"And Breathe Normally": The Low Emission Zone impacts on health and well-being in England

Habtamu Beshir[1] and Eleonora Fichera[1]

[1]Economics Department, University of Bath

Outline

Background

- Air pollution found to be detrimental to health and non-health outcomes (cognition, human capital, decision making and labour productivity)
- And recently air pollution has been included in the death certificate for the first time:

Southwark Coroner's court and air pollution

Ella lived 25 metres from the South Circular Road, one of the capital's busiest roads

Motivation

- Car exhaust is a major source of urban air pollution (Schwandt & Alexander 2019, Currie & Walker 2011),
- Different policies have been adopted to tackle this problem in many countries/cities
  - Congestion pricing in Stockholm and London
  - License plate based restrictions in Mexico City and Beijing
  - Low Emission Zone and Clean Air Zone schemes in Europe (Germany, England)

Motivation

- While there is a lot of evidence on the effect of pollution on health and non-health outcomes
- Little is done on the effectiveness of transport polices on reducing pollution and improving health
- We investigate the air quality, health and well-being effects of the largest and toughest traffic air pollution policies in Europe, the Greater London LEZ and the Central London ULEZ

Literature Review (i)

A few studies looked at the air quality and health effects of some transport policies in different countries:

- congestion pricing in Stockholm and London (Simeonova et al. 2019, Green et al. 2020);
- license plate based restrictions in Mexico City and Beijing (Davis 2008, Viard & Fu 2015);
- Low Emission Zone schemes popular in Europe (Pestel and Wozny, 2021; Wolf and Perry,2010; Ellison et al., 2013; Wolf, 2014; Margaryan, 2021; Gehrsitz, 2017).

Literature Review (ii) - congestion p policies

Simeonova et al. (2019) Investigate the effect of Stockholm congestion pricing (CPZ) on air pollution and health

- They find that the CPZ reduced NO_2 and PM_{10} levels by 15- 20 and 10-15 percent, respectively
- Find a significant reduction in visits for acute asthma attacks among children aged 0-5

Green et al. (2020) investigate the effect of London congestion charge (CCZ) on air pollution

- They find that the CCZ reduced CO, NO, and PM_{10}
- However, NO_2 increased after the implementation of CCZ in central London

Literature Review (iii) - license plate restrictions

License plate based restrictions in Mexico City and Beijing (Davis 2008, Viard & Fu 2015);

- They do not find evidence of improvement in air quality during any period for any pollutant
- Instead, evidence on change in the composition of vehicles toward used, and thus higher-emitting, vehicles
- And shows a slight increase in the use of taxis

Literature Review (iv) - Low Emission Zones policies (a)

- In Germany, many cities adopted Low Emission Zones (LEZ) since 2007
- Pestel & Wozny (2021) explore the air pollution and health impacts of these low emission zone policies
- Focus on pollutants PM_{10} and NO_2; and health outcomes related to cardiovascular and respiratory diseases
- Find that the LEZs improve air quality
- Incidences of diseases related to the circulatory and the respiratory system are also lower as a result of LEZ

Literature Review (iv) - Low Emission Zones policies (b)

- Similarly Margaryan (2021) studied the air pollution and health effects of LEZs in Germany
- Find that LEZs significantly reduce PM_{10}, and smaller and no significant effect on NO_2
- Importantly, study finds that LEZs decreased the number of patients with cardiovascular disease
- Strong effect for those above the age of 65 and for cerebrovascular diseases

Literature Review (iv) - Low Emission Zones policies (c)

- Ellison et al. (2013) studied the effect of LEZ in Greater London on air pollution
- Find 13% reduction in PM_{10} inside LEZ
- The study, however, used a before and after comparison to estimate the effect of LEZ

Our contributions

- We evaluate the largest LEZ in Europe (Greater London's) and the toughest one in the world (ULEZ in Central London)
- We use DiD strategy exploiting the time of LEZ and ULEZ introduction and comparing Greater and Central London to compared unexposed cities in England
- We are able to control for a number of individual and area-level characteristics that can impact both air pollution and health
- We, for the first time, evaluate the effectiveness of ULEZ both on air pollution and Health.
- Also, using Annual Population Survey (APS), we investigate the effect of ULEZ on Well-being outcomes beyond the traditional health outcomes used in the literature.

Policy 1: Low Emission Zone (LEZ)

- London LEZ was started in February 2008
- Other cities followed to implement LEZ style policies: Oxford in 2014, Brighton in 2015, Norwich in 2008
- The LEZ in London:
  - Phase I: started with Euro III standard for vehicles with gross vehicle weight (GVW) of more than 12 tonnes operating in the LEZ
  - Phase II: in July, 2008, this was extended to freight vehicles with a GVW of more than 3.5 tonnes as well as buses and coaches with a GVW of more than 5 tonnes
  - Phase III: in January 2012, Euro III for larger vans minibuses and Euro IV for HGVs, Buses and Coaches
  - non-compliers pay charge £100 for large vans or £200 for heavy vehicles

