# Evaluating the effects of road pricing schemes

## Evidence from London and Milan

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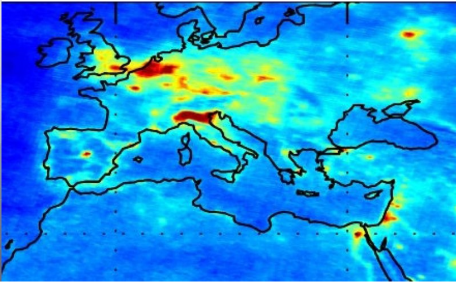
IEFE-FEEM Seminar



# Socio-economic issues of urban traffic

- The cost of congestion to the London economy was \$8.5bn in 2013, and would rise to \$14.5bn in 2030. The cumulative cost over that period would be more than \$200bn (Inrix, 2014).
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- 7,000 deaths in London and 2,000 deaths in Milan (WHO, 2012)

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# Transport policy actions

- Transportation is the largest single source of air pollution (estimates vary considerably)
- A variety of transport policy actions have been implemented in the past decades (limited access areas, park pricing, public transit expansion, traffic restrictions during certain days, etc)
- Recently, a group of cities has implemented road pricing schemes (i.e. a charge to enter the city center). Among them, London (London Congestion Charge, 2003)) and Milan (Ecopass, 2008)
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# The research in a nutshell

- In this talk, I shall present results of a research program on the impacts of road pricing schemes in London and Milan
- By using regression discontinuity in time, the London Congestion Charge and the Ecopass/Area C are evaluated in terms of variation in pollution concentration and traffic flows (Extensions: housing rents and accidents)
- Results:
  - Reduction of pollution in the city center in London and increase in the surrounding area
  - Substantial reduction of pollution in the short run in Milan; no effect in the long run
  - Possibly adverse impact on traffic composition (increase in motorbikes usage)
  - Increase in the number of vehicles in the surrounding area.
  - (Further outcomes: +0.75% in housing rents in the charged area and no effect on accidents reduction in Milan)

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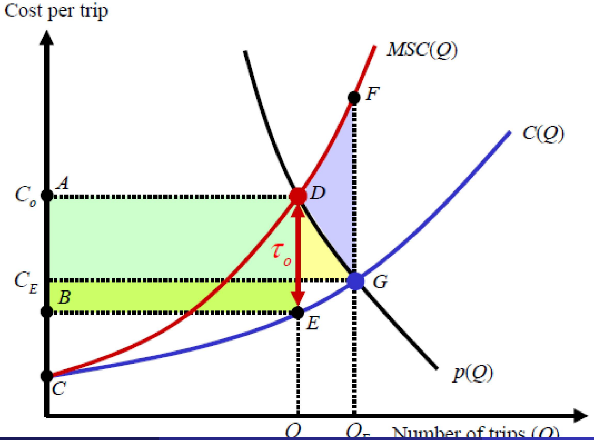
# The simple economics of road pricing

Figure: Road pricing as a Pigouvian tax



# Recent literature on road pricing

- Most of the literature deals with the theory of road pricing: bottlneck model and cordon pricing in monocentric cities.
- A crucial point is the substantial equivalence between first best and second best road pricing under endogenous location of households (Verhoef, 2005).
- Recent research on the political economy - acceptability of road pricing (DeBroek and Proost, 2013; Russo, 2013; Percoco, 2014).
- Empirical literature on CBA (London and Milan) with mixed results: negative for London (Prud'homme and Bocarejo, 2005) or slightly positive for Milan (Rotaris et al., 2012).
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# Methodology

Estimate the parameter $\rho$ on treatment of this form:

$$y_{it} = \alpha_i + \rho Post_t + \gamma Post_t \cdot Treated_i + f(\tilde{x}_t) + \varepsilon_i \quad (1)$$

where:

$y_{t,T}$ is the (log) concentration of a given pollutant in day $t$ in station $i$

$\tilde{x}_{t,T}$ is the forcing variable properly normalized (a time trend centered at the date of the introduction of the LCC, i.e. 17 February 2003). $f(\tilde{x}_{t,T})$ is a 5-th order parametric polynomial trend

*Post* is the treatment variable. It measure the average impact in the whole city London

$Treated_i$ is a dummy taking the value of 1 for monitoring stations within the treated area.

