Low Depression Zones?
The Effect of Driving Restrictions on Air Pollution and Mental Health

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with Henri Gruhl (RWI), Robin Kottmann (RWI), and Laura Schmitz (DIW Berlin)

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Motivation: Effects of air pollution

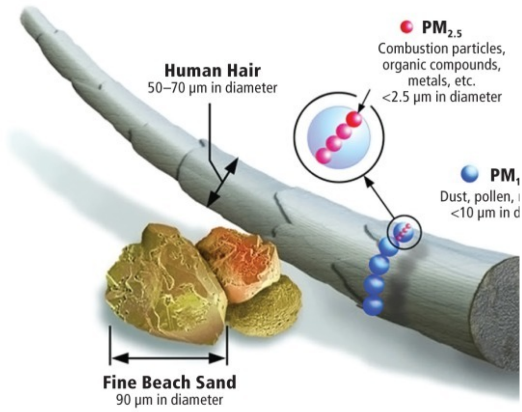

Figure: Size of PM particles

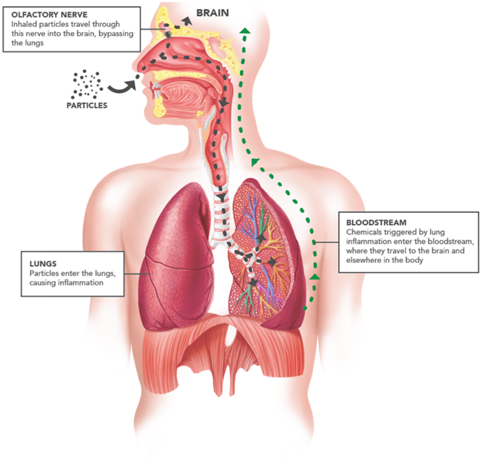

Figure: Ways to enter the brain

Motivation: Air pollution effects on the brain

▸ Mechanism Literature

- Gawryluk et al. (2023): 120 Min. exposure to diesel exhausts yields a decrease in functional connectivity of default mode network (DMN) compared to exposure to filtered air

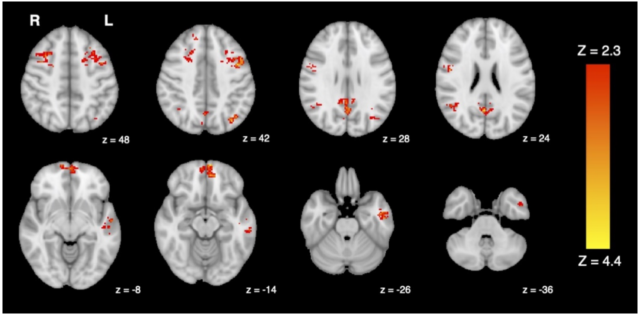

Figure: Immediate effects of traffic pollution on the brain

- Decreased connectivity in the DMN associated with several psychiatric conditions, e.g., depression & anxiety

Motivation: Air pollution effects on the brain

- Animal studies:
  - Air pollution causes **inflammation and oxidative stress**, associated with neurological impairment (Laumbach et al., 2014; Kelly and Fussell, 2015; Rückerl et al., 2011; Arias-Pérez et al., 2020)
  - Pollution affects brain chemistry by lowering levels of **serotonin** (Paz and Huitrón-Reséndiz, 1996; Murphy et al., 2013), regulating aggression and impulsivity
  - Exposure can lead to changes in other **emotional behaviors**, including anxiety and depressive behavior (Yokota et al., 2009; Ehsanifar et al., 2019).
- Epidemiological evidence for humans
  - Associations between air pollution and mental health (Borroni et al., 2022; Zundel et al., 2022; Braithwaite et al., 2019; Zeng et al., 2019)

Motivation: Mental health crisis

- One billion people worldwide grappled with mental health disorders in 2019 (WHO, 2022)
- with suicide claiming more than 1 in 100 lives (WHO, 2022)
- Germany: costs for treating mental illnesses reached 680€per inhabitant in 2020 (Federal health reporting, 2024) → largest share of healthcare expenditure, total costs (productivity, unemployment etc.) even higher
- Role of contemporary environmental drivers under-investigated

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This Paper

Research question

- Does air pollution affect mental health?

