THE ECONOMIC COST OF AIR POLLUTION: EVIDENCE FROM EUROPE

oe.cd/air-pollution-costs

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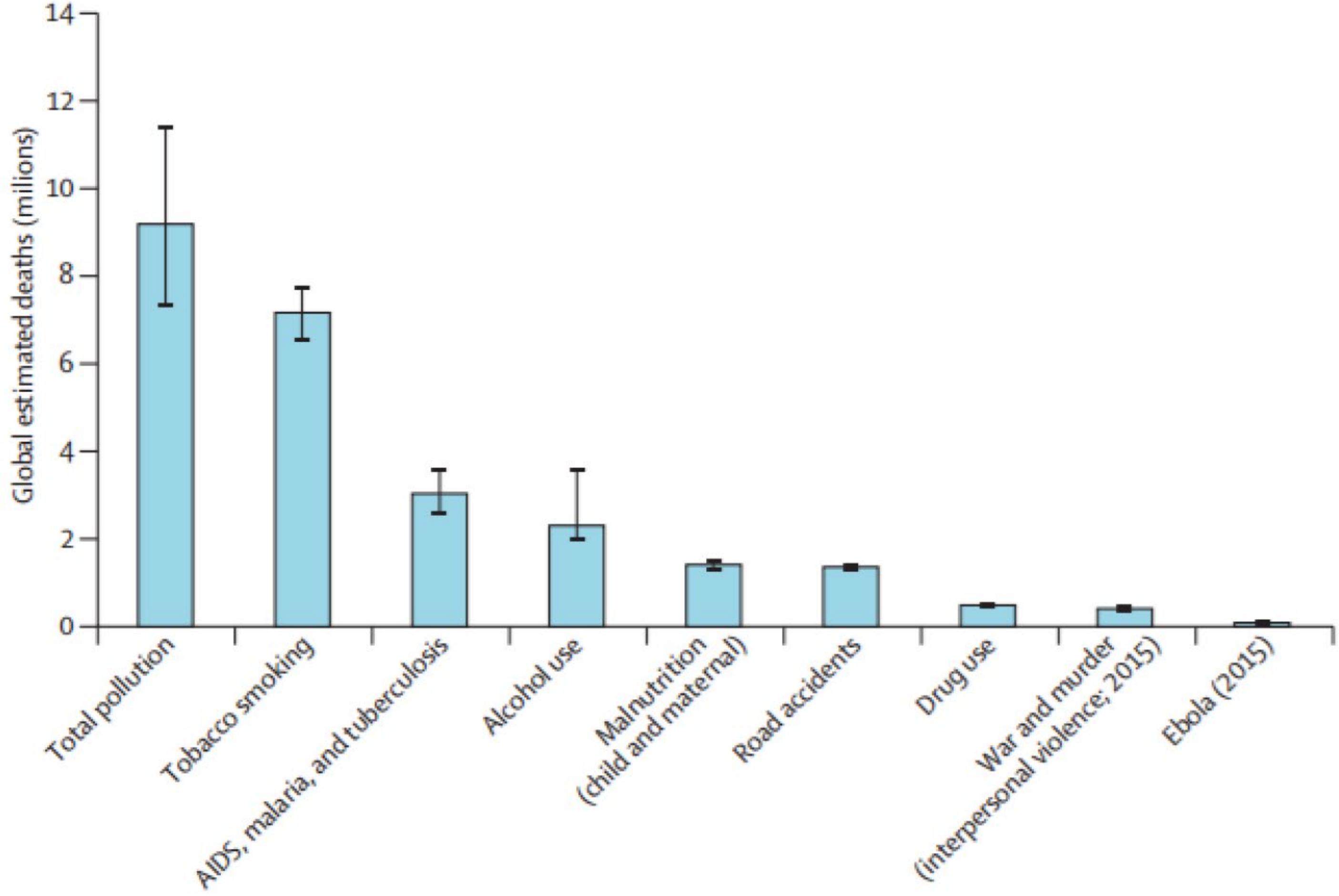
BETTER POLICIES FOR BETTER LIVES

Motivation

- Human health consequences of air pollution well known
  - Particularly PM2.5: 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
  - Only 1 in 10 people live in areas where air pollution is below recommended WHO levels (10 μg/m3 annual average PM2.5).
  - WHO: 7 million people per year die from air pollution (1 in 8 deaths worldwide)

Air pollution: a major death cause



Source: The Lancet

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, 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

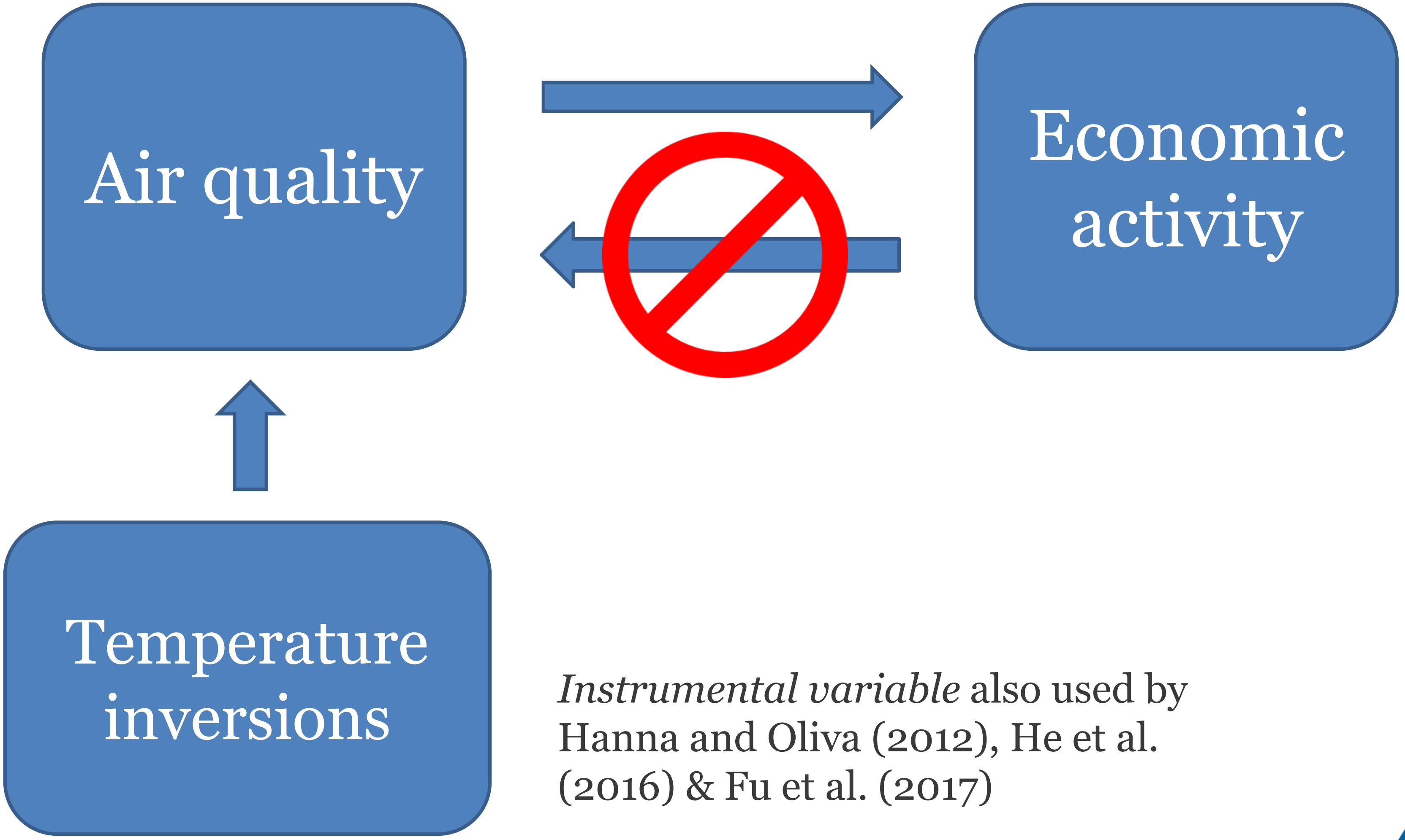
But air pollution also directly affects economic activity