Adjustment for seasonality (month, day fixed effects), weather conditions (temperature, wind speed, rain and humidity ), 5 days of temporal lags.

# Data

Overall dataset: daily concentration of eight pollutants (CO, NO, NO2, NOX, O3, PM2.5, PM10, SO2) from 136 monitoring stations over the years 2000-2013. Data from the LAQN (London Air Quality Network).

Data used in this research: daily data January-March 2003 for stations within 10 km from the city center.

Pollutants: PM10, O3, CO, NOX, SO2.

Furthermore, information on: temperature, wind speed, rain and humidity is also available.

# Descriptive statistics

Table: Descriptive statistics

| | Pre | Post | Difference |
|---|---|---|---|
| PM10 | 27.78 | 25.497 | -2.285*** |
| O3 | 32.11 | 34.92 | 2.81*** |
| CO | 0.68 | 0.412 | -0.268*** |
| NOX | 113.65 | 97.897 | -15.753*** |
| SO2 | 6.99 | 4.346 | -2.642*** |

Figure: The effect of the LCC

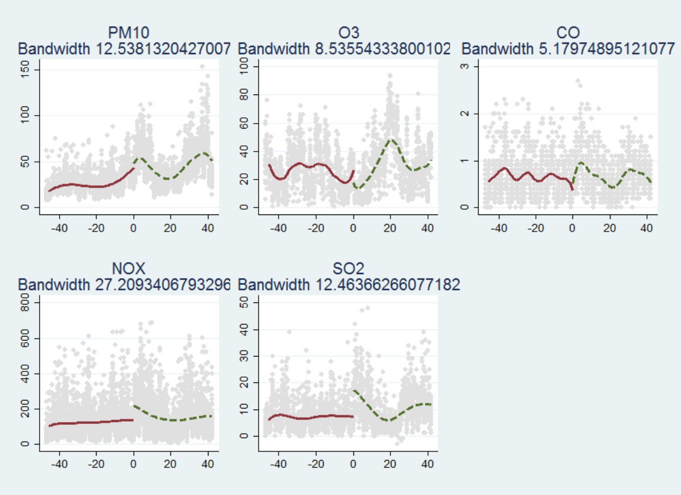


Figure: The effect on CO

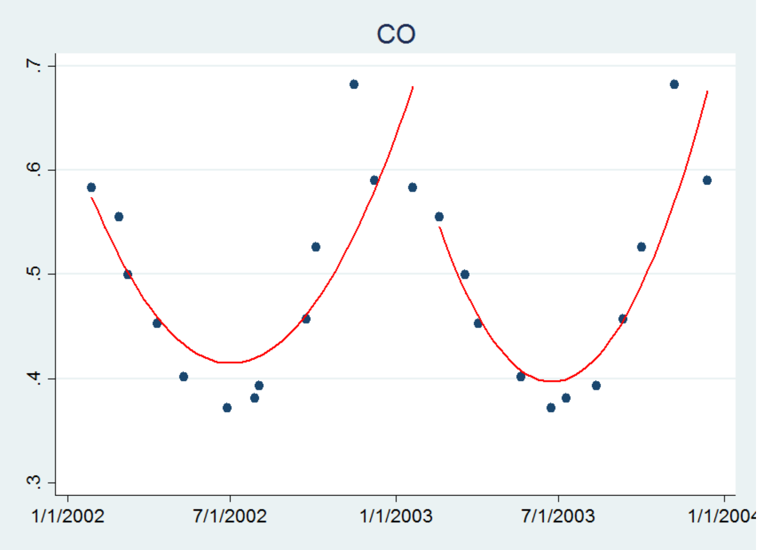


Figure: The effect on PM2.5

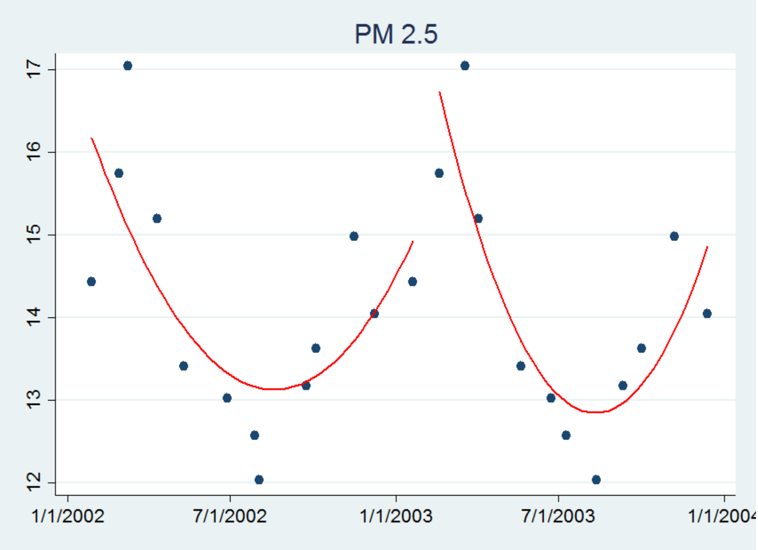
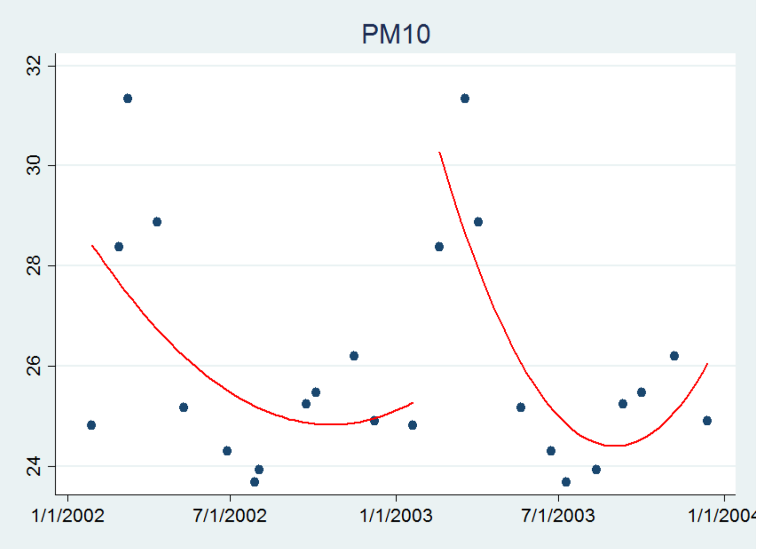


Figure: The effect on PM10



# Results

Table: Baseline results

| | PM10 | O3 | CO | NOX | S02 |
|---|---|---|---|---|---|
