Clearing the Air on the Benefits and Costs of Road Infrastructure

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Road infrastructure & pollution

- Expanding road infrastructure regarded as important for economic development (Redding and Turner 2015, Foster et al. 2023)
- But roads also bring traffic, and traffic brings pollution
- Cost of traffic-related pollution particularly high in developing countries: high congestion, weak regulation, severe impacts.

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Research questions:

- What is the role of traffic in shaping pollution levels?
- When accounting for pollution: how do gains from urban road infrastructure compare with losses?
  - On average
  - By location

This paper's setting: Lahore, Pakistan

Record Air Pollution Hospitalizes Hundreds in Pakistani City

The authorities in Lahore, home to 13 million people and the country's second-biggest city, have told half the work force to stay home.

New York Times, 7 November 2024

WHO "safe" limits for PM2.5: $5 \mu g/m^3$ annual average

Lahore: avg. $\sim 80 \mu g/m^3$, sometimes exceeds $1000 \mu g/m^3$.

Greenstone & Fan (2019): average resident of Lahore loses 5.3 years of life expectancy due to air pollution

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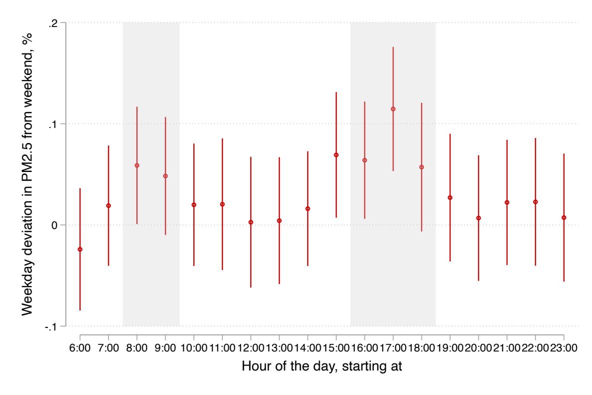
- Present empirical evidence showing that traffic is a non-negligible contributor to pollution concentrations in this setting
- Develop quantitative urban equilibrium model integrating atmospheric pollution dispersion
- Calibrate using novel data on emissions, pollution, commuting, goods trade in Lahore (work in progress)
- Estimate distribution of economic and pollution-related impacts from road improvements (work in progress)

Pollution peaks during rush hour, consistent with key role of traffic

Data: PM2.5 concentrations from 13 ground-level sensors.

Graph shows **weekday deviations** ($\rightarrow$ rush hour) of PM2.5 concentrations from (de-meaned) averages

Morning rush hr: +5%, uncond. avg.: 100μg/m^3; **Evening rush hr:** +10%, uncond. avg.: 65μg/m^3



Notes: The graph shows the average weekday (Monday to Thursday) deviations in $PM_{2.5}$ concentrations, in percent, from the unconditional averages, by hour of the day. Shaded regions correspond to the morning and evening rush hours. The underlying regression excludes Fridays (because or less regular work hours due to Friday prayers), and includes sensor, day, and hour-of-the-day fixed effects as well as controls for third-order polynomials in temperature, humidity, wind speed, precipitation, and cloud cover. The regression weighs observations by the inverse of the number of observations available for each sensor, to correct skewness in data availability.

Meteorological conditions affect influence of emissions on pollution

Wind speed, temperature, humidity, cloud cover, precipitation etc all affect PM2.5 concentrations.

It's complicated. We know from physics/chemistry that concentrations are not linear in these determinants.

In order to capture these effects accurately, we need to integrate meteorology/physics/chemistry.

	Dependent variable: PM2.5 concentration (ug/m3)				
	(1)	(2)	(3)	(4)	(5)
Weekend dummy	-17.93***	-22.15***	-19.90***	-24.59***	-22.65***
	(2.21)	(2.07)	(2.98)	(2.88)	(2.74)
Ramadan dummy	-21.38***	-20.07***	-49.55***	-13.46	-47.25***
	(5.57)	(5.70)	(9.52)	(11.2)	(9.71)
Log GPS trucks			7.479***	7.916***	9.438***
			(2.01)	(1.94)	(1.90)
Wind speed (std)		-12.80		-13.68***	-37.15**
		(10.9)		(1.57)	(11.9)
Temperature (std)		-45.99***		-57.92***	-50.57***
		(5.51)		(3.90)	(5.99)
Humidity (std)		-38.70***		16.90***	-31.66***
		(4.31)		(2.00)	(6.77)
Cloud cover (std)		34.91*		7.291***	-2.016
		(17.0)		(1.52)	(20.7)
Precipitation (std)		-0.311		-2.194*	-1.291
		(3.39)		(1.11)	(3.98)
Inv Ventilation coeff (std)		16.50***		0.314	24.27***
		(4.78)		(1.78)	(6.11)
Sensor FE	X	X	X	X	X
Hour of the day FE	X	X	X	X	X
Week FE	X	X	X	X	X
Additional controls		X			X
R^2	0.595	0.647	0.599	0.627	0.658
Observations	112329	103693	34380	31727	31727