- Reduced productivity and absenteeism:
  - Graff Zivin and Neidell (2012): air pollution reduces productivity of agricultural workers in California
  - Low skilled workers in manufacturing: Chang et al (2016), Adhvaryu et al (2014) and He et al (2016)
  - High skilled workers: Heyes et al (2016), Archsmith et al (2016), Chang et al. (2016b)
  - high-school examinations: Ebenstein et al., 2016; Roth, 2018

A new OECD study

- Existing studies suggest higher air pollution causes lower productivity and economic output, but
  - use data from idiosyncratic industries—box packers, call centre workers
  - focus on individual productivity and concurrent exposure to pollution
- **Do these impacts translate into aggregate effects economy-wide?**
- We use data from across Europe from 2000-2015 to estimate the **causal impact** of higher air pollution on overall market economic activity

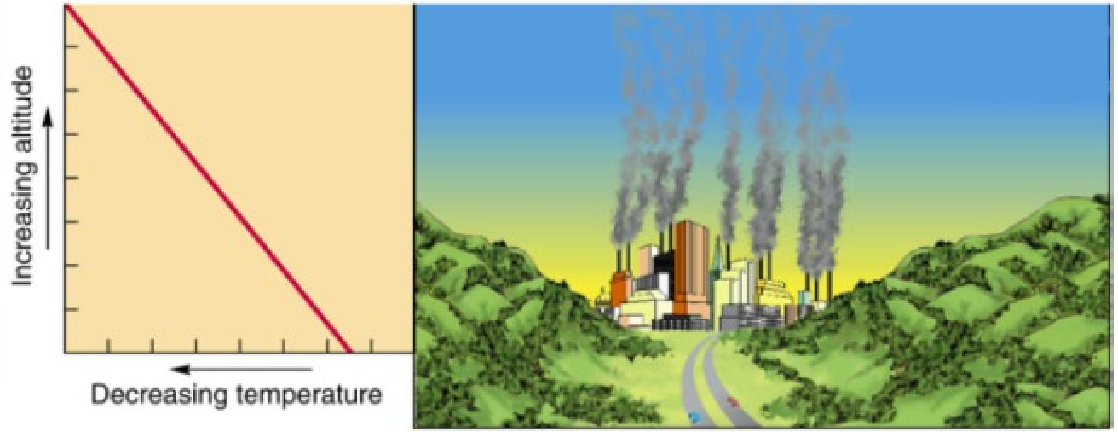
Empirical challenge: Breaking the reverse causation



Instrumental variable also used by Hanna and Oliva (2012), He et al. (2016) & Fu et al. (2017)

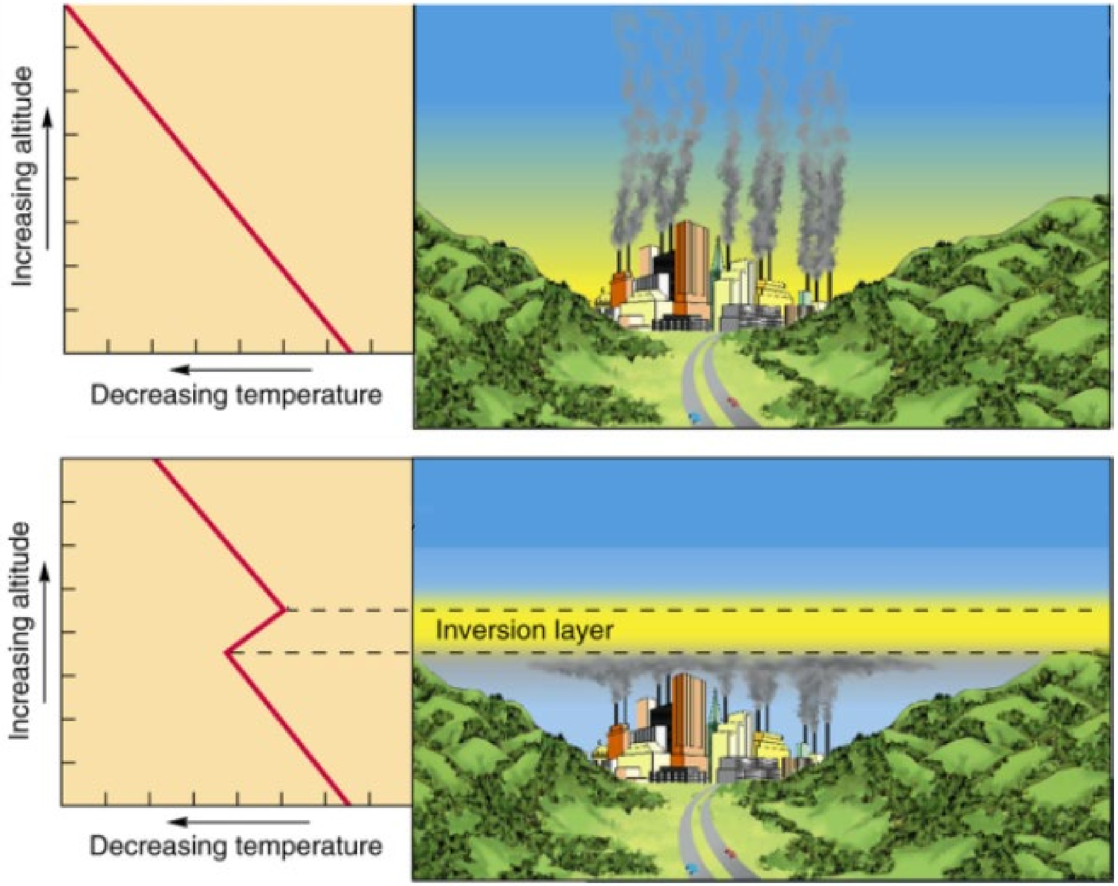
Thermal inversion & pollution dissipation

