High-Speed Rail's Hidden Costs: Uneven Pollution Burdens

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Selected Poster prepared for presentation at the 2025 AAEA & WAEA Joint Annual Meeting in Denver, CO: July 27-29, 2025

Greener on the Track, Dirtier by the Plant: The Air Pollution Costs of High-Speed Rail

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INTRODUCTION

Research Background

- China has the largest high-speed rail (HSR) network in the world, which accounts for 70%+ of global HSR mileage.
- Prior research focuses more on economic benefits while **underexploring environmental costs.**

Key Problem

- **Spatial Mismatch:** Environmental costs from HSR operations concentrate around coal power plants, not along HSR corridors.
- **Coal Dependency:** 60% of China's electricity from coal creates substantial pollution externalities.

Research Contribution

- **Novel Approach:** Quantify HSR pollution costs by linking PM2.5 near power plants to HSR electricity demand.
- **Policy Relevance:** Inform compensation mechanisms between HSR beneficiaries and pollution-bearing communities.

INSTITUTIONAL BACKGROUND

• Fully Electrified System

All HSR trains in China rely entirely on electricity delivered through overhead lines.

• Provincial Grid Structure

In China, electricity markets are organized primarily at the **provincial level**. Most HSR electricity demand is met locally—within the same province where the train operates.

• Equal Share Dispatch Rule

In China, a substaintial part of power load was allocated under **a non-market rule** called Equal Share Dispatch, whereby coal plants with similar capacity were assigned equal operating hours regardless of cost or efficiency.

• Implication for Attribution

This dispatch rule allows me to **approximate plant-level electricity supply responsibility** based on installed capacity—essential for linking HSR operations to pollution near specific coal plants.

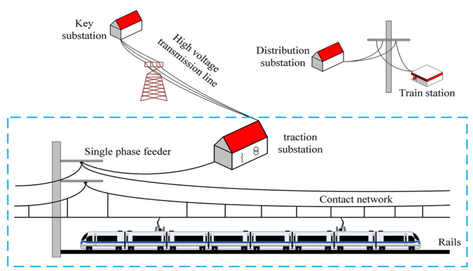

Fig.1 The HSR Power Supply System Structure Diagram

Source: Liu, Chang & Yang, Shiwu & Cui, Yong & Chu, Shaotong & Xiong, Qihui. (2021). An improved quantitative assessment method on hazardous interference of power lines to the signal cable in high-speed railway. IET Electrical Systems in Transportation.

RESEARCH DESIGN

Train-kilometers as Proxy for Electricity Demand

- Missing train model specifications and occupancy rates.
- Accurate electricity demand modeling of trains requires complex aerodynamics calculations.
- Train-kilometers is a standard proxy for railway operation intensity.
- Higher train-kilometers --> Higher electricity consumption

Aggregate Train-kilometers by Province

- HSR draws power from local provincial grids.
- To capture province-level HSR-induced power load, I compute daily HSR train-kilometers across provinces by summing the travel distances of individual trains operating within each province:

$$\text{Train\_km}_{it} = \sum_{k \in \{\text{trains in province } i \text{ on day t}\}} \text{Travel Distance of Train } k \text{ in province } i$$

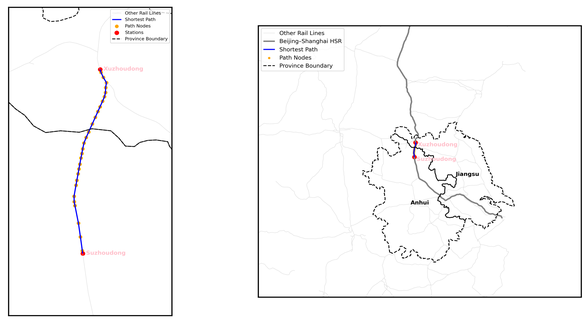

Fig.2 Illustration of Calculating Railroad Travel Distance

Plant-Level Allocation of HSR Load

- Calculate the plant-level workload according to the Equal Share Dispatch Rule.

$$\text{Train\_km}_{j,it} = \text{Train\_km}_{it} \times \frac{\text{Capacity}_{j,i}}{\sum_j \text{Capacity}_{j,i}}$$

Estimate the pollution cost of HSR

- Regress the daily PM2.5 concentrations around power plants on their HSR workload.

$$\ln \text{PM}_{j,it} = \alpha \text{ Train\_km}_{j,it} + \mathbf{Weather}_{j,it}\boldsymbol{\beta} + \eta_j + \text{DOW}_t + \theta_{it} + u_{j,it}$$

- α mearsures the pollution cost of powering HSR trains
- Weather controls √
- Power plant fixed effects √
- Day-of-week fixed effects √
- Province-by-month fixed effects √