Integrated spatial-environmental framework

- Quantitative spatial equilibrium model of Lahore integrating:
  - Commuting and trade (Allen & Arkolakis 2022)
    - Tractable expressions for traffic volumes on each edge
  - Model the emission and dispersion of local air pollutants (ADMS-Urban model):
    - to simulate dispersion & mixing of pollutant particles under counterfactual scenarios

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- Calibrate model using fine-grained data on commuter and goods traffic

- <u>Counterfactuals:</u> switch off roads. How do (market integration) benefits and (pollution) costs from roads compare?

Model setup: primitives

- **Locations** within the city, indexed by i, j
- **Edges** (roads) e connecting locations
- **Residential population** L_i^0 commutes to work, sources consumption goods from other locations
- **Firms** have location-specific productivity, with agglomeration/congestion forces
- **Pollution concentrations** m_i (endogenous)
  - from traffic (commuters, goods) along all edges
  - from production in all locations
- **Congestion forces in traffic**. More traffic on $e \Rightarrow$ higher transportation cost.

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- **Pollution concentrations** m_i (endogenous) $\Rightarrow$ reduce utility (residents), effective labor supply (workers)
  - from traffic (commuters, goods) along all edges
  - from production in all locations

- **Congestion forces in traffic**. More traffic on e $\Rightarrow$ higher transportation cost.

Commuting and trade (and route choice) very similar to Allen and Arkolakis (2023).

- yields closed-form expressions for goods traffic Ξ_e^y and commuter traffic Ξ_e^l as function of trade costs and (goods/commuter) market access terms
- allows for solving for *changes* in market access terms (Dekle-Eaton-Kortum)

New part: Air pollution externalities:

$$m_j = \underbrace{\sum_{i \in I} \gamma_{ji} \mu_y Y_i}_{\text{Pollution from industry}} + \underbrace{\sum_{e \in E} \gamma_{je} \mu_{\Xi_y} \Xi_e^y}_{\text{Pollution from goods traffic}} + \underbrace{\sum_{e \in E} \gamma_{je} \mu_{\Xi_l} \Xi_e^l}_{\text{Pollution from commuter traffic}} \tag{1}$$

The parameters γ_{ji} tell us: *"if you increase emissions in i by 1 unit, how many units do concentrations increase in j?"* $\leftarrow$ this is where the pollution dispersion model comes in.

Local pollutant concentrations

Atmospheric dispersion model of pollution

ADMS Multi-Model Air Quality System (Hood et al 2018) calibrated to Punjab province (with assistance from CERC)

- Captures pollution from local sources and long-range chemical transport/mixing
- Concentration of particulate matter ($PM_{2.5,10}$), NO_x over space and time
- Model inputs:
  - Hourly historical meteorological conditions (ECWMF ERA5)
  - Background chemical concentrations (CAMS reanalysis data)
  - Traffic emissions from traffic volumes (traffic surveys, truck GPS, population density) and exhaust and non-exhaust pollutant emissions factors (COPERT) by vehicle type
  - Gridded inventory of spatially aggregated non-traffic emissions in 23 sectors (EDGAR)

Validated using air quality data from pollution monitors (ground-level sensor data)

Counterfactual to change transportation costs $\bar{t}$: Pollution Concentrations

$$m_j = \sum_{i \in I} \gamma_{ji} \mu_y Y_i + \sum_{e \in E} \gamma_{je} \mu_{\Xi_y} \Xi_e^y + \sum_{e \in E} \gamma_{je} \mu_{\Xi_l} \Xi_e^l$$

