AIR POLLUTION AND PRODUCTIVITY

Large scale micro evidence from Europe

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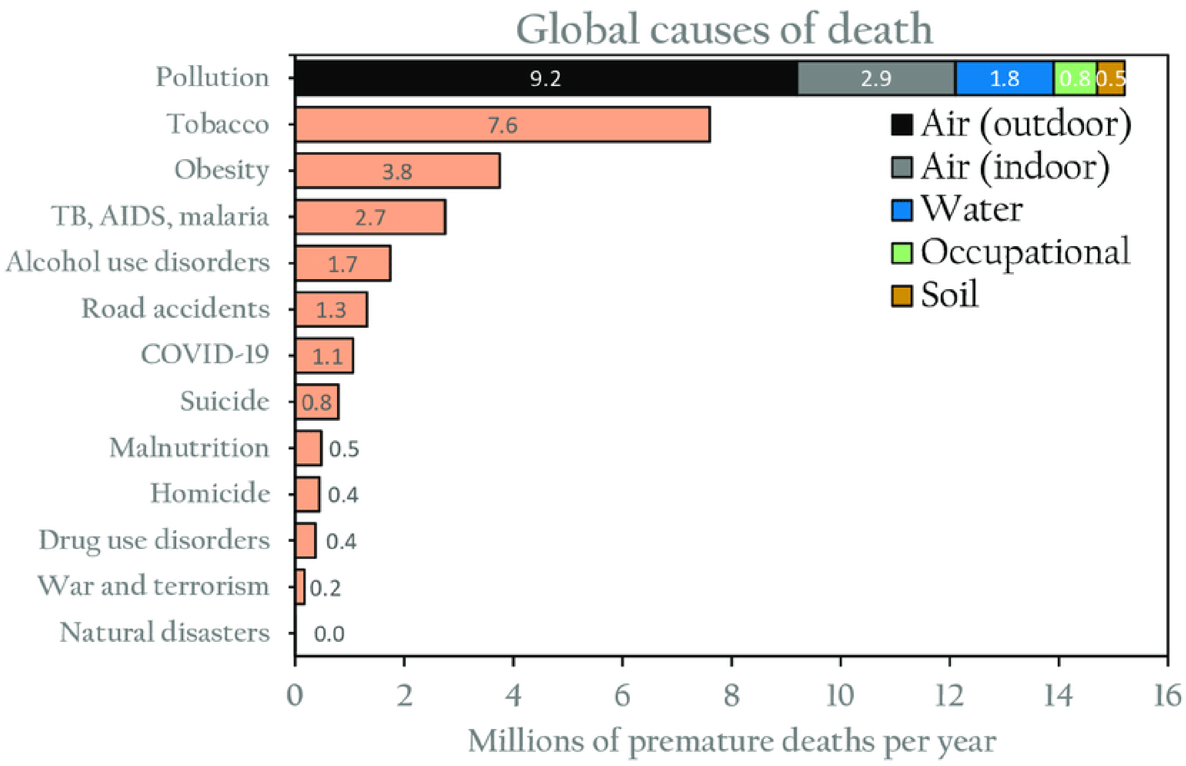
Antoine Dechezleprêtre (STI/PIE)
Veronica Vienne Aranciba (STI/PIE and University of Huddersfield)

BETTER POLICIES FOR BETTER LIVES

Motivation

- Human health consequences of air pollution well known
  - Particularly $PM_{2.5}$: respiratory and cardiopulmonary impacts, permeates indoors
- Outdoor air pollution is a large and growing public health problem worldwide
  - Especially in low- and middle-income countries, but not only: 12m deaths/year worldwide, 800k in Europe
  - Only **1 in 100** people live in areas where air pollution is below recommended WHO levels



So, how stringent should air pollution reduction policies be?

- Environmental protection typically seen as a trade-off:
  - Benefits to health, biodiversity, etc
  - But costs on the economy
  - “Jobs versus the environment” (Morgenstern et al. 2002)
- In Cost Benefit Analyses (CBA), dominant benefits are non-market (esp. health)
  - US EPA and EU: mortality reductions = 90% of benefits of pollution reduction
  - Market benefits (e.g. absenteeism at work, reduced crop productivity) of second order importance

But air pollution also affects economic activity

Absenteeism:

- Holub, Hospido and Wagner (2021): a 10% reduction in pollution **reduces sick leaves by 0.8%** in Spain
- Chan, Pelli and Vienne (2023): exposure to **wildfire smoke reduces the hours worked** by 2% (about 1 hour each week) in Chile
- Leroutier and Ollivier (2023): 10% increase in monthly **$PM_{2.5}$ exposure increases worker absenteeism** in the same month by 1% in France

Productivity on the job:

- **Low-skilled workers** in agriculture (Graff, Zivin and Neidell, 2012); manufacturing (Chang et al., 2016; Adhvaryu et al., 2014; He et al., 2016), **high-skilled workers** (Heyes et al., 2016; Archsmith et al., 2016; Chang et al., 2016b)
- Fu, Viard and Zhang (2021): a 1 μg/m3 decrease in PM2.5 increases output per worker in **China's manufacturing firms** by 0.82%

This study

- What is the impact of air pollution on firms' productivity (value added per worker) in a developed economy setting?

- Examine the **causal impact of air pollution on firms** using large-scale micro data for Europe from 2000-2022 combined with air pollution and weather data
  - 2.6 million companies across 22 European countries
  - Largest-scale micro evidence to date

