The Largest Low Emission Zone of Europe: Traffic and Air Quality in London

Hendrik Wolff and Muxin Zhai

University of Washington

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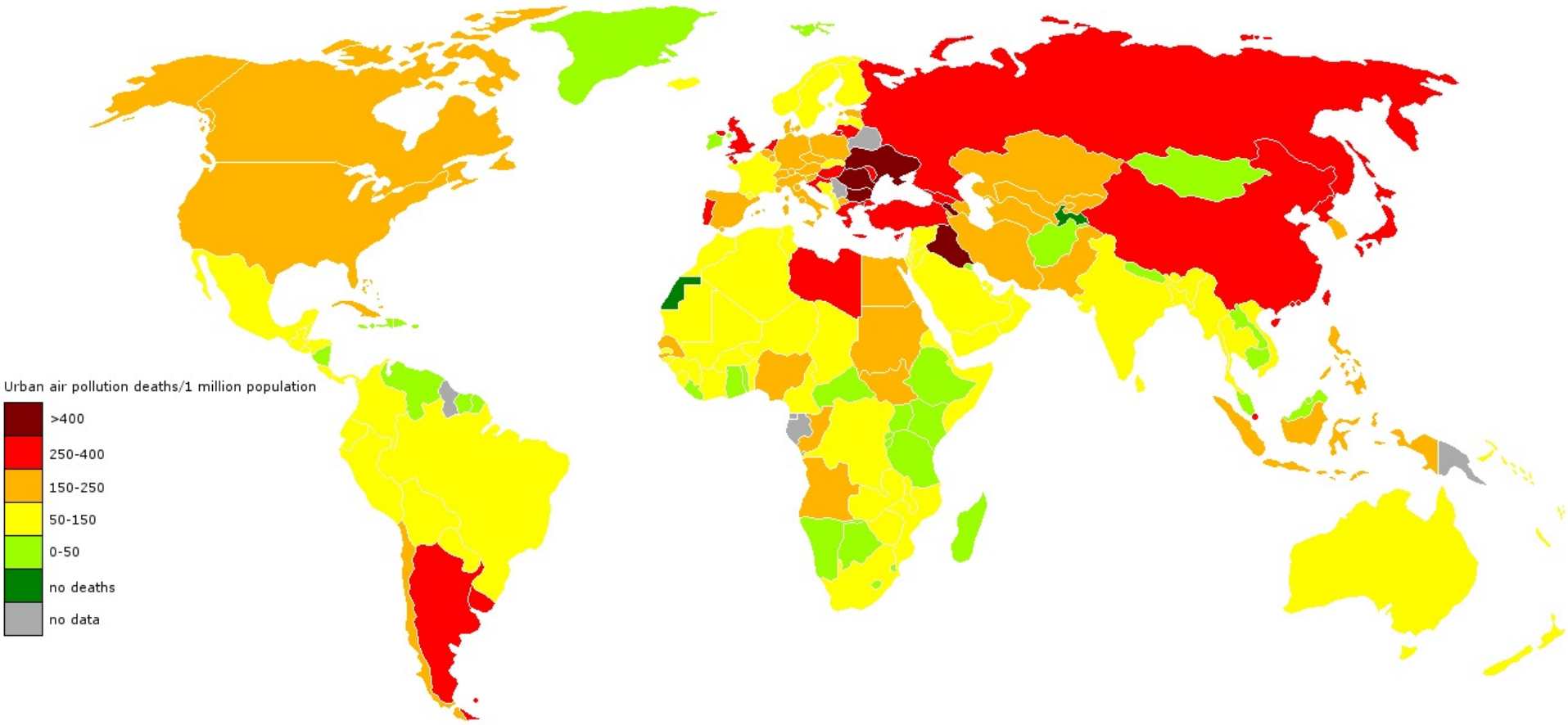
Table of contents

Table of Contents

Why do we care?



Why do we care?

- Exposure to air pollution accounted for 7 million deaths worldwide in 2012, including almost 600,000 in the WHO European Region. (WHO report, March 24, 2014)
- In Europe alone, the direct costs to society from air pollution amount to about €23 billion per year, and the external costs from health impacts are estimated at €330-940 billion (3-9% of EU GDP). (The European Commission, EUROPA, 2014)

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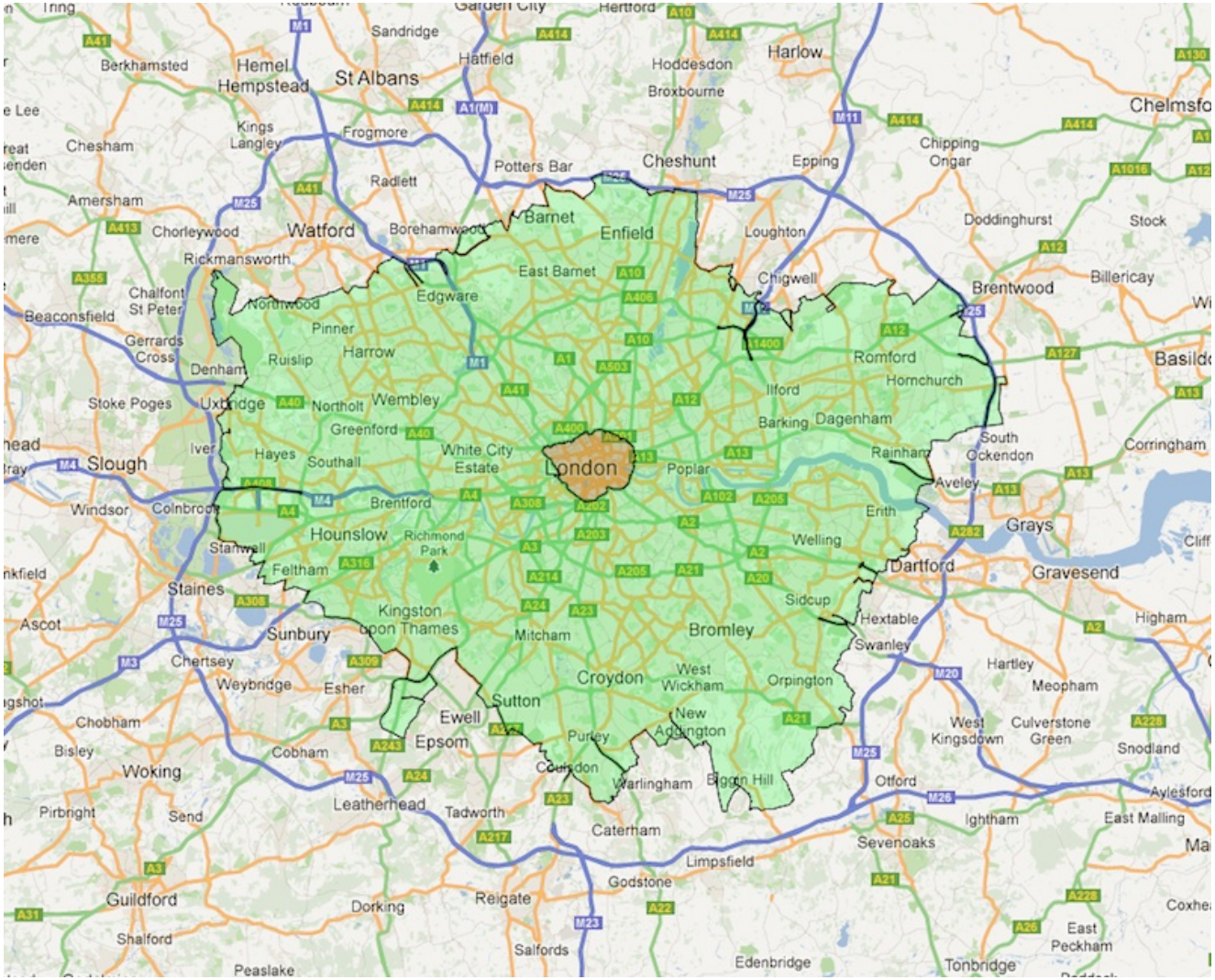
Traffic Regulation

- Direct regulation: Command-and-control
  - License plate program
    - Davis, L. (2008 JPE): *The Effect of Driving Restrictions on Air Quality in Mexico City*
    - Chen, Y., Ginger, Z., Kumar, N., Shi, G. (2013 JEEM): *The Promise of Beijing: Evaluating the Impact of the 2008 Olympic Games on Air Quality*
  - Low emission zone
    - Wolff, H. (forthcoming): *Keep Your Clunker in the Suburb: Low Emission Zones and Adoption of Green Vehicles*
- Indirect regulation: Economic-incentive
  - Congestion charge zone
    - Leape, J. (2006 JEP): *The London Congestion Charge*
  - Low emission zone: London

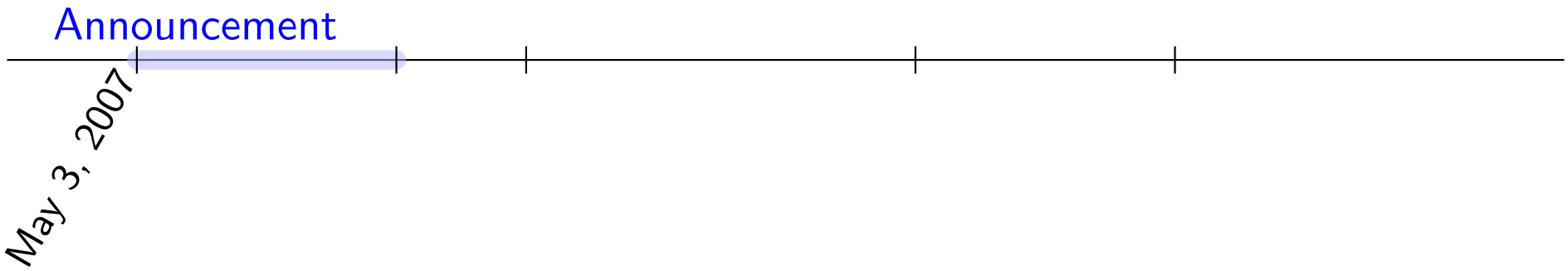
This paper...