Identification

- Exploit air quality improvements caused by Low Emission Zones (LEZ) in Germany
- Two-way fixed effects design with staggered implementation (Sun and Abraham, 2021)

Data & Outcome

- Administrative health insurance data
- Diagnoses, prescriptions, specialist visits, billings

Findings

- Robust effects: better air quality leads to better mental health outcomes
- Young people benefit the most

Literature and Contributions

- **Air pollution and health:** Respiratory and cardiovascular health (e.g., Currie and Neidell, 2005; Chay and Greenstone, 2003; Klauber et al., 2024; Margaryan, 2021; Pestel and Wozny, 2021; Wolff, 2014)

→ *Contribution*: Mental health as an understudied dimension

- **Non-health effects of air pollution:** Human capital (Sanders, 2012; Isen et al., 2017), productivity (Künn et al., 2023; Chang et al., 2019) , academic performance (e.g. Heissel et al., 2022; Andersen et al., 2024), school absenteeism (Currie et al., 2009), decision making (e.g. Dong et al., 2021; Künn et al., 2023), and labour market outcomes (Isen et al., 2017)

→ *Contribution*: Mental health conditions as a potential mechanism

- **Air pollution and mental health:** Mostly on China (Chen et al., 2024; Ju et al., 2023; Zhang et al., 2017; Li et al., 2021) with notable exceptions:
  - Beshir and Fichera (2025): London's ultra-low emission zone (ULEZ) improved feelings of happiness, worthiness and satisfaction
  - Persico and Marcotte (2022): Effects of air pollution on suicide as an extreme mental health outcome

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Policy: Low Emission Zones in Germany

▸ Healthcare system

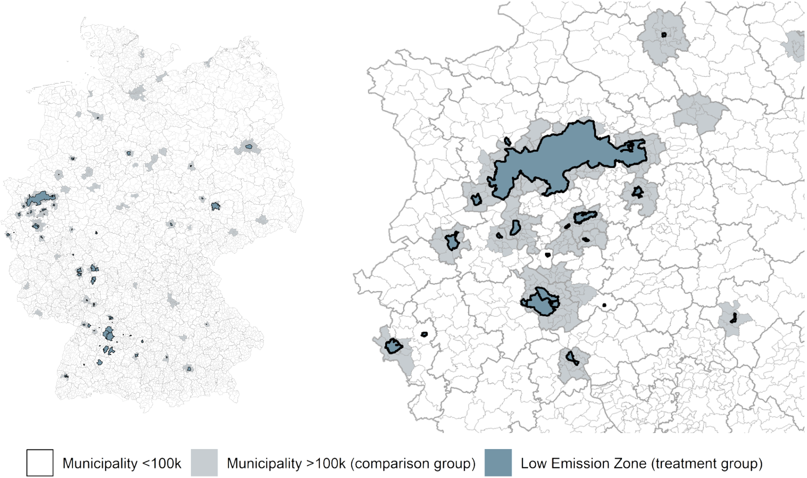
- Policy to comply with EU legislation limiting the level of pollution in urban centers
- Enforced through colored stickers
- De-facto ban of old, emission-intensive diesel vehicles
- Penalty for violation: 100€
- Staggered implementation: First LEZs introduced in 2008, 56 in Germany until 2019;
  currently 38 active LEZs

Figure: Example of an LEZ sign

Administrative health insurance data

- **Health Insurance Records** ▸ Regional distribution ▸ Details ▸ Descriptives
  - Anonymized data from one of Germany's largest public health insurers (˜9 mio. individuals)
  - Age, sex, education, zip code residence
  - Complete health records: diagnoses, prescriptions, medical billings, specialist visits
- **Low Emission Zones (LEZ)**
  - Implementation history & stringency from German Environmental Agency (UBA)
  - Geographic coverage and spatial changes from *OpenStreetMaps*
- **Air pollution**
  - UBA: NO_2, PM_{10}, SO_2, O_3
  - $PM_{2.5}$ data from satellite-based measurements (Van Donkelaar et al., 2021)
- **Socio-economic** (RWI-GEO-GRID)
  - unemployment rate, purchasing power, demographic composition at zip-code level
- **Weather** (German Weather Service)
  - sunshine duration, wind speed & direction, precipitation, temperature, humidity

Low Emission Zones



▸ Descriptives

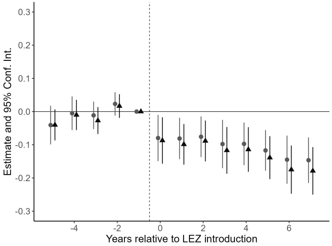
Difference-in-differences design

- Two-Way Fixed Effects (TWFE)