| | *Panel A: Whole sample* | | | | |
| Post Feb 13 2003 | 0.0669* | -0.394*** | 0.463*** | 0.423*** | 0.472*** |
| | (0.0337) | (0.0773) | (0.0875) | (0.0633) | (0.117) |
| Post x Treated area | -0.0592*** | 0.00397 | -0.0219 | -0.0451*** | -0.0186 |
| | (0.0172) | (0.0145) | (0.0344) | (0.0129) | (0.0406) |
| N. Obs | 4,149 | 1,827 | 1,691 | 5,126 | 2,139 |
| R-sq. | 0.620 | 0.329 | 0.306 | 0.397 | 0.366 |
| | *Panel B: Excluding treated area, within 5 km* | | | | |
| Post Feb 13 2003 | 0.106** | -0.491** | 0.424*** | 0.416*** | 0.513* |
| | (0.0344) | (0.0690) | (0.0296) | (0.0314) | (0.187) |
| N. Obs | 1,016 | 340 | 487 | 1,242 | 604 |
| R-sq. | 0.622 | 0.380 | 0.377 | 0.402 | 0.418 |

# Results (cont'd)

| | PM10 | O3 | CO | NOX | S02 |
|---|---|---|---|---|---|
| | Panel C: Excluding treated area, more than 5 km | | | | |
| Post Feb 13 2003 | 0.0768* | -0.277** | 0.646** | 0.484*** | 0.540*** |
| | (0.0336) | (0.101) | (0.218) | (0.0985) | (0.134) |
| N. Obs | 2,896 | 1,183 | 1,029 | 3,672 | 1,262 |
| R-sq. | 0.623 | 0.313 | 0.311 | 0.397 | 0.365 |

# Discussion

Previous results hold also for the Western Expansion (Percoco, 2015)

Overall, econometric results of both the aggregated and the spatial model show unclear effects of the congestion charge in London.

