Heterogeneous effects of weather shocks on firm economic performance

WP

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FINPRO 4

Barcelona, September 26th, 2024

Motivation

- Within-country heterogeneity mostly neglected in discussions on distributional aspects of climate damages
- Accounting for **damages heterogeneity** is crucial for
  - **Policy**: identifying **"winners and losers"** to support the design of tailored mitigation and adaptation policies: **climate industrial policies? climate redistribution?**
  - **Economics**: identify whether average marginal effect is correctly identifying climate damages or averaging out opposing effects.
    - Europe is an ideal setting: located at the "bliss" point in aggregate analysis (Burke et al. 2015)

Research Question

Are climate damages heterogeneous across firms?

This paper explores the economic impacts of increasing temperatures on firms' economic performance across firms characteristics.

Results Preview

- Average relationship between temperature and economic performance generally consistent with previous (global-level) literature
  - Inverted-U-shaped
  - Persistent but not-significant growth effect
- Damages heterogeneity identifies winners and losers:
  - **winners:** most productive firms
  - **losers:** least productive firms

Overall Contribution

This paper contributes to three strands of literature:

- **Climate Economics:** identifies sources of heterogeneity in climate damages;
- **Climate Econometrics:** addresses methodological issues highlighted in the literature (model selection, nonstationarity);
- **Aggregate Productivity:** discusses economy-wide effects of climate damages heterogeneity in firms productivity levels (convergence, aggregate productivity slow-down) - informative also for the literature on Firm Dynamics

Climate Econometrics Literature

Economic Performance

Country-level:

- Dell et al. (2012); Burke et al. (2015); Acevedo (2020);

Regional-level:

- Burke and Tanutama (2019); Kalkuhl and Wenz (2020); Groom et al. (2023); Kotz et al. (2024);

However:

- Country or regional analyses can not account for within-units heterogeneity. This can only be addressed using granular data.

Firm-level climate damages

Firm-level damages from weather fluctuations, channels:

- effect on labour productivity and supply
- effect on capital productivity and stock
- effect on costs
- effect on supply chain

Firm-level Literature and Contribution

Literature:

- impact of temperatures in China (Chen and Yang 2019; Zhang et al. 2018), the US (Addoum et al. 2020), Italy (Caggese et al. 2023)
- revenues response to daily maximum temperatures (Nath 2020)
- impact of hot and cold days on manufacturing firm performance in the US (Ponticelli et al. 2023)

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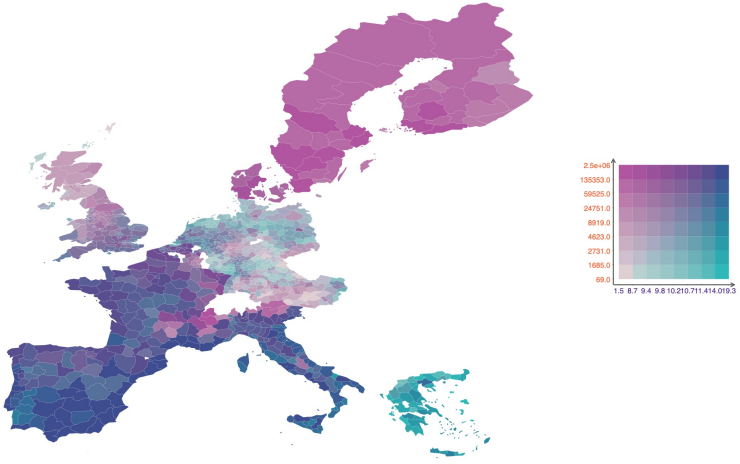
Contribution:

- focus on Europe
- extend analysis on firms' characteristics heterogeneity: TFP-category (today), Industry and size (in the paper)
- include non-listed and small and medium enterprises (SME), relevant part of European economies
- publicly available database covering large part of the firms universe (clean dataset $\approx$ 68m observations and 8.7m firms in Europe)

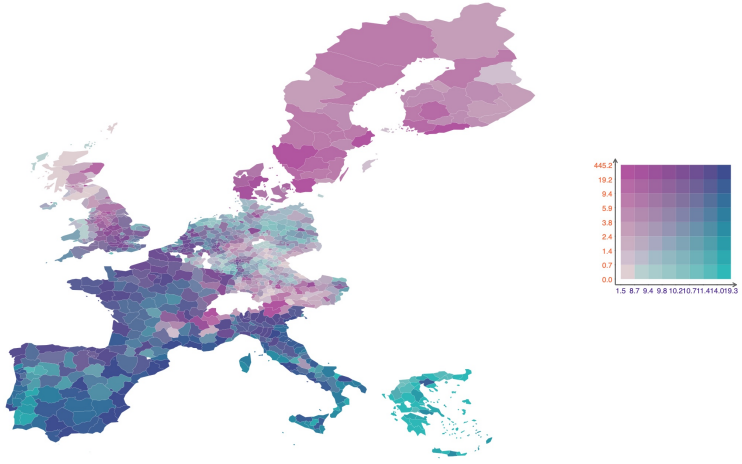
Data and Identification Strategy

Data

- BvD Orbis, European yearly data, different coverage by country Coverage
- merged with Copernicus ERA5-Land data (0.1° grid $\sim$ 9 km)
- inverse-distance weighting matching
- temperature distribution dispersed, dropped firms in top and bottom 1% T-Distribution



(a) Temperature and N firms



(b) Temperature and tot GO

Figure: Bivariate spatial distributions, values aggregated at the Nuts 3-level

Empirical Strategy I

General Model

$$\Delta y_{i,t} = g(T_{i,t}) + f(P_{i,t}) + \sum_{\ell \geq 1} h(T_{i,t-\ell}) + \delta_i + \boldsymbol{\delta_{-i}} + \varepsilon_{i,t}$$