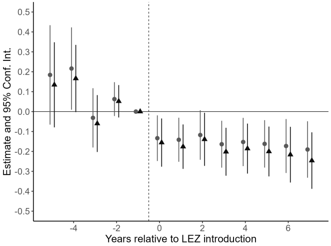
$$Y_{it} = \beta^{TWFE} LEZ_{it} + \gamma X_{it} + \lambda_i + \phi_t + t \times \theta_c + \varepsilon_{it}$$

  where:
  - Y_{it}: Average mental health outcome for zip code i in year t
  - LEZ_{it}: Indicator for being within an LEZ in year t
  - λ_i: Zip code fixed effects
  - ϕ_t: Year fixed effects
  - $t \times \theta_c$: County-specific time trend
  - X_{it}: Time-varying socio-economic and weather characteristics at the zip code level
  - ε_{it}: Clustered standard errors at the county level
- We use the estimator by Sun and Abraham (2021) to account for potential bias arising from the staggered treatment.

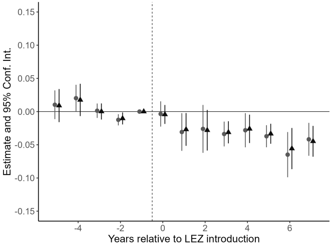
Pollution effects



(a) PM_{10}, ATT: 10.5%



(b) NO_2, ATT: 15.3%



(c) $PM_{2.5}$, ATT: 3.1%

Mental health effects: extensive margin

Table: Effect of LEZ introduction on extensive margin mental health outcomes

Dependent Variables (in logs):				
Panel A: Antidepressant probability	Model 1	Model 2	Model 3	Model 4
ATT	-0.0474***	-0.0512**	-0.0542**	-0.0377***
	(0.0178)	(0.0233)	(0.0246)	(0.0122)
Mean	0.074	0.074	0.074	0.074
Panel B: Specialist visit probability				
ATT	-0.0878**	-0.0851**	-0.0885**	-0.0661**
	(0.0339)	(0.0376)	(0.0395)	(0.0267)
Mean	0.062	0.062	0.062	0.062
Observations (zipcode $\times$ year)	19,345	19,345	19,345	19,345
Socioeconomic controls	–	✓	✓	✓
Weather controls	–	–	✓	✓
County$\times$Year linear trend	–	–	–	✓
Year fixed effect	✓	✓	✓	✓
Zip code fixed effect	✓	✓	✓	✓

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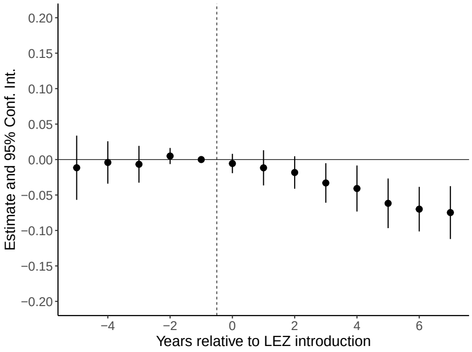
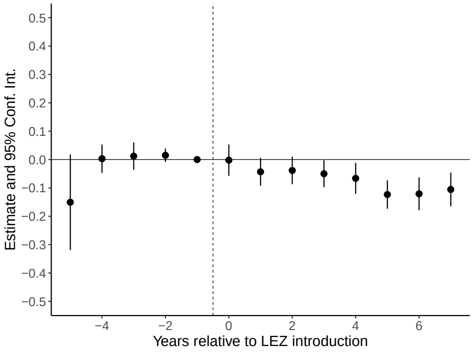
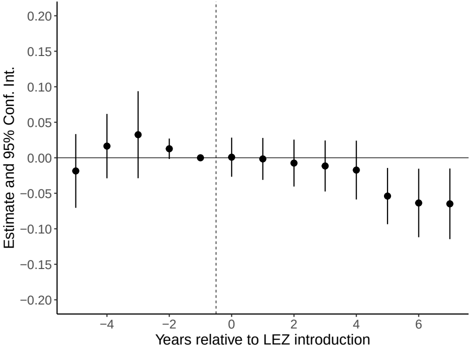