DATA

- **Davis et al. (2025) :** GIS information of HSR routes, stations, and speed limits in shapefiles.
- **Zhang et al. (2022):** timetable records of 3,399 HSR trains, from October 8, 2019 to January 27, 2020.
- **Global Coal Plant Tracker:** geographic location and capacity information of all coal-fired units witn an installed capacity of 30 MW or greater.
- **Wei et al. (2023):** 1-km gridded PM2.5 concentration dataset for China

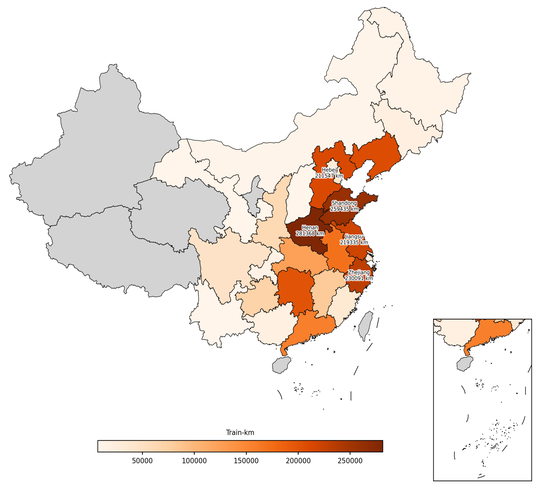

Fig.3 Provincial Train-kilometer Heat Map on 01/01/2020

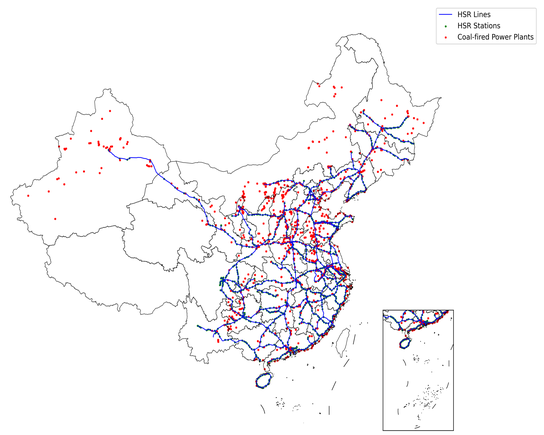

Fig.4 HSR Network and Coal-fired Power Plants in China (2020)

RESULTS

Baseline results

- For an individual power plant, powering an additional 1,000 km of HSR travel increases nearby PM2.5 levels by 2.39%–2.84%.
- This translates to an increase of 1.33–1.58 μg/m³ in PM2.5 concentration near the power plant in the sample period.
- Results are robust when air pollution is measured using aerosol optical depth (AOD).

Table 1 Baseline Regression Results

	(1) lnPM	(2) lnPM	(3) lnPM	(4) lnPM
HSR Train-kilometers (10^3 km)	0.0432	0.0284	0.0239	0.0284
	(0.0113)	(0.0080)	(0.0079)	(0.0103)
Precipitation (mm)	-0.0249	-0.0219	-0.0224	-0.0230
	(0.0014)	(0.0011)	(0.0011)	(0.0013)
Wind Speed (m/s)	-0.2202	-0.1771	-0.1734	-0.1453
	(0.0095)	(0.0092)	(0.0091)	(0.0082)
Air Pressure (hPa)	-0.0103	-0.0066	-0.0066	-0.0078
	(0.0007)	(0.0005)	(0.0005)	(0.0016)
Temperature (°C)	-0.0300	0.0155	0.0137	0.0144
	(0.0012)	(0.0017)	(0.0017)	(0.0024)
Constant	14.2810	10.4675	10.4256	11.5417
	(0.7010)	(0.4931)	(0.5234)	(1.5024)
Plant FE	Yes	Yes	Yes	Yes
Province-by-Month FE	No	Yes	Yes	Yes
Day-of-Week FE	No	No	Yes	No
Day FE	No	No	No	Yes
Adj. R^2	0.468	0.594	0.603	0.673
Observations	78064	78064	78064	78064

Notes: Standard errors clustered at the city level are reported in parentheses below the estimates.

Pollution Costs across Provinces

Overall, HSR-induced pollution **costs are significant** in provinces with **both a high coal share and intense HSR operations** — many of which are located in Eastern China.

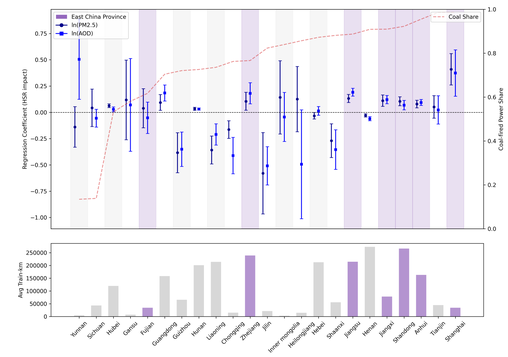

Fig.5 Coal-fired Power Shares and Pollution Costs across Provinces

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