- uses a unique dataset on air quality and weather conditions throughout England
- is the first empirical analysis on the world largest low emission zone - the London LEZ
- is the first empirical research to exploit the spatial heterogeneity on both:
  - the type of vehicles (i.e. Heavy vs. Light truck)
  - WHERE these vehicles drive (road stations vs. industrial stations)

London Low Emission Zone: Map



London Low Emission Zone: Timeline



London Low Emission Zone: Timeline

£200

HGV, truck

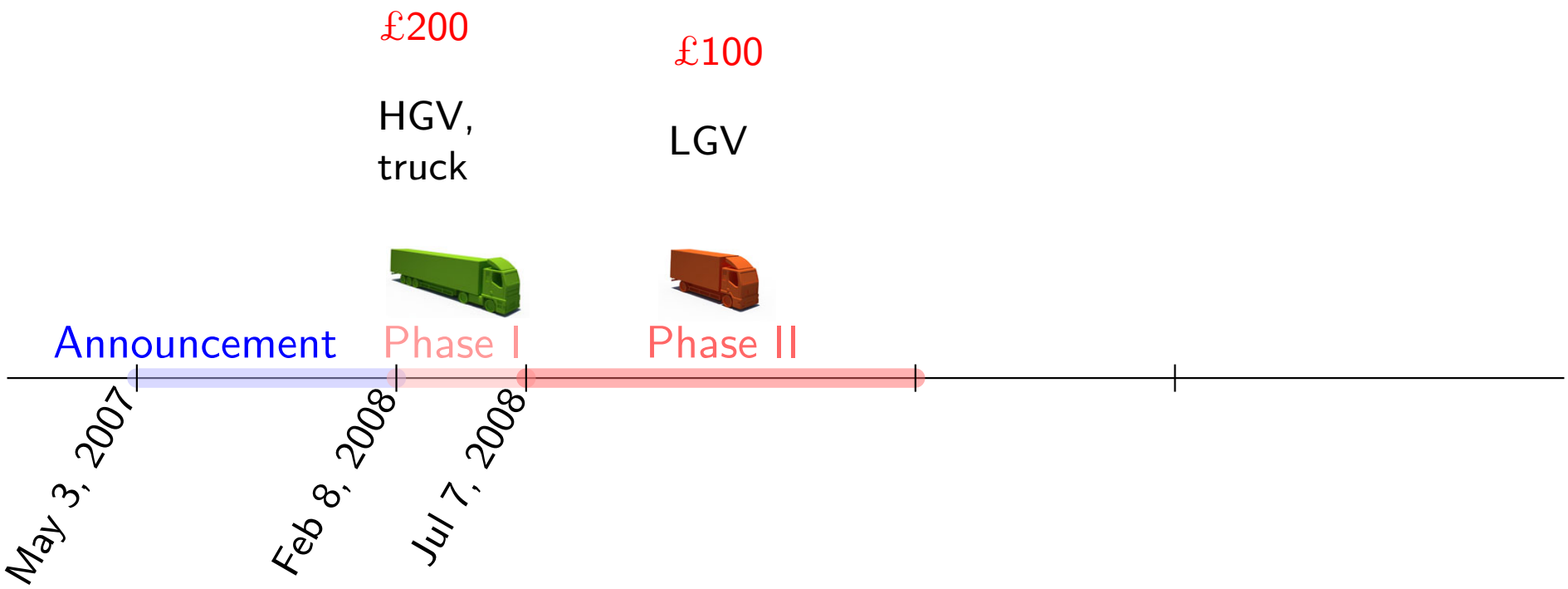
Announcement

Phase I

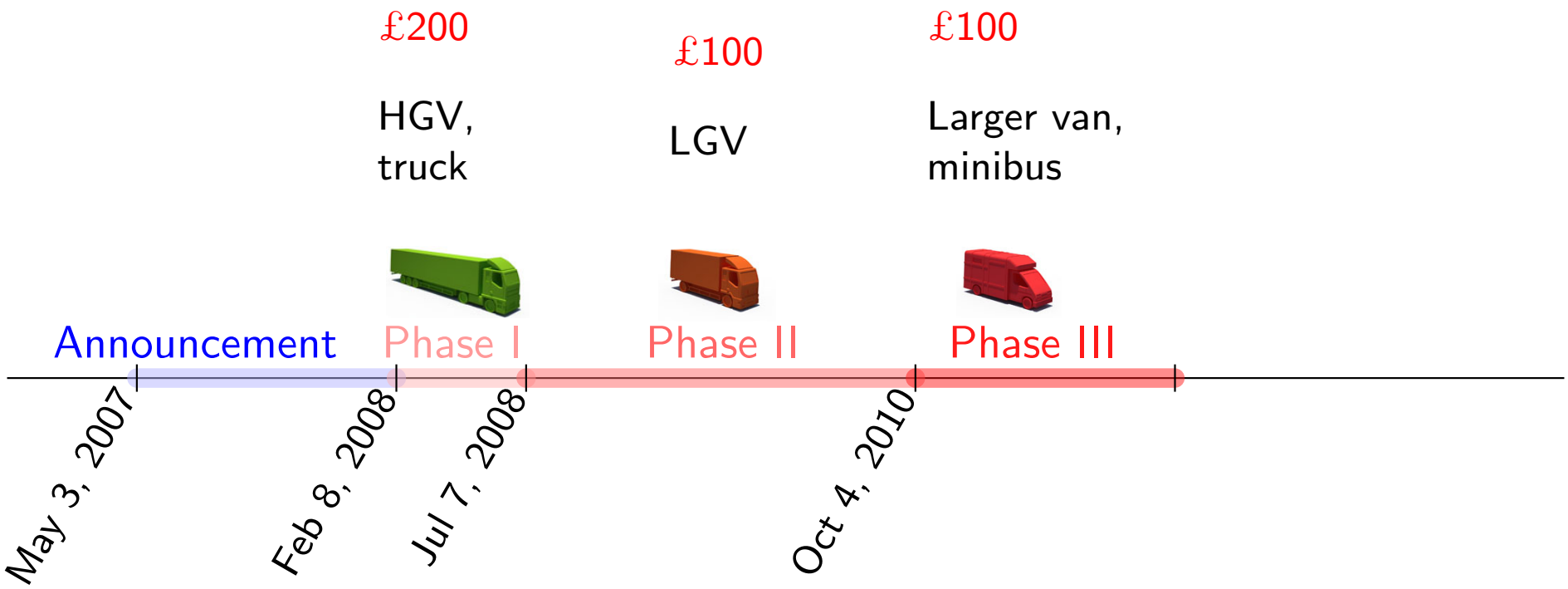
May 3, 2007

Feb 8, 2008

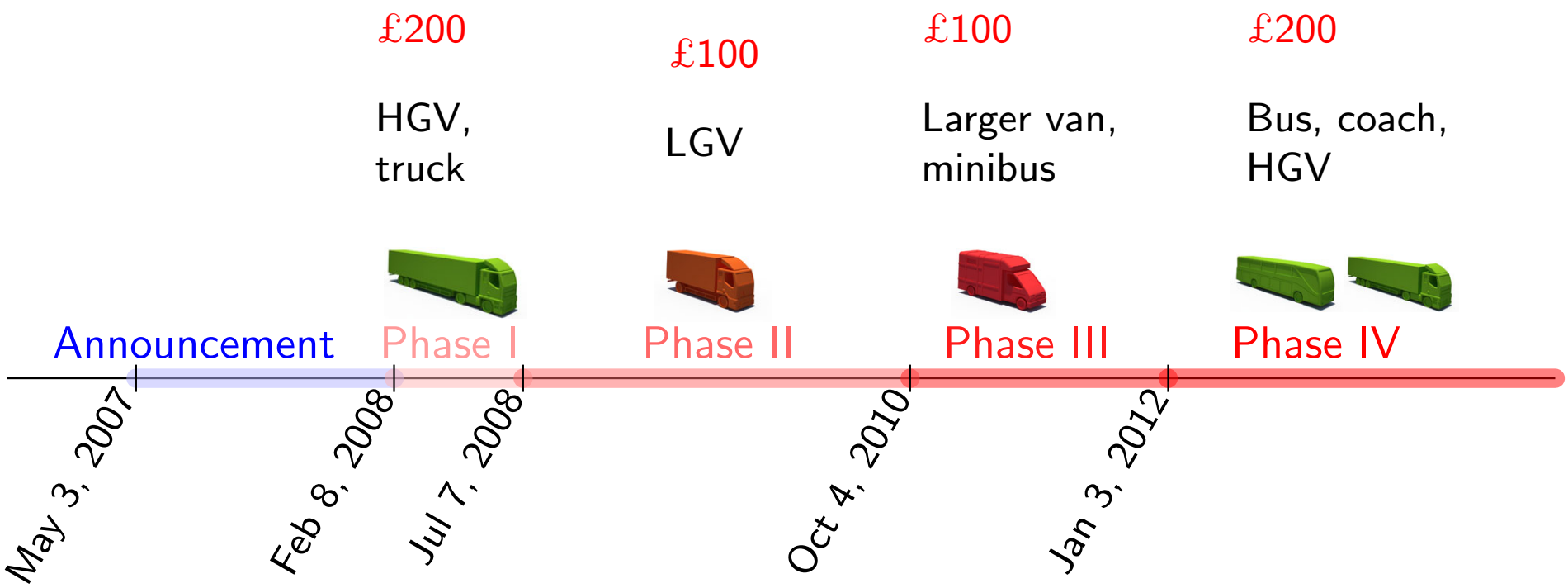
London Low Emission Zone: Timeline



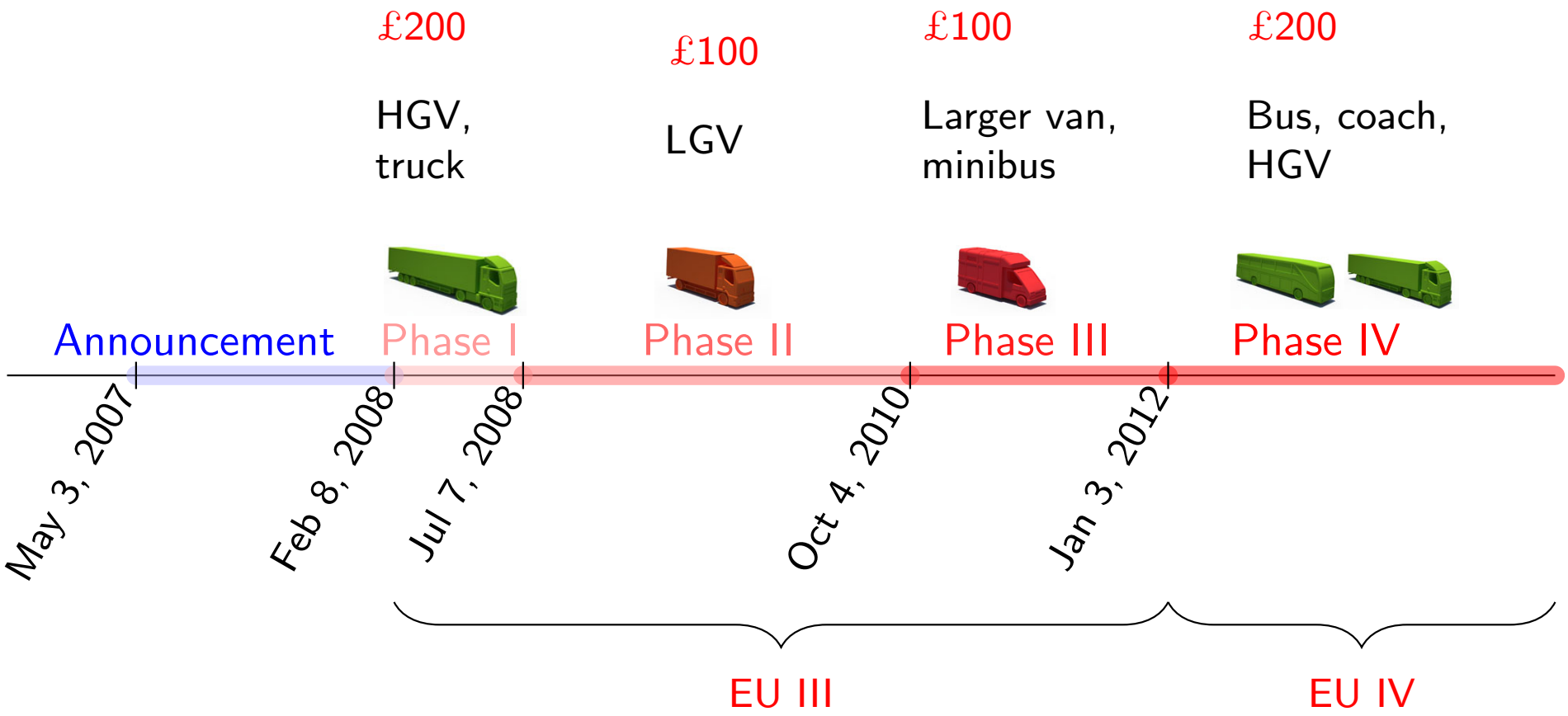
London Low Emission Zone: Timeline



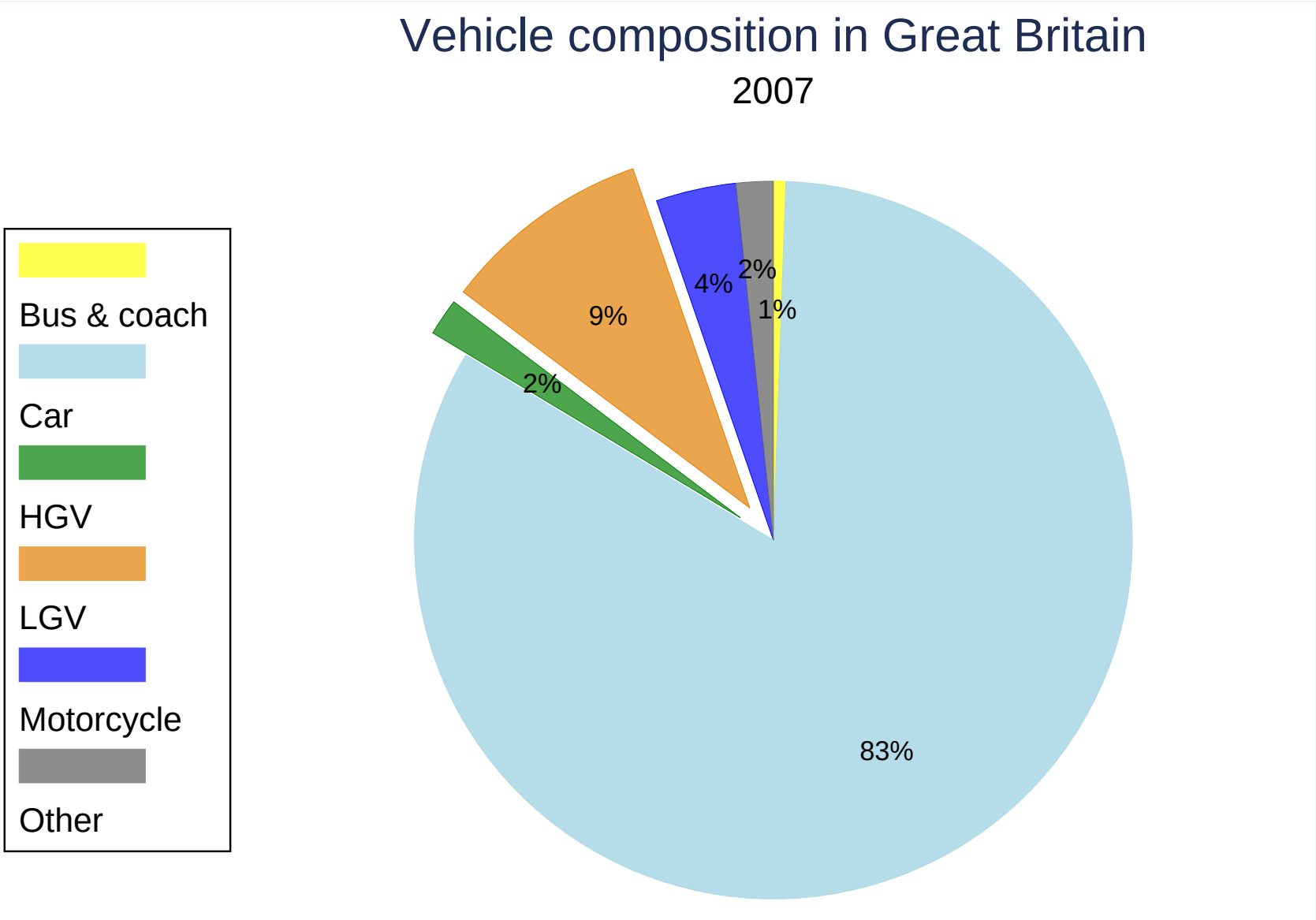