(a) Antidepressant probability, ATT: 3.8%

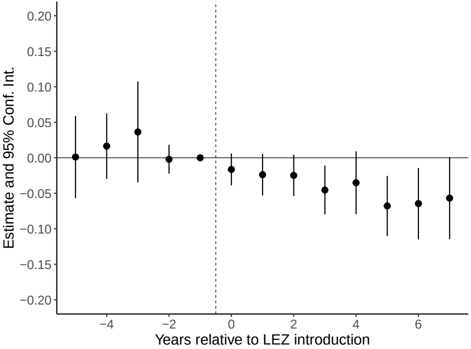


(b) Specialist visit probability, ATT: 6.6%

Mental health effects: extensive margin

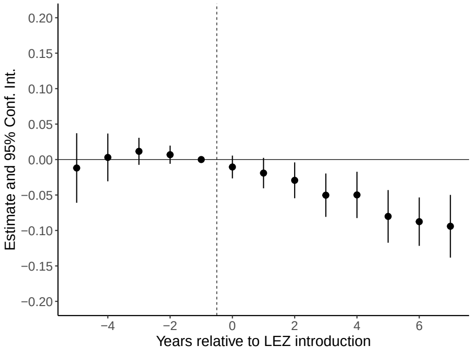


(a) Depression probability, ATT: (2.6%)

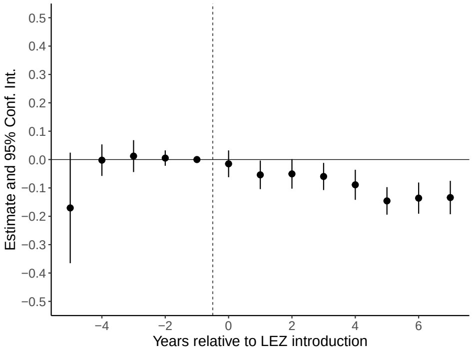


(b) Anxiety probability, ATT: 4.1%

Mental health effects: intensive margin

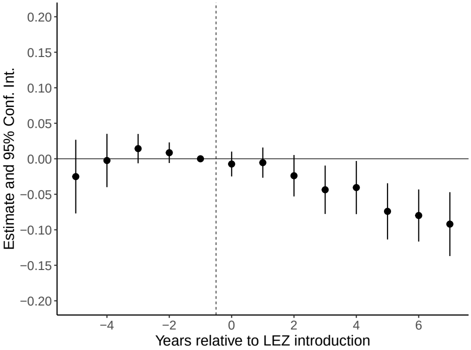


(a) Antidepressant prescriptions, ATT: 5.1%

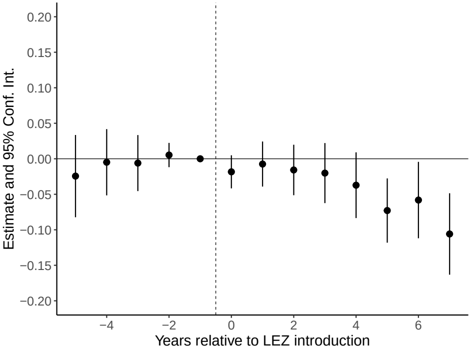


(b) Specialist visits, ATT: 8.3%

Mental health effects: intensive margin



(a) Antidepressant daily dosages, ATT: 4.4%

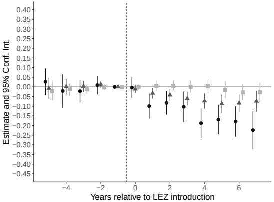


(b) Specialist billings, ATT: 4.0%

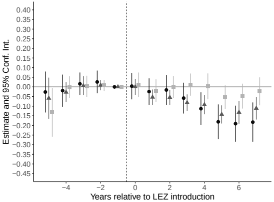
Robustness Exercises

- Confirmatory and placebo exercises results
- Accounting for spillovers results results
- Including movers results
- Alternative estimators results results

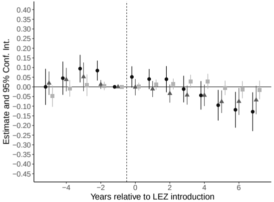
Heterogeneity: Age



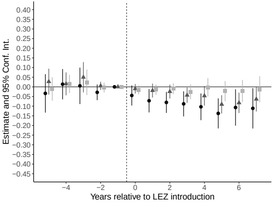
(a) Antidepressant prescription probability



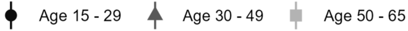
(b) Specialist visit probability



(c) Depression probability



(d) Anxiety probability



Mechanisms linking LEZs to mental health

- **Direct effects:** Reduced air pollution impacts the brain, improving mental health outcomes.
- **Indirect effects through physical health:**
  - Better air quality improves cardiovascular health, lowering stress and depressive symptoms.
- **Traffic reduction and noise:**
  - Lower noise pollution reduces risks of depression, anxiety, and sleep disorders.
  - Reduced traffic volume lowers stress, accident risks, and anxiety.
- **Economic activity:**
  - Cleaner air enhances productivity and reduces absenteeism.
  - Short-term costs for retrofitting vehicles may affect businesses.
  - Changes in neighborhood socio-economic composition can influence mental health.