Methodology

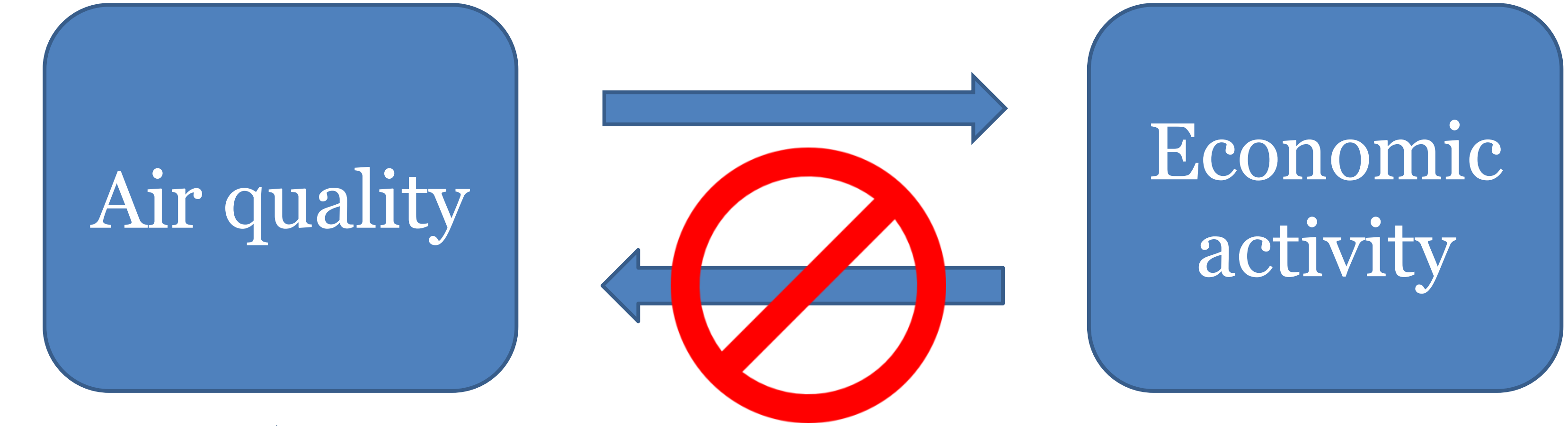
Basic relationship between VA per worker in firm *i* and year *t* and pollution concentration at firm's location:

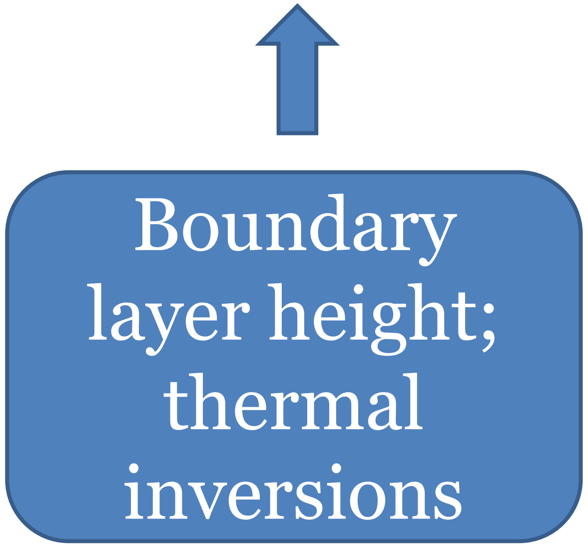
$$\ln\left(\frac{VA_{int}}{L_{int}}\right) = \alpha + \beta_1 P_{it} + \beta_2 f(W_{it}) + \rho_{ct} + \eta_{nt} + \mu_i + \varepsilon_{int}$$

Where:

- $\frac{VA_{int}}{L_{int}}$ = value added per worker
- P_{it} = pollution concentration (e.g. $PM_{2.5}$)
- $f\ (W_{it})$ = weather controls
- μ_i = firm fixed effects
- ρ_{ct} = country-year fixed effects
- η_{nt} = sector-year fixed effects

Empirical challenge: breaking the reverse causation



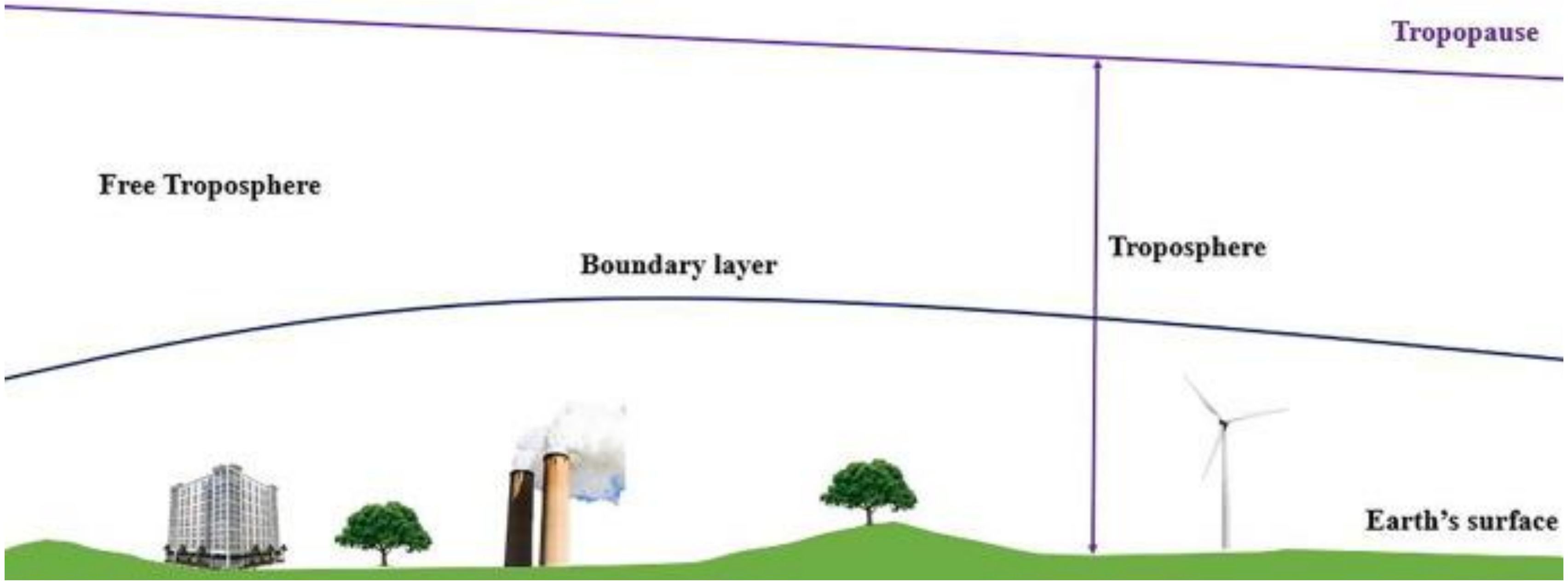


BLH: lowest part of the atmosphere characterized by strong vertical mixing of air, causing dispersion of pollutants

TI: Break in the monotonic relation between temperature and altitude

What is BLH?

