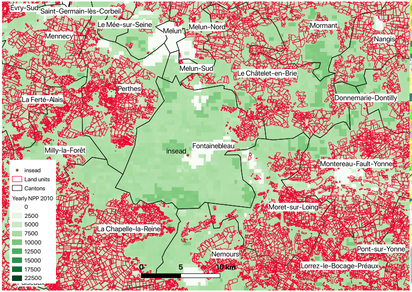


(b) The summer slowdown

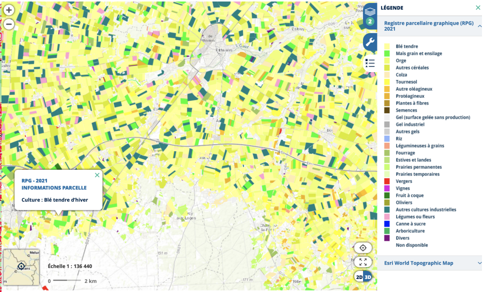
Measurements from the land

Measurements from the land

Figure: Snapshot of cadastral data



(a) The farm level (2010-2021)



(b) The crop level (2015-2021)

We divide information in ≈ 4000 cantons

Measurements from the land: main variables

Cantonal Land Inequality:

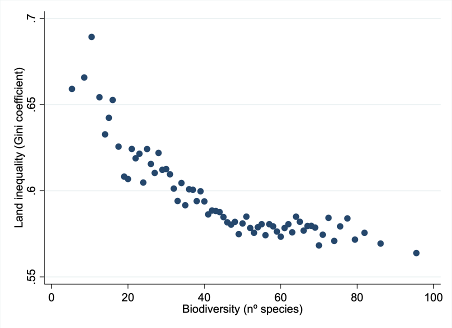
- Uses georeferenced information on farm borders
- Farm level $\neq$ owner level

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

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

Weather shock specification

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

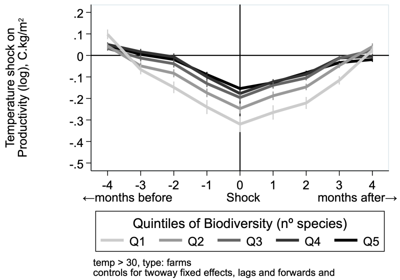
$$ln(GPP_{ct}) = \gamma_c + \lambda_t + \sum_{\tau=0}^{3} \beta_{-\tau} \times D_{c,t-\tau} + \sum_{\tau=1}^{3} \beta_{\tau} \times D_{s,t+\tau} + \epsilon_{c,t} \quad (1)$$

- $D_{c,t} = 1$ if there is a temperature shock in canton c in month t
- γ_c, λ_t canton and time fixed effects

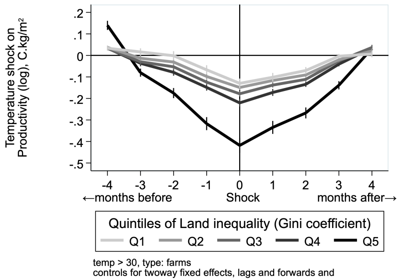
- **Compare impact over quantiles of land Gini and crop diversity**

Heterogeneous impacts on monthly productivity

Figure: What cantons suffer more losses?



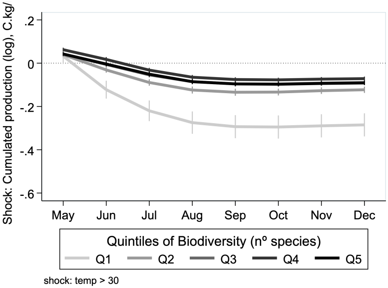
(a) Least diverse



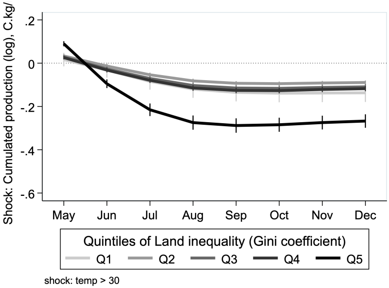
(b) Most unequal

.. what about yearly cumulative production?

Figure: What cantons perform better under heat shocks?



(a) More diverse crops



(b) ... and less unequal land

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)

Steps forward and further questions:

- Weighted shocks
- Finer temperature data
- What particular crop-mixes perform better?
- Is this a portfolio effect or a symbiotic one?