- $y_{i,t}$ = log of firm i's variable of interest in year t
- $g(T_{i,t})$ = function of yearly average temperature for firm i in year t
- $h(T_{i,t-\ell})$ = function of yearly average temperature for firm i in year $t - \ell$
- $f(P_{i,t})$ = function of yearly total precipitation for firm i in year t
- δ_i = firm fixed effects
- $\boldsymbol{\delta_{-i}}$ = context-specific fixed effects
- $\varepsilon_{i,t}$ = autocorrelated and spatially correlated errors

Identification assumption (strict exogeneity)

$$\mathbb{E}[\varepsilon_{i,t} \mid g(T_{i,t}), f(P_{i,t}), \{h(T_{i,t-1}), \ldots, h(T_{i,t-L})\}, \delta_i, \boldsymbol{\delta_{-i}}] = 0 \qquad \forall \quad t = 1, \ldots, T$$

Empirical Strategy II

Identification issues

1. **Nonstationarity**: issue raised for temperature series
   - in this panel, large N and short T $\rightarrow$ concern $\downarrow$ (Greene 2003)
   - panel unit root tests (ADF) reject nonstationarity of temperature.
2. **Identification**: T-bins VS yearly average temperature
   - T-bins: clear identification and interpretation, but under strong assumptions
   - Yearly average temperature: less assumptions and broadly used in macroeconomic models, but identification not as clear
3. **Model specification**: literature generally relies on quadratic model with L lags
   - post-estimation Information Criteria and Machine Learning Cross-Validation suggest higher order polynomials and more lags
   - IC and CV do not converge, largest relative improvement (%) for 2^{nd} order polynomial with 2 lags (elbow rule spirit) Result

Empirical Strategy III

2^{nd} order polynomial

$$\Delta y_{i,t} = \alpha + \beta_0 T_{i,t} + \gamma_0 T_{i,t}^2 + \sum_{\ell \geq 1} \beta_\ell T_{i,t-\ell} + \sum_{\ell \geq 1} \gamma_\ell T_{i,t-\ell}^2 + \zeta_0 P_{i,t} + \zeta_1 P_{i,t}^2 + \delta_i + \lambda_{c,n,t} + \varepsilon_{i,t}$$

- $y_{i,t}$ = log of firm i's variable of interest in year t
- $T_{i,t}$ = yearly average temperature for firm i in year t
- $P_{i,t}$ = yearly total precipitation for firm i in year t
- δ_i = firm fixed effects
- $\lambda_{c,n,t}$ = country-industry-year fixed effects
- $\varepsilon_{i,t}$ = autocorrelated and spatially correlated errors (SE clustered at Nuts 3 province level)

Results

Marginal Effects

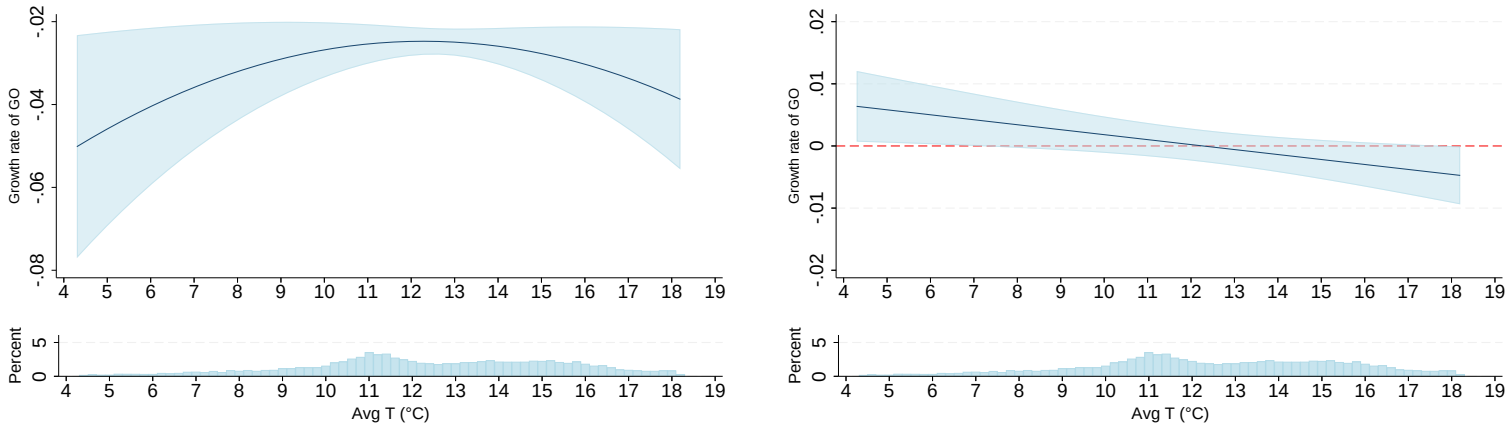
	(1) ΔGO	(2) ΔVA	(3) ΔTFP	(4) ΔL	(5) ΔK	(6) ΔM
T	0.0098**	0.0043	0.0015	0.00063	0.0096***	0.0015
	(0.0042)	(0.0037)	(0.0029)	(0.0027)	(0.0027)	(0.0030)
T^2	-0.00040**	-0.00024	-0.00013	-0.000066	-0.00035***	-0.00011
	(0.00016)	(0.00015)	(0.00011)	(0.00012)	(0.00011)	(0.00012)
$(\ell 1)T$	0.00078	-0.0056	-0.0029	-0.0088***	0.0097***	-0.0049
	(0.0051)	(0.0048)	(0.0045)	(0.0024)	(0.0032)	(0.0040)
$(\ell 1)T^2$	-0.00011	0.000031	0.000033	0.00011	-0.00034***	0.00012
	(0.00021)	(0.00020)	(0.00018)	(0.00011)	(0.00012)	(0.00016)
$(\ell 2)T$	0.0047	0.0012	-0.00090	0.0011	0.011***	0.0049*
	(0.0042)	(0.0045)	(0.0046)	(0.0023)	(0.0032)	(0.0029)
$(\ell 2)T^2$	-0.00023	-0.000099	-0.0000044	-0.000024	-0.00037***	-0.00015
	(0.00020)	(0.00021)	(0.00020)	(0.00010)	(0.00013)	(0.00014)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Cou-Ind-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.16	0.14	0.12	0.14	0.15	0.15
N	43,010,224	32,189,101	18,442,532	25,570,937	38,146,624	31,095,285

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table: Point estimates and standard errors from the regressions of weather variables on the growth rates of GO, VA, TFP, L, K, and M (P and P^2 not reported for presentational reasons).