- BLH is the lowest level of the troposphere, where the weather takes place
- Most importantly, it has a stochastic behaviour (Franzese, Luhar, Borgas, 1999)



BLH and pollution dissipation

- The boundary layer height caps vertical ventilation. The air and pollutants below it cannot flow upwards, limiting ventilation
  - Pollution gets trapped low in the atmosphere

- Instrumental variable also used by Bind and Koutrakis (2017) and Godzinski and Suarez Castillo (2021)

Low boundary layer height episode in Paris

A good instrument

- BLH increases pollution
- BLH not caused by pollution or economic activity
  - No feedbacks from pollutants to BLH (at European levels)
  - BLH associated with large-scale movement of air masses, so unlikely to be affected by shifts in firms' economic activity
- BLH only affects economic output via its effect on pollution
  - BLH is above ground level (where economic activity takes place)
  - BLH linked with weather, which can influence economic activity on the ground, so important to control for on-the-ground weather conditions in our regressions.

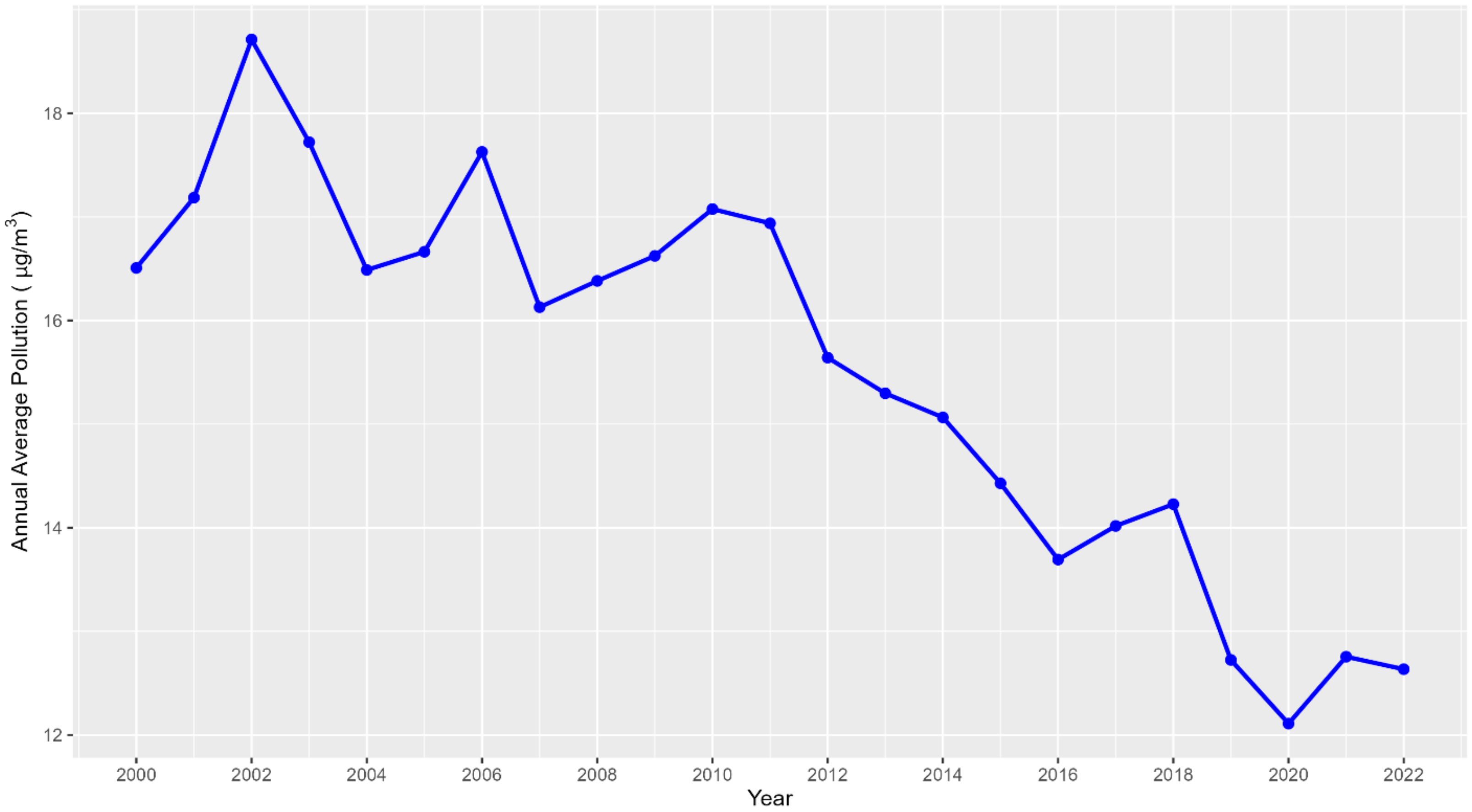
Instruments definition

- Boundary layer height:
  - Annual average BLH
  - 10 bins allocating the number of 6-hour periods p.a. where BLH was within a range (0-50m, 50-100m, etc)
  - Other definitions: summer/winter BLH, daytime/nighttime BLH, and their squared terms
- Thermal inversions: number of 6-hour periods p.a. where there was a thermal inversion
  - Used in many papers, but less variation (Arceo, Hanna, and Oliva, 2016; Fu et al., 2021; etc)