- Normally, the higher altitude is colder



Instrument: Thermal inversion

- Normally, the higher altitude is colder



Thermal inversion in Scottish town

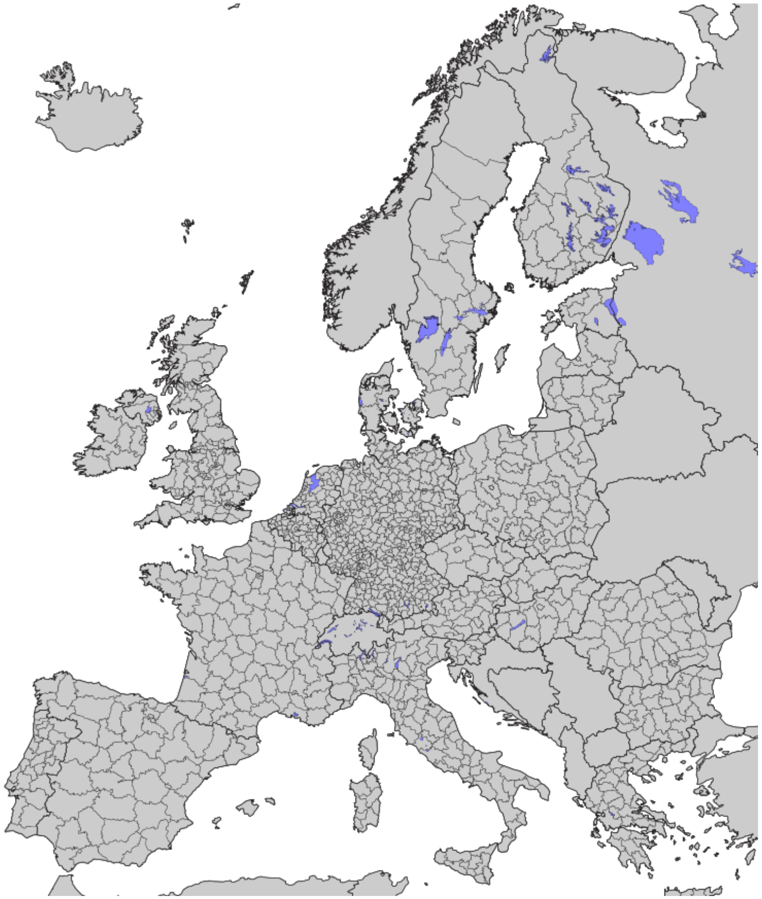
Economic & population data

- GDP & population: Eurostat
- NUTS3 regions

≈ US counties

(430 in Germany, 90 in France)