Insignificant Contemporaneous Effect

- Inverted-U-shaped relationship Country-level
- Contemporaneous ($T_{i,t}$) marginal effect statistically and economically not significant



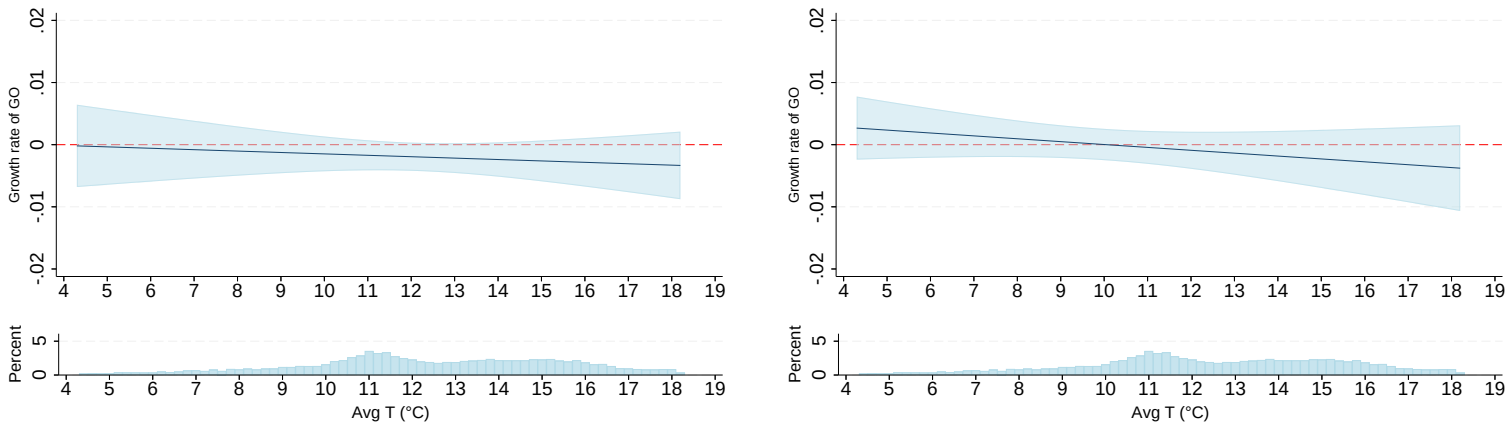
(a) 2^{nd} order polynomial prediction

(b) 2^{nd} order polynomial marginal effect

Figure: Contemporaneous Prediction (a) and marginal effect (b) of temperature on the growth rate of gross output. Point estimates and 95% CI reported

Lagged Damages

- Downward-sloping lagged marginal effects
- Economically and statistically insignificant estimates
- Evidence of persistent growth effect, though imprecisely estimated



(a) 2^{nd} order polynomial marginal effect of $T_{i,t-1}$ (b) 2^{nd} order polynomial marginal effect of $T_{i,t-2}$

Figure: Marginal effect of temperature on the growth rate of gross output in $T_{i,t-1}$ and $T_{i,t-2}$. Point estimates and 95% CI reported

Insignificant Pooled Results

What is driving insignificant marginal effects?

- Europe is not affected by weather shocks
- European firms have already adapted to warmer climate
- **Heterogeneous opposite effects average out in insignificant results**

TFP-Category Heterogeneity

- TFP categories defined over the first 2 available years
- Upward-sloping marginal effect for more productive firms (Adhvaryu et al. 2022)
- Downward-sloping marginal effect for less productive firms Country-level

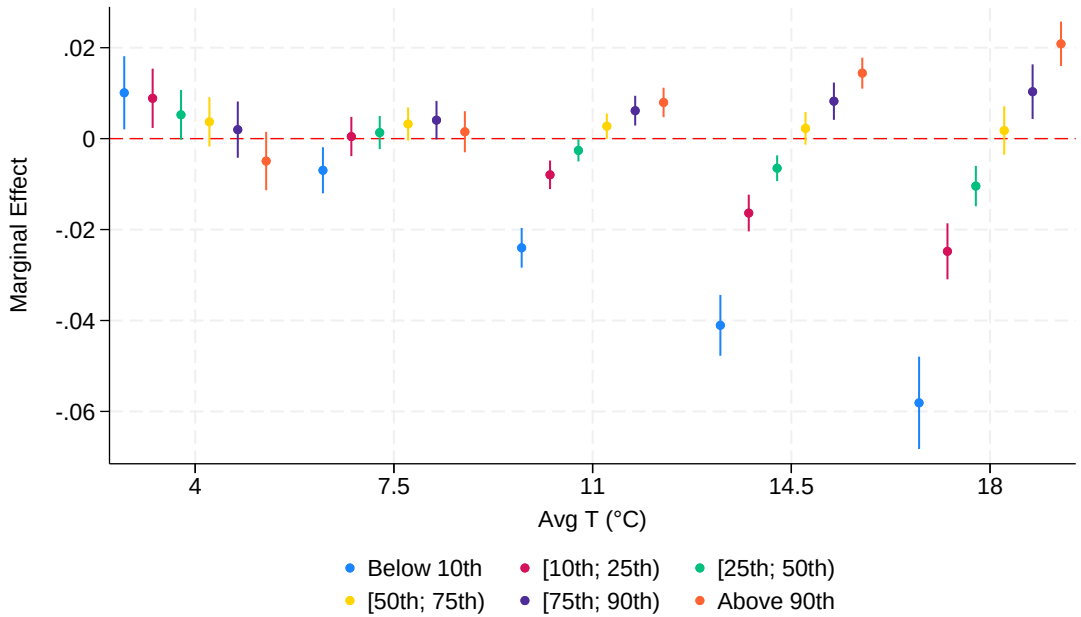


Figure: Marginal effect of yearly average temperature on gross output (growth rates) by firm TFP category (95% confidence intervals).