Data

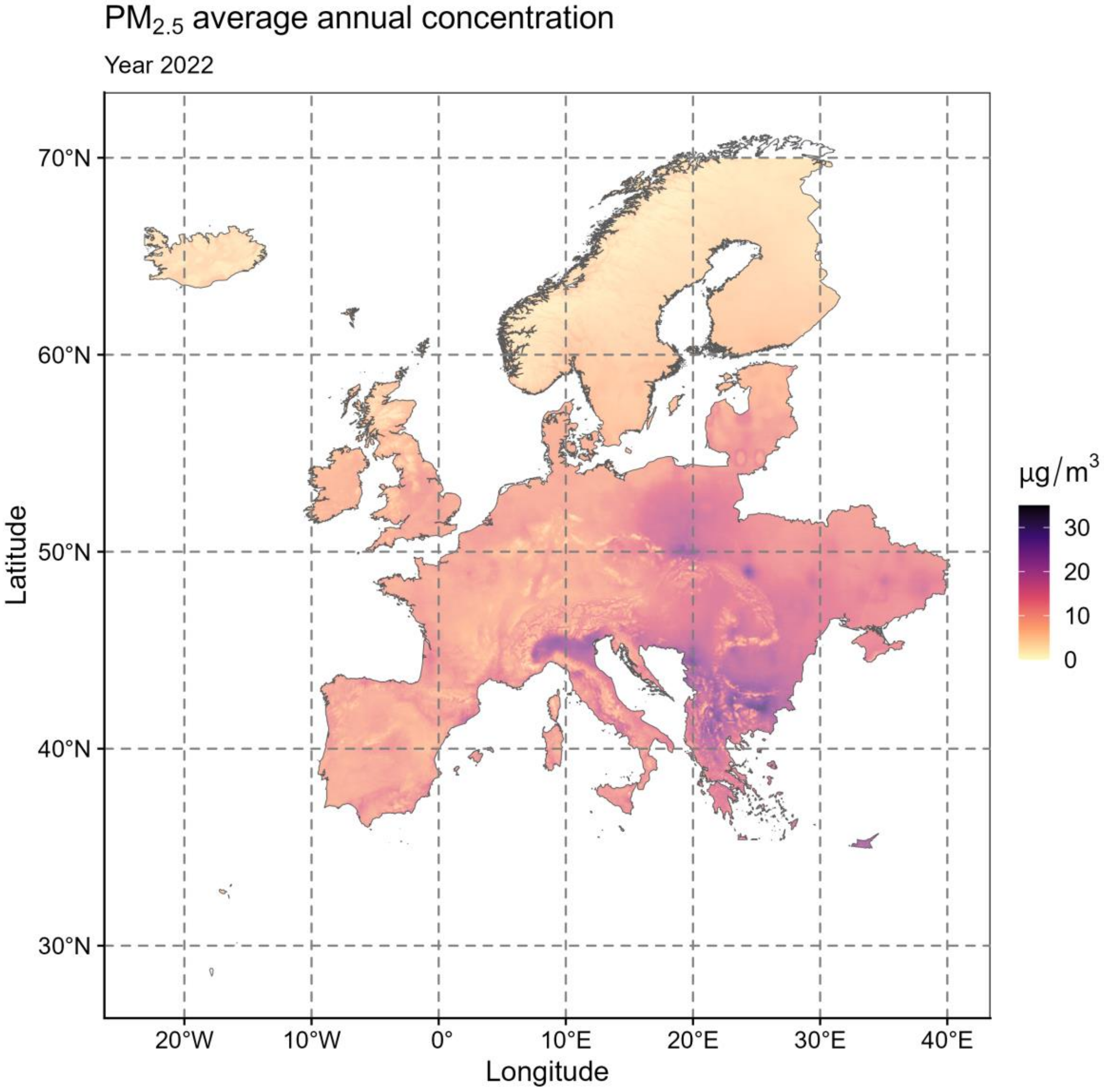
1. **Productivity**: Orbis data (VA per worker, firm location)
   - Keep unconsolidated accounts; drop multi-sector firms and section H of NACE classification (Transport activities) to limit measurement error
   - Location details (zip code, municipality)
2. **Air pollution**:
   - Van Donkelaar et al. (2021) → Resolution: 0.01° x 0.01° grids (1x1 km), but annual average
   - ECMWF → daily data, but 0.75° x 0.75° grids (80x80km)
3. **BLH & thermal inversions**: ERA5 (0.25° x 0.25° grid)
4. **Weather data** (ground temperature, relative humidity, precipitation, wind speed): ERA5-land
   - 0.1° x 0.1° grids

Average air pollution across Europe 2000-2022

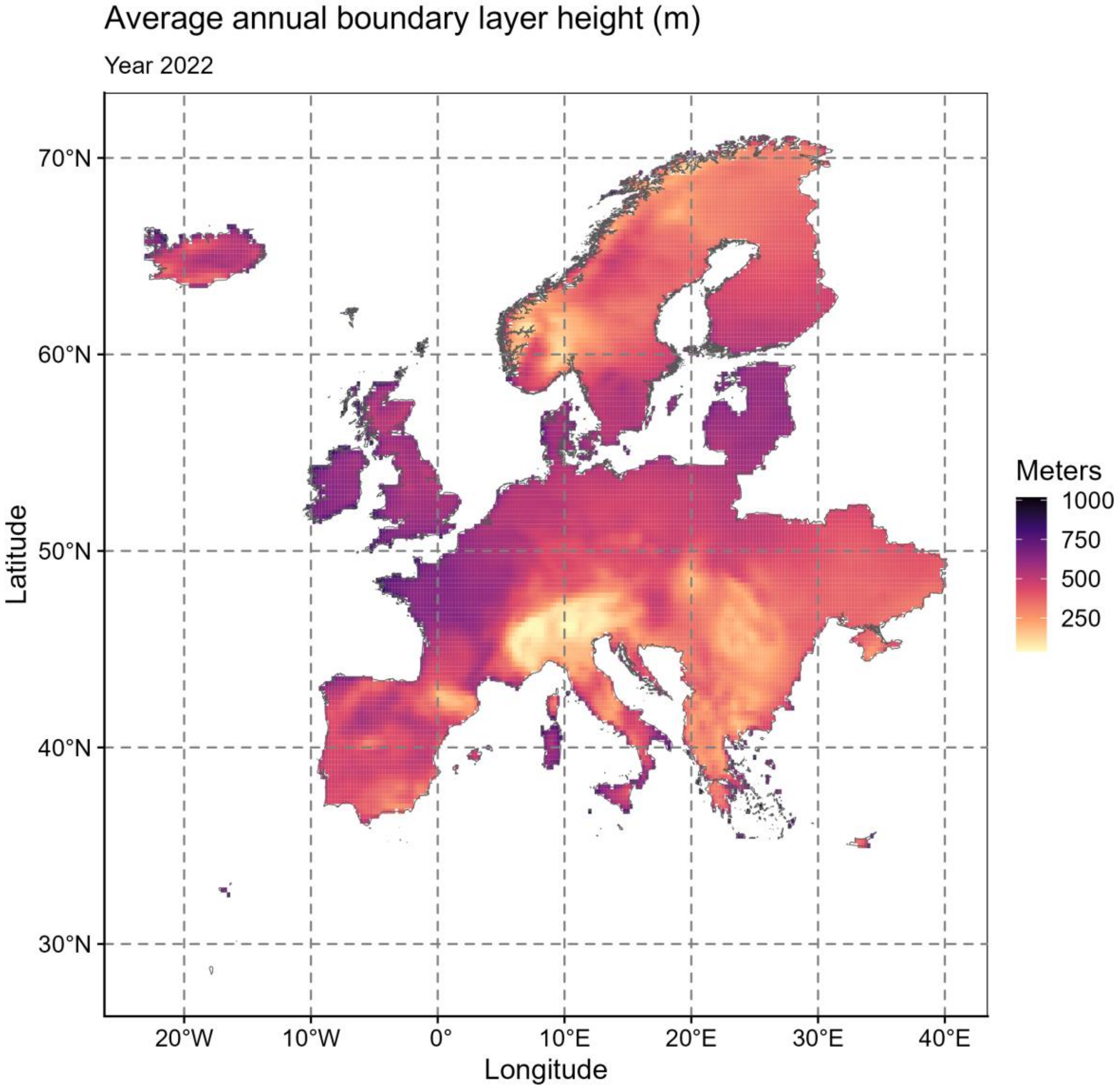


Note: unweighted average across European countries, from 0.01° × 0.01° resolution grid
Source: Van Donkelaar et al. (2021)