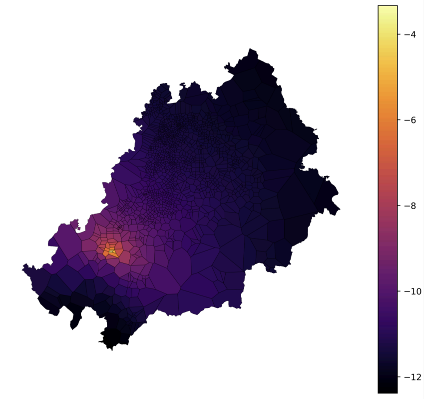
$$\downarrow$$

$$\hat{m}_i = \sum_j \hat{Y}_j \mathbf{M}_{ij}^y + \sum_{j,k} \hat{\Xi}_{jk}^y \mathbf{M}_{i,jk}^{\Xi^y} + \sum_{j,k} \hat{\Xi}_{jk}^\ell \mathbf{M}_{i,jk}^{\Xi^\ell}$$

- $\mathbf{M}_{ij}^y, \mathbf{M}_{ij}^{\Xi_y}, \mathbf{M}_{ij}^{\Xi_\ell}$: concentration share in i from industrial, goods traffic, commuter traffic in j

1. Simulate pollution transport matrix γ_{ij} using ADMS model (2018, avg'ed)
2. Estimate emission rates $\mu_y, \mu_{\Xi_y}, \mu_{\Xi_l}$ using gridded top-down sectoral emissions inventory (EDGAR)
3. Generate $\mathbf{M}_{ij}^y, \mathbf{M}_{ij}^{\Xi_y}, \mathbf{M}_{ij}^{\Xi_\ell}$ using γ_{ij}, $\mu_y, \mu_{\Xi_y}, \mu_{\Xi_l}$ and output in each location

Example of a row γ_{ij}



Notes: This figure shows an example of γ_{ij} for a given row i. These can be interpreted as the proportion of concentrations in mauza i which are attributable to mauza j. These are calculated using the source apportionment option of the ADMS model with mauzas modelled as areas with homogenous emissions, receptors placed in a 500m$\times$500m grid and using 2018 meteorological data. γ_{ij} are calculated as the PM2.5 concentration from mauza j as a share of concentration from all sources, averaged across all receptors in i.

Other Data Inputs

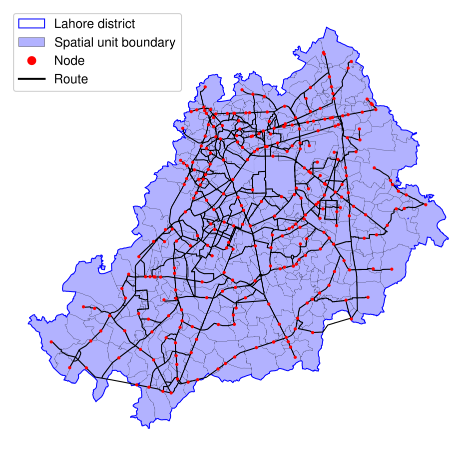
For counterfactual, need coefficient matrices:

- **Output Y_i:** from Pakistan's VAT data (Balboni et al., 2025)
- **Traffic:**
  - **Commuter traffic:** mobile phone signals from Quadrant (2024), projected on edges, scaled by volumes from Punjab traffic survey
  - **Goods traffic:** GPS tracker data from original equipment manufacturer (Balboni et al., 2025), projected on edges, scaled by volumes from Punjab traffic survey
- **Residential population:** 30m grid from Meta (2021) using satellite imagery and census data
- **Employment:** Residential population times commuting matrix (from cellphone data)

Empirical Implementation of the Model

Locations = 361 'mauzas' (admin. units), network of major roads (OpenStreetMap)

Currently working on finer economic geography (not today ▸ ok, fine)



Calibrated elasticities

Parameter (with symbol)	Value	Method / source
Route elasticity (θ)	6.83	Allen & Arkolakis 2022
Traffic congestion elasticity (λ)	0.092	Allen & Arkolakis 2022
Agglomeration parameter (α)	-0.12	Allen & Arkolakis 2022
Relative congestion effect (ν)	5.01	TRB 2010, JICA 2010, Farooq & Akram 2018
Utility elasticity w.r.t. pollution (σ_h)	0.36	Greenstone et al 2025, Ebenstein et al 2017
Earnings elasticity w.r.t. pollution (σ_w)	0.09	Adhvaryu et al 2022