Low Emission Zone in Greater London

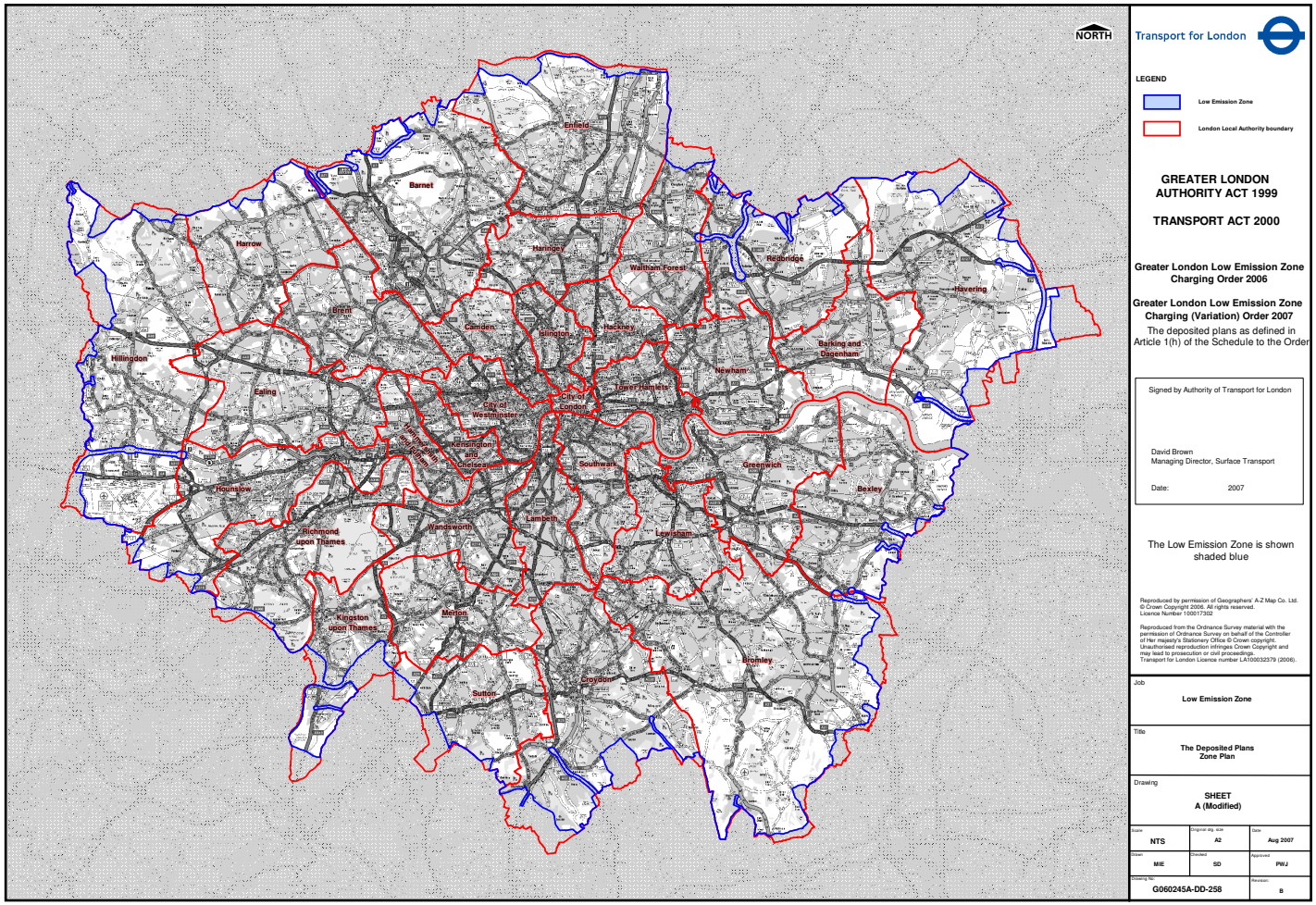


Figure 1: Areas covered by LEZ

Policy 2: Ultra Low Emission Zone (ULEZ)

- First of, LEZ is also operational in Central London, which is part of Greater London.
- On October 2017, T-Charge was introduced in Central London as stepping-stone for ULEZ
- In April 2019 ULEZ replaced T-Charge
- Standards:
  - Euro 4 for petrol cars and vans (vehicles less than fourteen years old in 2019);
  - Euro 6 for diesel cars and vans(vehicles less than five years old in 2019), lorries, buses and coaches;
  - Euro 3 for motorcycles and other L-category vehicles;
  - Those who do not meet these standards must pay: £12.50 per day for cars, motorcycles and vans or £100 per day for lorries, buses and coaches. It operates 24h a day, every day of the year

Ultra Low Emission Zone, Central London

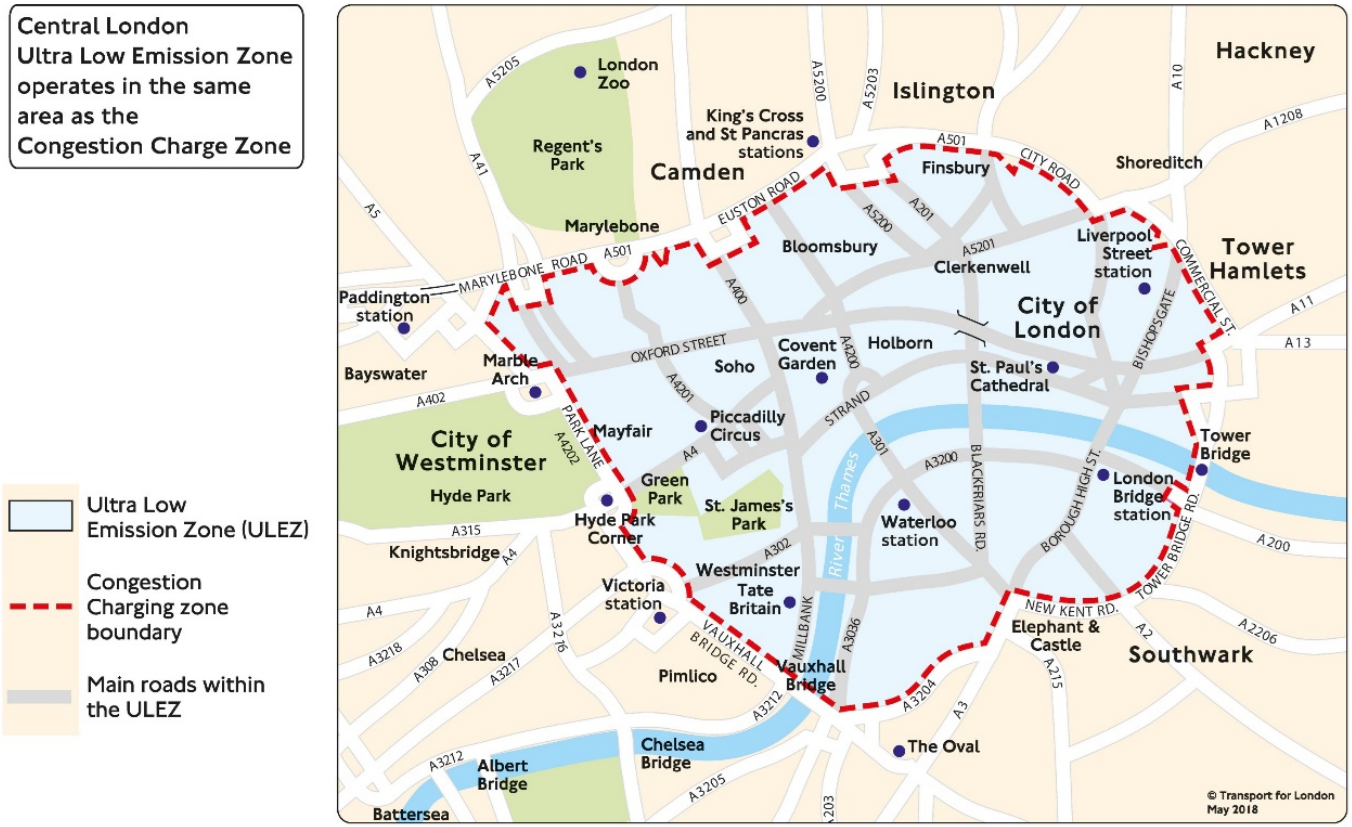


Figure 2: Areas covered by LEZ

Air Quality effects of LEZ

$$P_{ict} = \alpha_0 + \beta_0(\text{London}_c * \text{Post}_t) + \theta_0 \text{London}_c + \gamma_0 \text{Post}_t + \pi_0 W_{ict} + \zeta_0 \tau_t + S_i + \varepsilon_{ict} \quad (1)$$

- P_{ict} is air pollution level (NO_2, PM_{10}) of station i, located in city c, at time/date t;
- London_c is an indicator that takes 1 for London LEZ; and 0 otherwise
- Post_t takes 1 for the period after the implementation of LEZ; and 0 otherwise;
- W_{ict} is weather (rain, temp, wind) controls;
- we control for month fixed effects, year fixed effects and treatment specific time trends (τ_t) and station fixed effects (S_i);
- β_0 estimates the air pollution effects of LEZ in the exposed city relative to other unexposed cities in England

Air Quality effects of ULEZ

$$P_{ict} = \alpha_1 + \beta_1(\text{CL}_c * \text{PostLEZ}_t) + \beta_2(\text{CL}_c * \text{PostTC}_t) + \beta_3(\text{CL}_c * \text{PostULEZ}_t) + \theta_1 \text{CL}_c + \gamma_1 \text{Post}_t + \pi_1 W_{ict} + \zeta_1 \tau_t + S_i + \eta_{ict} \quad (2)$$

- P_{ict} is air pollution level (NO_2, PM_{10}) of station i, located in city c, at time/date t;
- CL_c is an indicator that takes 1 for central London; 0 otherwise
- Post_t takes 1 for the period after the implementation of ULEZ and the others policies in CL (TC and LEZ); and 0 otherwise;
- W_{ict} is weather (rain, temp, wind) controls;
- we control for time fixed effects and trends and station fixed effects, τ_t and S_i;
- β_1, β_2 and β_3 estimates the air pollution effects of LEZ, TC and ULEZ

