Adaptation to Extreme Temperature Shocks in French Viticulture: Are Grape Growers "Dumb-Farmer"?

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Context

- Bunch of studies estimating climate effects on crop yields (e.g., Schlenker & Lobell, 2010; Chen et al., 2016; Zhang et al., 2017).
- Preferred **two-step** approach: (i) estimate yield–weather responses with panel data; (ii) apply to *future* weather distributions to project impacts.
- Common assumption: yield responses to *temperature* are **uniform across space and time** ⇒ "*dumb-farmer*" scenario.
- **Tension with economic intuition**: profit-seeking farmers *do* adapt to local climate.
- **Open question**: does this assumption bias forecasts?
    - No/Limited bias: Schlenker & Roberts (2009); Gammans et al. (2017).
    - Evidence of potential bias: Butler & Huybers (2013); Keane & Neal (2020).

This Paper: Adaptation in French Viticulture

- **Step 1**: estimate grape-yield responses to temperature, with special attention to how **extreme temperature** effects **vary across regions** $\Rightarrow$ *infer the magnitude of historical adaptation.*

- **Step 2**: use *first-step heterogeneity* to predict climate impacts under **two adaptation scenarios**:

  $\Rightarrow$ **Historical adaptation —** incorporate *current spatial heterogeneity* in sensitivities.

  $\Rightarrow$ **Prospective adaptation —** *extrapolate* the sensitivity–climate relationship to *future* climates.

  $\rightarrow$ **No adaptation —** use *uniform* yield responses; shown as a **benchmark for comparison**.

First Step: Yield Data — French FADN

- **Primary source**
  - French Farm Accountancy Data Network (FADN)
  - Nationally representative annual farm surveys
- **Sample**
  - Farms specialized in viticulture
  - Analysis window: 2001–2021
- **Key variables**
  - Farm-level total grape production (quintals)
  - Vineyard area in production (ha)
  - $\text{Yield} = \dfrac{\text{Grape Production}}{\text{Vineyard Area}}$ (quintals/ha)

First Step: Weather Data — SAFRAN

- **Source**: SAFRAN — daily gridded weather across France.
- **Variables used**: daily minimum and maximum temperature.
- **Growing-season indicators**:
    - Built from daily temperatures for the growing season **April 1 – September 30**.
    - Capture **cumulative exposure to temperature** within distinct segments of the distribution.
- **Indicator formulas**:

$$\mathrm{KDD} = \int_{27}^{\infty} (T - 27)\,\Phi(T)\,dT$$

$$\mathrm{GDD} = \int_{10}^{27} (T - 10)\,\Phi(T)\,dT$$

$$\mathrm{FDD} = \int_{-\infty}^{0} (0 - T)\,\Phi(T)\,dT$$

where $\Phi(T)$ is the time distribution of temperature.

First Step: Method for Estimating Responses to Temperature

Baseline (uniform responses). Log grape yield as a piecewise-linear function of temperature exposure:

$$y_{igt} = f_i + \beta_1 FDD_{gt} + \beta_2 GDD_{gt} + \beta_3 KDD_{gt} + \epsilon_{igt}. \quad (1)$$

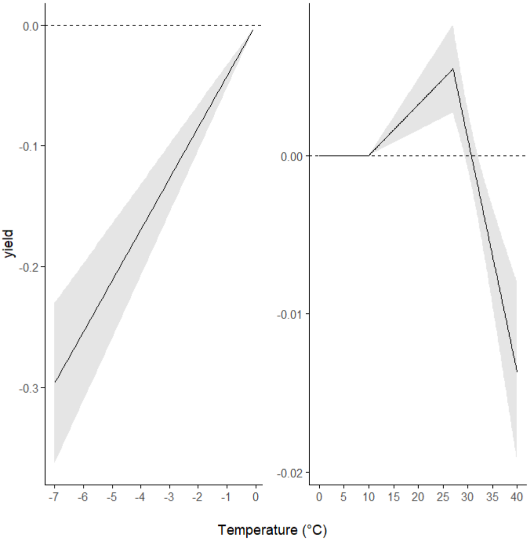
Identification: presumably random year-to-year variation in temperature (Deschênes & Greenstone, 2007).