London Low Emission Zone: Timeline



London Low Emission Zone: Timeline



London Low Emission Zone: Subject vehicles



London Low Emission Zone: Signs

Sourses: Traffic for London

Table of Contents

Data Sources

- Airborne particulate matter (PM10) data
  - Data Source:
    - London Air Quality Network (LAQN)
    - Air Quality England (AQE)
  - Number of stations: 58
  - Data time range: 2005 - 2010, daily level
- Weather data
  - Data source: WeatherSpark
  - We match each LAQN and AQE station with the nearest WeatherSpark station

Station Types

- Each LAQN or AQE station has a classification according to its relative distance to major sources of pollution.

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- Roadside station

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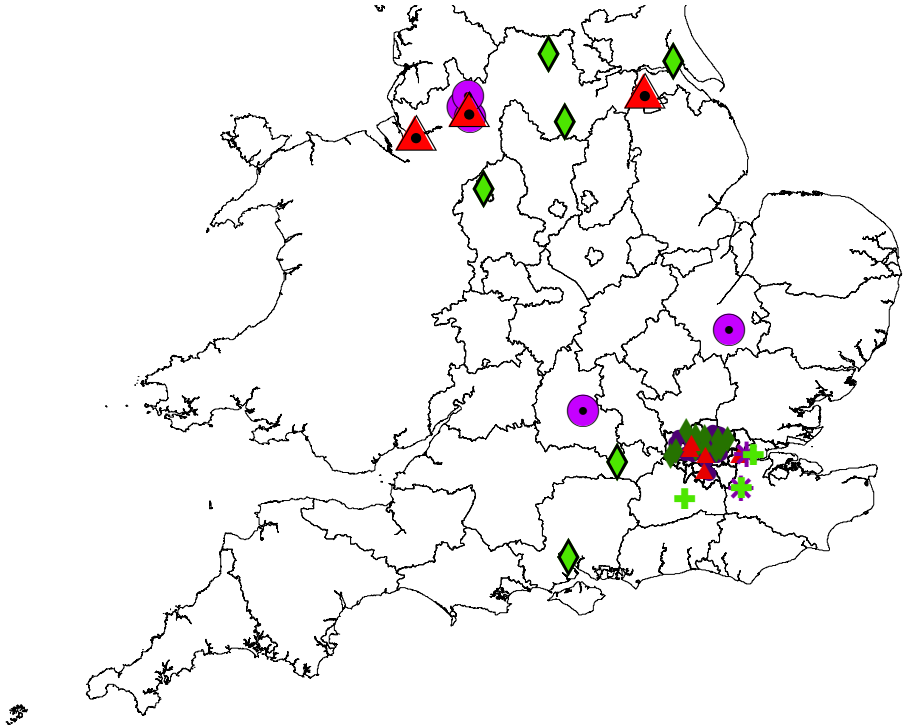
- Roadside station