Health effects of LEZ

$$H_{imct} = \alpha_2 + \delta_0(\text{London}_c * \text{Post}_t) + \vartheta_0 \text{London}_c + \chi_0 \text{Post}_t + \lambda_0 X_{imct} + \xi_0 \tau_t + D_m + \upsilon_{imct} \quad (3)$$

- H_{imt} is physical health of individual i living in MSOA m, at time/date t;
- X_{imt} contains pre-determined individual characteristics such as age, gender, ethnicity as well as area level controls (house price, IMD);
- we also include linear differential time trends and month, year FE; as well as MSOA FE (D_m)
- δ_0 estimates the health effects of LEZ in the exposed city relative to other unexposed cities in England

Health effects of ULEZ

$$H_{imat} = \alpha_3 + \delta_1(\text{CL}_a * \text{PostLEZ}_t) + \delta_2(\text{CL}_a * \text{PostTC}_t) + \delta_3(\text{CL}_a * \text{PostULEZ}_t) + \vartheta_1 \text{CL}_a + \chi_1 \text{Post}_t + \lambda_1 X_{imat} + \xi_1 \tau_t + D_m + \nu_{imat} \quad (4)$$

- H_{imat} is physical health and well-being of individual i living in MSOA m, but working in area a at time/date t
- X_{imt} contains pre-determined individual characteristics such as age, gender, ethnicity; as well as area level controls (house price, IMD);
- we also include linear differential time trends and month, year FE; as well as MSOA FE (D_m)
- δ_1, δ_2 and δ_3 estimates the health and well-being effects of LEZ, TC and ULEZ

Inference

- We report robust standard errors that are clustered at the city level
- In our case, we have a single treated group (Central London for ULEZ and Greater London for LEZ).
- In such a case, alternative inference methods are considered (Donald and Lang, 2007; Conley and Taber, 2011; Cameron et al., 2008).
- However, in cases where there is heteroskedasticity generated from variation in group sizes, these methods are not preferred as well.
- As a result, we also report p-values produced by the procedure proposed by Ferman and Pinto (2019) in our main results

Data (i) - LEZ/ULEZ coverage

- We obtain LEZ and ULEZ postcodes from Transport for London (TfL) using FOI
- Unexposed Areas only include major cities and towns in England
- In ULEZ analysis: Exclude other parts of London from control group and consider only Central London

Data (ii) - Pollution Data

- Daily Pollution (NO_2, PM_{10}) data from UK Air Quality Archive from
- LEZ sample: 2003 to 2015
- ULEZ Sample: 2003 to 2019
- Daily Weather (rainfall, temperature and wind) data from Met Office – MIDAS Land Surface Stations data

Table 1: Descriptive statistics of main variables

	Mean	Standard Dev.	Min	Max	Observation
	Panel A: LEZ sample (2003-2015)				
NO_2	34.906	22.515	0.000	265.000	271479
PM_{10}	21.671	12.243	0.000	194.000	151519
Average Precipitation	2.008	4.244	0.000	88.200	271477
Average Temperature	11.415	5.697	-11.950	32.150	271479
Mean Wind Speed	8.511	4.656	0.000	50.750	271479
Mean Wind Direction	196.808	71.296	0.000	359.167	271479
	Panel B: ULEZ sample (2003 to 2019)				
NO_2	29.574	17.813	0.000	183.000	309402
PM_{10}	19.158	10.898	0.000	194.000	164160
Average Precipitation	2.112	4.421	0.000	192.000	309395
Average Temperature	11.255	5.637	-11.950	32.800	309402
Mean Wind Speed	8.623	4.722	0.000	50.750	309402
Mean Wind Direction	199.303	69.211	0.000	359.167	309402