Climate-driven heterogeneity (adaptation). Sensitivities vary with historical exposure (above-median groups):

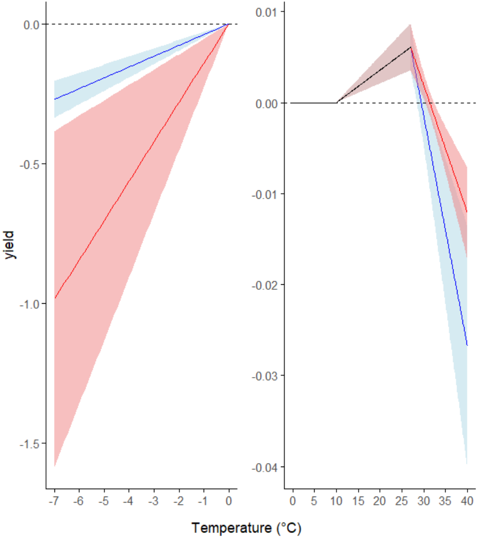
$$\begin{aligned} y_{igt} = f_i + \beta_{11} FDD_{gt} + \beta_{12}\, FDD_{gt} \times \mathbf{1}(\overline{FDD}_g > c) + \beta_2 GDD_{gt} \\ + \beta_{31} KDD_{gt} + \beta_{32}\, KDD_{gt} \times \mathbf{1}(\overline{KDD}_g > c') + \epsilon_{igt}. \end{aligned} \quad (2)$$

Interpretation: β_{11}, β_{31} = responses in less-exposed areas; β_{12}, β_{32} = differentials in more-exposed areas.

First Step: Yield Responses to Temperature (Homogeneous Case)



First Step: Yield Responses to Temperature (Heterogeneous Case)



Second Step: Climate-Dependent Yield–Temperature Relationship

- **Setup**: we adopt a **climate-dependent** specification that lets **extreme-temperature sensitivities** vary with local **climatologies**.

$$
\begin{aligned}
y_{igt} = f_i &+ \beta_{11} FDD_{gt} + \beta_{12}\, FDD_{gt} \;\times f_{\overline{FDD}}(\overline{FDD}_g) \\
&+ \beta_2\, GDD_{gt} + \beta_{31}\, KDD_{gt} \\
&+ \beta_{32}\, KDD_{gt} \;\times f_{\overline{KDD}}(\overline{KDD}_g) + \epsilon_{igt}
\end{aligned}
$$

- **Functional forms**:

  $\rightarrow$ Linear: $f(x) = x$

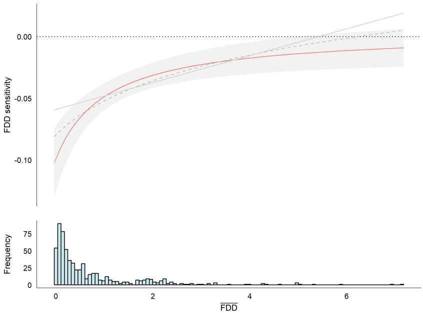
  $\rightarrow$ Logarithmic: $f(x) = \ln x$

  $\rightarrow$ Inverse: $f(x) = \dfrac{1}{x}$

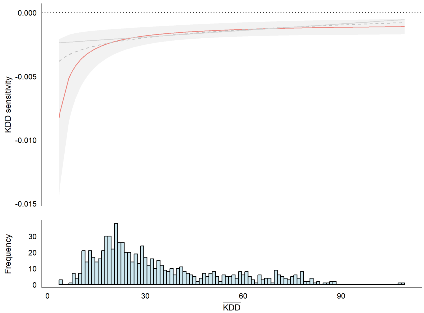
  for $x \in \{\overline{FDD}_g,\ \overline{KDD}_g\}$.

- **Model selection**: test all combinations of $f_{\overline{FDD}}(\cdot)$ and $f_{\overline{KDD}}(\cdot)$; choose the best-fitting by lowest **AIC/BIC**.