- Industrial station

- Urban background station

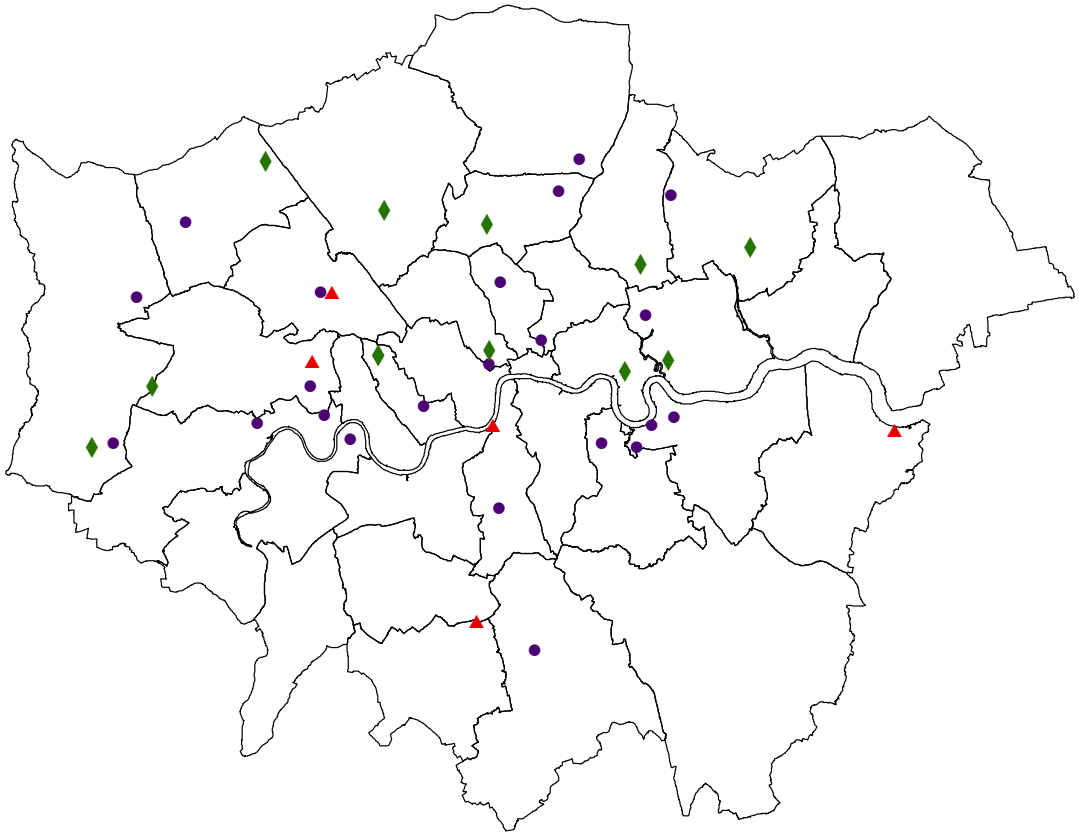
Station Locations: LAQN and AQE



Station locations in southern England

- Treated - Roadside
- Treated - Urban Background
- Treated - Industrial
- Control - Roadside
- Control - Urban Background
- Control - Industrial
- Outside - Roadside
- Outside - Urban Background

Station Locations: LAQN and AQE



Station locations within Greater London

▲ Industrial ♦ Urban Background • Roadside

Summary Statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
Air pollutant					
PM10 ($\mu g/m^3$)	26.08	15.11	0	383	115777
Station groups					
Treated (1=treated)	0.67	0.47	0	1	127078
Outside (1=outside)	0.09	0.28	0	1	127078
Control (1=control)	0.24	0.43	0	1	127078
Station Types					
Roadside (1=roadside)	0.5	0.5	0	1	127078
Industrial (1=industrial)	0.14	0.34	0	1	127078
Urban background (1=urban)	0.36	0.48	0	1	127078
Weather conditions					
Humidity (%)	0.78	0.11	0.27	1	126954
Hours of rain (*hours*)	3.31	4.48	0	24	127078
Light rain (1=light rain)	0.13	0.33	0	1	127078
Moderate rain (1=mod. rain)	0.24	0.43	0	1	127078
Heavy rain (1=heavy rain)	0.01	0.11	0	1	127078
Air pressure ($mBar$)	1014.6	10.8	966.6	1046	126910
Temperature (^oC)	10.99	5.82	-10.45	28.02	127002
Average wind speed (m/s)	4.22	1.84	0.00	22.73	126990
Maximum wind speed (m/s)	6.79	2.61	0.1	35.2	126990
Other covariates					

Table of Contents

Difference-in-Differences Approach

- Main specification:

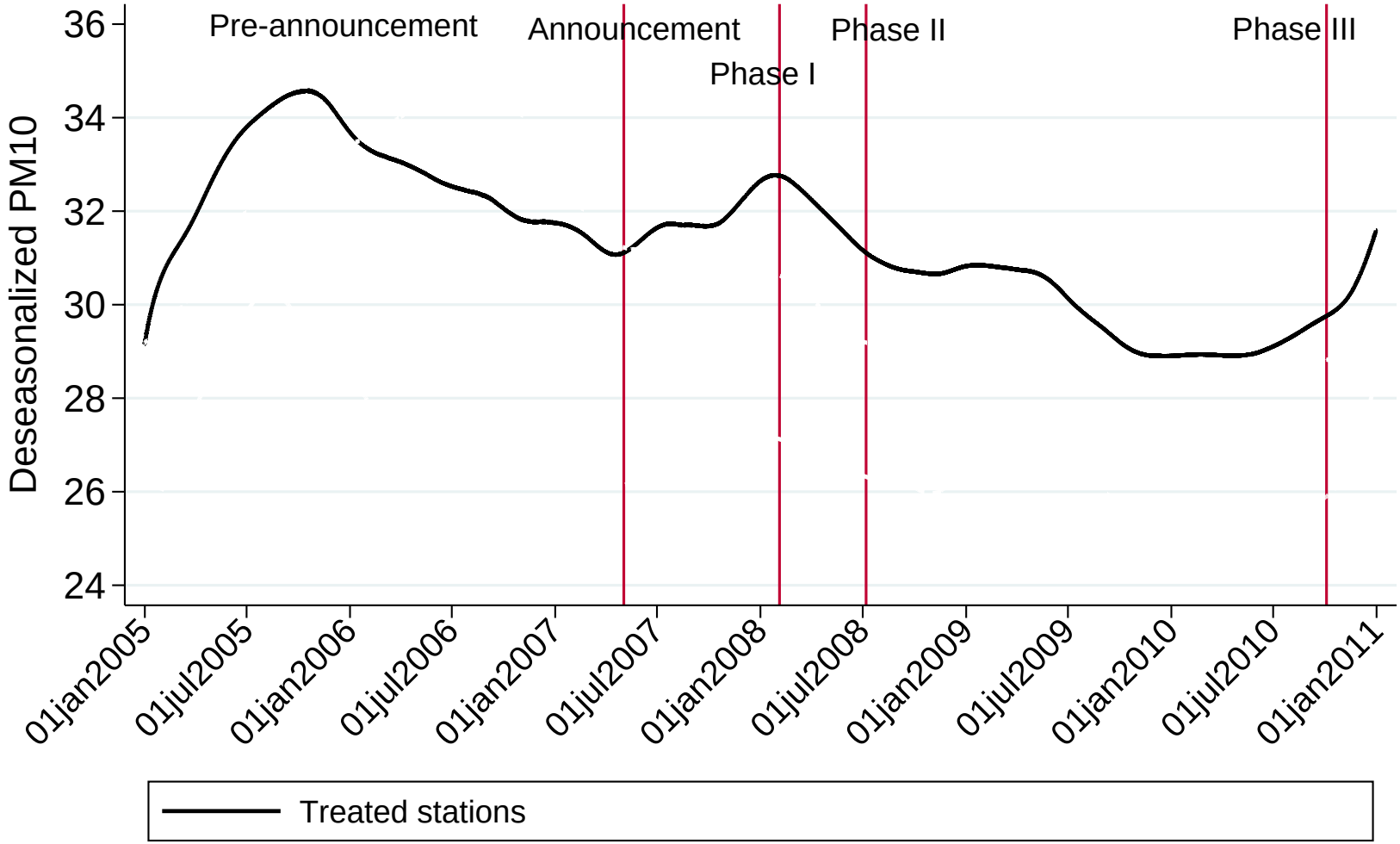
$$\log(PM10_{it}) = \sum_{\tau=0}^{\tau=3} \beta_\tau P_\tau + \sum_{\tau=0}^{\tau=3} \gamma_\tau P_\tau Tr_i + \sum_{\tau=0}^{\tau=3} \delta_\tau P_\tau Out_i + \theta_i + f(\lambda_t) + \mathbf{X_{it}}\boldsymbol{\Gamma} + \varepsilon_{it} \quad (1)$$

  - P_τ is the indicator for LEZ phases (0=announcement, 1=phase I, 2=phase II, 3=phase III)
  - Tr_i and Out_i are time-invariant group indicators for "treated" and "outside" stations
  - θ_i captures unobserved station specific fixed effects (FE)
  - $f(\lambda_t)$ captures year fixed effects (FE) and month fixed effects (FE)
  - $\mathbf{X_{it}}$ is a covariate matrix
  - ε_{it} is robust standard errors clustered at station level