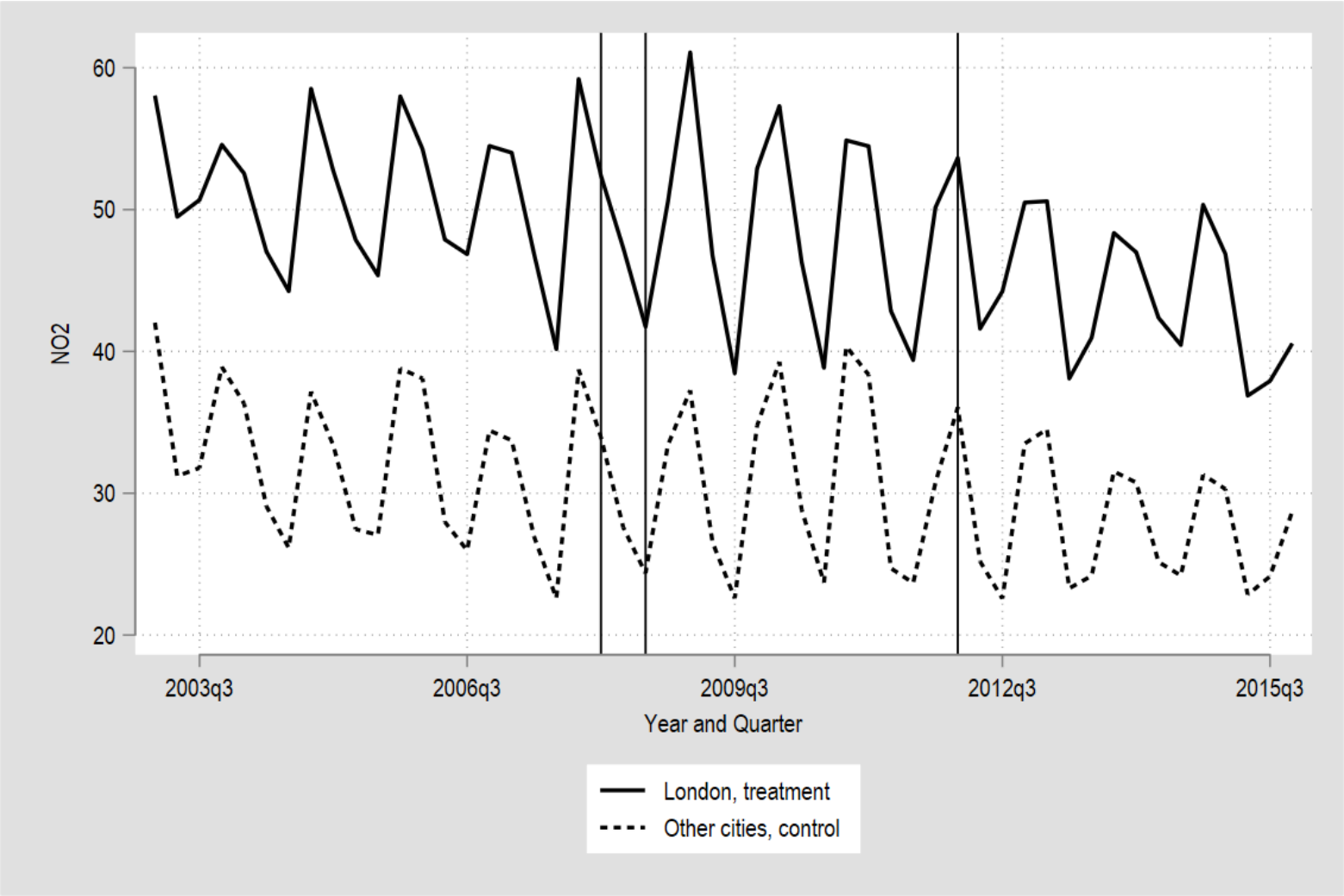


Figure 3: NO_2 trend before and after LEZ

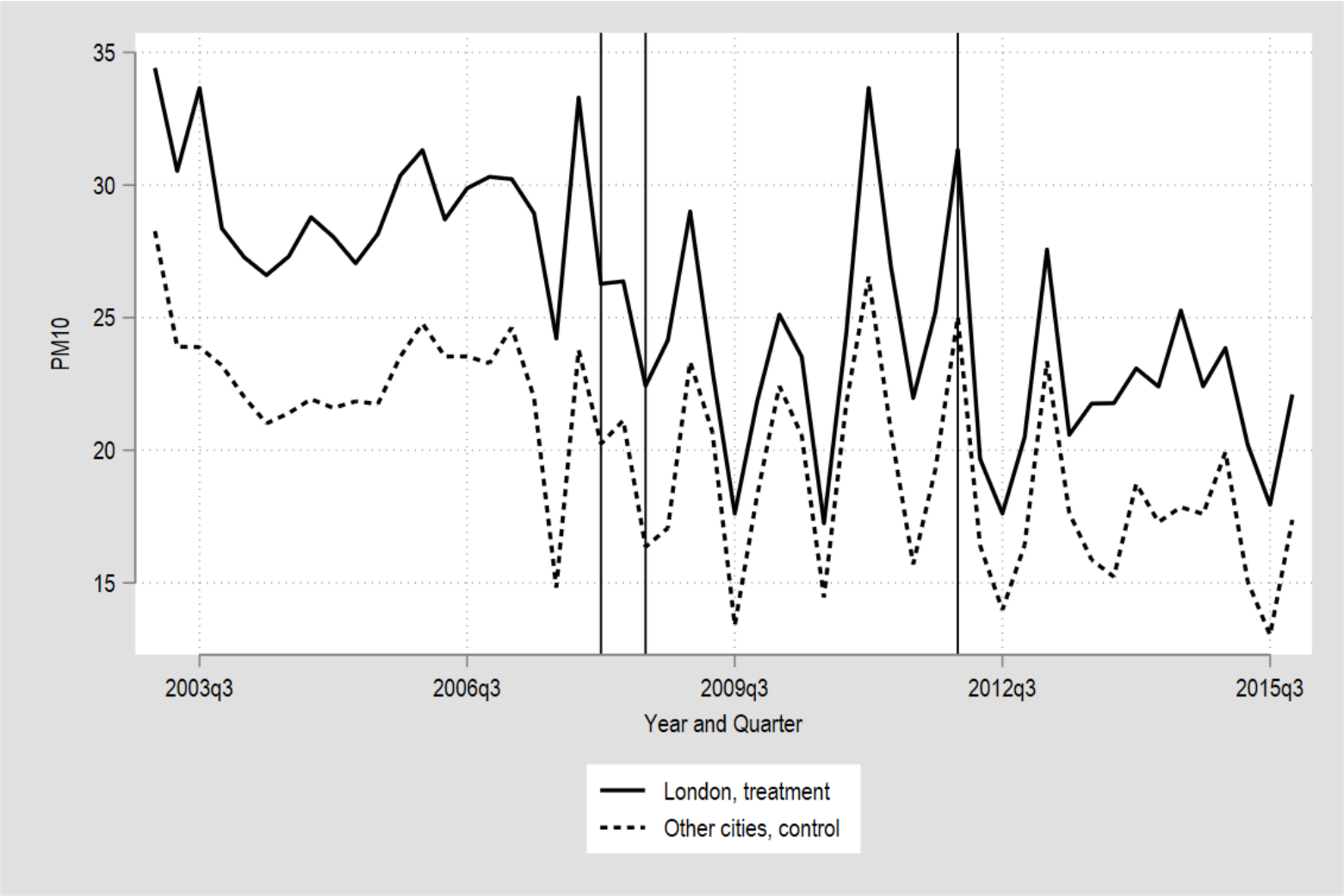


Figure 4: PM_10 trend before and after LEZ

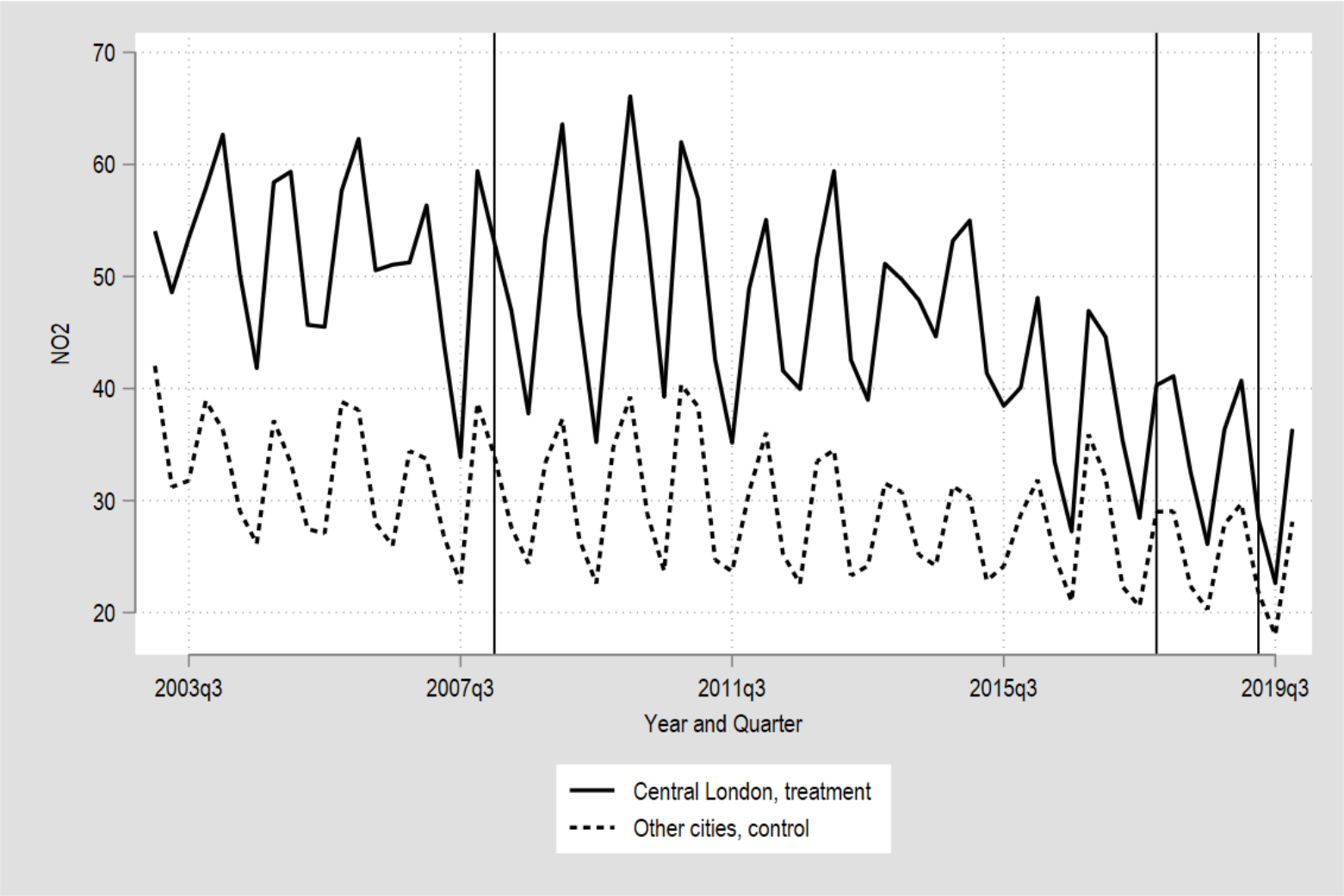


Figure 5: NO_2 trend before and after ULEZ

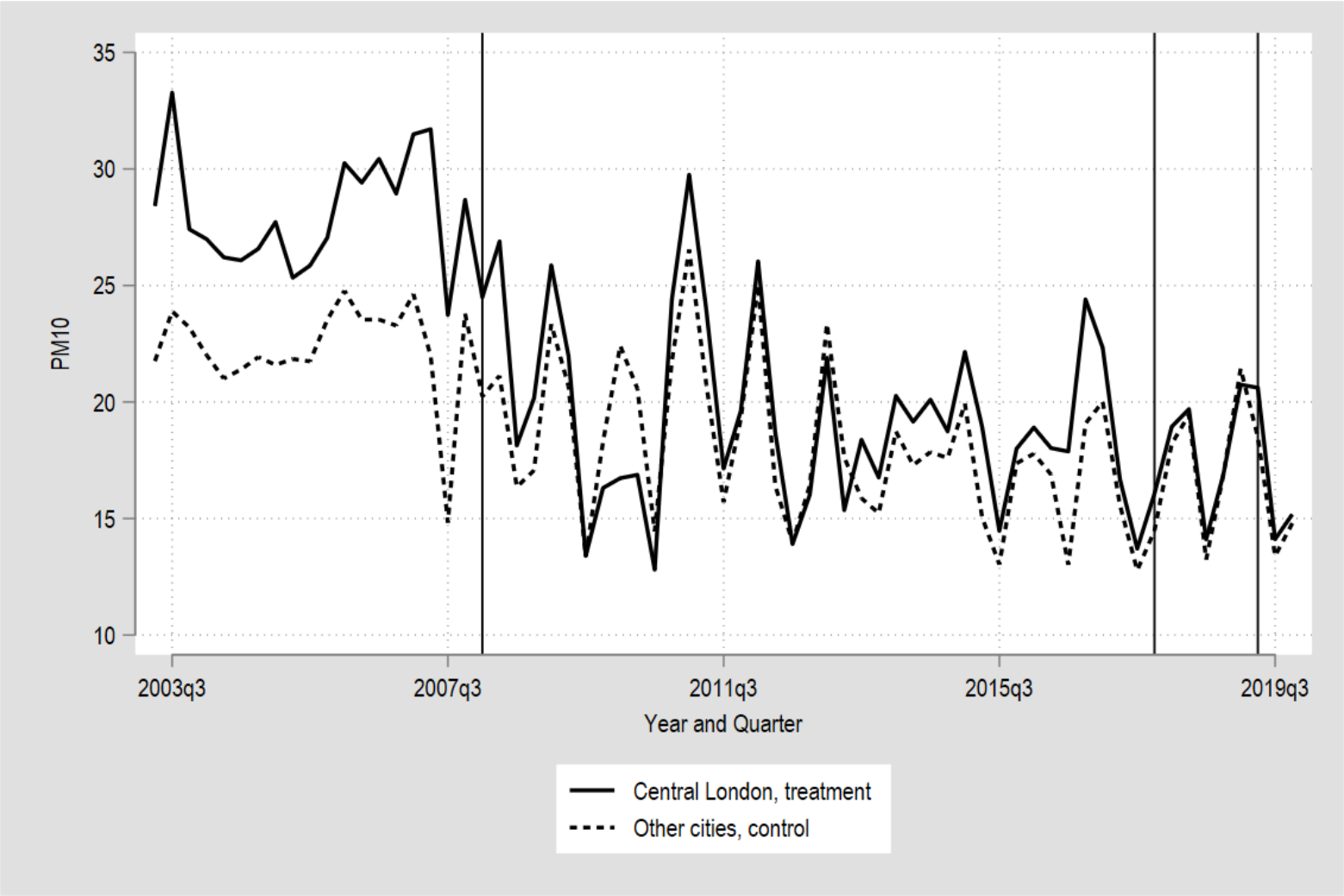


Figure 6: PM_10 trend before and after ULEZ

Data (iii): Health and Well-being Data

- For health, we use the Quarterly Labour Force Survey (QLFS)
- The data is a large survey that collects information from approximately 40,000 households and approximately 100,000 individuals every quarter since 1992.
- It contains rich socio-economic information, particularly with regards to employment
- Annual Population Survey (APS) for well-being and general health
  APS has 4 well-being questions:
  - overall, how satisfied are you with your life nowadays?
  - overall, to what extent do you feel the things you do in your life are worthwhile?
  - overall, how happy did you feel yesterday?
  - overall, how anxious did you feel yesterday?
  - People are asked to respond on a scale of 0 to 10, where 0 is "not at all" and 10 is "completely".

Table 2: Descriptive statistics of main variables in health effect of LEZ

	Mean	SD	Obs.
	LEZ Sample: QLFS January 2005 to December 2015		
Ever had health problem longer than 12 month (1=yes)	0.339	0.473	1250779
Chest/ breathing problems, asthma, bronchitis (1=yes)	0.075	0.264	1250779
Health problem limits activity (1=yes)	0.190	0.392	1250769
Heart, blood pressure, blood circulatory problems (1=yes)	0.113	0.317	1250779
No. of health conditions	0.758	1.464	1250779
Had any sick leave in the last week(1=yes)	0.024	0.152	784656
Gender	0.476	0.499	1256836
Age	42.739	15.938	1256836
Ethnicity:			
White	0.805	0.396	1255679
Asian	0.091	0.287	1255679
Other ethnic	0.104	0.305	1255679
Type of Housing:			
Owner	0.234	0.423	1256040
Mortgage	0.397	0.489	1256040
Renting	0.369	0.483	1256040
Economic activity status:			
In Employment	0.626	0.484	1256836
Area level controls:			
Rank of IMD score (1= least deprived)	0.5	0.289	32482
log House Price (real)	12.293	0.52	129489

Table 3: Descriptive statistics of main variables in health and wellbeing effects of ULEZ

	Mean	SD	Obs.
	ULEZ Sample: QLFS January 2005 to December 2019		