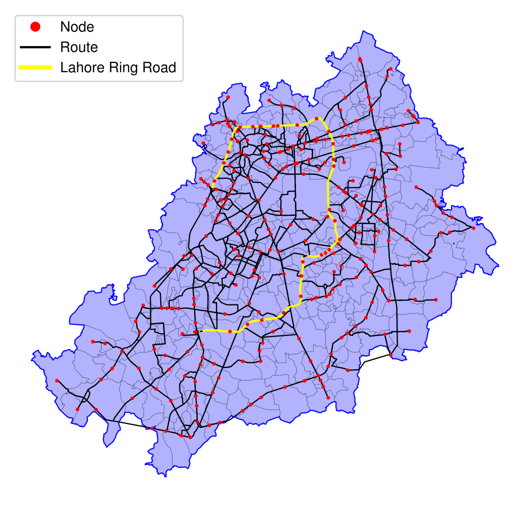
Counterfactual simulations

1. Does pollution change welfare assessment of road projects?
    - Evaluate opening of Lahore ring road from 2012-2024
2. Are there roads that have a net *negative* impact on welfare?
    - Estimate welfare effects of removing each road segment across city

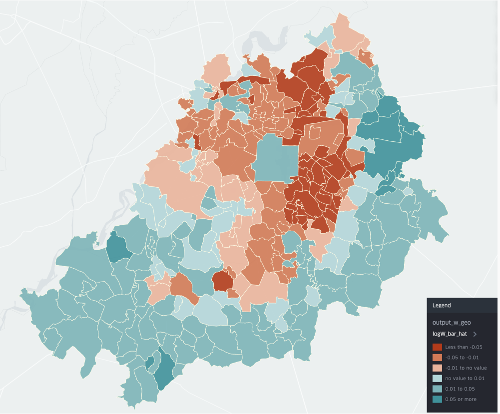
DISCLAIMER: Results are preliminary, numbers may change

Lahore ring road

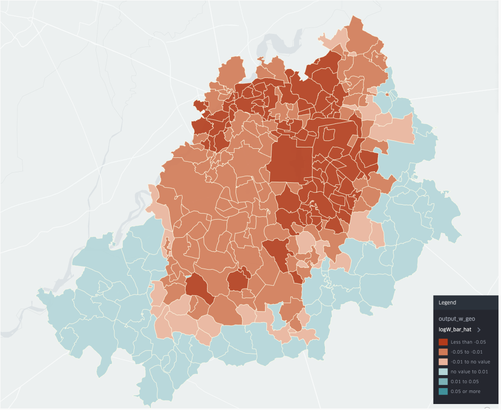
- Major orbital highway surrounding central city, opened in phases from 2012-2024
- Carries 400,000-500,000 vehicles daily
- Counterfactual triples the cost of using any part of the ring road ($\hat{\bar{t}} = 3$)



Pollution alters aggregate and distributional impacts of ring road



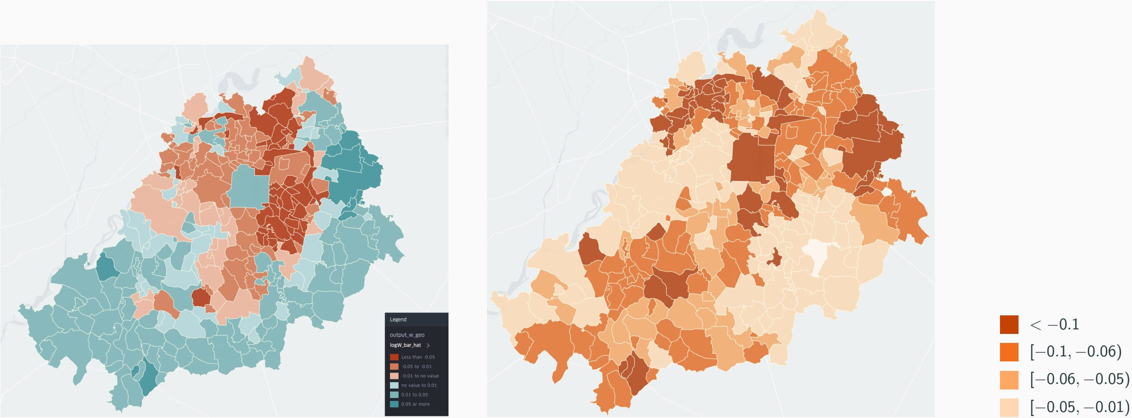
(a) Overall changes: $\Delta \log W^{\text{avg}} = -1.2\%$