Table of Contents

Graphical Representation: PM10

- Roadside stations



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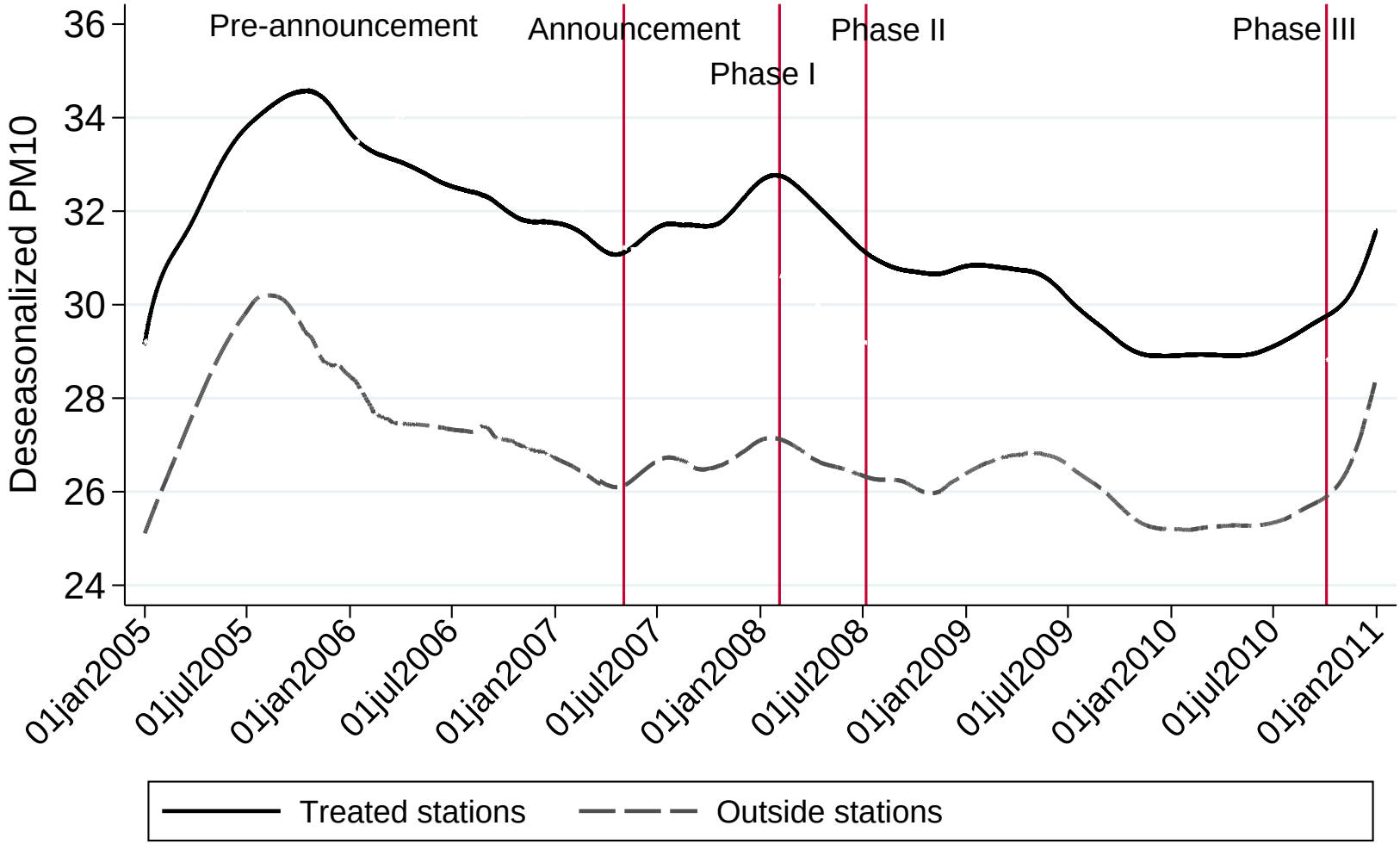

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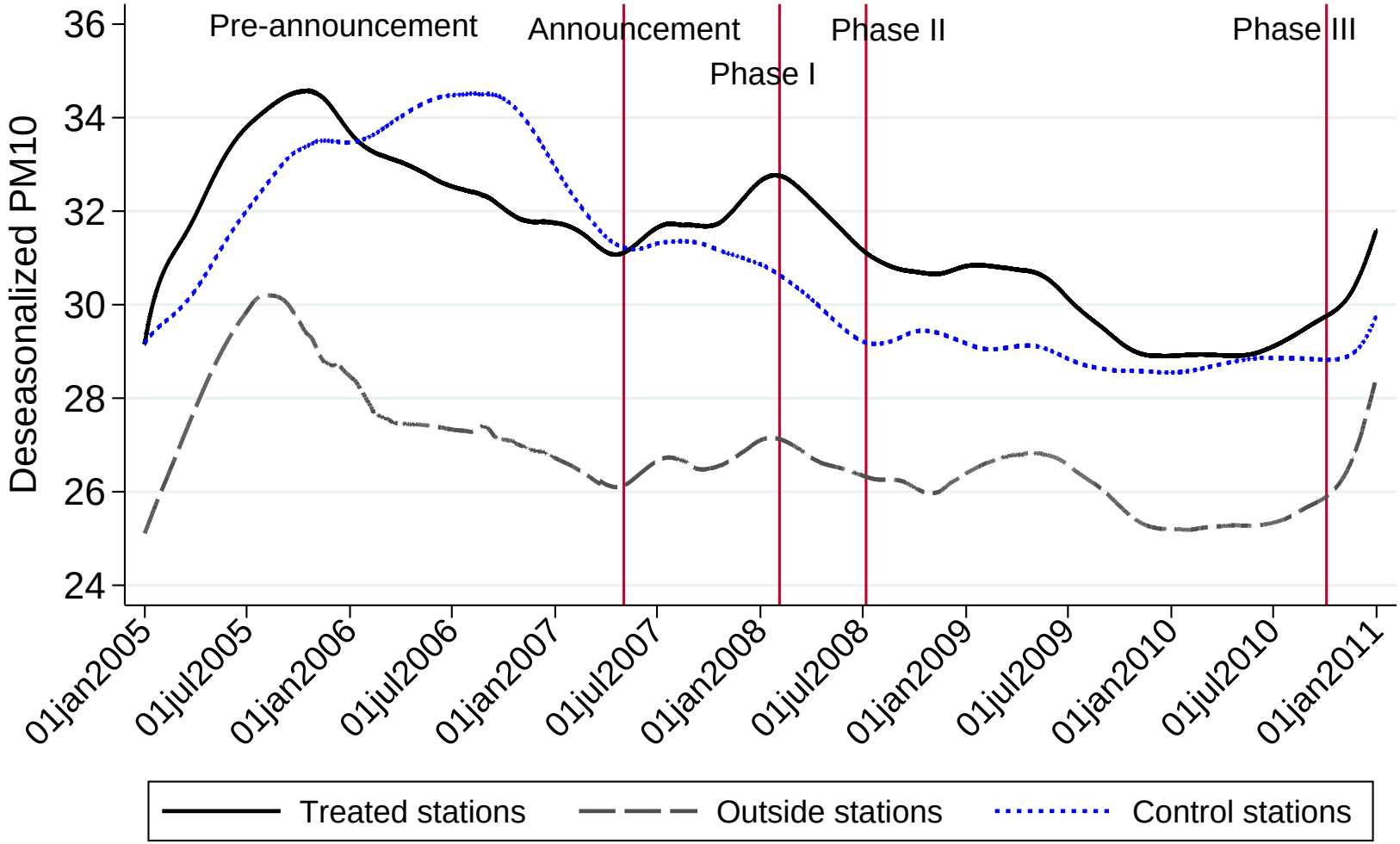
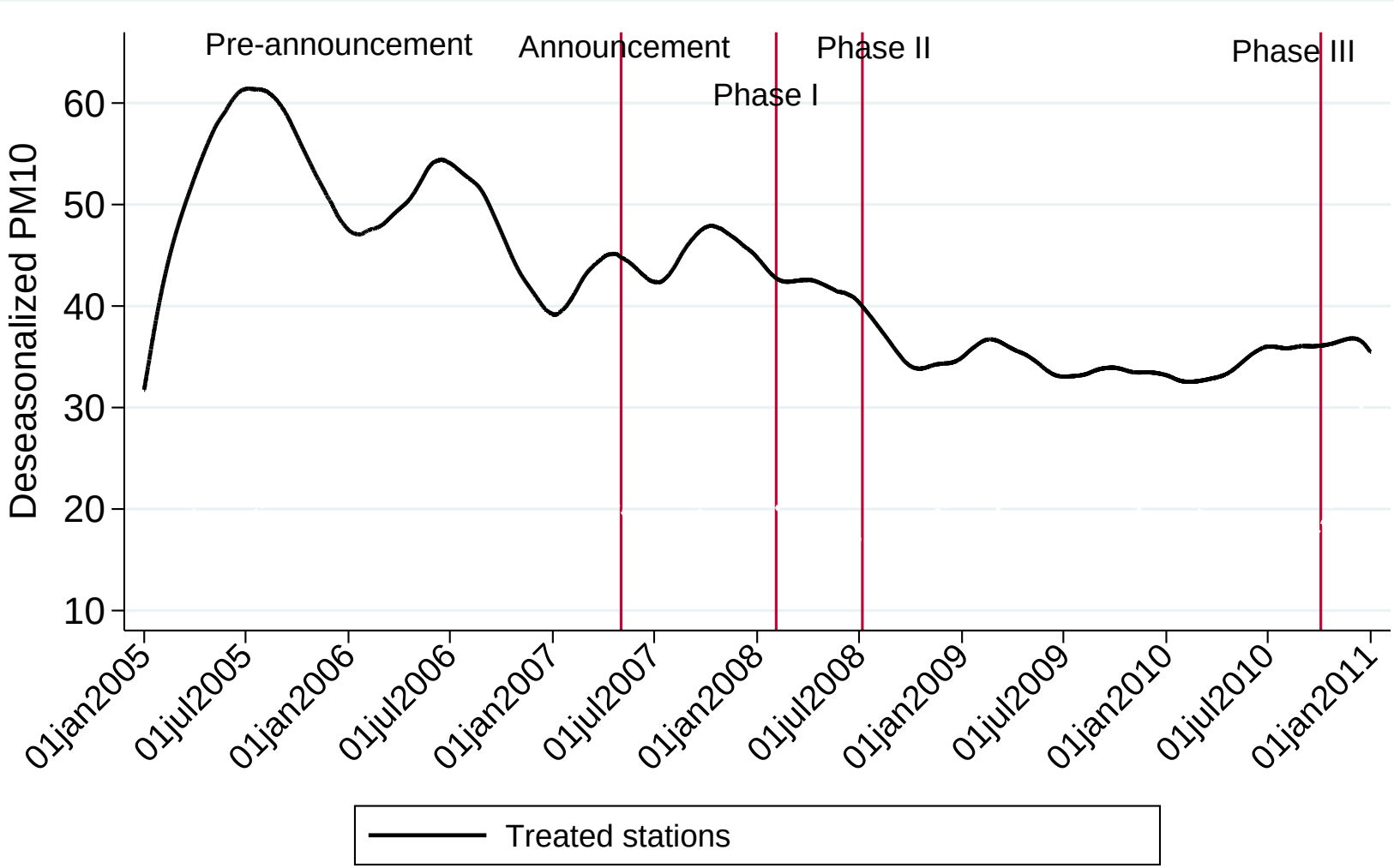