Ever had health problem longer than 12 month (1=yes)	0.261	0.439	2113166
Chest/ breathing problems, asthma, bronchitis (1=yes)	0.054	0.225	2113166
Heart, blood pressure, blood circulatory problems (1=yes)	0.066	0.249	2113166
No. of health conditions	0.445	0.965	2113166
Had any sick leave in the last week(1=yes)	0.022	0.145	2119110
Gender	0.515	0.500	2119228
Age	42.099	13.132	2119228
Ethnicity:			
White	0.920	0.272	2118370
Asian	0.037	0.188	2118370
Other ethnic	0.043	0.204	2118370
Type of Housing:			
Owner	0.212	0.409	2118404
Mortgage	0.542	0.498	2118404
Renting	0.246	0.431	2118404
Area level controls:			
Rank of IMD score (1= least deprived)	0.5	0.289	32482
log House Price (real)	12.293	0.52	129489

			ULEZ Sample: APS April 2012 to March 2020
General Health	1.739	0.756	697513
Good Health	0.856	0.351	697513
Feeling Happy	7.491	1.992	447039
Feeling Worthiness	7.948	1.485	446321
Feeling Satisfied	7.708	1.563	447108
Feeling Anxious	2.871	2.753	446748
Gender	0.510	0.500	712579
Age	42.852	13.226	712579
Ethnicity:			
White	0.901	0.299	712242
Asian	0.046	0.209	712242
Other ethnic	0.054	0.225	712242
Type of Housing:			
Owner	0.223	0.416	712245
Mortgage	0.499	0.500	712245
Renting	0.278	0.448	712245
Area level controls:			
Rank of IMD score (1= least deprived)	0.5	0.289	32844
log House Price (real)	12.293	0.52	129615

The Effect of LEZ on Air Quality

Table 4: Estimated effect of LEZ on NO_2 and PM_{10}

	(1) NO_2	(2) PM_{10}
London*Post	-0.368	-3.455***
	(0.835)	(0.490)
Ferman-Pinto p-values	[0.504]	[0.000]
Baseline mean	50.903	29.160
Observations	271,477	151,519
Adjusted R-squared	0.661	0.374
Monitoring Station FE	Yes	Yes
Month FE	Yes	Yes
Year FE	Yes	Yes
Weather Controls	Yes	Yes
Treatment Specific Linear Trends	Yes	Yes

Robust standard errors (clustered at the city level) in parentheses. Ferman-Pinto p-values in brackets. The asterisks next to the coefficients are for p-values associated with the main (non-Ferman-Pinto p-values) regressions. *** p<0.01, ** p<0.05, * p<0.1. Weather controls include: Average precipitation, average temperature, mean wind speed, and mean wind direction. Baseline mean refers to average concentrations of the respective pollutant at stations inside LEZ before the implementation of the zone in Greater London.