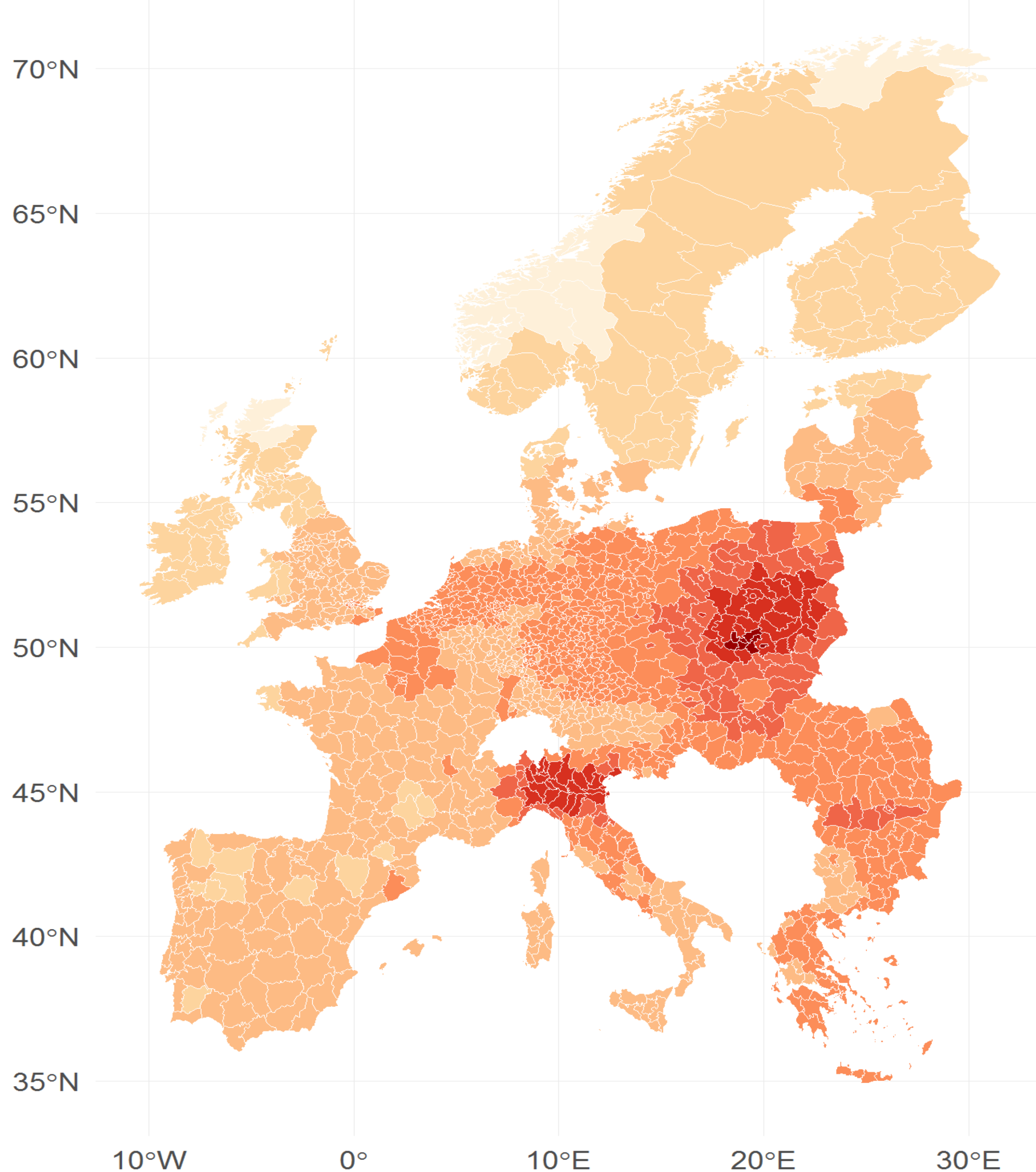
- Weight each region by its population



Pollution data

- *PM2.5* from Van Donkelaar et al (2016)
  - Satellite air quality measurements of AOD combined with particulate transport model & data from surface air monitoring stations
  - Resolution grid 0.1 degree
  - Used by OECD and WHO (GBOD)
- Combined with gridded population data to obtain population-weighted PM2.5 concentration at the NUTS3 level
  - European Commission's Global Human Settlement
- Result: annual average population-weighted concentration

AVERAGE PM2.5 2000-2015

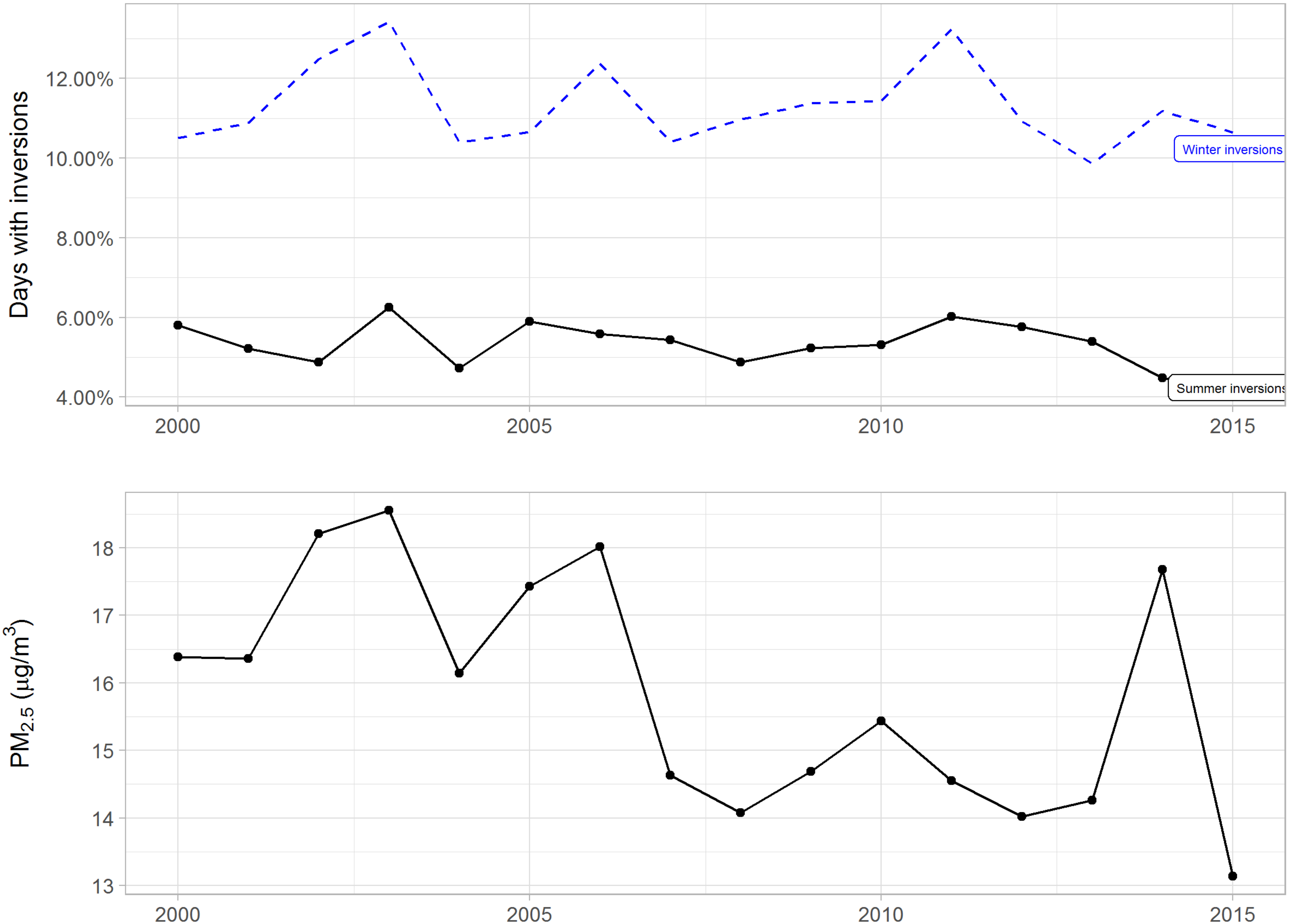


$PM_{2.5}$ ($\mu g/m^3$)

- (0,5]
- (5,10]
- (10,15]
- (15,20]
- (20,25]
- (25,30]
- (30,35]

Weather & atmospheric data

- *Thermal inversion data* from NASA MERRA-2
  - Daily mean air temperature for altitude levels between surface and 1 km above sea level
  - Inversion if temperature higher at any level below 1,000m than at surface
  - Count days (& strength) of inversions
  - Distinguish between summer and winter inversions
- *Weather conditions*
  - Daily surface temperature, precipitation, and sea level pressure from European Climate Assessment and Dataset
  - Daily wind speed and relative humidity from MERRA