Second Step: Extreme Temperature Sensitivities Versus Climatologies



a) FDD



b) KDD

Second Step: Projected Climate Data — ALADIN

- **Data source**: ALADIN regional climate model — historical and future daily min/max temperature simulations across France.
- **Periods**: historical (**1976–2005**) and end-of-century (**2070–2099**) under RCP 8.5.
- **Location-specific (grid cell g level) climate indicators**:

$$\overline{FDD}_g^P = \frac{1}{30}\sum_{t\in P} FDD_{gt}, \qquad \overline{GDD}_g^P = \frac{1}{30}\sum_{t\in P} GDD_{gt}, \qquad \overline{KDD}_g^P = \frac{1}{30}\sum_{t\in P} KDD_{gt},$$

where $P \in \{\text{hist (1976–2005)}, \text{ fut (2070–2099)}\}$.

- **Climate shifts** (future minus historical):

$$\Delta\overline{X}_g = \overline{X}_g^{fut} - \overline{X}_g^{hist}$$

where $X \in \{\, FDD,\ GDD,\ KDD\}$.

Second Step: Forecast Methodology

- **(i) No adaptation** (*uniform yield–temperature response*)

$$\Delta y_g^{(NA)} = -0.042\,\Delta\overline{FDD}_g + 0.00032\,\Delta\overline{GDD}_g - 0.0015\,\Delta\overline{KDD}_g$$

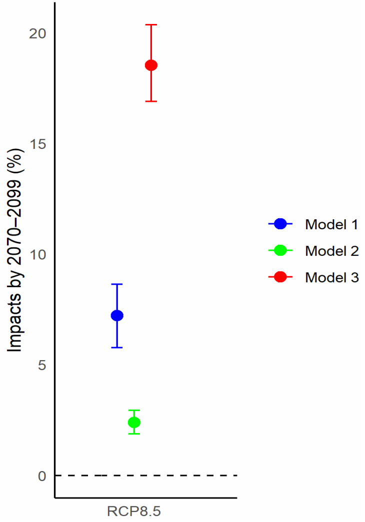
- **(ii) Historical adaptation only** (*sensitivities fixed at historical climatology*)

$$\Delta y_g^{(HA)} = \left[0.004 - \frac{0.11}{\overline{FDD}_g^{hist}}\right]\Delta\overline{FDD}_g + 0.00038\,\Delta\overline{GDD}_g + \left[-0.0008 - \frac{0.031}{\overline{KDD}_g^{hist}}\right]\Delta\overline{KDD}_g$$

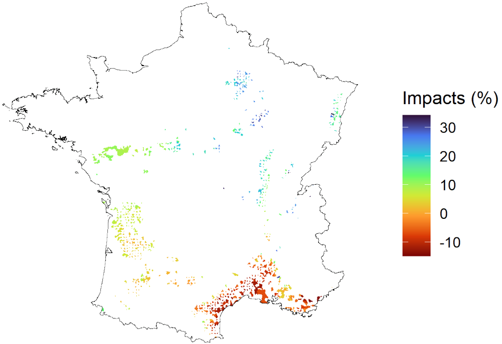
- **(iii) Prospective adaptation** (*sensitivities follow contemporaneous climate*)

$$\Delta y_g^{(PA)} = \left[0.004 - \frac{0.11}{\overline{FDD}_g^{fut}}\right]\overline{FDD}_g^{fut} - \left[0.004 - \frac{0.11}{\overline{FDD}_g^{hist}}\right]\overline{FDD}_g^{hist} + 0.00038\,\Delta\overline{GDD}_g + \left[-0.0008 - \frac{0.031}{\overline{KDD}_g^{fut}}\right]\overline{KDD}_g^{fut} - \left[-0.0008 - \frac{0.031}{\overline{KDD}_g^{hist}}\right]\overline{KDD}_g^{hist}$$

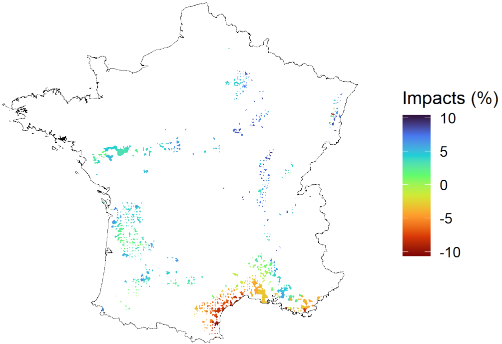
Second Step: Predicted Global Impacts of Climate Change