Graphical Representation: PM10

- Industrial stations



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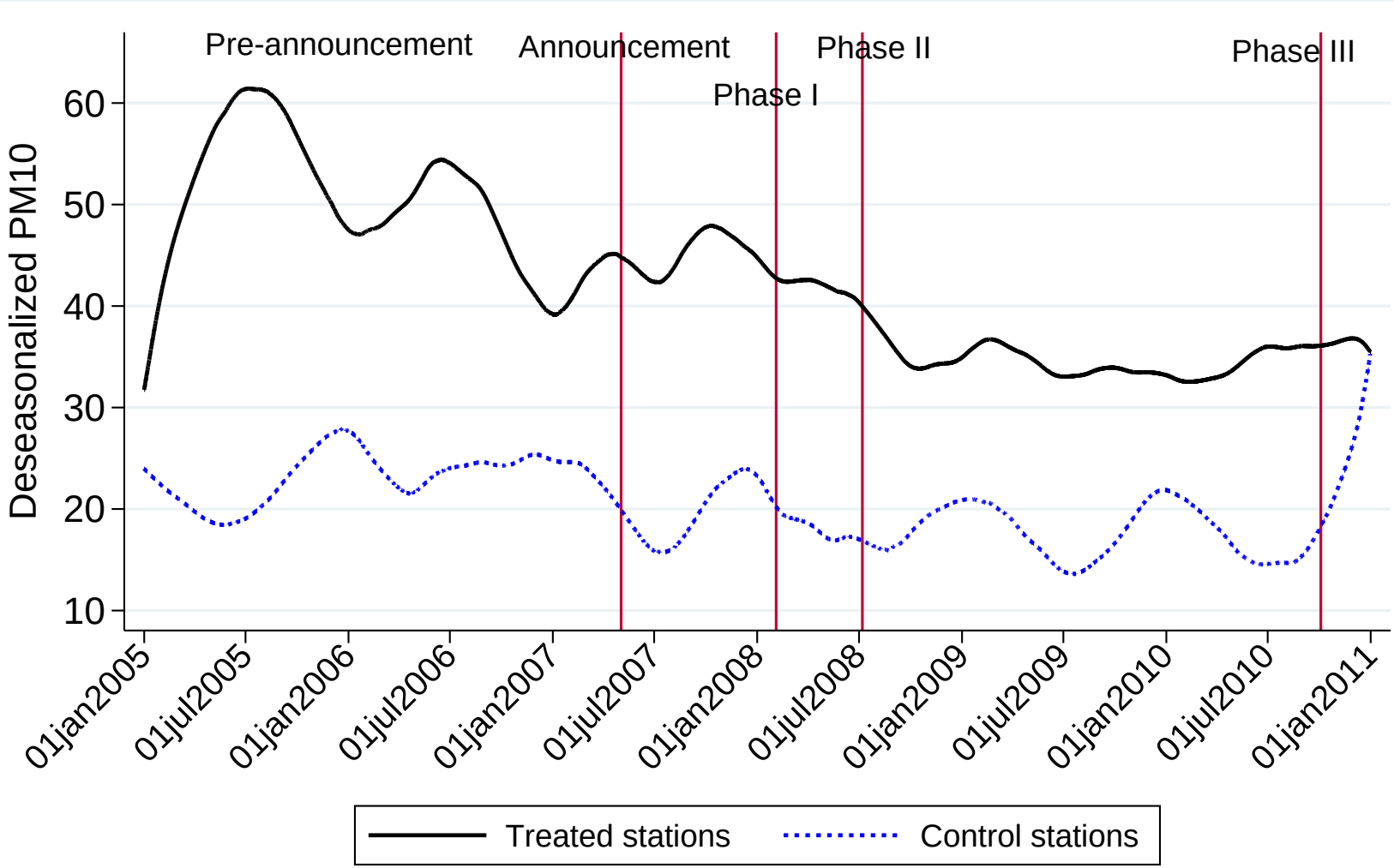

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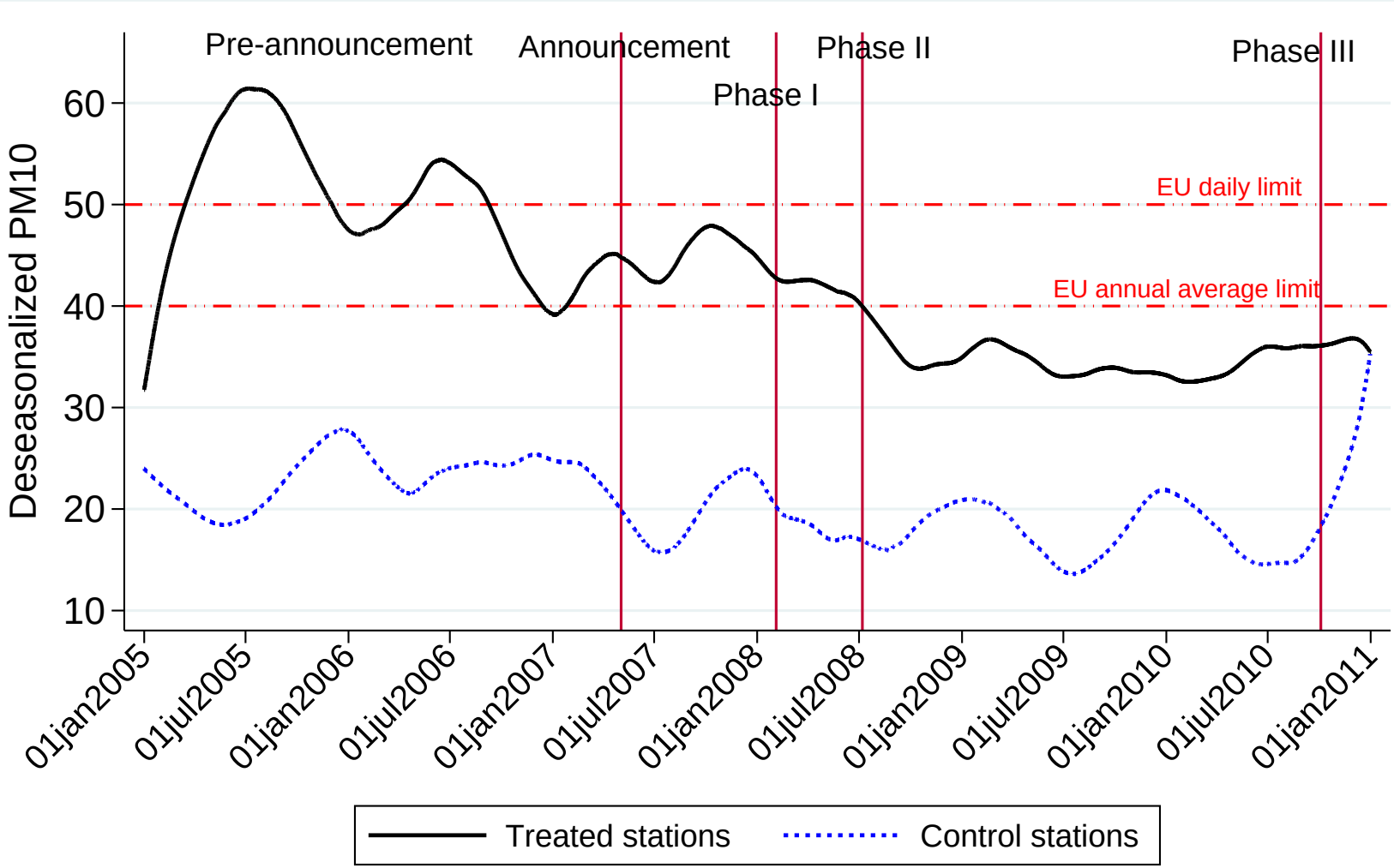