Average $PM_{2.5}$ concentration and boundary layer height in 2022

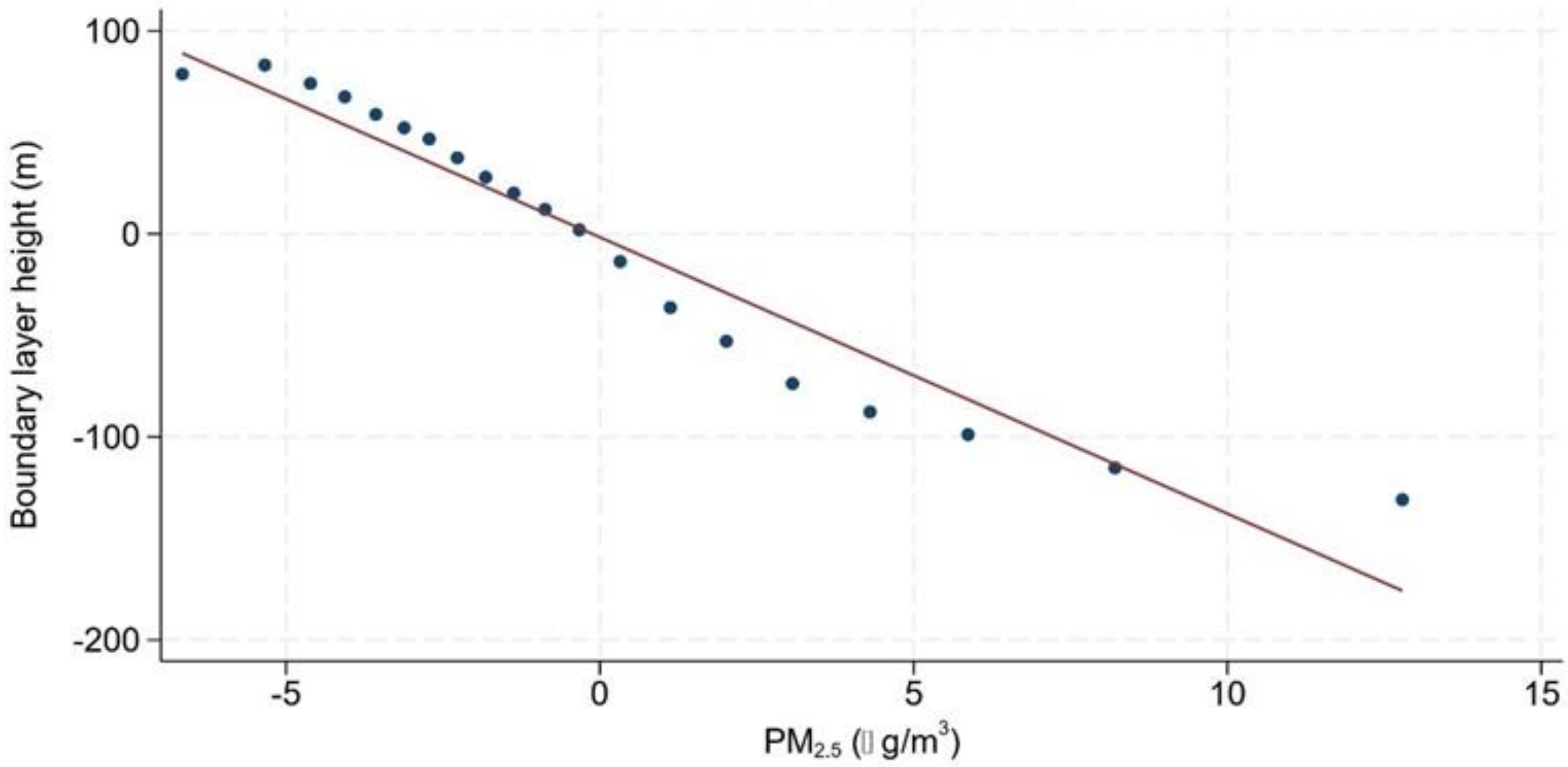


Source: van Donkelaar et al. (2021)



Source: ECMWF ERA5 (2024)

Higher BLH is associated with lower pollution



This is confirmed by regression analysis

	(1) Dependent variable: Annual average $PM_{2.5}$
Annual average boundary layer height (m)	-0.00638*** (0.00002)
10 temperature bins	Yes
10 relative humidity bins	Yes
10 wind speed bins	Yes
Precipitation (mm)	Yes
Observations	18,946,331
R2	0.98

Reduced form: Effect of boundary layer height on worker productivity

Dependent variable: log(Value added per worker)	(1)
Annual average boundary layer height (m)	0.00004*** (0.00001)
10 temperature bins	Yes
10 relative humidity bins	Yes
10 wind speed bins	Yes
Precipitation (mm)	Yes
R2	0.72
Observations	18,946,331

Note: * p<0.1,** p<0.05,*** p<0.01. Clustered standard errors (at firm-level) are in parentheses. Temperature bins, relative humidity bins, wind speed bins, and annual precipitation, included in all regressions (not shown for brevity). Year by country, year by industry, and firm-level fixed effects included in all regressions.