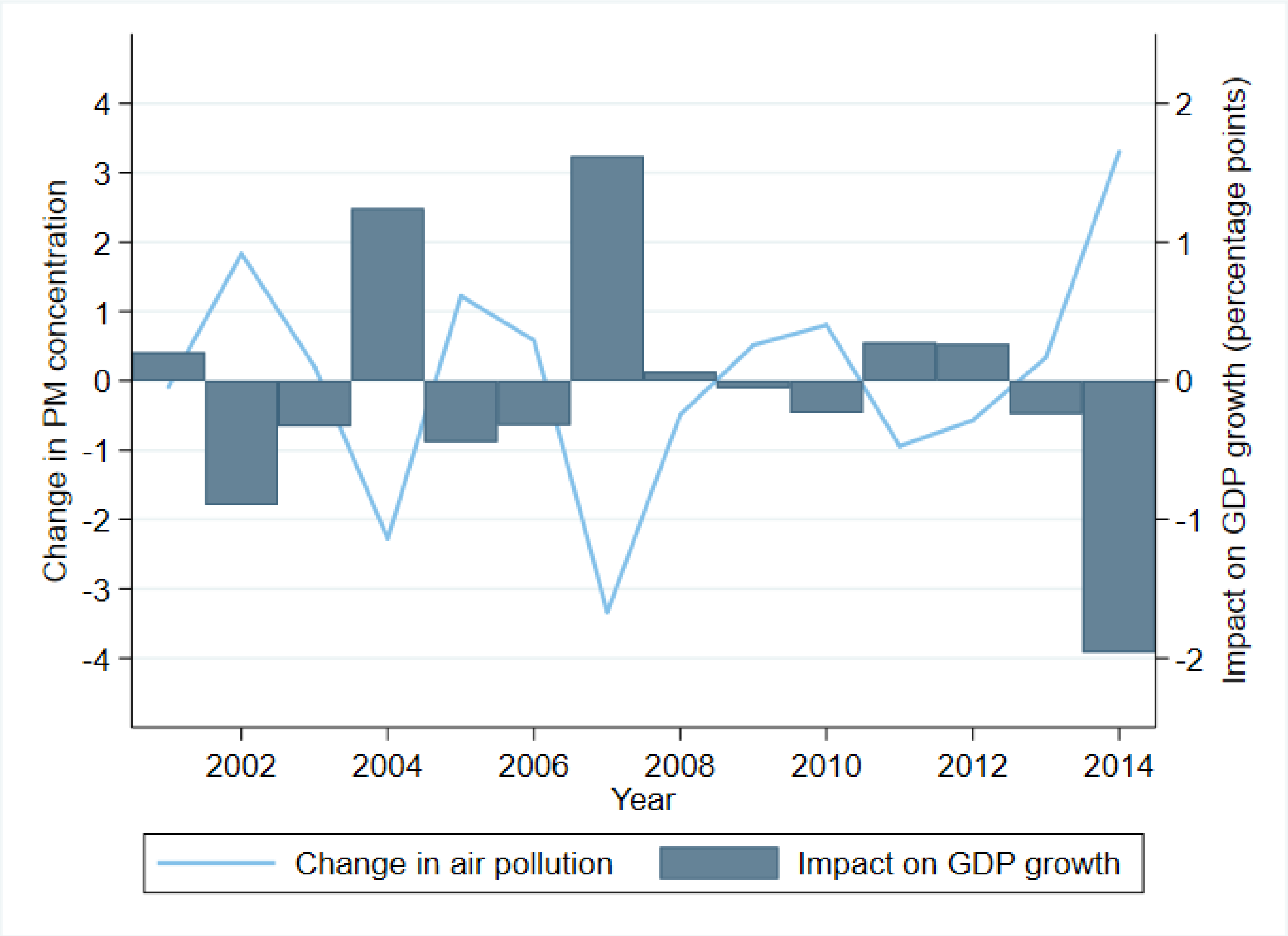


Days with inversions
12.00%
10.00%
8.00%
6.00%
4.00%
Winter inversions
Summer inversions
2000
2005
2010
2015
$PM_{2.5}$ (µg/m^3)
18
17
16
15
14
13
2000
2005
2010
2015

Main finding from econometric analysis

- An increase of PM2.5 concentration by 1µg/m^3 reduces real GDP by 0.8%
  - 95% of the impact due to reduced output per worker
- Reductions in air pollution explain up to 15% of recent GDP growth in Europe
- Results robust to multiple sensitivity and robustness checks
  - including controlling for other pollutants (SO2)

Air pollution changes & GDP growth



Comparison with abatement costs

Compliance costs for $PM_{2.5}$ concentration reduction scenarios in Europe, 2008 Air Quality Directive 2008/50/EC

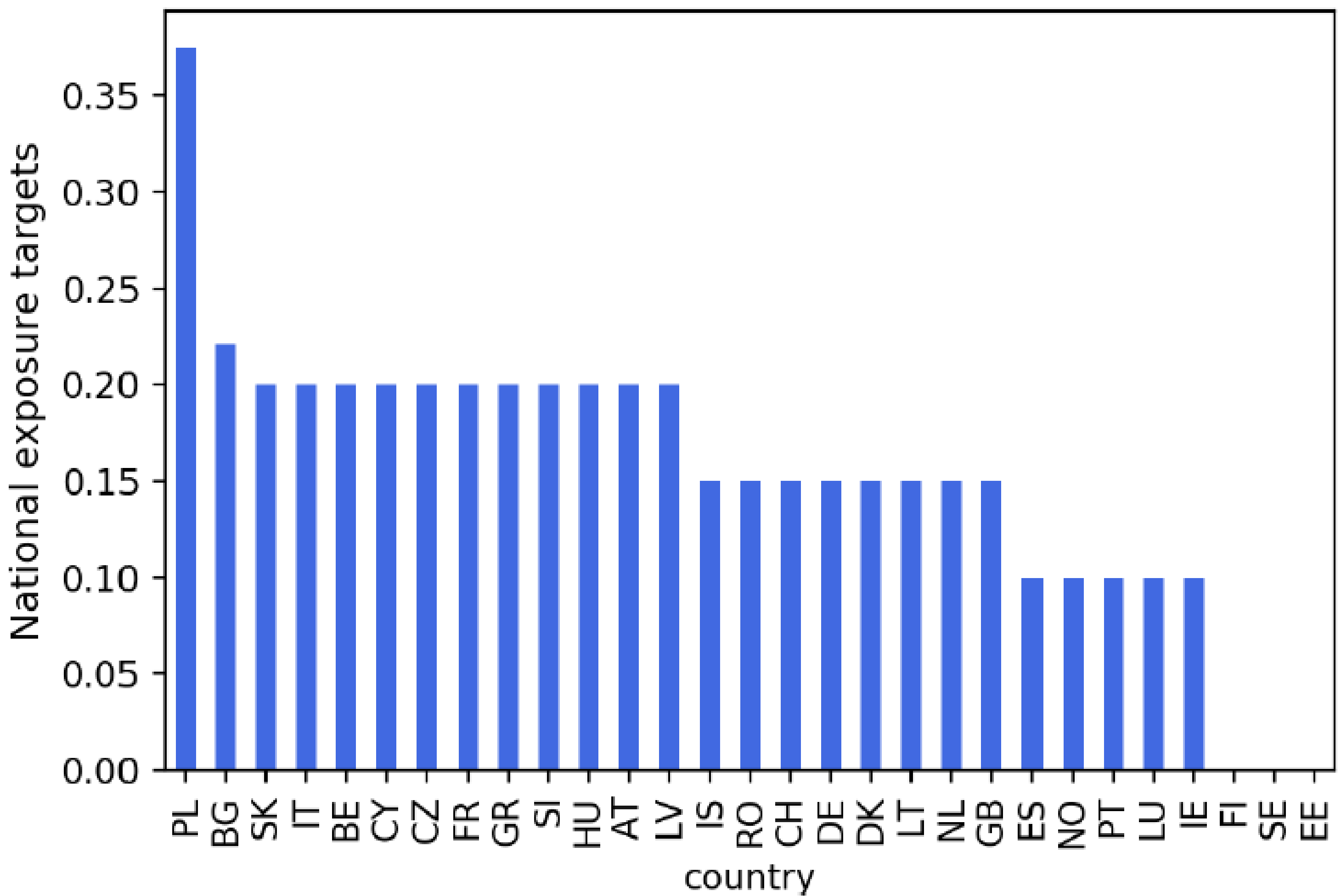
2020 scenario (EU25)	Scenario A	Scenario B
Reduction in average urban background concentration of $PM_{2.5}$	-20%	-25%
Marginal abatement cost (M€/year)	4974.4	8079.6
Marginal abatement cost (€/person/year)	10	16
GDP	-0.03%	-0.06%