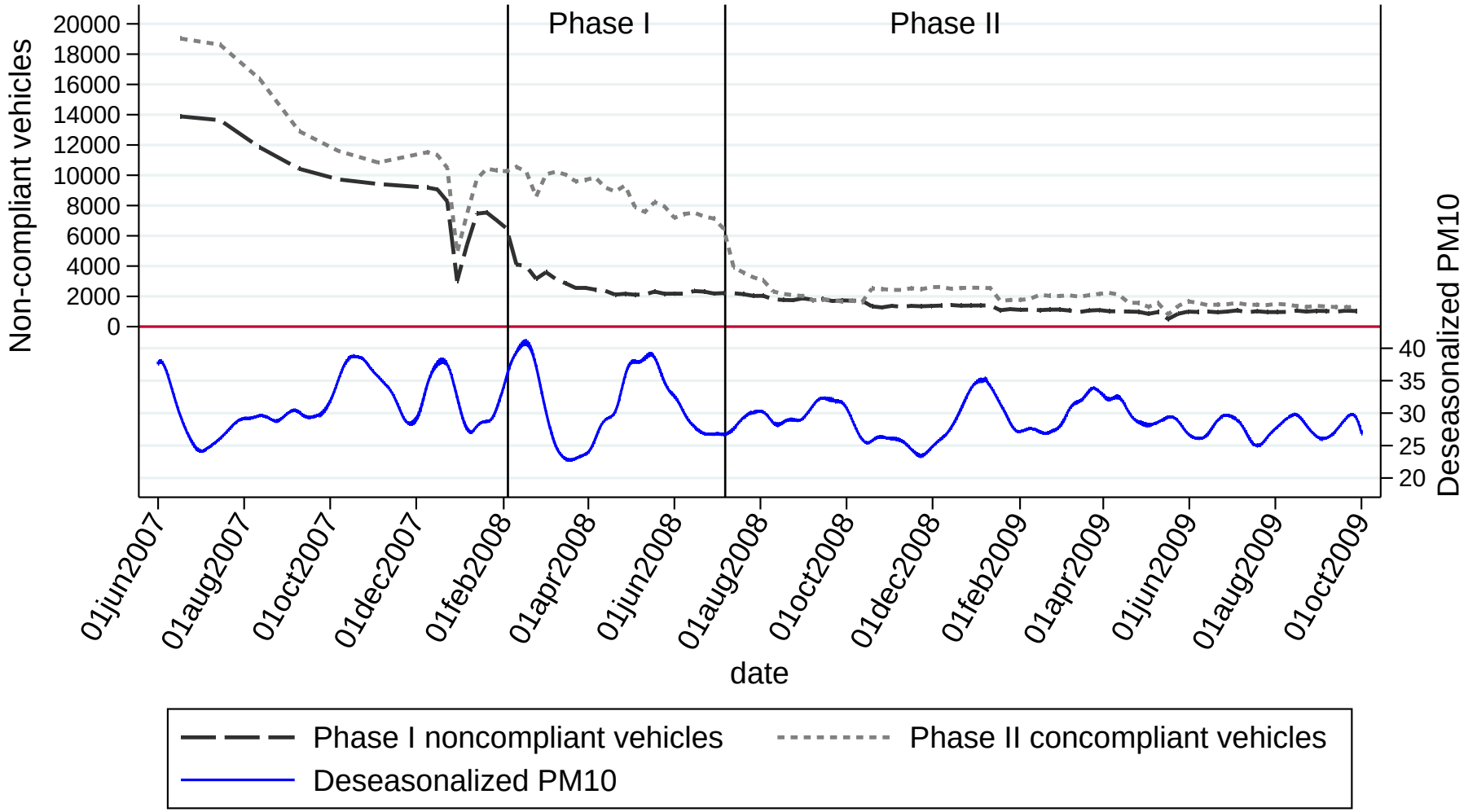
Estimation Results: Pooled Data

	(1)	(2)	(3)	(4)	(5)	(6)
Treatment effects						
LEZ announcement × treated	0.081*	0.081*	0.081*	0.061	0.057	0.056
	(0.042)	(0.042)	(0.042)	(0.041)	(0.041)	(0.041)
LEZ phase I × treated	0.019	0.041	0.040	0.025	0.036	0.036
	(0.038)	(0.035)	(0.035)	(0.033)	(0.033)	(0.033)
LEZ phase II × treated		-0.026	-0.025	0.006	-0.007	-0.005
		(0.026)	(0.027)	(0.027)	(0.027)	(0.027)
LEZ phase III × treated			-0.001	0.023	0.001	0.002
			(0.040)	(0.036)	(0.036)	(0.036)
Spillover trends						
LEZ announcement × outside	0.027	0.028	0.027	0.014	0.011	0.009
	(0.041)	(0.041)	(0.041)	(0.040)	(0.040)	(0.040)
LEZ phase I × outside	0.150***	0.057	0.057	0.034	0.045	0.046
	(0.046)	(0.035)	(0.035)	(0.034)	(0.034)	(0.034)
LEZ phase II × outside		0.109***	0.106***	0.140***	0.127***	0.128***
		(0.039)	(0.039)	(0.039)	(0.039)	(0.039)
LEZ phase III × outside			0.028	0.052	0.031	0.032
			(0.043)	(0.039)	(0.038)	(0.039)
Time trends						
LEZ announcement	-0.131***	-0.145***	-0.137***	-0.098**	-0.102**	-0.105***
	(0.039)	(0.039)	(0.039)	(0.039)	(0.039)	(0.039)

Estimation Results: Spatial Heterogeneity

	(1) Roadside	(2) Industrial	(3) Urban Background
Treatment effects			
LEZ announcement × treated	-0.018	0.113	0.079
	(0.031)	(0.136)	(0.062)
LEZ phase I × treated	0.094**	-0.050	0.010
	(0.044)	(0.076)	(0.060)
LEZ phase II × treated	-0.038*	-0.061	0.029
	(0.022)	(0.063)	(0.052)
LEZ phase III × treated	0.044	-0.022	-0.013
	(0.052)	(0.077)	(0.052)
Spillover effects			
LEZ announcement × outside	-0.041		0.026
	(0.028)		(0.059)
LEZ phase I × outside	0.094**		0.038
	(0.043)		(0.056)
LEZ phase II × outside	0.003		0.201***
	(0.024)		(0.050)
LEZ phase III × outside	0.065		0.004
	(0.051)		(0.057)
Time trends			
LEZ announcement	-0.025	-0.111	-0.159**

Graphical Representation: Compliance



Effect of Compliance on PM10

	Roadside stations			Industrial stations	
	(1)	(2)	(3)	(4)	(5)
	Inside	Nearby	Far	Inside	Far
Panel A: Non-compliance to phase I					
Non-compliant vehicles to phase I	0.002	-0.003	0.010	0.022*	0.006
	(0.002)	(0.006)	(0.006)	(0.008)	(0.010)
Observations	17120	1555	3974	3928	2249
R^2	0.515	0.584	0.374	0.366	0.493
Panel B: Compliance rate of phase I					
Compliance rate of phase I	-0.159	0.110	-0.519	-1.156*	-0.327
	(0.105)	(0.293)	(0.317)	(0.452)	(0.513)
Observations	17120	1555	3974	3928	2249
R^2	0.516	0.584	0.375	0.367	0.493

Effect of Compliance on PM10

	Roadside stations			Industrial stations	
	(1)	(2)	(3)	(4)	(5)
	Inside	Nearby	Far	Inside	Far
Panel C: Non-compliance to phase II					
Non-compliant vehicles to phase II	0.003*	-0.002	0.007	0.018*	0.006
	(0.001)	(0.004)	(0.004)	(0.006)	(0.008)
Observations	17120	1555	3974	3928	2249
R^2	0.516	0.584	0.375	0.370	0.495
Panel D: Compliance rate to phase II					
Compliance rate of phase II	-0.168***	0.014	-0.339	-0.792**	-0.301
	(0.055)	(0.157)	(0.160)	(0.283)	(0.309)
	(0.321)	(0.164)	(1.845)	(1.157)	(4.498)
Observations	17120	1555	3974	3928	2249
R^2	0.517	0.584	0.377	0.375	0.496

Table of Contents

Robustness Checks

- Standard errors
  - Baseline - clustered standard errors at station level
  - Alternatives - clustered standard errors at station-year level, at type-region level, and newey-west standard errors
- Sample observations
  - Baseline - full sample
  - Alternatives - exclude likely outliers that exceed 95 percentile of station-level PM_{10} distribution

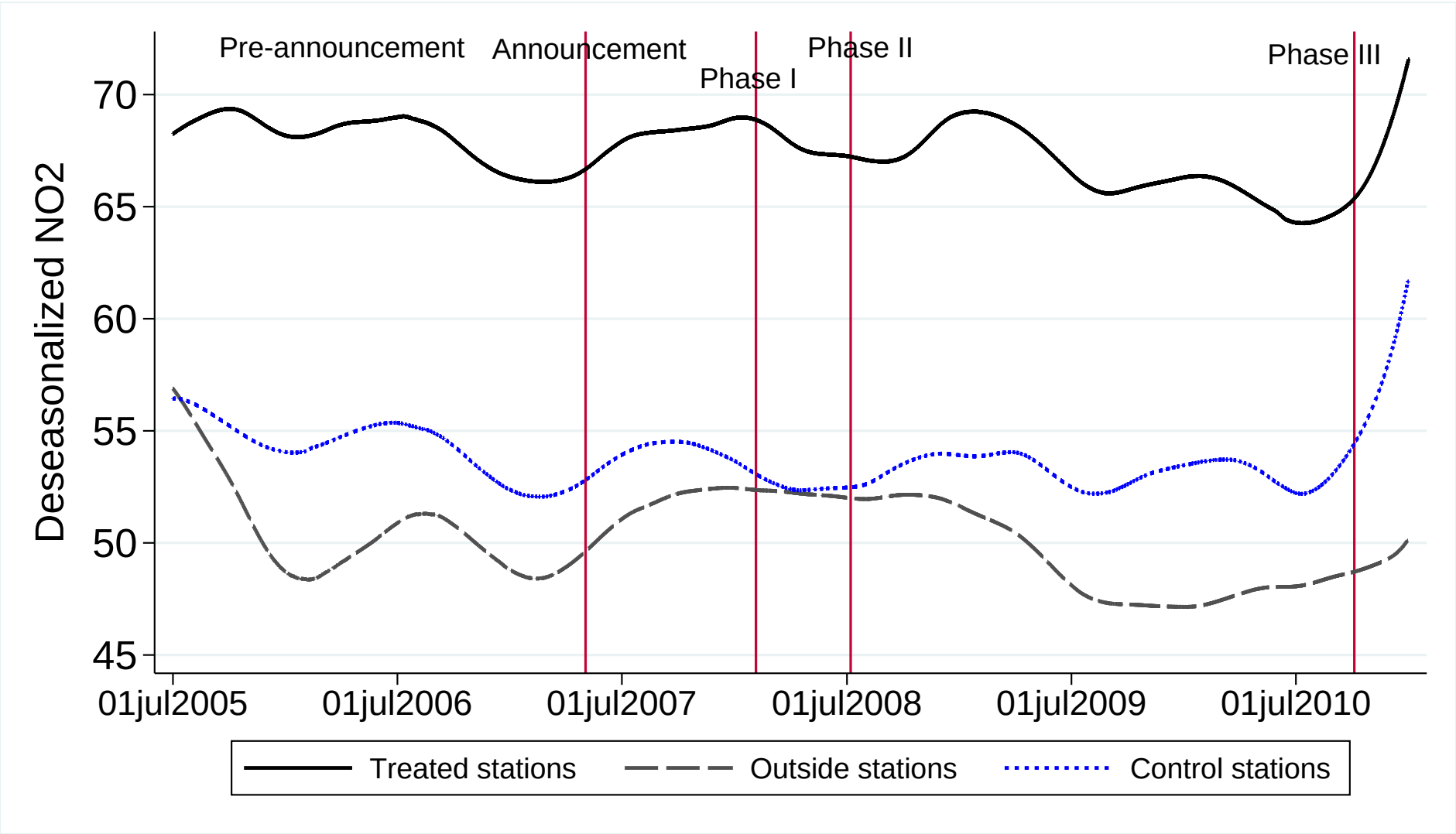
	Full sample				Short sample ($\leq$ 95 percentile)			
	(1) Baseline	(2) S.E. clust. by station-year	(3) S.E. clust. by type-region	(4) Newey-west s.e	(5) Baseline	(6) S.E. clust. by station-year	(7) S.E. clust. by type-region	(8) Newey-west s.e
Treatment effects								
LEZ announcement	0.056	0.056*	0.056	0.056***	0.070	0.070**	0.070*	0.070***
× treated	(0.041)	(0.033)	(0.034)	(0.018)	(0.042)	(0.032)	(0.036)	(0.017)
LEZ phase I	0.036	0.036	0.036	0.036	0.039	0.039	0.039	0.039*
× treated	(0.033)	(0.035)	(0.028)	(0.026)	(0.032)	(0.034)	(0.028)	(0.023)
LEZ phase II	-0.005	-0.005	-0.005	-0.005	0.004	0.004	0.004	0.004
× treated	(0.027)	(0.023)	(0.027)	(0.022)	(0.025)	(0.021)	(0.028)	(0.020)
LEZ phase III	0.002	0.002	0.002	0.002	0.009	0.009	0.009	0.009
× treated	(0.036)	(0.034)	(0.039)	(0.027)	(0.035)	(0.032)	(0.040)	(0.025)