This can be due to the diversion of traffic from the city center to external areas, with a subsequent increase in the kilometers traveled and the potential of polluting emissions.

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# Discussion

Traffic counts for the period 2000-2013 from UK DOT, with *annual* observations for 2,141 count points.

Count points have been geolocalized: CENTER, SURROUNDING[1], Control.

DiD model estimated over the years 2000-2005:

$$traffic_{it} = \alpha_i + \beta trend_t + \gamma post_t + \delta_1 Treat_i \cdot Post_t +$$
$$+ \delta_2 SURROUNDING_i \cdot post_t + \varepsilon_{it}$$

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# The spatial effects on traffic

Table: LCC and traffic diversion (in '000)

| | Descriptive Stat. | Least squares | Least squares |
|---|---|---|---|
| Treated x Post | -128.538 | -12.358 | 77.973 |
| | (123.444) | (90.738) | (83.302) |
| SURROUNDING x Post | 111.325*** | | 279.596*** |
| | (23.332) | | (89.434) |
| Control | -207.296 | | |
| | (231.211) | | |
| Obs. | | 12,846 | 12,846 |
| R. sq. | | 0.094 | 0.094 |

# Further discussion

Table: LCC and traffic composition (in '000)

| | Heavy goods vehicle | Light goods vans | Cars | Motorbikes | Bikes |
|---|---|---|---|---|---|
| Treated x Post | -13.434* | 7.002 | 41.967 | 34.664*** | 30.335*** |
| | (7.121) | (15.401) | (77.960) | (11.123) | (8.338) |
| SURROUNDING x Post | -3.952 | 31.497 | 242.441** | 3.592 | -3.479 |
| | (9.541) | (20.818) | (101.360) | (8.988) | (12.804) |
| N. Obs. | 12,846 | 12,846 | 12,846 | 12,846 | 12,846 |
| R. sq | 0.012 | 0.012 | 0.013 | 0.016 | 0.014 |

# Conclusion

- Significant reduction in O3 in the whole city.
- A significant decrease in the concentration of PM10 and NOX was found in the treated area; and a contemporary increase in the concentration of: PM10, CO and NOX was discovered out of the charged area.
- This pattern in the estimates is consistent with the hypothesis that the introduction of the congestion charge has diverted traffic in space and shifted drivers from charged to uncharged routes and, eventually, vehicles.
- Traffic data show that the number of circulating vehicles in the area surrounding the treated area by 279,596 vehicles; 242,441 of which were cars. In terms of kilometers traveled, a decrease by 45,000 kilometers $\times$ vehicles was estimated in the treated area, along with an increase by 39,000 kilometers $\times$ vehicles in the surrounding area.
- A substantial increase in the number of motorbikes and of bikes has also been detected in the city center.

# The Ecopass/Area C

- "Ecopass" introduced in January 2008 in an area of 8.2 squared kilometers on weekdays between 7:30 am and 7:30 pm. The amount of the charge depended on the vehicle's engine emissions standard and fees vary from 2 euros to 10 euros. Residents in the treated area were also charged, although at lower fees.
- AMAT estimates a decrease from 125 days to 83 days i which particulate matters exceding the limit of 50 mg/m3 between 2002/2007-2008.
- Rotaris et al. (2010) in a CBA test found limited (although positive) effect of the Ecopass.
- In a public consultation on June 13 2011, the vast majority of voters (79%) approved the introduction of the Ecopass, which was re-established on January 16 2012 under the name of Area C (flat tax for all vehicles, excluding motorbikes and green veh.).