Conclusions

- Economic incentives lead to more land concentration and less diversity
- Once resiliency effects are taken into account, the new optimum depends on risk aversion
- This is a trade-off that some farmers have already started using
- The problem lies in the extremes

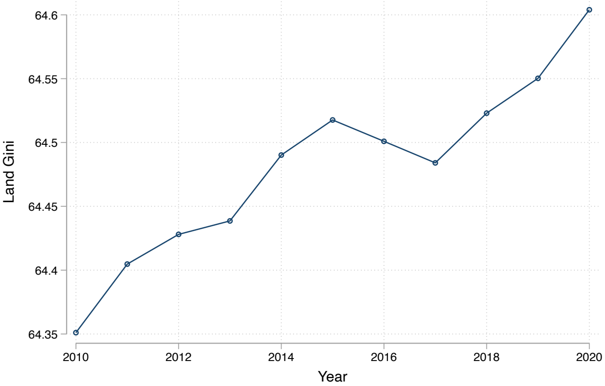
Appendix

Appendix: Critical temperatures in staple crops

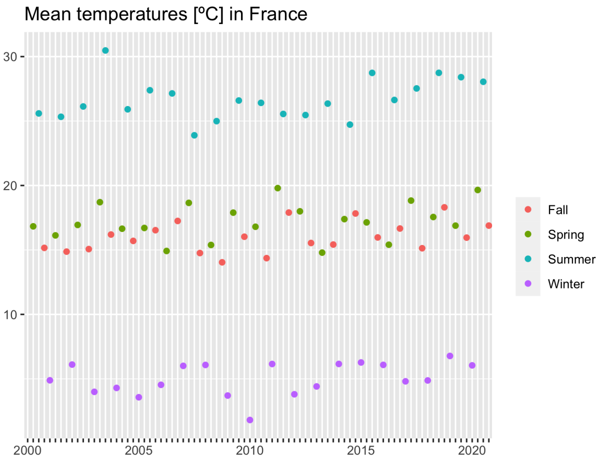
	Surface		Max. temperatures (C)	
Crop type	% of total	Cumulative	Optimal	Absolute
Blé/Wheat	30.8	30.8	23.0	27.0
Corn/Maize	17.3	48.0	33.0	47.0
Barley	10.7	58.8	20.0	40.0
Rapeseed	6.1	64.8	25.0	41.0
Sunflower	4.3	69.2	34.0	45.0
Grape	3.8	73.0	30.0	38.0
Common lucerne	2.8	75.8	27.0	45.0
Beet	2.6	78.4	25.0	35.0
Durum wheat	1.8	80.2	25.0	30.0
Potato	1.3	81.5	25.0	30.0
Green Pea	1.2	82.7	24.0	30.0
Soybean	1.0	83.7	33.0	38.0
Oat	0.7	84.3	20.0	30.0
Other crops (smaller %)	5.2	89.5	25.6	32.6
Unmatched	10.5	100.0	NA	NA

Notes. Compiled by the authors based on Ecocrop (FAO) and Cadastral data

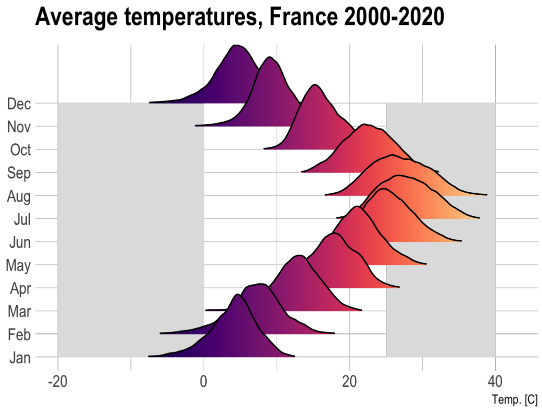
Appendix: Consistent trend with census



Appendix: Seasonal temperatures

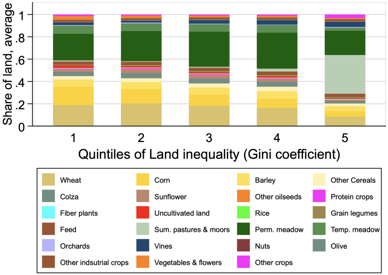


Appendix: Average monthly temperatures (ºC)

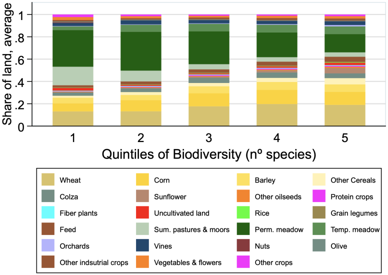


Appendix: Crop composition by quintile

Figure: Composition in farmland



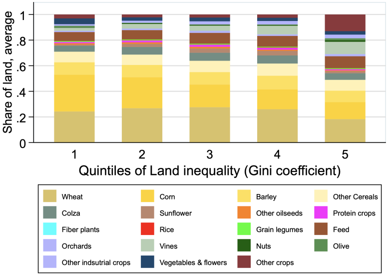
(a) Quintiles of Gini



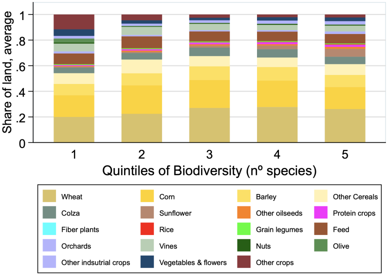
(b) Quintiles of diversity

Appendix: Crop composition by quintile

Figure: Composition in farmland (food only)