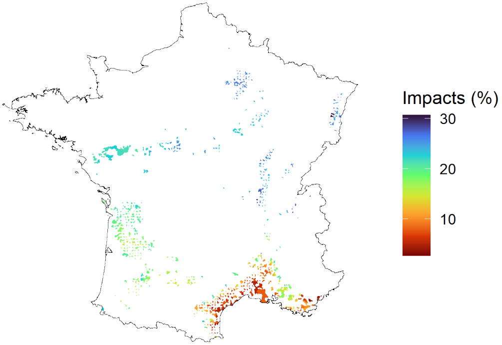
Second Step: Predicted Local Impacts — No Adaptation ("Dumb-Farmer" Scenario)



Second Step: Predicted Local Impacts — Historical Adaptation Only

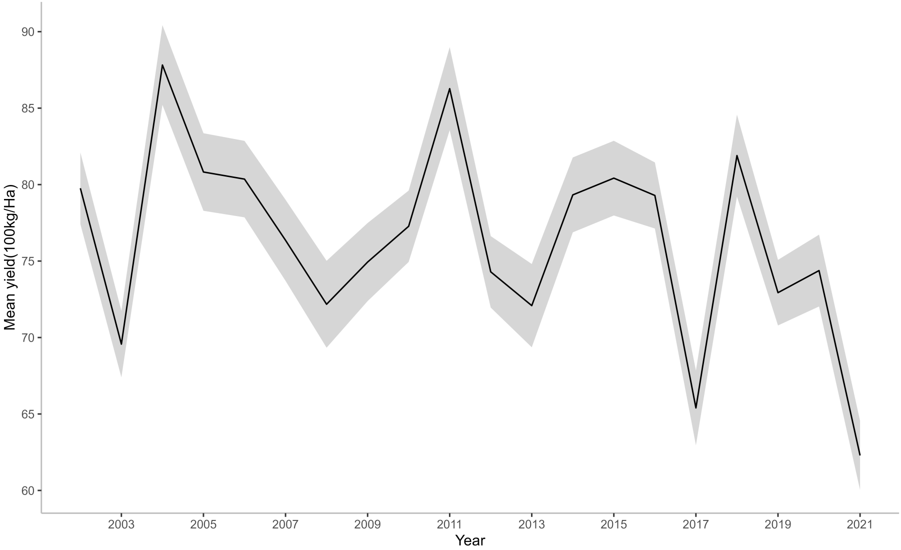


Second Step: Predicted Local Impacts — Historical and Prospective Adaptation

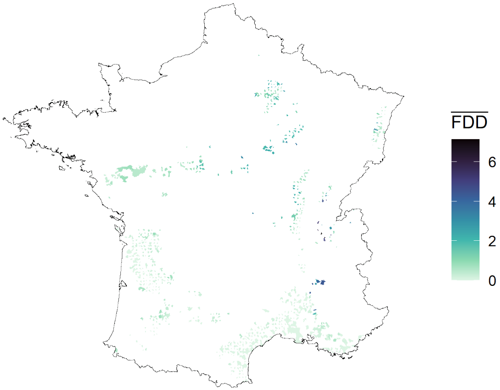


Thanks for your attention!

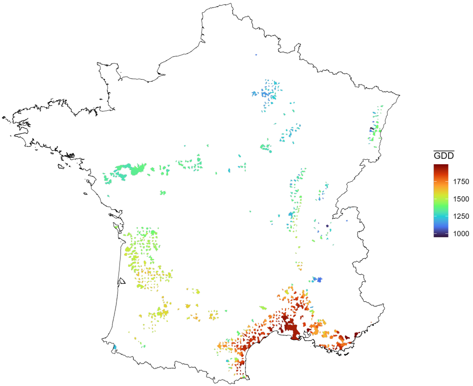
First Step: Average Yield Over Years



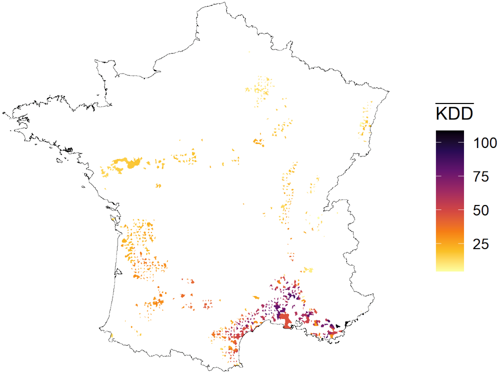
First Step: Spatial Heterogeneity in FDD Climatologies