Source: European Commission (2008).

- Direct economic benefits of pollution control vastly outweigh abatement costs
- Regulations to improve air quality could be warranted based solely on economic grounds, even ignoring mortality benefits

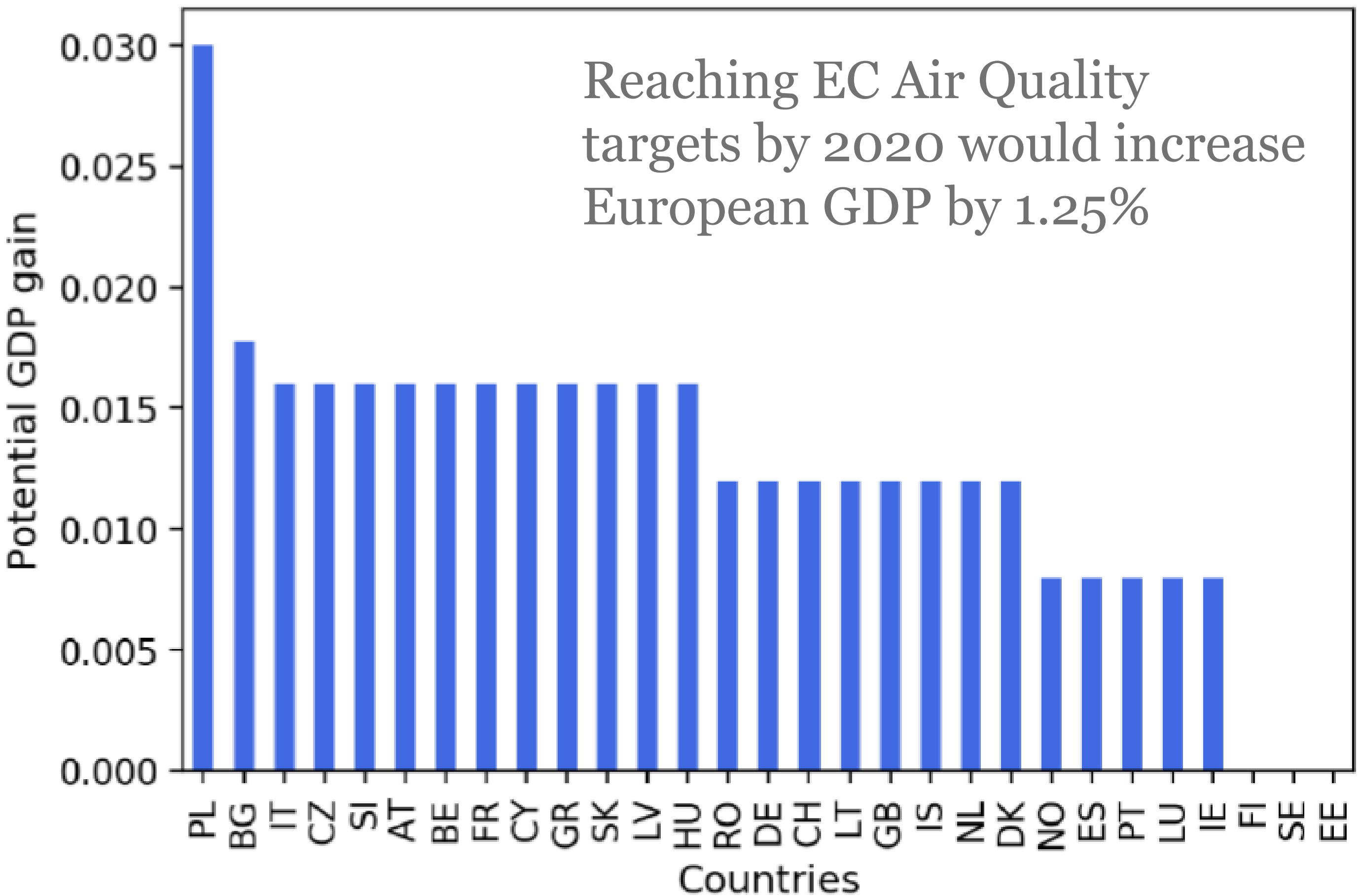
Contribution of environmental policy to growth: example EC Directive 2008/50

- Air pollution reduction targets:



Contribution of environmental policy to growth: example EC Directive 2008/50

- Potential GDP gain:



Conclusion

1. Large market costs of air pollution (in line with recent micro-studies) in addition to well-established non-market costs (mortality)
2. Regulations to improve air quality could be warranted *based solely on economic grounds*
   – Direct economic benefits of pollution control vastly outweigh abatement costs
3. Air pollution control policies may *contribute positively to economic growth*
   – Reaching EC Air Quality targets by 2020 would increase European GDP by 1.25% (up to 3% for most polluted countries)


Thank you for your attention!
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ADDITIONAL SLIDES

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Methodology

Basic relationship between economic output and pollution concentration in region i in year t :

$$\ln Y_{it} = \beta_1 P_{it} + \beta_2 f\,(W_{it}) + \eta_i + \gamma_{ct} + \varepsilon_{it}$$