The Effect of LEZ on Air Quality

Table 5: Estimated effect of Different Phases of LEZ on NO_2 and PM_{10}

	(1) NO_2	(2) PM_{10}
London*Post Phase 1	3.123***	-1.721**
	(1.111)	(0.712)
Ferman-Pinto p-values	[0.029]	[0.095]
London*Post Phase 2	-0.537	-4.196***
	(0.941)	(0.610)
Ferman-Pinto p-values	[0.348]	[0.000]
London*Post Phase 3	1.229	-4.185***
	(1.435)	(1.065)
Ferman-Pinto p-values	[0.161]	[0.000]
Baseline mean	50.903	29.160
Observations	271,477	151,519
Adjusted R-squared	0.662	0.375
Monitoring Station FE	Yes	Yes
Month FE	Yes	Yes
Year FE	Yes	Yes
Weather Controls	Yes	Yes
Treatment Specific Trends	Yes	Yes

Robust standard errors (clustered at the city level) in parentheses. Ferman-Pinto p-values in brackets. The asterisks next to the coefficients are for p-values associated with the main (non-Ferman-Pinto p-values) regressions. *** p<0.01, ** p<0.05, * p<0.1. Weather controls include: Average precipitation, average temperature, mean wind speed, and mean wind direction. Baseline mean refers to average concentrations of the respective pollutant at stations inside London before the implementation of the LEZ in Greater London.

The Effect of ULEZ on Air Quality

Table 6: Estimated effect of LEZ, TC and ULEZ on NO_2 and PM_{10}

	(1) NO_2	(2) PM_{10}
CL*Post LEZ	1.914***	-5.286***
	(0.717)	(0.456)
Ferman-Pinto p-values	[0.151]	[0.000]
CL*Post TC	-0.599	-7.518***
	(1.031)	(0.696)
Ferman-Pinto p-values	[0.668]	[0.000]
CL*Post ULEZ	-5.982***	-7.850***
	(1.276)	(0.918)
Ferman-Pinto p-values	[0.002]	[0.000]
Baseline mean	52.301	28.120
Observations	309,395	164,157
Adjusted R-squared	0.619	0.323
Monitoring Station FE	Yes	Yes
Month FE	Yes	Yes
Year FE	Yes	Yes
Weather Controls	Yes	Yes
Treatment Specific Trends	Yes	Yes

Robust standard errors (clustered at the city level) in parentheses. Ferman-Pinto p-values in brackets. The asterisks next to the coefficients are for p-values associated with the main (non-Ferman-Pinto p-values) regressions. *** p<0.01, ** p<0.05, * p<0.1. Weather controls include: Average precipitation, average temperature, mean wind speed, and mean wind direction. Baseline mean refers to average concentrations of the respective pollutant at stations inside Central London before the implementation of first policy (LEZ).

The Effect of LEZ on Health

Table 8: Estimated Effect of LEZ on Health

	(1) Ever had health problems longer than 12 month	(2) Chest/ breathing problems, asthma, bronchitis	(3) Health problems limiting activity	(4) Heart, blood pressure, circulatory problems	(5) No. health conditions	(6) Sick leave
London* Post LEZ	-0.012***	-0.006***	-0.012***	-0.000	-0.009	-0.004***
	(0.004)	(0.002)	(0.003)	(0.002)	(0.010)	(0.001)
Ferman-Pinto p-values	[0.219]	[0.137]	[0.001]	[0.932]	[0.683]	[0.148]
Baseline mean	0.283	0.0547	0.173	0.0908	0.565	0.0280
Observations	1,249,127	1,249,127	1,249,117	1,249,127	1,249,127	783,666
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
MSOA FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Treatment Specific Trends	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors (clustered at the city level) in parentheses. Ferman-Pinto p-values in brackets. The asterisks next to the coefficients are for p-values associated with the main (non-Ferman-Pinto p-values) regressions. *** p<0.01, ** p<0.05, * p<0.1. We include age, gender, ethnicities, type of housing, employment status, LSOA level IMD rank, and MSOA level average house price as controls. Baseline mean refers to average value of the respective outcome for those in London before the implementation of LEZ. We apply weights provided by the survey.

The Effect of LEZ on Health

Table 9: Estimated Effect of Different Phases of LEZ on Health

	(1) Ever had health problems longer than 12 month	(2) Chest/ breathing problems, asthma, bronchitis	(3) Health problems limiting activity	(4) Heart, blood pressure, circulatory problems	(5) No. health conditions	(6) Sick leave
London*Post phase 1	-0.008**	-0.002	-0.002	-0.000	0.010	0.001
	(0.004)	(0.002)	(0.004)	(0.003)	(0.012)	(0.001)
Ferman-Pinto p-values	[0.498]	[0.619]	[0.891]	[0.951]	[0.759]	[0.904]
London*Post phase 2	-0.013***	-0.008***	-0.012***	-0.005*	-0.034***	-0.004***
	(0.004)	(0.002)	(0.003)	(0.003)	(0.011)	(0.001)
Ferman-Pinto p-values	[0.000]	[0.002]	[0.005]	[0.065]	[0.001]	[0.000]
London*Post phase 3	-0.012*	-0.009***	-0.007	-0.012***	-0.063***	-0.002
	(0.006)	(0.003)	(0.005)	(0.004)	(0.019)	(0.002)
Ferman-Pinto p-values	[0.000]	[0.003]	[0.027]	[0.000]	[0.000]	[0.317]
Baseline mean	0.283	0.0547	0.173	0.0908	0.609	0.0235
Observations	1,249,127	1,249,127	1,249,117	1,249,127	1,249,127	783,666
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
MSOA FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Treatment Specific Trends	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors (clustered at the city level) in parentheses. Ferman-Pinto p-values in brackets. The asterisks next to the coefficients are for p-values associated with the main (non-Ferman-Pinto p-values) regressions. *** p<0.01, ** p<0.05, * p<0.1. We include age, gender, ethnicities, type of housing, employment status, LSOA level IMD rank, and MSOA level average house price as controls. Baseline mean refers to average value of the respective outcome for those in London before the implementation of LEZ. We apply weights provided by the survey.