Conclusions

Conclusions

- Inverted-U-shaped relationship between temperatures and economic performance in pooled analysis - effect mostly insignificant
- Damages heterogeneity identifies winners and losers: Policy implications
  - Across Countries
  - Across firm TFP categories (more pronounced and consistent across samples)
  - Across industries
  - Across firm size categories

Thank you!

WP available on SSRN:

For any comments:

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Appendix

Temperature Distribution

- Distribution of yearly average temperature across all firm-year observations Back

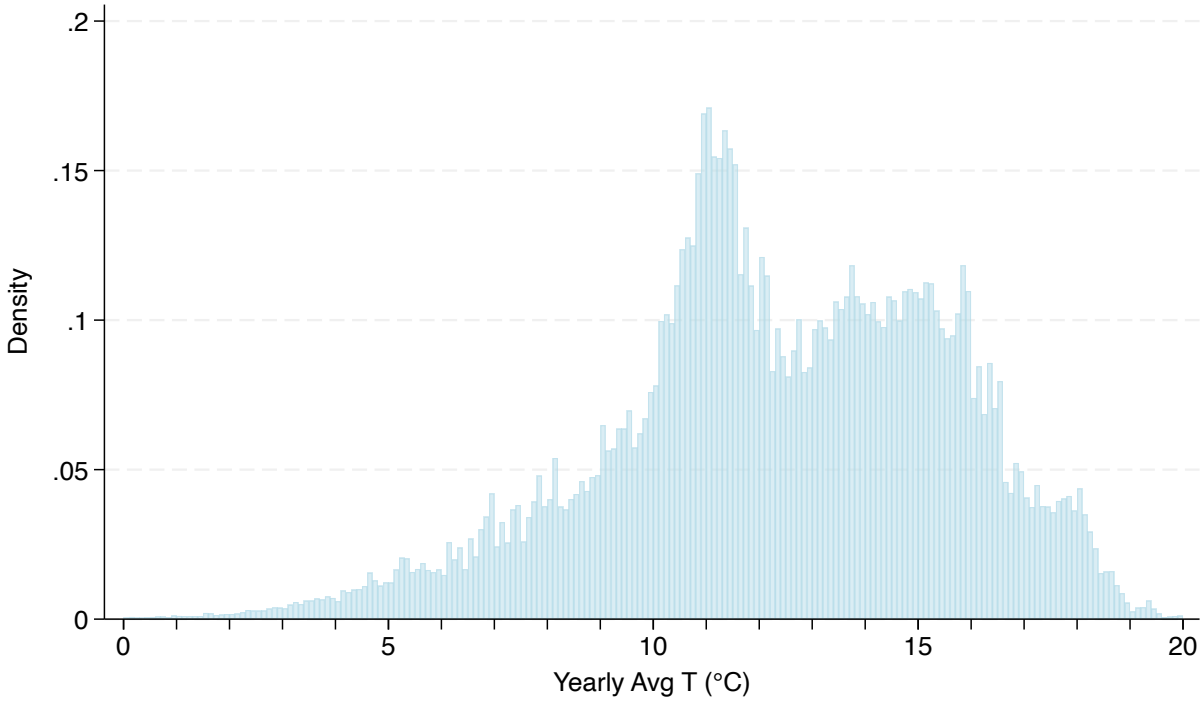


Figure: Coverage of the Orbis dataset across Country and years

Data Coverage

- Orbis coverage by country and year, calculated as a share between total GO of firms in Orbis and total gross output in EUROSTAT Back