Where:

- Y_{it} = real GDP
- P_{it} = average annual concentration of PM2.5
- $f\,(W_{it})$ = weather controls
- η_i = region fixed effects
- γ_{ct} = Country-year fixed effects

Take first differences to sweep out region FE:

$$\Delta\ln Y_{it} = \beta_1 \Delta P_{it} + \beta_2\,\Delta f\,(W_{it}) + \Delta\gamma_{ct} + \Delta\varepsilon_{it}$$

A good instrument

- Inversions increase pollution
- Inversions are not caused by pollution or economic activity
  - No feedbacks from pollutants to thermal inversions (at European levels)
  - Inversions associated with large-scale movement of air masses, so unlikely to be affected by shifts in small-scale regional activity
- Inversions only affect economic output via their effect on pollution
  - Inversions happen above ground level (where economic activity takes place)
  - Inversions linked with weather, which can influence economic activity on the ground, so important to control for on-the-ground weather conditions in our regressions.

Weather controls

- Temperature (20 bins)
- Precipitation (20 bins)
- Wind speed (12 bins)
- Humidity and humidity squared
- Interactions between temperature and humidity

Instrumental Variable method

2-stage least square:

- First stage:

$$\Delta P_{it} = \alpha_0 + \alpha_1 \Delta \mathrm{TI}_{it} + \alpha_3 \Delta f(W_{it}) + \Delta \lambda_{ct} + \pi_{it}$$

Where TI_{it} is frequency of thermal inversions

- Second stage:

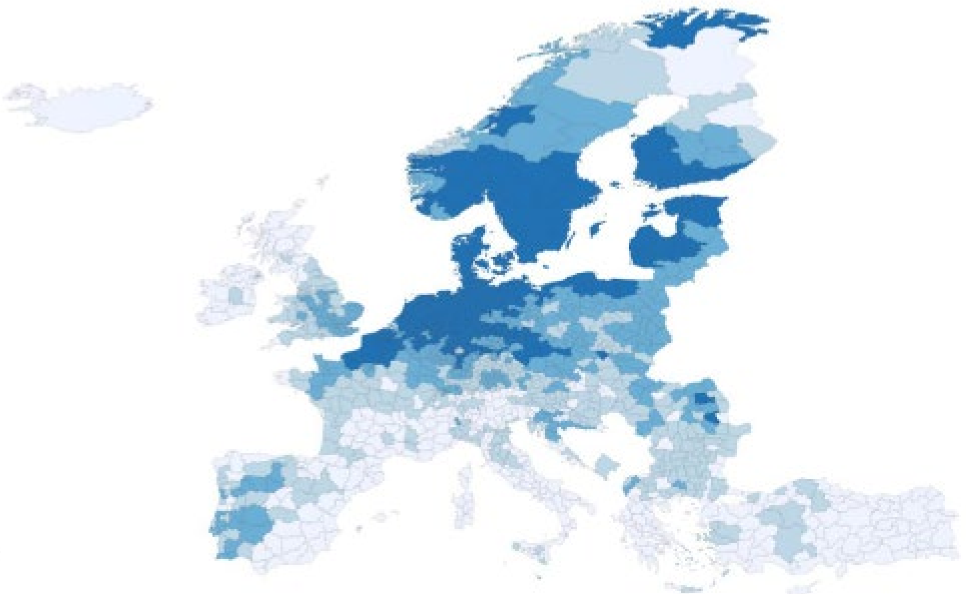
$$\Delta \ln Y_{it} = \beta_0 + \beta_1 \widehat{\Delta P_{it}} + \beta_2 \Delta f(W_{it}) + \Delta \gamma_{ct} + \nu_{it}$$