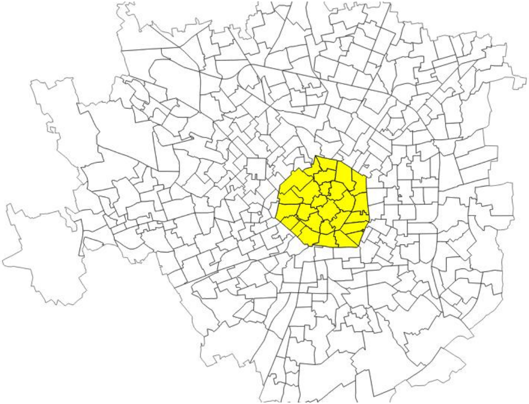


Figure: Milan and the treated area

# Data and methodology

The dataset we use contains information on pollution concentration and on weather variables on a daily basis from January 1 2007 to December 31 2008.

Pollutants in the sample are $C_6H_6CO, O_3, No_2,\ PM_{10}, PM_{2.5}$ and $SO_2$, whereas weather variables are solar radiation, preassure, wind speed, temperature, precipitation and humidity.

The estimated equation is:

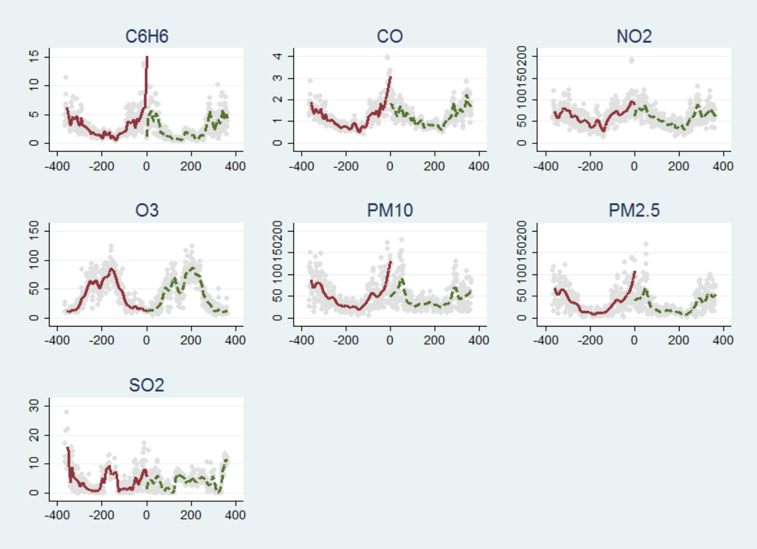
$$y_{t;T} = \alpha + \tau T_t + \sum_{s=1}^{5} \beta_s \tilde{x}_t^s + \gamma season_t + \delta weather_t + \varepsilon_t \tag{2}$$

Table: Descriptive statistics

| | Before (2007) | After (2008) | Difference |
|---|---|---|---|
| C6h6 | 2.927 | 2.561 | -0.366*** |
| CO | 1.338 | 1.218 | -0.120*** |
| O3 | 37.457 | 42.026 | 4.568*** |
| PM10 | 51.409 | 44.319 | -7.091*** |
| PM25 | 38.795 | 29.926 | -8.870*** |
| NO2 | 60.079 | 58.295 | -1.784** |
| SO2 | 7.565 | 3.479 | -4.086*** |

Significance: ***: $p<0.01$; **: $p<0.05$; *: $p<0.1$.

Figure: The effect of the Ecopass on pollution concentration



# Results

Table: Baseline regressions

| | C6H6 | CO | O3 | PM10 | PM2.5 | NO2 | SO2 |
|---|---|---|---|---|---|---|---|
| | *5th order polinomial and weather variables (2004-2011)* | | | | | | |
| *Ecopass* | *0.122* | *-1.209**** | *-7.069**** | *-74.04**** | *-86.45**** | *2.280* | *7.069**** |
| *Observations* | *2,877* | *2,922* | *2,922* | *2,921* | *1,968* | *2,922* | *2,759* |
| *R-squared* | *0.578* | *0.458* | *0.847* | *0.525* | *0.576* | *0.667* | *0.500* |
| | *Only 2007-2008* | | | | | | |
| *Ecopass* | *0.628* | *-1.429**** | *-10.41*** | *-94.38**** | *-97.94**** | *1.977* | *0.406* |
| *Observations* | *707* | *731* | *731* | *731* | *656* | *731* | *682* |
| *R-squared* | *0.652* | *0.759* | *0.860* | *0.591* | *0.610* | *0.694* | *0.439* |

# Further results

- Results are robust to asymmetric trends and autoregression in the dependent variable
- No evidence of displacement of pollution from the city center to the surrounding area
- No evidence of a change in the effectiveness under Area C
- Open question: Is Ecopass/Area C effective in the long run?