(b) Excluding pollution: $\Delta \log W^{\text{avg}} = -4.3\%$
$\sigma_h = \sigma_w = 0$

< -0.05 $[-0.05, -0.01)$ $[-0.01, 0)$ $[0, 0.01)$ $[0.01, 0.05)$

Some places are made better off despite losing market access



(a) Welfare: $\Delta \log W$ **(b)** Pollution: $\Delta \log m$

Places with net welfare gains despite loss in market access are those with large reduction in pollution concentrations

▸ $\Delta \log Y$

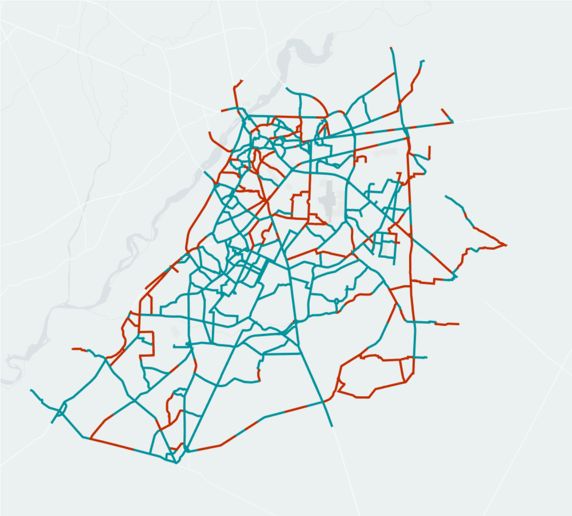
25% roads have negative aggregate welfare effects incorporating pollution

Loop over all roads:

For each road calculate population-weighted aggregate welfare if the road is switched off.

Roads where welfare goes up when road is shut down are colored in red.

▸ Euro-2 fuel standards



Notes: The figure shows the location of roads, colored in red, where aggregate (i.e. population-weighted) welfare $\bar{W}_i$ would increase when the road is shut down (simulated as a $100\times$ increase in trade costs). All other roads are colored in green.

Conclusions

- Air pollution literature: “air pollution has large impacts on health, productivity, etc”
- Trade/spatial literature: “gains from market integration are small in standard static QSM/QTM”

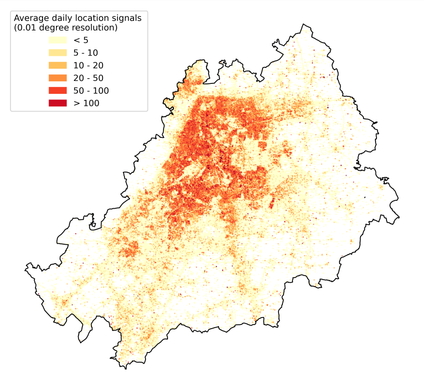
Integrated framework to compare both channels.

Take-aways:

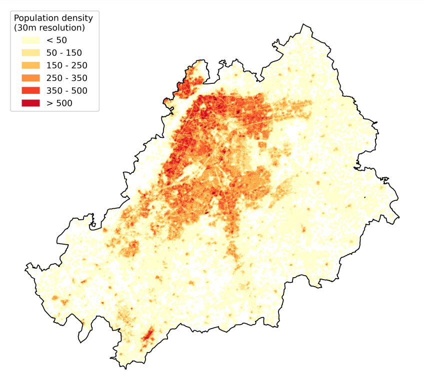
- Traffic is a non-negligible source of air pollution (in the context we study)
- Accounting for impacts from pollution can substantially affect welfare evaluation of transportation infrastructure
  - Aggregate & distributional impacts