$$Coverage_{C,t} = \frac{\sum_{i \in C} GO_{i,t}}{\sum_{r \in C} GO_{r,t}}$$

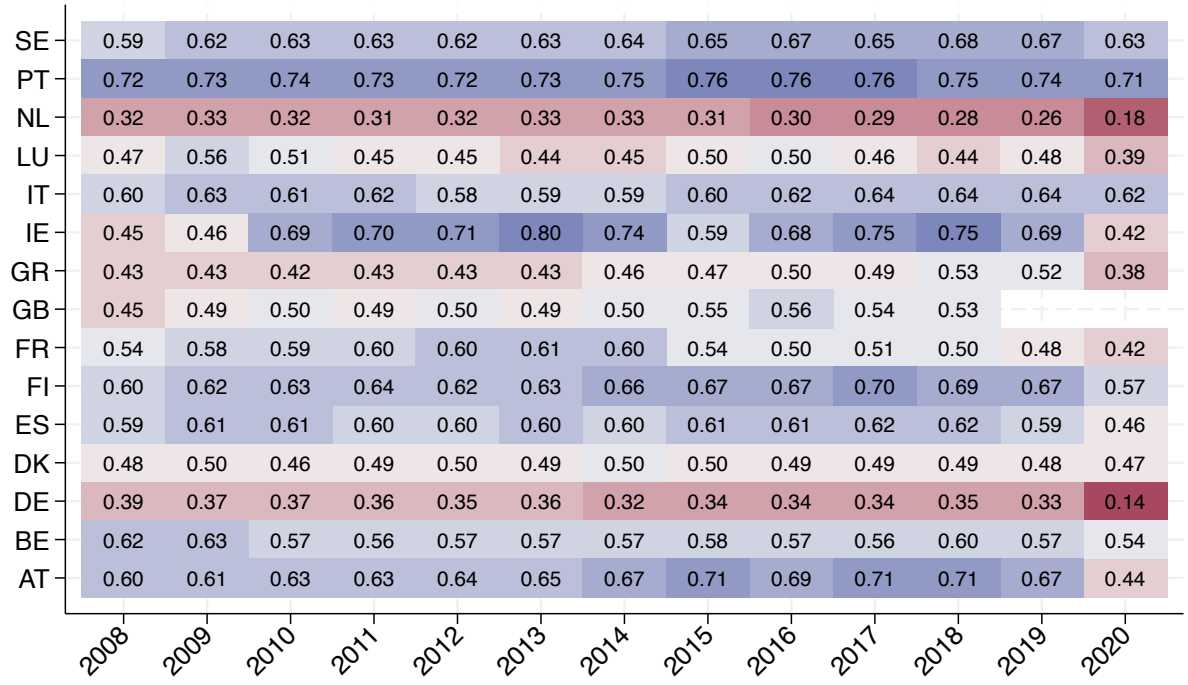


Figure: Coverage of the Orbis dataset across Country and years

Data by Industry (Nace2 Rev. 2)

- Number of observations by Nace2 revision 2 1-digit industry Back

NACE2 1-digit	2000	2010	2020
A-Agriculture forestry and fishing	25,129	58,787	54,194
B-Mining and quarrying	4,923	7,174	4,560
C-Manufacturing	233,167	383,233	265,411
D-Electricity gas steam and air conditioning supply	4,129	21,133	23,767
E-Water supply sewerage waste management	5,905	14,921	11,703
F-Construction	201,733	498,560	300,410
G-Wholesale and retail trade repair of motor vehicles	385,209	744,214	485,038
H-Transportation and storage	58,885	124,987	97,082
I-Accommodation and food service activities	75,343	208,508	148,328
J-Information and communication	75,570	146,280	119,609
K-Financial and insurance activities	44,500	104,811	85,355
L-Real estate activities	120,510	335,598	252,419
M-Professional scientific and technical activities	138,312	365,279	295,435
N-Administrative and support service activities	72,921	161,534	115,258
O-Public administration and defence	395	915	632
P-Education	12,856	45,652	39,987
Q-Human health and social work activities	20,826	89,015	85,058
R-Arts entertainment and recreation	20,474	54,947	48,940
S-Other service activities	34,817	79,179	47,122
T-Activities of households as employers	12,418	16,145	3,161
U-Activities of extraterritorial organisations and bodies	52	201	110

Table: Total number of observations by Industry (Nace2 Rev. 2). Source: Orbis.

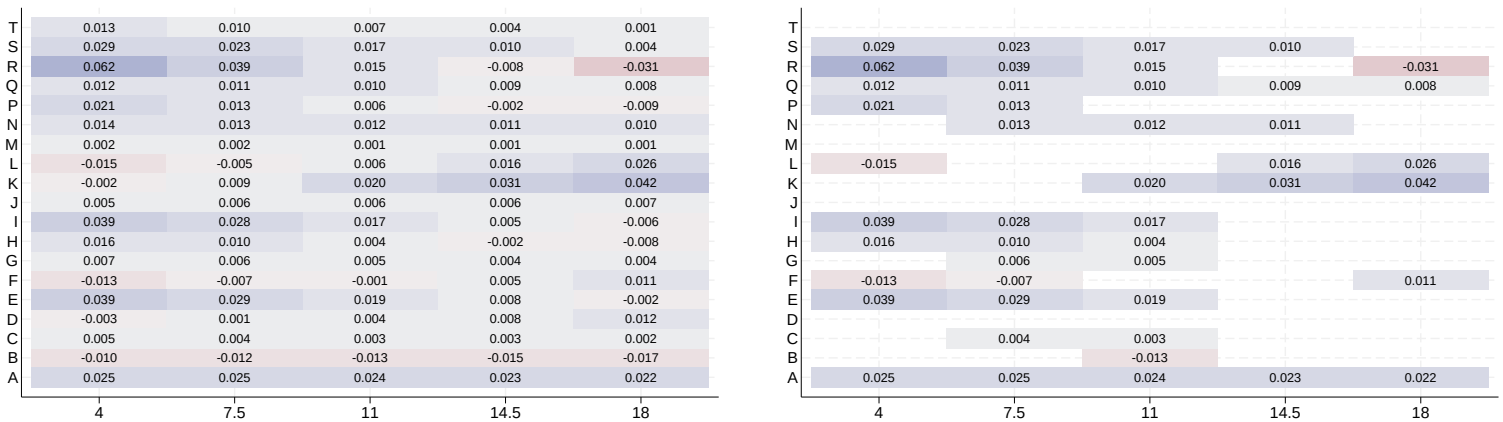
Identification: Post-estimation IC and ML CV