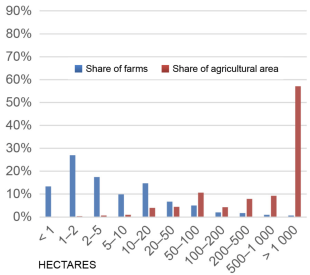
(a) Quintiles of Gini



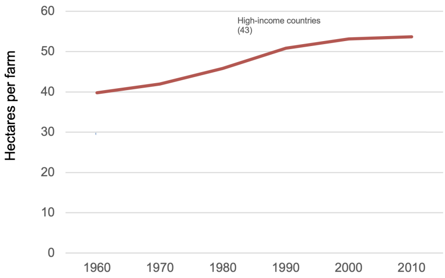
(b) Quintiles of diversity

Appendix: Agricultural land in 43 high-income countries

Figure: Facts from census data (Lowder, Sánchez, and Bertini, 2019)



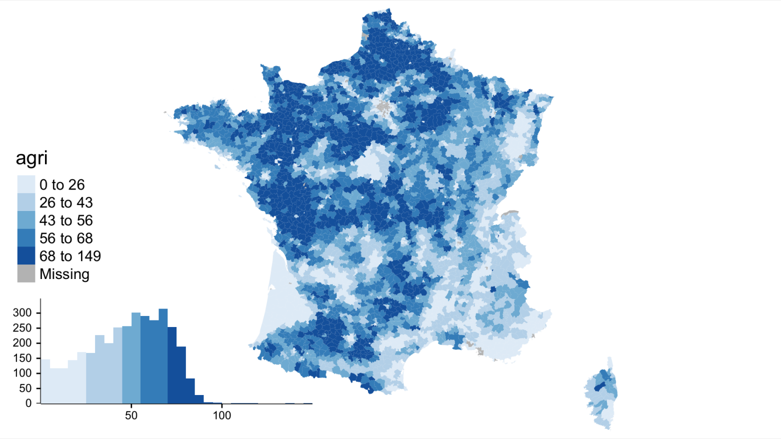
(a) Extremely concentrated



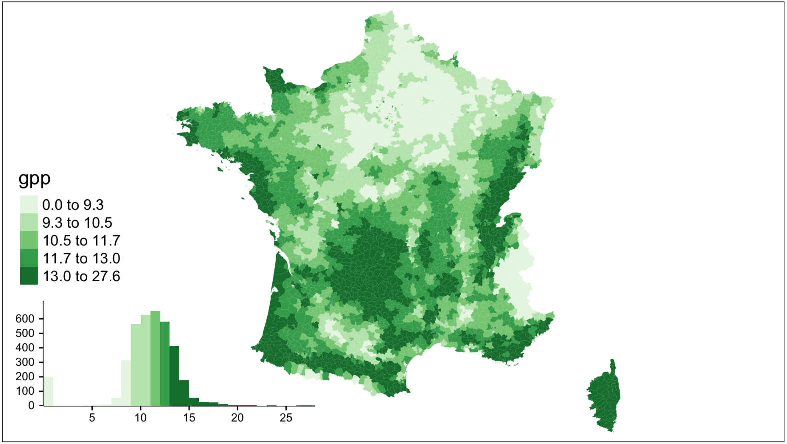
(b) Farm sizes have increased

- In the meantime, total agricultural area and number of farms have been decreasing

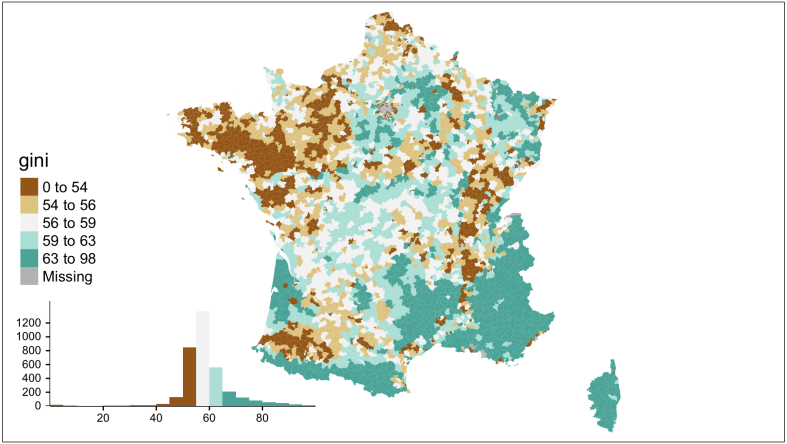
Appendix: Agricultural area by canton (%)



Appendix: Cumulated GPP in 2020



Appendix:



gini
0 to 54
54 to 56
56 to 59
59 to 63
63 to 98
Missing
1200
1000
800
600
400
200
0
20
40
60
80