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# Effect in the long run (rudimentary evidence)

Table: The effect of the Ecopass after one week

| | *C6H6* | *CO* | *O3* | *PM10* | *PM2.5* | *NO2* | *SO2* |
|---|---|---|---|---|---|---|---|
| | *5th order polinomial and weather variables* | | | | | | |
| *Ecopass* | 9.053 | 0.657 | -25.47 | -133.5 | -183.9 | 4.081 | 60.92 |
| *Observations* | 2,870 | 2,914 | 2,914 | 2,913 | 1,960 | 2,914 | 2,751 |
| *R-squared* | 0.580 | 0.456 | 0.847 | 0.526 | 0.575 | 0.667 | 0.503 |

# The effect in the long run (more serious evidence)

- Problem of non-overlapping between treated and control periods $\rightarrow$Application of the Angrist and Raikkonen (2013).
- We match days after and before the introduction of the Ecopass on the basis of some observed variables $z_t$ such that

$$y_{t,T} = \alpha + \beta x_t + \tau T_t + \delta z_t + \gamma season_t + \varepsilon_t \tag{3}$$

The condition $\beta = 0$ implies that the correlation with pollution is captured by variables in $z_t$ and no longer by the forcing variable .

- Covariates $z_t$ mimic (or are correlated with) the forcing variable (trend).
- The condition $\beta = 0$ can be tested on given (longest possible) time intervals.

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- The condition $\beta = 0$ can be tested on given (longest possible) time intervals.

# The idea

***Step 1:***

Indentify a time window in which the forcing variable (the time trend) is correlated with the set of covariates. Running a series of regressions (4) over given time intervals and observing the significance of the coefficient of the linear trend.

If it is not significant, then a time window in which the correlation between the forcing variable and the covariates is broken is identified.

***Step 2:***

Covariates are used to predict the treatment status across days and hence to match days on the basis of similar covariates (weather variables and their lag) and observe differences in the outcome variables far from the threshold. Nearest neighbor is used.

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# Test of $\beta = 0$

Variables in $z_t$ are wheather variables and their temporal lag (and seasonality). The idea is that the choice of these controls allow to couple days very similar.

Table: Standard BCIA test

| Sample | $C_6H_6$ | $CO$ | $NO_2$ | $O_3$ | $PM_{10}$ | PM25 | $SO_2$ |
|---|---|---|---|---|---|---|---|
| *trend*-1 year | 0.000 | 0.000*** | 0.002 | 0.004 | -0.007 | 0.002 | 0.000 |
| p-value | (0.724) | (0.007) | (0.658) | (0.132) | (0.445) | (0.782) | (0.893) |
| *trend*-180 days | -0.000 | 0.000 | -0.005 | -0.006 | 0.009 | 0.004 | 0.004 |
| p-value | (0.771) | (0.332) | (0.818) | (0.687) | (0.726) | (0.829) | (0.262) |
| *trend*-90 days | -0.007 | 0.001 | 0.122 | 0.046** | 0.080 | -0.036 | -0.004 |
| p-value | (0.318) | (0.331) | (0.135) | (0.026) | (0.409) | (0.637) | (0.682) |

# The effect of the Ecopass in the long run

Table: Propensity Score Matching (Standard Model)

| | Pre Matching | | | | | Post Matching | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Pollutant | Before | Afteer | Difference | S.E. | t | Before | After | Difference | S.E. | t |
| $C_6H_6$-1 year | 2.382 | 3.273 | -0.890 | 0.194 | -4.59 | 2.382 | 2.645 | -0.262 | 0.263 | -1.00 |
| $CO$-180 days | 1.167 | 1.472 | -0.305 | 0.074 | -4.07 | 1.167 | 1.099 | 0.068 | 0.328 | 0.21 |
| $NO_2$-1 year | 57.228 | 65.655 | -8.426 | 2.034 | -4.14 | 57.228 | 58.979 | -1.750 | 2.531 | -0.69 |
| $PM_{10}$-1 year | 43.054 | 55.517 | -12.462 | 2.725 | -4.57 | 43.054 | 46.431 | -3.376 | 4.190 | -0.81 |
| $PM_{2.5}$-1 year | 30.606 | 41.551 | -10.944 | 2.630 | -4.16 | 30.606 | 31.820 | -1.213 | 3.910 | -0.31 |
| $SO_2$-1 year | 3.854 | 3.273 | 0.580 | 0.335 | 1.73 | 3.854 | 3.499 | 0.354 | 0.546 | 0.65 |