Back

	Information Criteria		Cross Validation	
	Akaike IC	Bayesian IC	CV Mean	CV SD
poly 1 lag 0	96666180.21	96666243.25	0.69367565	0.00063269
poly 1 lag 1	96665325.27	96665404.08	0.69355397	0.00063970
poly 1 lag 2	72071995.82	72072089.32	0.61998115	0.00055934
poly 1 lag 3	58401353.32	58401461.25	0.59890321	0.00042714
poly 1 lag 4	48108591.74	48108713.79	0.58396111	0.00040914
poly 1 lag 5	39916264.3	39916400.17	0.57248304	0.00069127
poly 2 lag 0	96666182.1	96666260.91	0.69368113	0.00063410
poly 2 lag 1	96665289.37	96665399.69	0.69354666	0.00063865
poly 2 lag 2	72071573.81	72071714.06	0.61981421	0.00055961
poly 2 lag 3	58400848.6	58401018.2	0.59834296	0.00042389
poly 2 lag 4	48107893.89	48108092.22	0.58379824	0.00042059
poly 2 lag 5	39914923.51	39915149.96	0.57270432	0.00070848
poly 3 lag 0	96666017.79	96666112.35	0.69371646	0.00063443
poly 3 lag 1	96665119.37	96665261.22	0.69353645	0.00063848
poly 3 lag 2	72070959.72	72071146.73	0.61976578	0.00055941
poly 3 lag 3	58399903.34	58400134.61	0.59842587	0.00042197
poly 3 lag 4	48106216.74	48106491.35	0.58416069	0.00041515
poly 3 lag 5	39913349.05	39913666.09	0.5729878	0.00070571
poly 4 lag 0	96665752.1	96665862.42	0.69370251	0.00063410
poly 4 lag 1	96664723.52	96664896.88	0.69354793	0.00063781
poly 4 lag 2	72070448.54	72070682.3	0.61970471	0.00055881
poly 4 lag 3	58399434.33	58399727.28	0.59849412	0.00041998
poly 4 lag 4	48105759.53	48106110.43	0.58422745	0.00041491
poly 4 lag 5	39912912.54	39913320.15	0.57305402	0.00071425

Heterogeneity I: Industry

- Marginal effects generally positive and low in magnitude across industries
  Nace
- Effect negative in some industries for firms located at high temperature, although not significant Country-level



(a) Marginal effects

(b) 95% significant marginal effects

Figure: Marginal effect of yearly average temperatures on gross output (growth rate) by firm industry (95% confidence intervals)

Heterogeneity II: Size

- Consistently upward-sloping marginal effect across firm sizes
- Small firms seem not to be affected at high temperatures Country-level

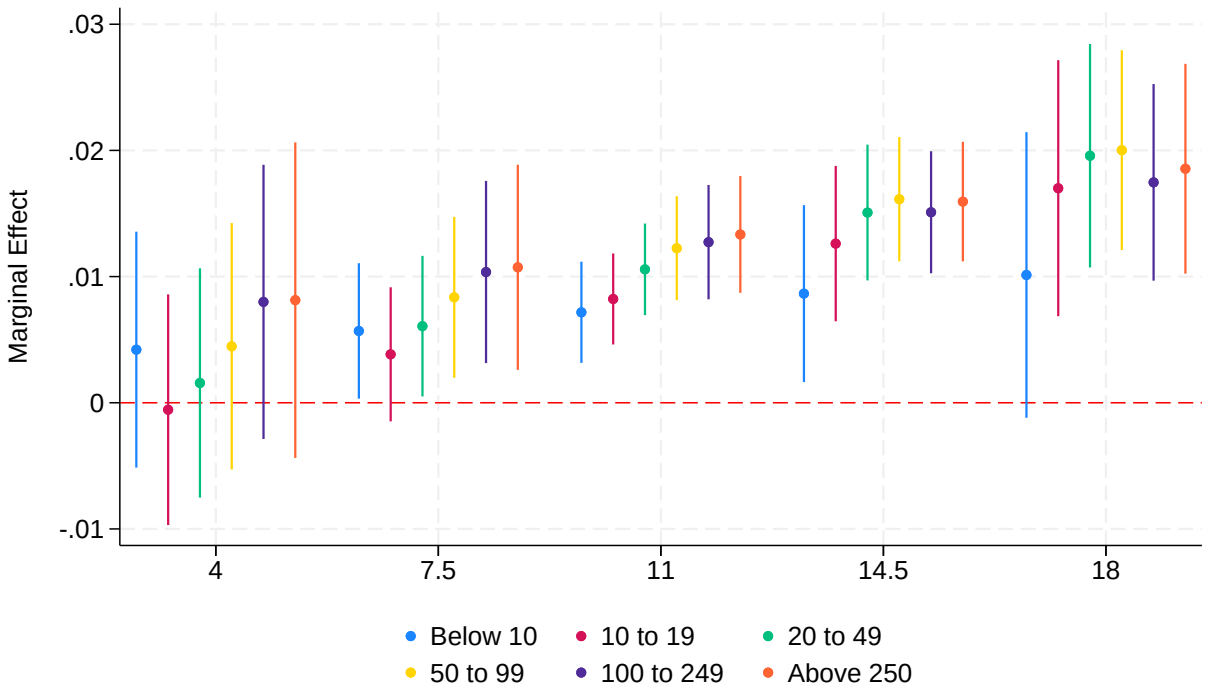
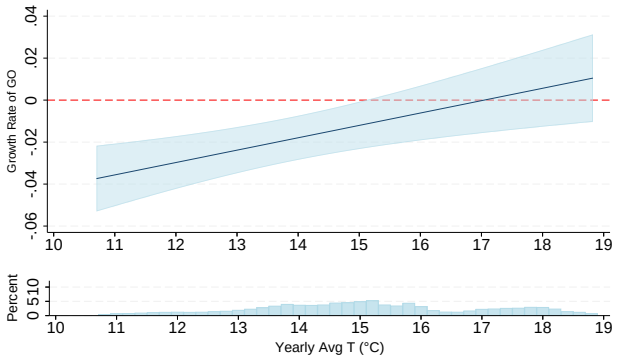