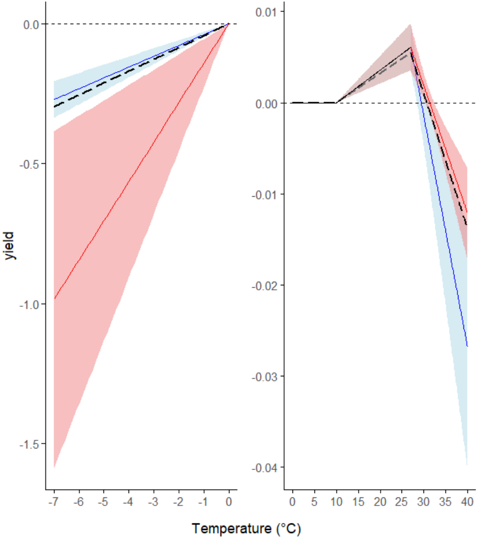
First Step: Spatial Heterogeneity in GDD Climatologies



First Step: Spatial Heterogeneity in KDD Climatologies



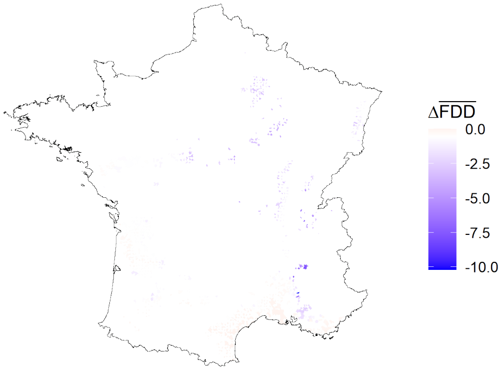
First Step: Homogeneous Versus Heterogeneous



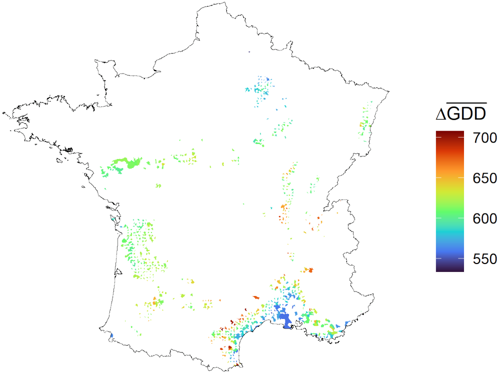
First and Second Step: Tabular Results

	(1)	(2)	(3)	(4)
FDD	-0.042***	-0.14***	-0.16***	0.004
	(0.005)	(0.05)	(0.05)	(0.010)
FDD×FDD-Prone		0.10**	0.10**	
		(0.04)	(0.04)	
FDD×$\overline{\text{FDD}}^{-1}$				-0.11***
				(0.02)
GDD	0.00032***	0.00036***	0.00036***	0.00038***
	(0.00008)	(0.00008)	(0.00008)	(0.00008)
KDD	-0.0015***	-0.0025***	-0.0026***	-0.0008**
	(0.0003)	(0.0006)	(0.0007)	(0.0004)
KDD×KDD-Prone		0.0011**	0.0011**	
		(0.0005)	(0.0005)	
KDD×$\overline{\text{KDD}}^{-1}$				-0.031**
				(0.014)
Individual F.E.	Farm	Farm	Farm	Farm
Clustered S.E.	Department	Department	Department	Department
Adj. R^2	0.641	0.642	0.642	0.643
Obs.	20854	20854	20847	20854

Second Step: Spatial Heterogeneity in Projected FDD Climatologies Shifts



Second Step: Spatial Heterogeneity in Projected GDD Climatologies Shifts



Second Step: Spatial Heterogeneity in Projected KDD Climatologies Shifts