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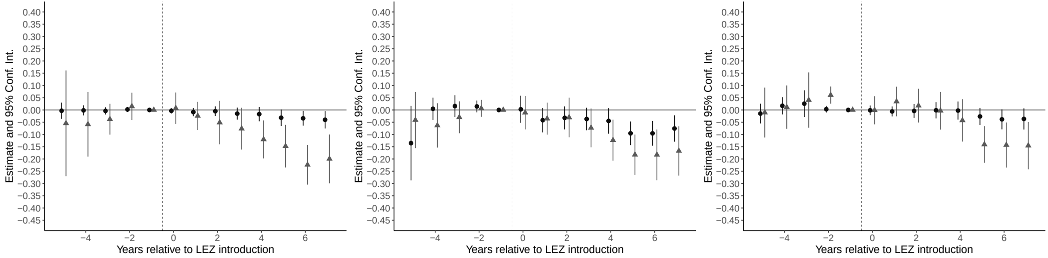
Mechanisms: Indirect effects through improved physical health

Figure: Effect of LEZ introduction depending on cardiovascular health



(a) Antidepressant prescription probability

(b) Specialist visit probability

(c) Depression probability

Cardiovascular diagnosis   No cardiovascular diagnosis

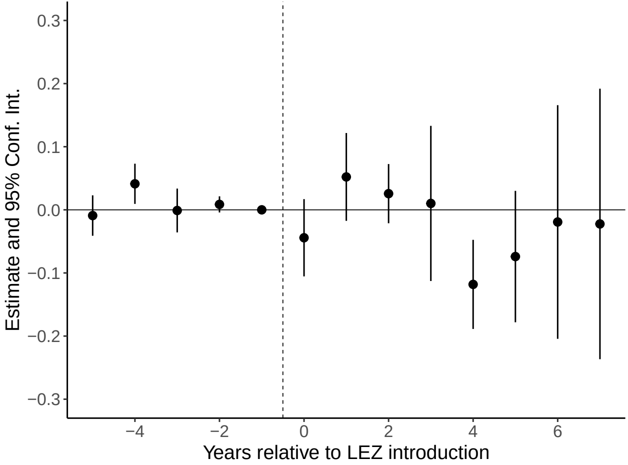
Mechanisms: Noise and traffic volume reduction

Table: Only zip codes without main streets ($\leq$ 4 lanes)

Dependent variables in log:	Antidepressant probability	Specialist visit probability	Depression probability	Anxiety probability
ATT	-0.0408***	-0.0803***	-0.0359*	-0.0536***
	(0.0133)	(0.0219)	(0.0207)	(0.0199)
Observations (zipcode $\times$ year)	14,306	14,284	14,298	14,297
Dependent variables in log:	Antidepressant prescriptions	Antidepressant DDD	Specialist visits	Specialist billings
ATT	-0.0560***	-0.0469***	-0.0973***	-0.0527**
	(0.0145)	(0.0141)	(0.0215)	(0.0205)
Observations (zipcode $\times$ year)	14,306	14,306	14,284	14,318
Socioeconomic controls	✓	✓	✓	✓
Weather controls	✓	✓	✓	✓
County$\times$Year linear trend	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✓
Zip code fixed effect	✓	✓	✓	✓

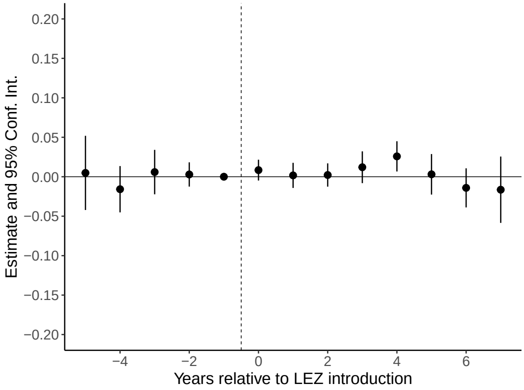
Mechanisms: Noise and traffic volume reduction