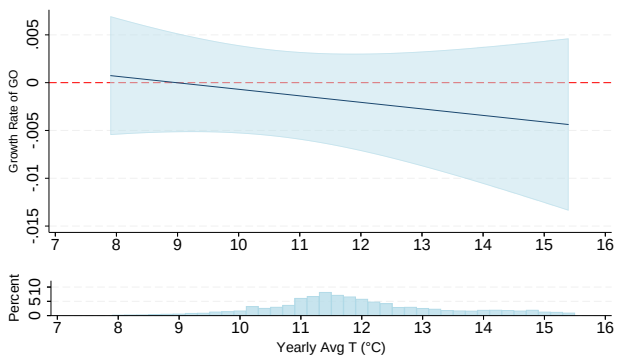
Figure: Marginal effect of yearly average temperatures on gross output (growth rate) by firm size (95% confidence intervals)

Aggregate Results by Country

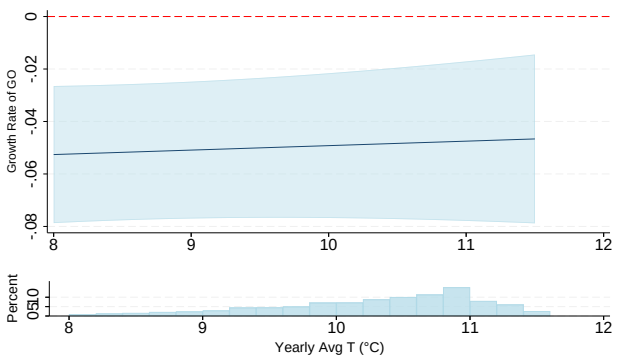
- Substantial cross-country heterogeneity Back
- Largest economies with good coverage are reported



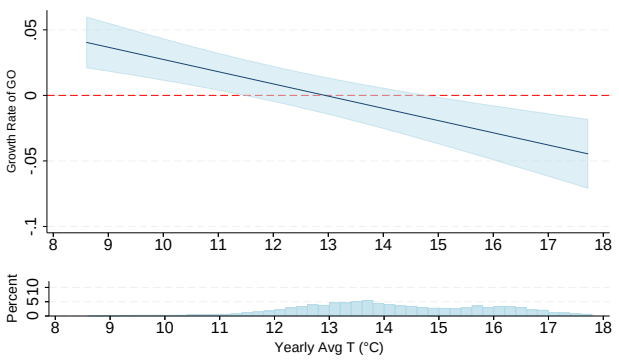
(a) Marginal Effect ES



(b) Marginal Effect FR



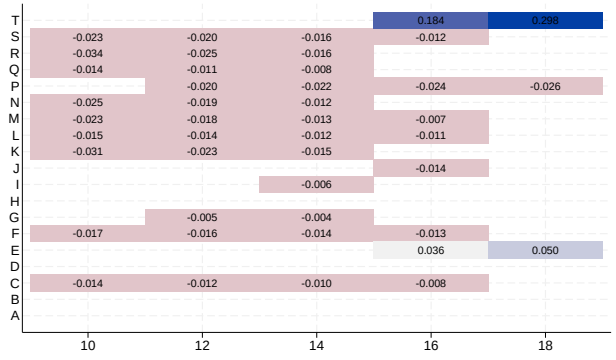
(c) Marginal Effect GB



(d) Marginal Effect IT

Heterogeneity by Country I: Industry

- Substantial cross-country heterogeneity Back
- Manufacturing consistently affected across countries



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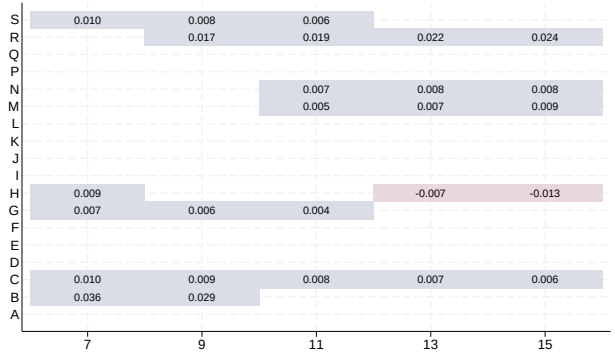
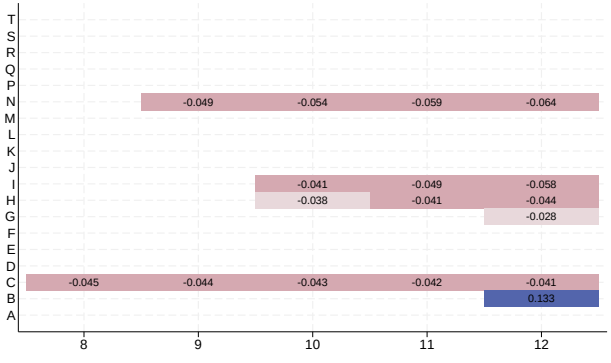
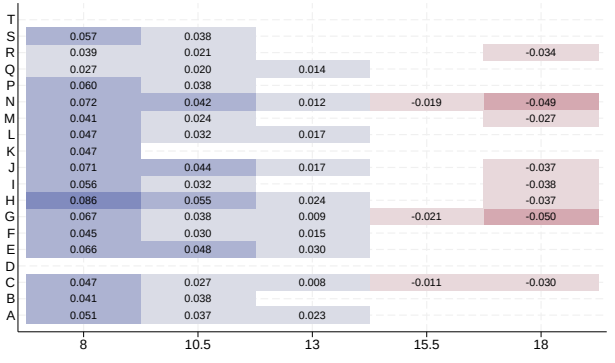