The Effect of ULEZ on Health

Table 10: Estimated Effect of LEZ, TC and ULEZ on Health

	(1) Ever had health problems longer than 12 month	(2) Chest/ breathing problems, asthma, bronchitis	(3) Heart, blood pressure, circulatory problems	(4) No. health conditions	(5) Sick leave
CL*Post LEZ	-0.012***	-0.007***	-0.007***	-0.038***	-0.005***
	(0.003)	(0.001)	(0.001)	(0.008)	(0.001)
Ferman-Pinto p-values	[0.058]	[0.027]	[0.056]	[0.001]	[0.000]
CL*Post TC	-0.031***	-0.008***	-0.012***	-0.063***	-0.004***
	(0.003)	(0.002)	(0.002)	(0.008)	(0.001)
Ferman-Pinto p-values	[0.000]	[0.040]	[0.002]	[0.000]	[0.026]
CL*Post ULEZ	-0.038***	-0.005	-0.008***	-0.075***	-0.005***
	(0.005)	(0.003)	(0.002)	(0.012)	(0.001)
Ferman-Pinto p-values	[0.000]	[0.449]	[0.226]	[0.010]	[0.004]
Baseline mean	0.169	0.0369	0.0419	0.251	0.0283
Observations	2,111,522	2,111,522	2,111,522	2,111,522	2,117,433
Month FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
MSOA FE	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes
Treatment Specific Trends	Yes	Yes	Yes	Yes	Yes

Robust standard errors (clustered at the region of work level) in parentheses. Ferman-Pinto p-values in brackets. The asterisks next to the coefficients are for p-values associated with the main (non-Ferman-Pinto p-values) regressions. *** p<0.01, ** p<0.05, * p<0.1. We include age, gender, ethnicities, type of housing, LSOA level IMD rank, and MSOA level average house price as controls. Baseline mean refers to average value of the respective outcome for those in London before the implementation of LEZ. We apply weights provided by the survey.

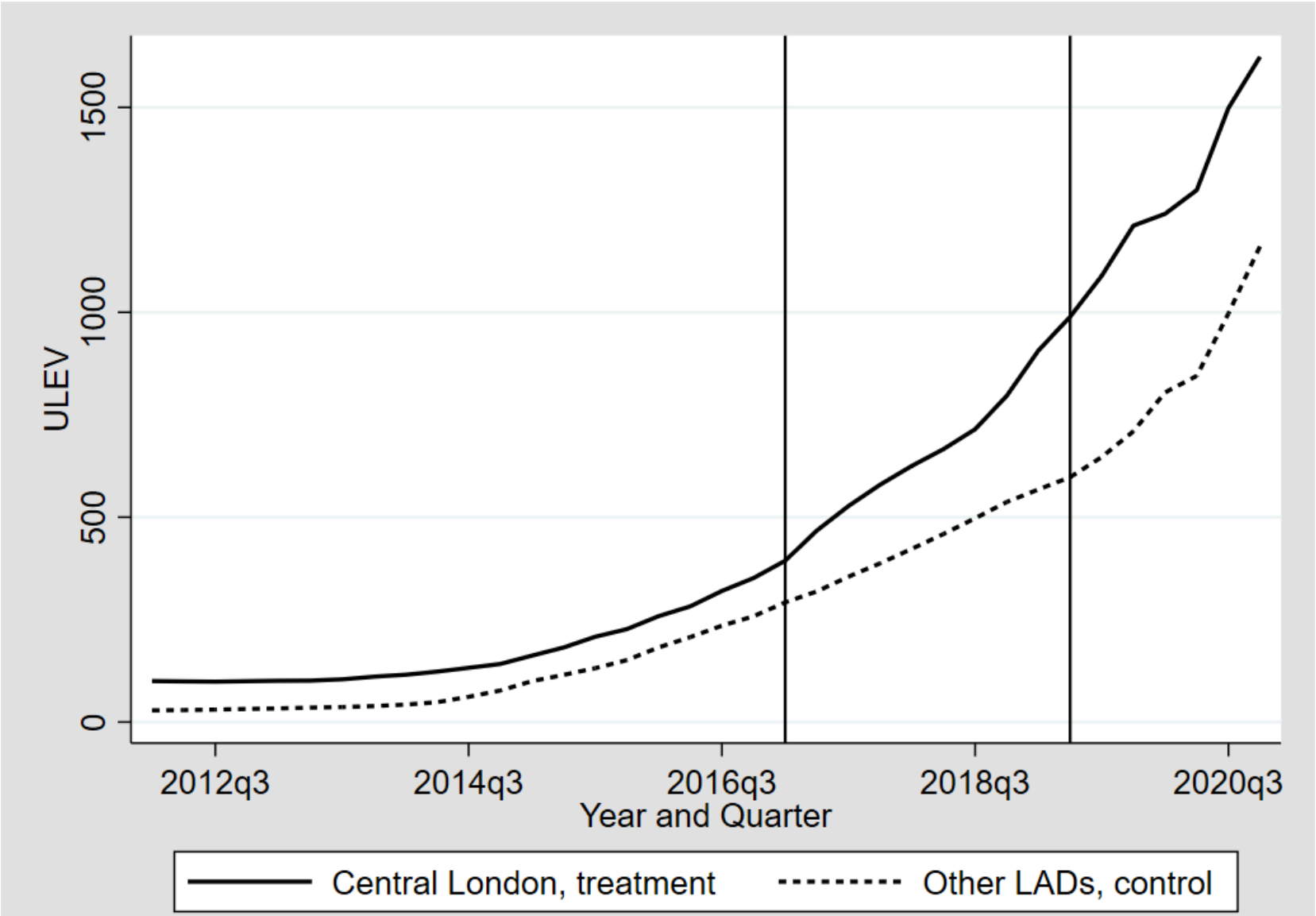
The Effect of ULEZ on Well-being

Table 11: Estimated Effect of TC and ULEZ on General Health and Well-being

	(1) General health	(2) Good health	(3) Happy	(4) Worthwhile	(5) Satisfied	(6) Anxious
CL*Post TC	0.001	-0.004*	0.006	-0.008	-0.047***	0.023
	(0.007)	(0.002)	(0.014)	(0.012)	(0.011)	(0.024)
Ferman-Pinto p-values	[0.953]	[0.495]	[0.901]	[0.678]	[0.065]	[0.622]
CL*Post ULEZ	-0.048***	0.012***	0.094***	0.113***	0.095***	-0.200***
	(0.010)	(0.002)	(0.019)	(0.016)	(0.016)	(0.034)
Ferman-Pinto p-values	[0.050]	[0.102]	[0.076]	[0.000]	[0.028]	[0.056]
Baseline mean	1.621	0.907	7.422	7.720	7.622	3.082
Observations	696,877	696,877	446,614	445,899	446,685	446,326
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
MSOA FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Treatment Specific Trends	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors (clustered at the region of work level) in parentheses. Ferman-Pinto p-values in brackets. The asterisks next to the coefficients are for p-values associated with the main (non-Ferman-Pinto p-values) regressions. *** p<0.01, ** p<0.05, * p<0.1. We include age, gender, ethnicities, type of housing, LSOA level IMD rank, and MSOA level average house price as controls. Baseline mean refers to average value of the respective outcome for those in London before the implementation of TC. We apply weights provided by the survey.

Change in the vehicle fleet due to ULEZ



Triple difference approach (DDD)

From the atmospheric sciences literature (Karner et al., 2010):

- NO and NO2 blows up to 565 meters from highway or major road
- PM10 only extends up to 200 metres
- we define an exposure buffer zone that is equal to 1 if the monitoring station is within 565 of a major A road (in case of NO2)
- with in 200 metres (in case of PM10).
- we run DDD estimations where this dummy is interacted with London and Post LEZ indicators.

Triple difference approach (DDD)

Table A.1: LEZ on pollution: Triple Difference (DDD) estimation

	(1) NO_2	(2) PM_{10}
	Panel A: LEZ	
London*Post LEZ*Near Major A Roads	-3.713***	-3.104***
	(1.204)	(0.853)
Observations	271,477	151,519
	Panel B: LEZ Phases	
London* Post Phase 1*Near Major A Roads	-0.376	1.534
	(1.826)	(1.233)
London* Post Phase 2*Near Major A Roads	-3.479**	-1.822**
	(1.349)	(0.890)
London* Post Phase 3*Near Major A Roads	-4.539***	-4.768***
	(1.291)	(1.014)
Observations	271,477	151,519
Monitoring Station FE	Yes	Yes
Month FE	Yes	Yes
Year FE	Yes	Yes
Weather Controls	Yes	Yes

Robust standard errors (clustered at the city level) in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Weather controls include: Average precipitation, average temperature, mean wind speed, and mean wind direction.