Figure: Effect of LEZ introduction on traffic volume

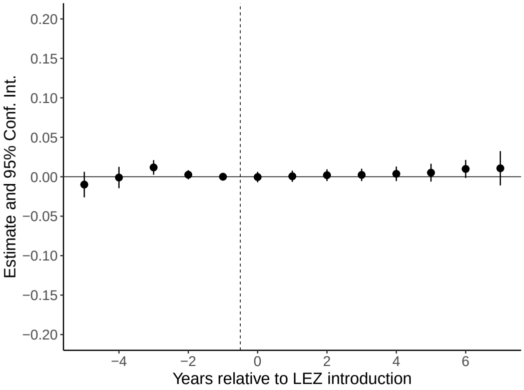


Mechanisms: Economic activity

Figure: Effect of LEZ introduction on socioeconomic characteristics



(a) Unemployment rate



(b) Purchasing power per capita

Cost-benefit analysis

- **Mental health benefits:**
  - LEZs reduce the probability of antidepressant prescriptions by 3.8%, preventing 28,000 cases annually.
  - Health care cost savings: €84 million to €140 million per year (cost per depression case: €3,000–€5,000).
  - Welfare gains: €50M per year (WTP to avoid depression: €1,800 per person annually).
  - Productivity gains: €45M per year (savings from reduced absenteeism).
  - Total mental health-related savings: €179 to €235 annually.

- **Private costs of vehicle upgrades:**
  - Wolff (2014) estimates costs at US$1,650 per car and US$1.1B in total
  - Khan et al. (2018) assume the same costs per car but find US$82.5 million in total
  - High uncertainty in cost estimates complicates direct comparison

- **Conclusion:**
  - Monetary benefits of avoided depression diagnoses alone likely outweigh private upgrading costs.
  - Including broader health and welfare savings, LEZs yield substantial net benefits.

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Conclusion

Key findings:

- LEZs improve mental health by reducing antidepressant prescriptions, mental health specialist visits, and diagnoses of depression and anxiety.
- Effects emerge gradually, with significant improvements 3–4 years after LEZ introduction.
- Youngest age group (15–29 years) experiences the largest benefits.

Policy

- Environmental policies improving air quality yield broad health benefits, including mental health.
- Stricter policies aligned with the revised EU Ambient Air Quality Directive could amplify mental health and broader health co-benefits.
- Expanding LEZs is a cost-effective strategy for reducing health costs.

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Thank you for your attention!

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Mechanisms

- Part of the adverse effects of air pollution on cardiovascular and respiratory diseases can be attributed to **inflammation and oxidative stress** (Laumbach et al. (2014); Kelly and Fussell (2015); Rückerl et al. (2011); Arias-Pérez et al. (2020))
- These processes are known to contribute to various psychiatric diagnoses (Coccaro et al. (2014); Miller and Raison (2016); Najjar et al. (2013); Salim (2014))
- Medical research: evidence of a negative correlation between air pollution and brain functioning (Zundel et al. (2022); Braithwaite et al. (2019))

Intro

Mental health in the German health care system

Back

- **Universal healthcare access:**
  - Public health insurance mandatory for employees earning below €69,300/year, students, pensioners, and unemployed (~90% coverage).
  - Private health insurance optional for high earners, self-employed, and civil servants.
- **Mental health care:**
  - Collaborative provision by psychiatrists, psychologists, psychotherapists, and general practitioners.
  - Psychotherapists per 100,000: Germany 13.2 (2015) vs. US 10.5 (2016).
  - Challenges with availability: average wait time ~5 months for therapy (2019).
  - 2017 reform: mandatory initial consultations and acute crisis treatment.

Mental health in the German health care system

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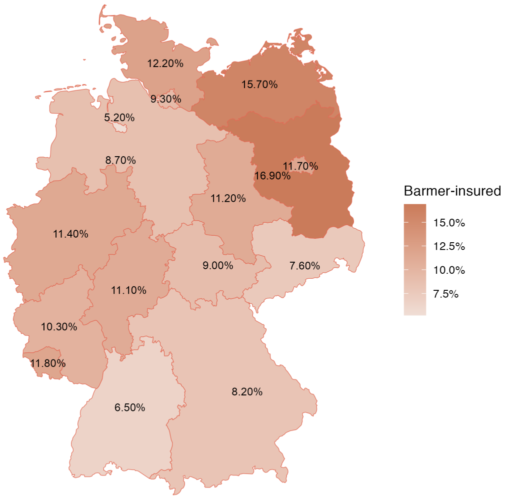
Administrative health insurance data

Back

- Anonymized data from one of Germany's largest public health insurers (~9 mio. individuals) Regional distribution
- Detailed individual characteristics:
  - Age, sex, education, zip code residence
  - Complete health records: diagnoses, prescriptions, medical billings, specialist visits
- Sample:
  - Focus on working-age individuals (15-65 years)
  - Exclude movers (results robust to including movers)
  - 2005 to 2019
- Outcomes aggregated at zip code-year level for privacy and computational reasons