Robustness checks

- Control stations
  - Baseline - use stations located in other areas of England as controls
  - Alternatives - use urban background stations located inside LEZ as controls

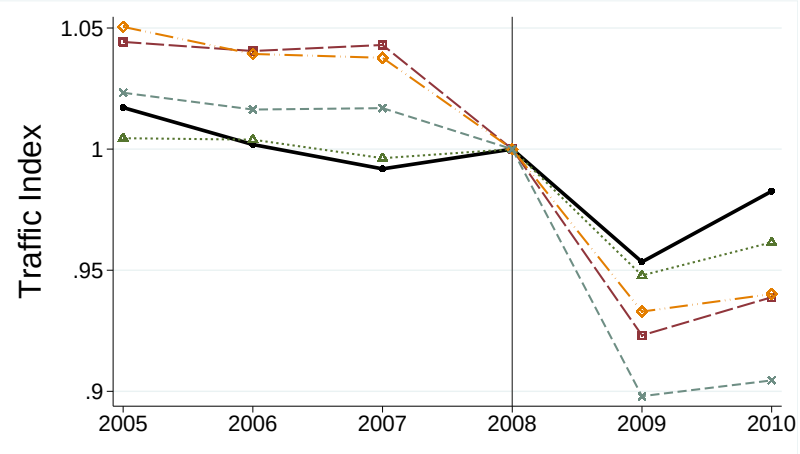
	Overall				Roadside	Industrial
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment effects						
LEZ announcement × treated	0.013	0.018	0.017	0.017	0.018	0.008
	(0.027)	(0.027)	(0.027)	(0.027)	(0.025)	(0.074)
LEZ phase I × treated	0.045	0.041	0.042	0.042	0.051	-0.002
	(0.039)	(0.037)	(0.037)	(0.036)	(0.037)	(0.057)
LEZ phase II × treated	-0.024	-0.021	-0.020	-0.020	-0.000	-0.099*
	(0.030)	(0.030)	(0.030)	(0.029)	(0.028)	(0.054)
LEZ phase III × treated	-0.045	-0.048*	-0.047*	-0.047*	-0.046	-0.075
	(0.027)	(0.027)	(0.027)	(0.027)	(0.029)	(0.048)

Supportive Evidence: NO2

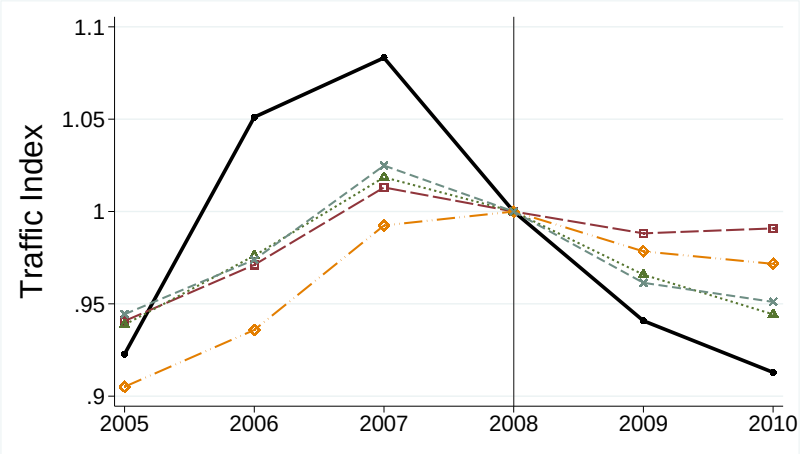


Traffic Flow: London vs. Other Regions

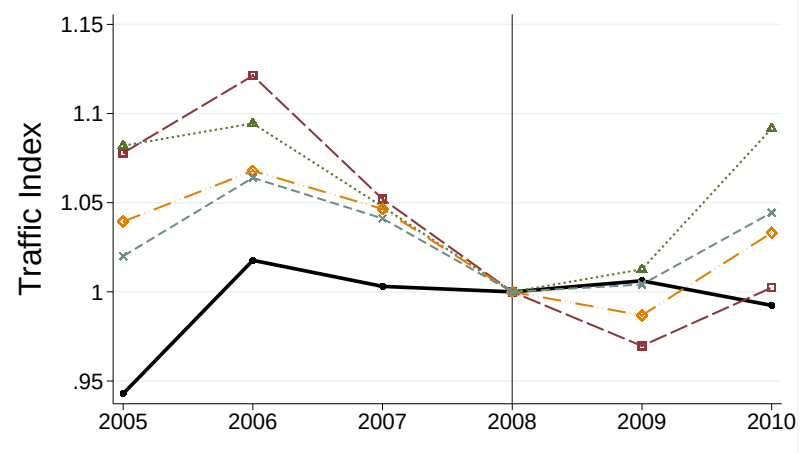
Panel A: Heavy goods vehicles



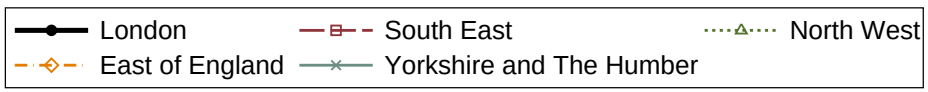
Panel B: Light goods vehicles



Panel C: Buses and coaches

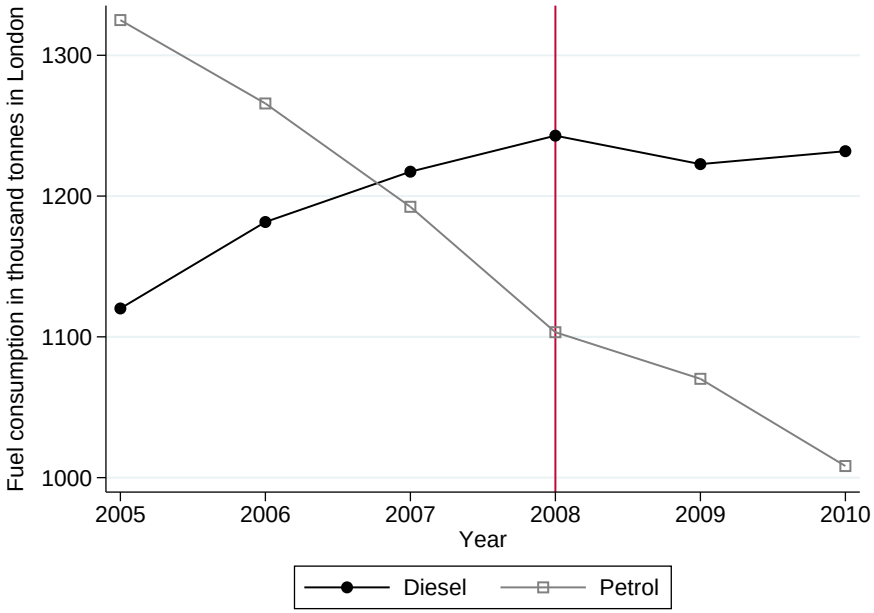


Panel D: Cars and taxis

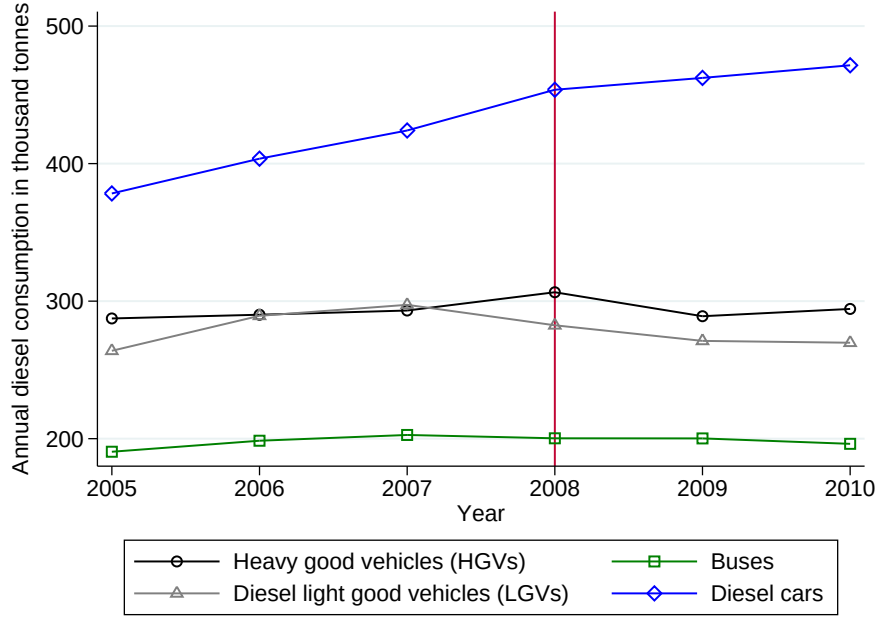


Fuel Consumption: London

By type of fuel



By type of vehicles



The end