BACKUP SLIDES

Mobile location data and population density

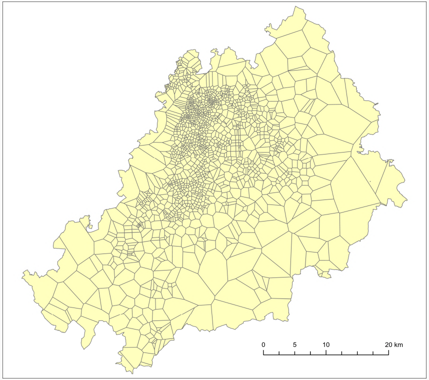


(a) Cellphone GPS signals

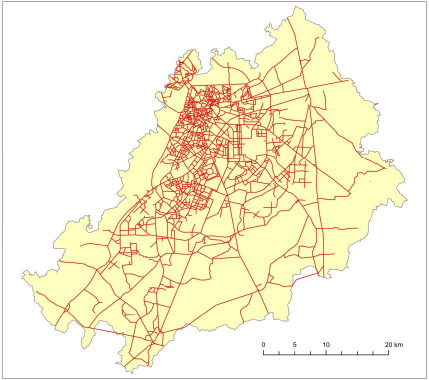


(b) Population density

More granular geography based on Voronoi cells



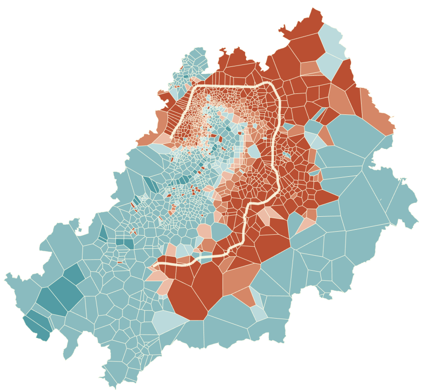
(a) Locations



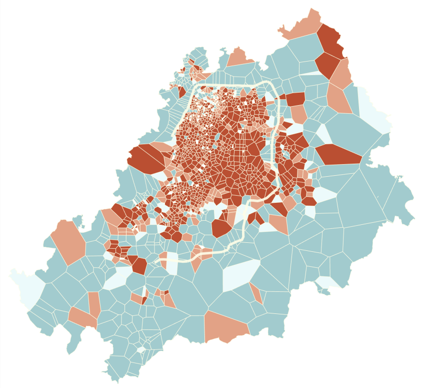
(b) Road network

▸ Back

Shutting down Ring Road in detailed geography



(a) Net welfare changes (red = drop)



(b) Change in traffic-related pollution (red = worsening)

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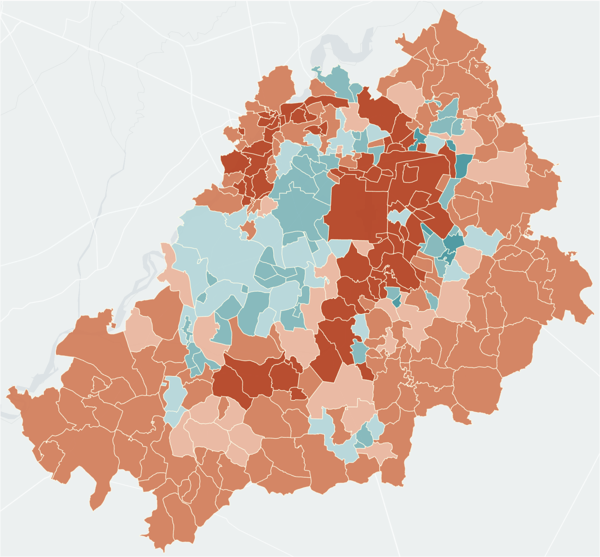
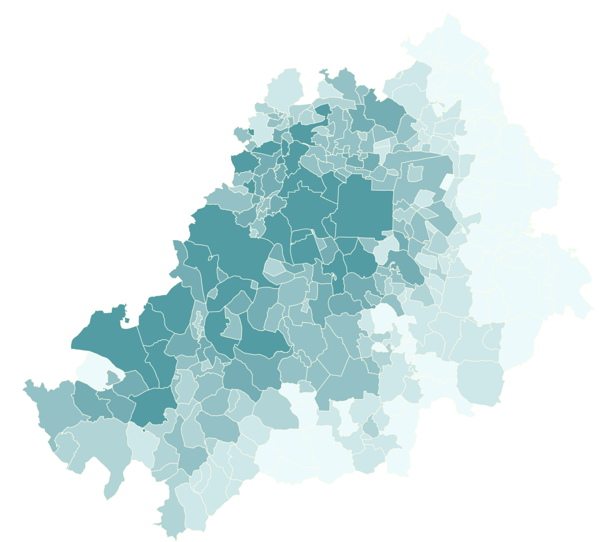
$\Delta \log Y$ from shutting down the Ring Road



■	< -0.05
■	$[-0.05, -0.01)$
■	$[-0.01, 0)$
■	$[0, 0.01)$
■	$[0.01, 0.05)$
■	≥ 0.05

$\Delta \log W$ from moving to cleaner Euro-2 fuel standards: $\Delta \log W^{\text{agg}} = 8\%$



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