Descriptives

BARMER insured distribution



▸ Data

Outcome variables

	Outside LEZs				Inside LEZs			
	mean	sd	min	max	mean	sd	min	max
Extensive Margin								
Antidepressant probability	0.07	0.02	0	0.18	0.07	0.02	0	0.16
Specialist visit probability	0.06	0.03	0	0.23	0.06	0.03	0	0.35
Depression probability	0.07	0.03	0	0.2	0.07	0.03	0	0.23
Anxiety probability	0.06	0.02	0	0.18	0.06	0.02	0	0.14
Intensive margin								
Antidepressant prescriptions	0.25	0.1	0	0.67	0.26	0.1	0	0.63
Antidepressant DDD	17.77	8.31	0	64.38	18.28	7.94	0	50.06
Specialist visits	0.18	0.08	0	0.62	0.18	0.09	0	0.88
Specialist billings	1.75	0.89	0.03	9.32	1.6	0.84	0	6.34
Confirmatory and Placebo Outcomes								
Cardiovascular disease probability	0.32	0.08	0	0.63	0.31	0.07	0.03	0.56
Cardiovascular prescription probability	0.21	0.07	0	0.42	0.19	0.06	0	0.46
Cardiovascular prescriptions DDD	128.05	48.71	0	342.95	113.11	47.15	0	346.63
Injury probability	0.11	0.03	0	0.21	0.11	0.03	0	0.25

Data

Socio-demographic composition in and outside LEZs

Table: Descriptive statistics treatment and control group

	Outside LEZs					Inside LEZs				
Controls	mean	sd	min	max	n	mean	sd	min	max	n
Socioeconomic										
Purchasing power per capita	22,492	4,523	11,934	42,257	10,767	22,871	4,417	12,362	41,332	11,226
Unemployment rate	8.12	4.2	0.16	25.3	10,767	7.23	4.43	0.21	23.49	11,226
Share of foreigners	13.06	8.49	0.57	49.92	10,767	16.7	8.68	0.37	51.08	11,226
Cars per household	0.74	0.23	0.18	1.47	10,767	0.79	0.34	0.25	1.53	11,226
Number of inhabitants	15,134	7,186	610	38,587	10,767	14,361	7,416	1,028	61,667	11,226
Number of insured individuals	668	448	21	7,103	10,767	511	403	21	6,388	11,226

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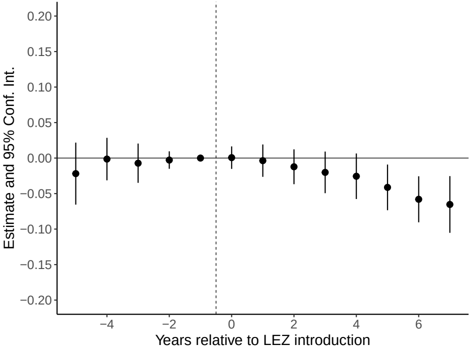
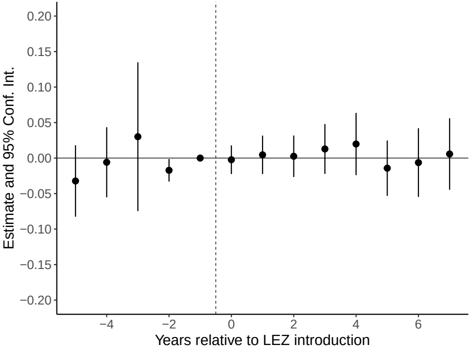
Robustness: Confirmatory and placebo exercise

Figure: Confirmatory exercise



(a) Probability of cardiovascular prescription



(b) Injury probability

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Robustness: Accounting for spillovers

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Table: Accounting for spillovers

Dependent variables in log:	Antidepressant probability	Specialist Visit probability	Depression probability	Anxiety probability
Panel A	Buffer: 1km			
ATT	-0.0477***	-0.0734***	-0.0332	-0.0522*
	(0.0173)	(0.0249)	(0.0235)	(0.0292)
Observations (zip code × year)	17,591	17,572	17,579	17,584
Panel B	Buffer: 5km			
ATT	-0.0617***	-0.0709***	-0.0374**	-0.0426
	(0.0159)	(0.0217)	(0.0149)	(0.0583)
Observations (zip code × year)	15,011	14,999	14,999	15,004
Socioeconomic and weather controls	✓	✓	✓	✓
County×Year linear trend	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✓
Zip code fixed effect	✓	✓	✓	✓