(b) Marginal Effect FR



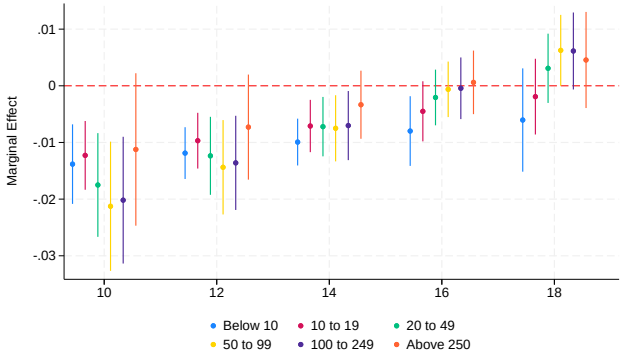
(c) Marginal Effect GB



(d) Marginal Effect IT

Heterogeneity by Country II: Size

- Substantial heterogeneity across size categories Back
- Small firms located in warmer areas seem to be negatively impacted
- Large firms located in warmer areas seem to be not impacted



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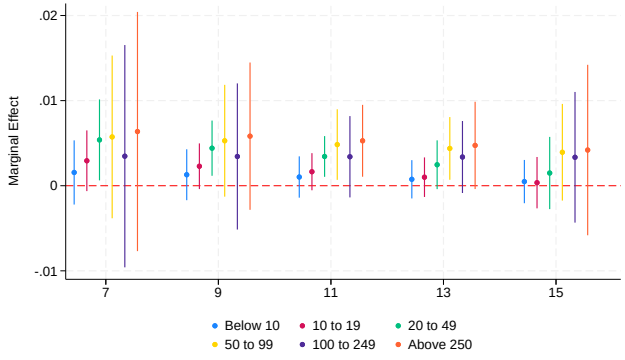
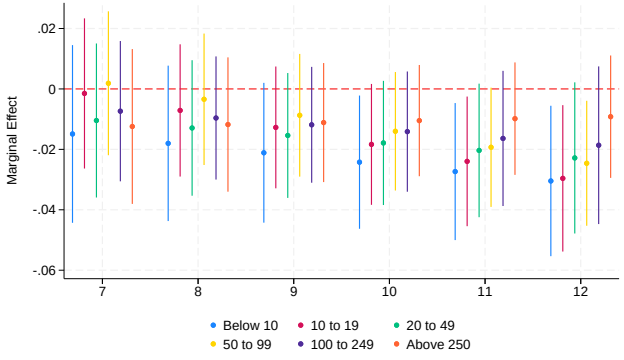


(b) Marginal Effect FR

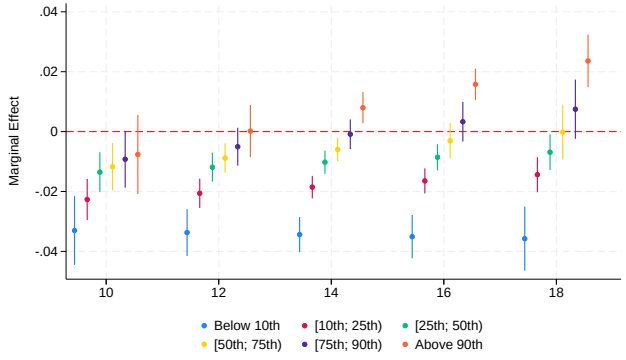


(c) Marginal Effect GB

(d) Marginal Effect IT

Heterogeneity by Country III: TFP categories

- Low productive firms consistently negatively impacted across countries Back
- High productive firms consistently positively or not impacted across countries



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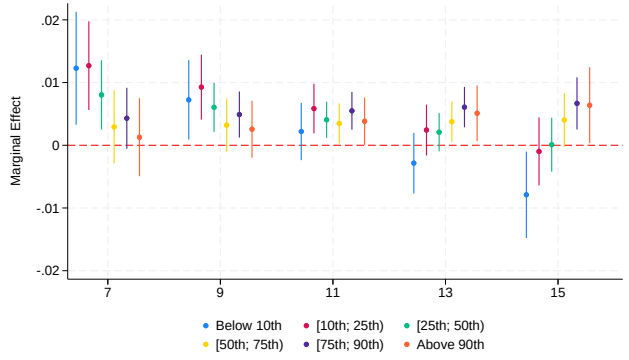

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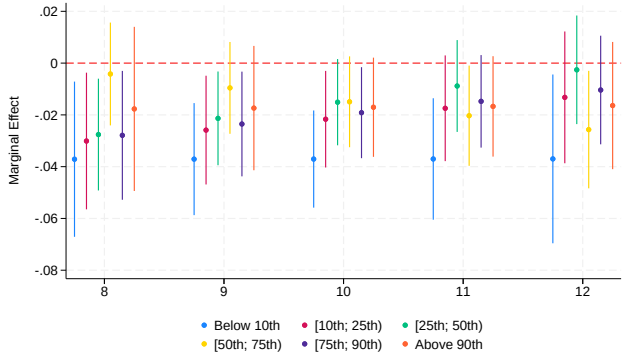
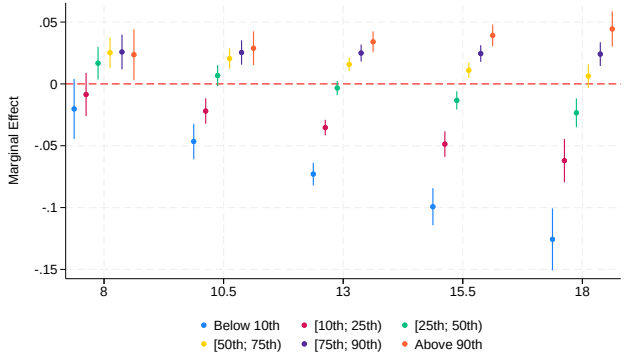


(c) Marginal Effect GB



(d) Marginal Effect IT

Damages heterogeneity: policy implications (?)

- policy debate on tackling climate change focuses on differences across Countries (e.g. developed VS developing)
- between-countries damages heterogeneity relevant also within developed countries
- within-country damages heterogeneity should also be considered when designing climate policies
- for example, larger firms or less impacted sectors can be subject to higher carbon taxes which could be used to subsidise emissions abatement for more impacted firms/sectors Conclusions