$PM_{2.5}$ reduces VA per worker

- An increase of $PM_{2.5}$ concentration by 1µg/m³ reduces VA per worker by 0.55%

Dependent variable: log(Value added per worker)	(1)
Instrument	Annual average BLH
Annual average PM2.5	-0.00545*** (0.00156)
10 temperature bins	Yes
10 relative humidity bins	Yes
10 wind speed bins	Yes
Precipitation (mm)	Yes
Observations	18,946,331

Robustness: instruments

Dependent variable: log(Value added per worker)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Instrument	Annual average BLH	BLH and squared term	Summer / winter BLH	Summer / winter BLH and squared terms	Daytime /nighttime BLH	Daytime /nighttime BLH and squared terms	Number of 6-hour periods per year with thermal inversions
Annual average $PM_{2.5}$	-0.00663*** (0.00195)	-0.01065*** (0.00173)	-0.00718*** (0.00181)	-0.00258* (0.00154)	-0.00320* (0.00166)	-0.00598*** (0.00143)	-0.00470*** (0.00124)
10 temperature bins	Yes	Yes	Yes	Yes	Yes	Yes	Yes
10 relative humidity bins	Yes	Yes	Yes	Yes	Yes	Yes	Yes
10 wind speed bins	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation (mm)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	18,946,331	18,946,331	18,946,331	18,946,331	18,946,331	18,946,331	18,946,331

Highly polluting days have greater effect

Dependent variable: log(Value added per worker)	(1)	(2)	(3)	(4)	(5)
Instrument	BLH bins	BLH bins	BLH bins	BLH bins	BLH bins
Air pollution measure	$PM_{2.5}$ (days above 75 µg/m³, WHO interim target 1)	$PM_{2.5}$ (days above 50 µg/m³, WHO interim target 2)	$PM_{2.5}$ (days above 37.5 µg/m³, WHO interim target 3)	$PM_{2.5}$ (days above 25 µg/m³, WHO interim target 4)	$PM_{2.5}$ (days above 15 µg/m³, WHO guideline level)
Air pollution	-0.00116 (0.00083)	-0.00157*** (0.00042)	-0.00040*** (0.00014)	-0.00017** (0.00008)	0.00001 (0.00007)
10 temperature bins	Yes	Yes	Yes	Yes	Yes
10 relative humidity bins	Yes	Yes	Yes	Yes	Yes
10 wind speed bins	Yes	Yes	Yes	Yes	Yes
Precipitation (mm)	Yes	Yes	Yes	Yes	Yes
Observations	17,800,409	17,800,409	17,800,409	17,800,409	17,800,409

Some firms/industries are more affected than others

	Dependent variable: log(Value added per worker) Instrument: BLH bins				
	NACE B - Mining and quarrying	NACE C - Manufacturing	NACE D/E - Electricity, gas, and water supply	NACE F - Construction	NACE G/S - Services, without transport
$PM_{2.5}$ (µg/m^3)	-0.03925 (0.02871)	-0.00352 (0.00397)	-0.0022 (0.01852)	-0.01132** (0.00445)	-0.00353* (0.00182)
Observations	59,040	3,738,587	202,142	2,813,031	12,133,415

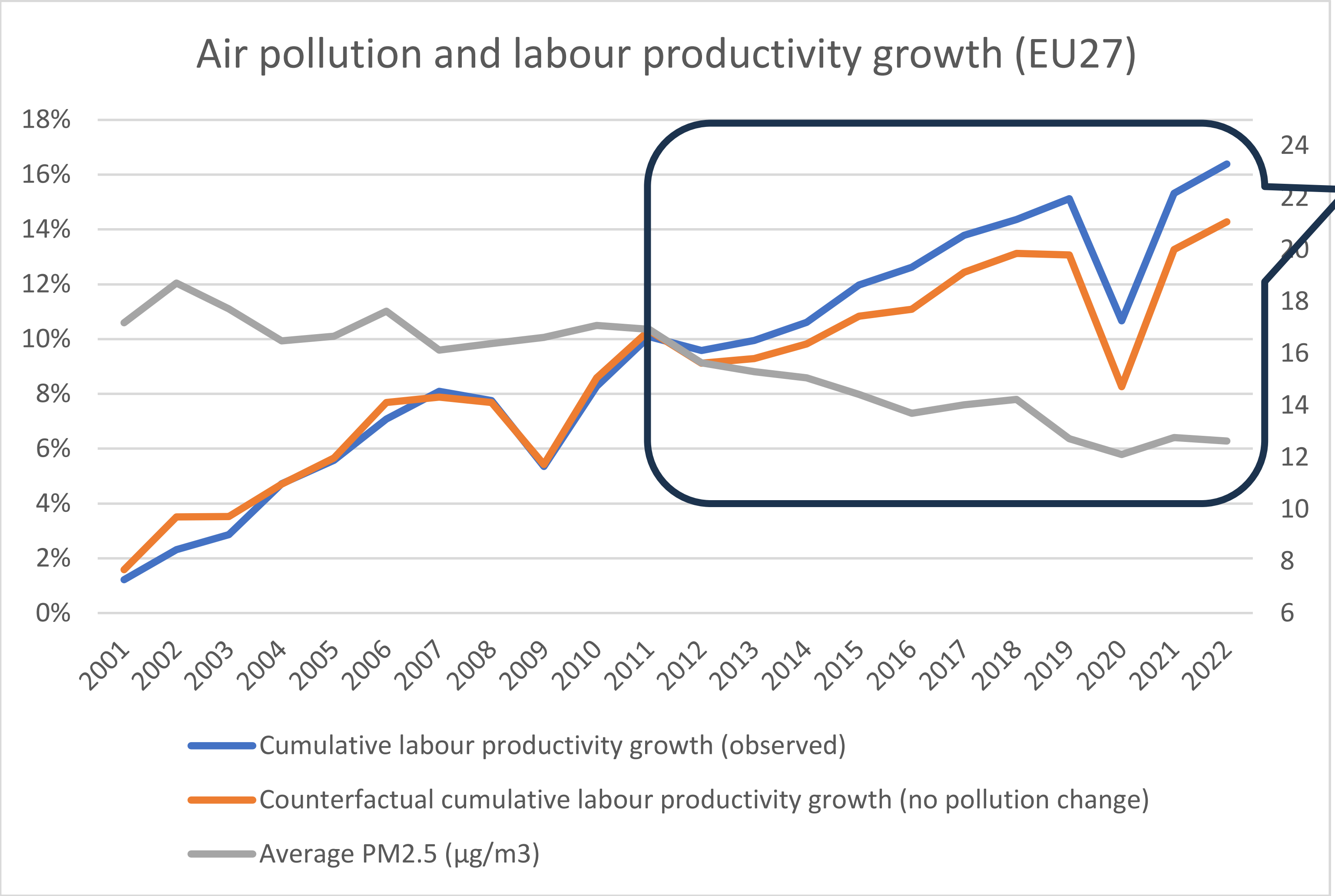
	Dependent variable: log(Value added per worker) Instrument: BLH bins		
	Micro firms (L≤10)	Micro and small firms (L≤50)	SMEs (L≤250)
$PM_{2.5}$ (µg/m^3)	-0.00486** (0.00201)	-0.00470*** (0.00161)	-0.00579*** (0.00157)
Observations	12,711,417	17,533,986	18,662,192