Robustness: Accounting for spillovers ▸ Back

Table: Accounting for spillovers

Dependent variables in log:	Antidepressant prescriptions	Antidepressant prescriptions DDD	Specialist visits	Specialist billings
Panel A	Buffer: 1km			
ATT	-0.0561***	-0.0434*	-0.0889***	-0.0474**
	(0.0177)	(0.0222)	(0.0260)	(0.0181)
Observations (zip code × year)	17,591	17,591	17,572	17,605
Panel B	Buffer: 5km			
ATT	-0.0663***	-0.0547***	-0.0931***	-0.0520**
	(0.0140)	(0.0181)	(0.0238)	(0.0199)
Observations (zip code × year)	15,011	15,011	14,999	15,025
Socioec. & weather controls	✓	✓	✓	✓
County×Year linear trend	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✓
Zip code fixed effect	✓	✓	✓	✓

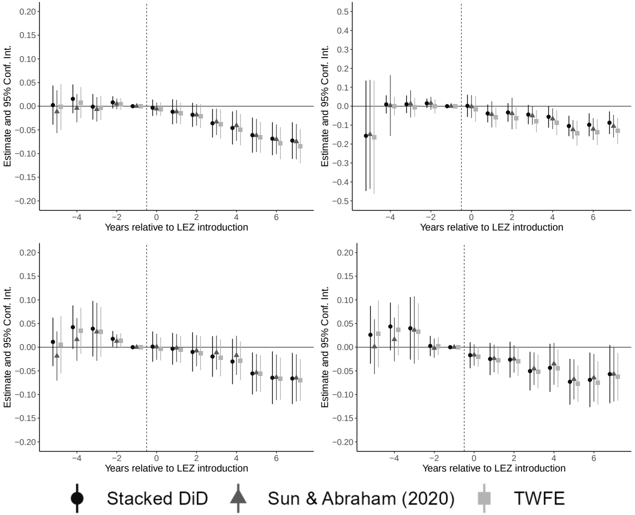
Robustness: Main results with movers

Back

Table: Main results including movers

Dependent variables in log:	Antidepressant probability	Specialist visit probability	Depression probability	Anxiety probability
ATT	-0.0377***	-0.0661**	-0.0256	-0.0407**
	(0.0122)	(0.0267)	(0.0172)	(0.0173)
Dependent variables in log:	**Antidepressant prescriptions**	**Antidepressant DDD**	**Specialist visits**	**Specialist billings**
ATT	-0.0505***	-0.0437***	-0.0829***	-0.0397**
	(0.0132)	(0.0143)	(0.0263)	(0.0186)
Observations (zipcode $\times$ year)	19,345	19,345	19,323	19,359
Socioeconomic controls	✓	✓	✓	✓
Weather controls	✓	✓	✓	✓
Demographic controls	✓	✓	✓	✓
County$\times$Year linear trend	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✓
Zip code fixed effect	✓	✓	✓	✓

Robustness: Alternative estimators



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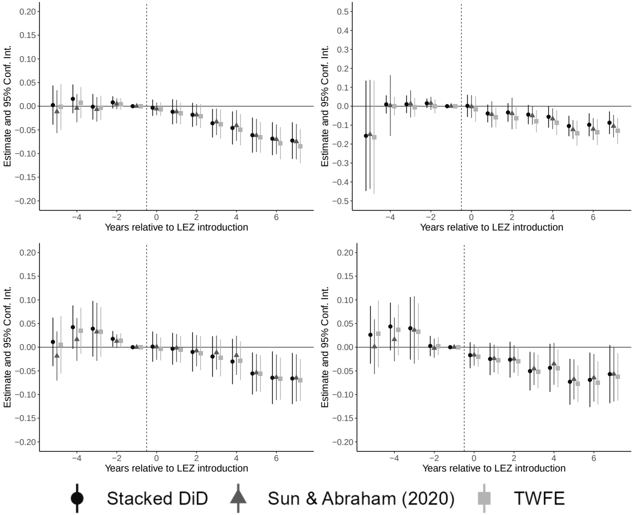
Robustness: Alternative estimators



▸ Back

Sleep disorder

▸ Back

Model	*Main specification*	*Excluding large streets*
Dependent variables in log:	Sleep disorder probability	Sleep disorder probability
ATT	-0.0477***	-0.0445***
	(0.0170)	(0.0150)
Observations (zipcode × year)	19,327	14,289
Socioeconomic controls	✓	✓
Weather controls	✓	✓
County×Year linear trend	✓	✓
Year fixed effect	✓	✓
Zip code fixed effect	✓	✓