- Weight coefficients by each region's population

Geographic variation in inversions

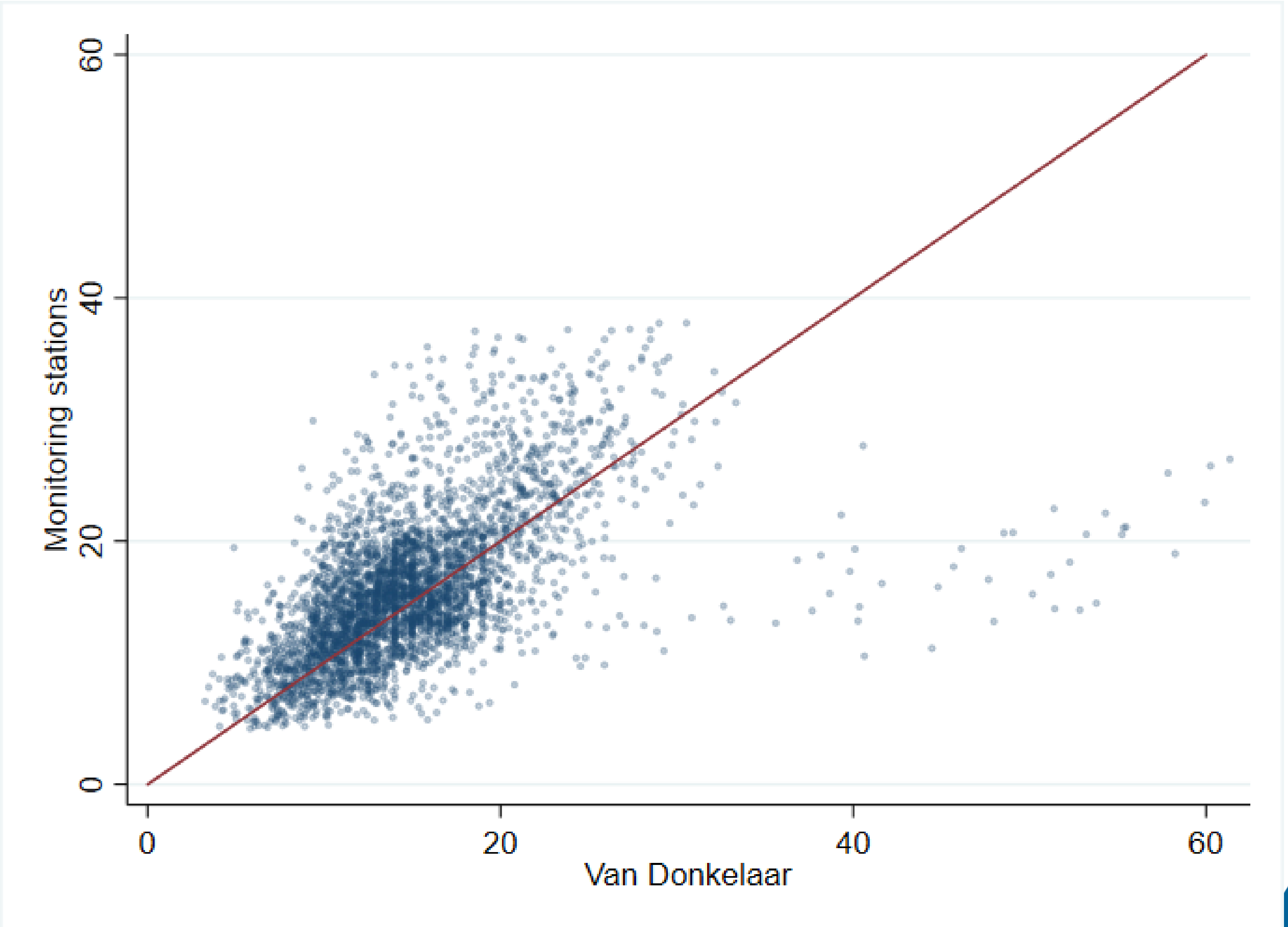
Summer

Winter



Standard deviation of annual inversion frequency in each NUTS3 region

Van Donkelaar vs monitoring stations



Are we picking up the effect of other pollutants?

- Focus on PM2.5: pollutant with largest estimated impacts on mortality and health outcomes
- Data on concentration of other pollutants not available in VD, except SO2
  - Control for SO2 concentration in rob. check

Table 1. Correlation between various pollutants

	$PM_{2.5}$	SO_2	O_3	NO_2
$PM_{2.5}$	1	0.49	-0.42	0.43
SO_2		1	-0.23	0.31
O_3			1	-0.65
NO_2				1

First stage results

- Inversions strongly increase pollution

	(1)	(2)	(3)
	$\Delta PM_{2.5}$	$\Delta PM_{2.5}$	$\Delta PM_{2.5}$
ΔSummer inversions	4.519 ***	4.488 ***	
	(1.094)	(1.089)	
ΔWinter inversions	2.046 **		2.002 **
	(0.859)		(0.854)
Observations	16462	16462	16462
R^2	0.592	0.596	0.611
Weak id. stat.	27.1	37.9	14.9

IV results

	(1)	(2)	(3)
	Δln(GDP per working pop)	Δln(GDP per capita)	Δln(GDP)
$\Delta PM_{2.5}$	-0.0080 **	-0.0081 **	-0.0083 **
	(0.0038)	(0.0038)	(0.0038)
Observations	16789	16789	16789
Weak id. stat.	9.391	9.391	9.391
Hansen J stat. p-value	0.115	0.121	0.103

- An increase of PM2.5 concentration by 1μg/m³ reduces real GDP by 0.83%
  - 95% of the impact due to reduced output per worker

Robustness check		Coefficient
Weather controls		
	70 temp. bins	-0.0071 **
	70 temp. bins interacted with humidity	-0.0084 **
Instrument choice		
	Low inversions (annual)	-0.0105 **
	Low inversions (4 seasons)	-0.0067 *
	Surface inversions (annual)	-0.0062 **
	Surface inversions (4 seasons)	-0.0056 **
Time trends and fixed effects		
	NUTS3-trends	-0.0083 **
	NUTS1-year fixed effects	-0.0145 *
	NUTS3-trends & NUTS1-year fixed effects	-0.0148 *
Additional controls		
	SO2 concentration	-0.0080 **
	Lagged GDP	-0.0096 **
Database choice		
	CAMS	-0.0147 **
	MERRA	-0.0135 *
	EEA monitoring data	-0.0078
Clustering		
	Clustered on NUTS3 + country-year	-0.0080 *
	Clustered on NUTS2	-0.0080 *
Outliers		
	Removing top and bottom 0.5%	-0.0078 **
	Removing top and bottom 2.5%	-0.0064 **
	Removing top and bottom 5%	-0.0059 *
	No outliers dropped	-0.0066

Magnitude

- A 1µg/m^3 increase of PM2.5 concentration reduces real GDP by about 0.8% (0.5%-1.5%)
- Pollution decreased by 0.2µg/m3 per year on average across Europe between 2000 and 2015
- Typical annual reduction in pollution boosts regional GDP by 0.16%
- Regional GDP grew by 1% per year on average over the period
- Reductions in air pollution could explain up to 15% of recent GDP growth in Europe

Regional heterogeneity

	(1)
	Δ ln(GDP)
Δ $PM_{2.5}$ (Urban)	-0.0070 **
	(0.0031)
Δ $PM_{2.5}$ (Intermediate)	-0.0063 **
	(0.0030)
Δ $PM_{2.5}$ (Rural)	-0.0089 **
	(0.0041)
Observations	16789
Weak id. stat.	-
Hansen J stat. p-value	-

Quantiles

	(1)
	Δ ln(GDP)
Δ $PM_{2.5}$ (1st quantile)	-0.0069 *
	(0.0042)
Δ $PM_{2.5}$ (2nd quantile)	-0.0034 *
	(0.0019)
Δ $PM_{2.5)}$ (3rd quantile)	-0.0032
	(0.0027)
Δ $PM_{2.5}$ (4th quantile)	-0.0020
	(0.0023)
Δ $PM_{2.5}$ (5th quantile)	-0.0064 **
	(0.0031)
Observations	16789
Weak id. stat.	4.759
Hansen J stat. p-value	0.00784

Sector heterogeneity

	(1)	(2)	(3)
	Agriculture	Construction	Manufacturing
Δ $PM_{2.5}$	-0.0462 **	-0.0135	-0.0093
	(0.0233)	(0.0119)	(0.0118)
Observations	16668	16789	16789
Weak id. stat.	10.69	4.957	6.409
Hansen J stat. p-value	0.119	0.971	0.691

Non-linearity

	(1)	(2)	(3)	(4)	(5)
	Interaction with pollution levels	Below region median	Above region median	Threshold model	Threshold model
Δ $PM_{2.5}$	0.0056	-0.0058	-0.0100 *		
	(0.0096)	(0.0065)	(0.0054)		
Δ $PM_{2.5}$ x $PM_{2.5}$	-0.0007				
	(0.0004)				
ΔDays($PM_{2.5}$ >10g/m^3)				-0.0004	
				(0.0004)	
ΔDays($PM_{2.5}$ >25g/m^3)					-0.0015 **
					(0.0007)
Observations	16789	8847	7911	16789	16789
Weak id. stat.	7.855	5.957	7.381	7.451	9.390
Hansen J stat. p-value	0.791	0.169	0.437	0.0128	0.148