Sectors with a higher share of low-skilled workers are hit less

- Data on share of hours worked by labour skill by industry-country-year (WIOD – 35 sectors)
- A 10 pp increase in low-skill intensity lowers the effect by 0.1%

	Dependent variable: log(Value added per worker) **Instrument: BLH bins**
	Low skill
$PM_{2.5}$ (µg/m^3)	-0.01044*** (0.00184)
PM2.5 * Low-skill intensity	0.00942*** (0.00071)
Observations	18,675,168

The contribution of air pollution reduction to labour productivity growth in Europe



2011-2022:

- PM2.5: -4 µg/m³
- VA/L: +6pp
- VA/L without air pollution decrease: +4pp
- 1/3 of LP growth due to air cleanup

Conclusion

- First large-scale micro evidence of the effect of air pollution in Europe from 2000 to 2022
  - An increase of $PM_{2.5}$ concentration by 1µg/m³ reduces VA per worker by 0.55%
  - Effect is higher for workers in construction (outdoors workers) and sectors with lower proportion of high-skilled workers
- Environmental policies may have large economic benefits
  - 2010 decade: average growth in labour productivity in Europe +0.7 %/year; average PM2.5 concentration -4µg/m³
  - Around 1/3 of labour productivity growth in Europe over that period could have been due to improvements in air quality

Thank you

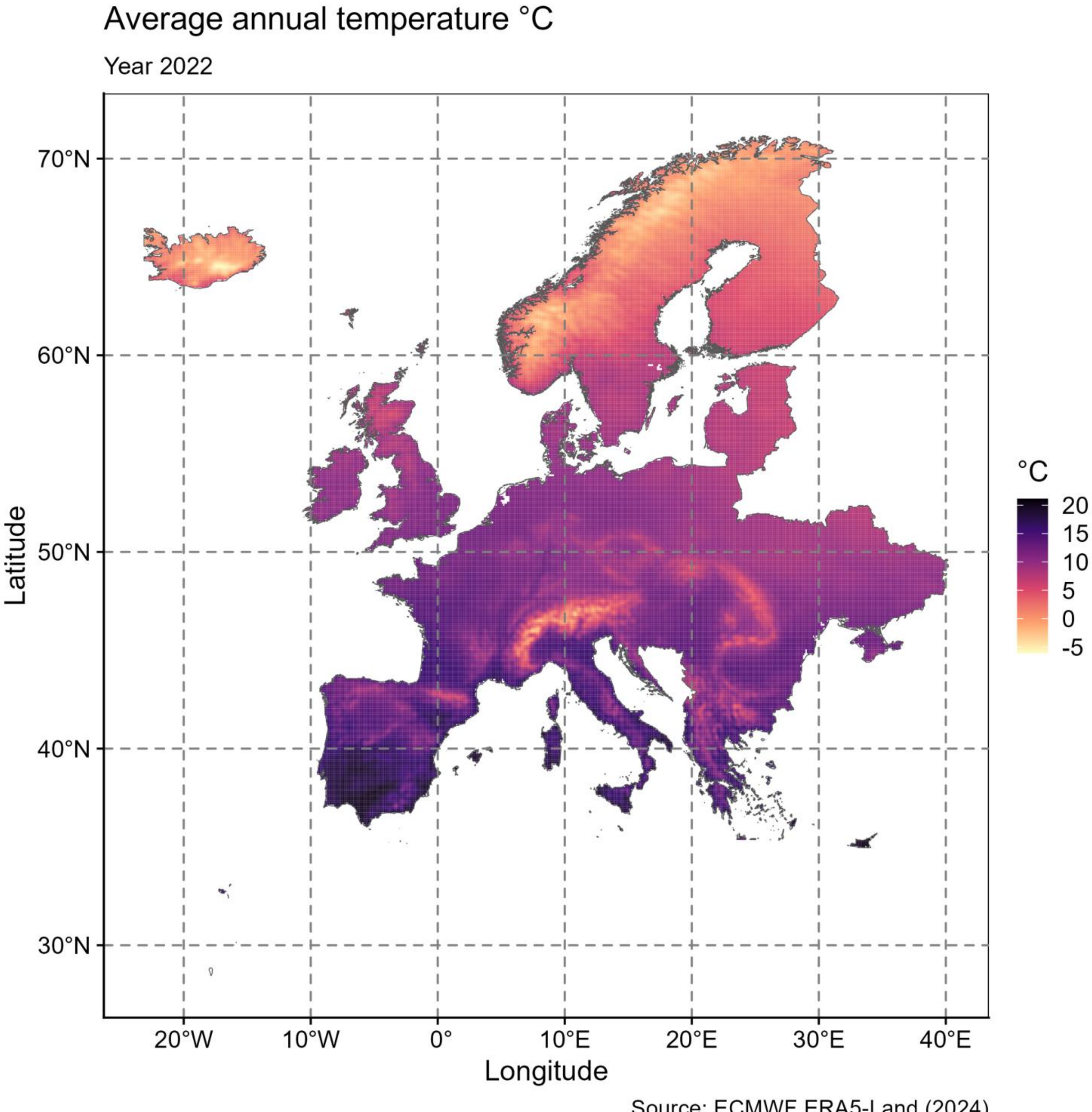
For more information:

Antoine.dechezlepretre@oecd.org

APPENDIX

Descriptive statistics

Variable	Mean	S.D.	Min	Max	Obs.
log(Value Added per Worker)	10.44	0.95	-1.61	22.35	18,946,331
Boundary layer height (m)	480.65	117.86	175.28	846.15	18,946,331
BLH summer (m)	550.94	170.04	232.46	1127.14	18,946,331
BLH winter (m)	410.11	113.53	94.61	932.43	18,946,331
BLH daytime (m)	604.74	104.68	288.24	959.97	18,946,331
BLH nighttime (m)	356.56	152.54	44.80	802.38	18,946,331
Thermal inversions (number of 6-hour periods per year)	603.87	85.91	136.00	941.00	18,946,331
Temperature (°C)	14.26	2.53	-2.33	19.94	18,946,331
Precipitation (mm)	0.14	0.07	0.02	0.71	18,946,331
Relative humidity (%)	72.04	6.84	50.57	88.30	18,946,331
Wind speed (m/s)	2.68	0.86	0.91	8.30	18,946,331
$PM_{2.5}$ (µg/m³)	14.83	5.46	4.30	35.90	18,946,331
$PM_{2.5}$ (days with concentration above WHO interim target 1, 75 µg/m³)	0.94	2.93	0	45	17,315,860
$PM_{2.5}$ (days with concentration above WHO interim target 2, 50 µg/m³)	4.51	11.10	0	166	17,315,860
$PM_{2.5}$ (days with concentration above WHO interim target 3, 37.5 µg/m³)	14.16	27.67	0	259	17,315,860
$PM_{2.5}$ (days with concentration above WHO interim target 4, 25 µg/m³)	48.93	61.63	0	342	17,315,860
$PM_{2.5}$ (days with concentration above WHO guideline, 15 µg/m³)	140.02	94.57	1	366	17,315,860
Year	2011.69	5.99	2000	2022	18,946,331



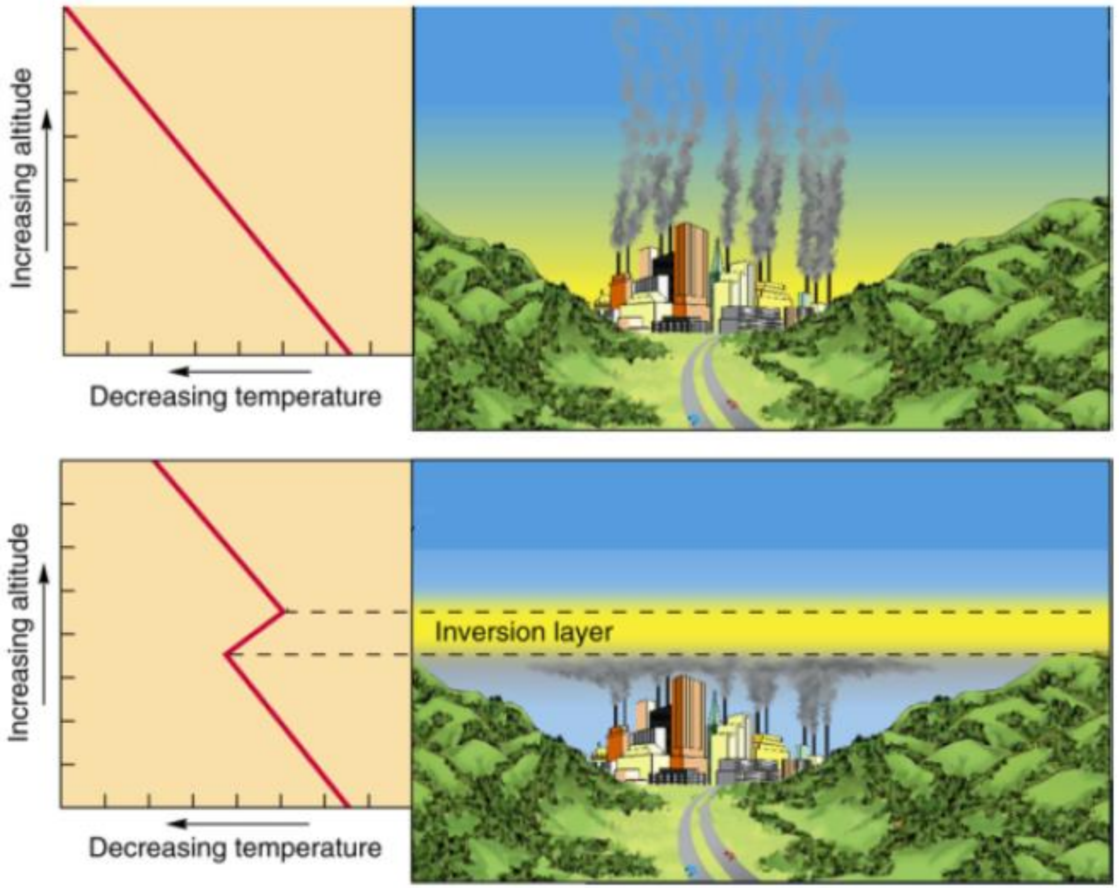
Average annual temperature °C
Year 2022
70°N
60°N
50°N
40°N
30°N
Latitude
20°W
10°W
0°
10°E
20°E
30°E
40°E
Longitude
°C
20
15
10
5
0
-5
Source: ECMWF ERA5-Land (2024)

Thermal inversions and air pollution

	Dependent variable: Annual average $PM_{2.5}$
No. of 6-h periods with thermal inversion p.a.	0.00461*** (0.00001)
10 temperature bins	Yes
10 relative humidity bins	Yes
10 wind speed bins	Yes
Precipitation (mm)	Yes
Observations	19,876,348
R^2	0.98

Thermal inversion & pollution dissipation

- Normally, the higher altitude is colder



Thermal inversion in Paris

Sample

- Regressions include data for 2,669,674 European firms from 2000 to 2022

Country	Number of firms
AT – Austria	6,171
BE – Belgium	13,150
CH – Switzerland	192
CZ - Czech Republic	25,974
DE – Germany	56,946
DK – Denmark	2,946
EE – Estonia	103
ES – Spain	1,025,291
FR – France	389,996
GB - United Kingdom	9,326
HU – Hungary	12,051

Country	Number of firms
IE – Ireland	241
IT – Italy	858,430
LU – Luxembourg	918
LV – Latvia	15
NL – Netherlands	522
NO – Norway	7,238
PL – Poland	34,051
PT - Portugal	135,974
SE - Sweden	26,624
SI – Slovenia	35,328
SK - Slovakia	28,187

Sample

- Regressions include data for 2,669,674 European firms from 2000 to 2022

Number of firms by broad industries				
NACE B - Mining and quarrying	NACE C - Manufacturing	NACE D/E - Electricity, gas, and water supply	NACE F - Construction	NACE G/S - Services, without transport
6,211	425,399	25,000	407,039	1,638,944