Anticipation of LEZ?

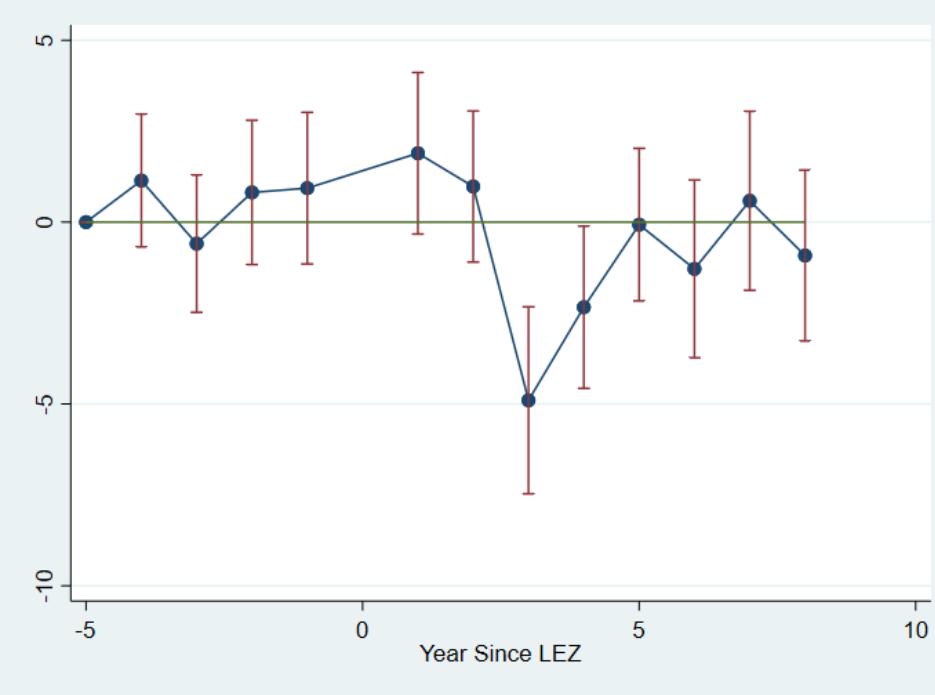


Figure 7: NO_2 event study graph

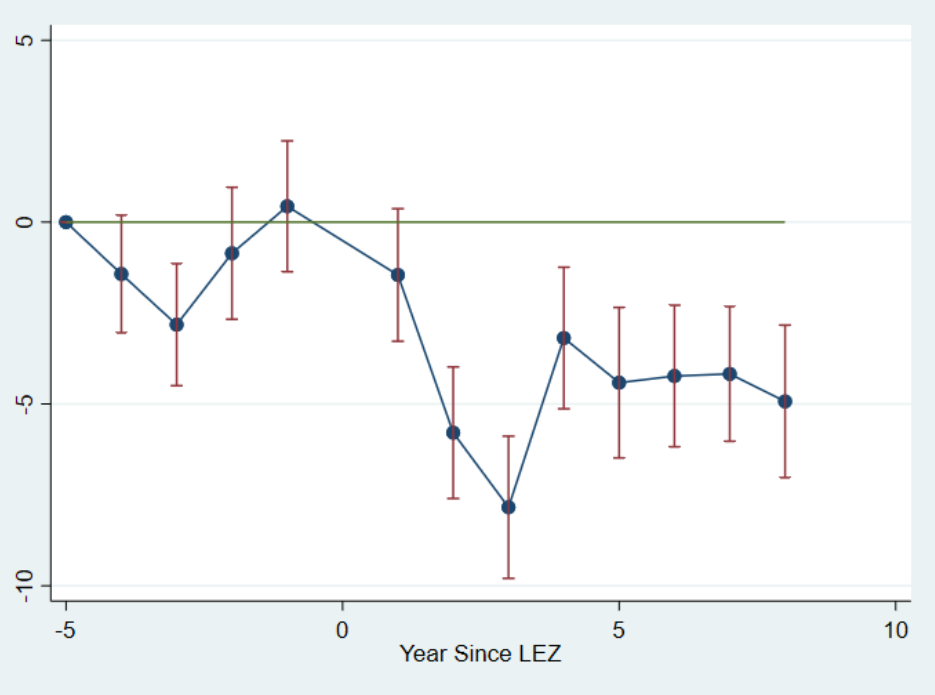


Figure 8: PM_{10} event study graph

Effects outside London?

Table A.13: LEZ on pollution: Near Major roads outside of London

	(1) NO_2	(2) PM_{10}
	Panel A: LEZ	
Near Major Roads* Post LEZ	0.746	-0.312
	(1.078)	(0.828)
Observations	203,443	117,260
	Panel B: LEZ Phases	
Near Major Roads* Post Phase 1	-1.895	-0.165
	(1.715)	(1.187)
Near Major Roads* Post Phase 2	0.583	-0.591
	(1.128)	(0.875)
Near Major Roads* Post Phase 3	1.346	-0.057
	(1.233)	(0.956)
Observations	203,443	117,260
Monitoring Station FE	Yes	Yes
Month FE	Yes	Yes
Year FE	Yes	Yes
Weather Controls	Yes	Yes

Robust standard errors (clustered at the city level) in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Weather controls include: Average precipitation, average temperature, mean wind speed, and mean wind direction.

Additional robustness

- Exclude from controls Oxford, Brighton, Norwich and include them in treatment
- Use city rather than treatment trends
- Exclude weather controls: reduction of LEZ on NO_2
- Control cities more similar to London, with over 100,0000 residents
- Exclude NYE and day because of fireworks

Back-of-the-envelope cost benefit analysis

- There is no official assessment of the costs and benefits of this policy
- TfL estimates the start up costs to be £36.5M, the operating costs to be £28.1 and the revenues to be £11.6
- Based on our findings, there are 357 extra ULEVs, at an average cost of £27,747 (ONS, 2021), this equals to £9,905,679;
- Using per capita cost of illness provided by Public Health England (2020) of £3,488 for COPD, and defining people with bronchitis as COPD patients who also have a limiting health condition for more than 12 months, our estimates are a lower bound figure;
- Applying our findings to the population estimate of COPD people in London, we have savings for just over 460,416M;
- Using the statutory sick pay (SSP) UK figure of £96.35 per week, for an estimated 141.4 million working days lost (ONS, 2018), and applying our estimates we have savings for £15.5M.
- The calculation leads to over £960M savings for the overall population, excluding the life satisfaction benefits.

Summary and Conclusions

- On air quality, we find that LEZ did not reduce NO2, but it decreased PM10 in Greater London by 12% in comparison with the pre-LEZ mean in the zone.
- ULEZ significantly reduced both NO2 by 12.4% and PM10 by 27% in Central London.

Summary and Conclusions

- On health, we find that LEZ reduced:
  - the probability of having long-term health problems by 4.6%, COPD by 14.5%,
  - the probability of having health problem that limits activity by 7%,
  - and the probability of asking sick leave by 17%

Summary and Conclusions

- For people working in central London:
  - LEZ reduces COPD by 19% and sick leave by 17.7%.
  - T-Charge also decreased long-term health problem by 18% , COPDs by 21.6% , heart diseases by 28.6%, and sick leave by 14%..
  - And ULEZ decreased long-term health problem by by 22.5% , number of health conditions by 29.8% and sick leave by 17.7%.
  - Furthermore, ULEZ improves feelings of happiness, worthiness and satisfaction while reducing anxiety.