# Discussion

- Why substantial ineffectiveness in the long run?
- Hp: effect on traffic composition

## Natural experiment

- 50 days suspension imposed between 25 July and 17 September 2012 due to a ruling by the Council of State after protests by parking owners in the center of the city.
- Daily data on traffic composition for 2012 for all vehicles entering the treated area. 10 cateogories (similar results in Percoco (2014) with with 87 types)

$$y_t = \alpha + \tau Susp_t + \sum_{s=1}^{5} \beta_s \tilde{x}_t^s + \gamma season_t + \delta weather_t + \varepsilon_t \tag{4}$$

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# Discussion - the suspension

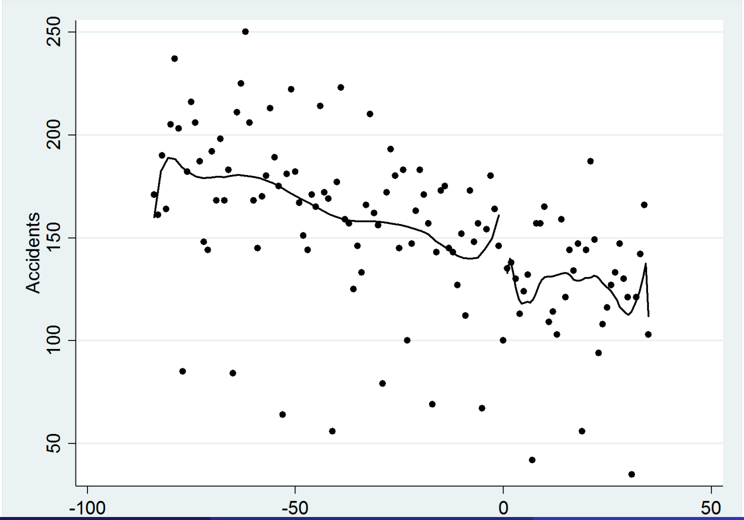
Table: The effect of Area C suspension

| | Cars - 1 | Cars - 1b | Cars - 2 | Cars - 3 | Vans - 1 |
|---|---|---|---|---|---|
| Suspension | -11.10** | -2,688*** | 4,662 | 861.6** | -1.425 |
| | (4.343) | (267.7) | (3244) | (288.9) | (1.134) |
| Observations | 365 | 365 | 365 | 365 | 365 |
| R-squared | 0.589 | 0.770 | 0.611 | 0.692 | 0.697 |
| | Vans - 1b | Vans - 2 | Vans - 3 | Moto. | Total |
| Suspension | -235.7*** | 159.4 | 363.0*** | -7,087*** | -3,978 |
| | (41.64) | (241.5) | (90.28) | (747.6) | (4,366) |
| Observations | 365 | 365 | 365 | 365 | 365 |
| R-squared | 0.849 | 0.832 | 0.747 | 0.835 | 0.710 |

Note: Baseline specification includes a constant, a temporal trend, and fixed effects for day of the week, month and year, time trend polynomial of the 5th order, daily average temperature, daily average wind speed, cumulative daily rainfalls, average daily humidity.Type 1 car are electric cars; type 1b cars are LPG, bi-fuel and hybrid cars, type 2 cars are Euro 1-4 fuel and Euro 4 diesel cars, type 3 cars are Euro 0 fuel and Euro 1-3 diesel cars. Type 1 vans are electric vans; type 1b vans are LPG, bi-fuel and hybrid vans, type 2 vans are Euro 1-4 fuel and Euro 4 diesel vans, type 3 vans are Euro 0 fuel and Euro 1-3 diesel vans. Significance: ***: $p<0.01$; **: $p<0.05$; *: $p<0.1$.

# Extension 1: the effect on accident

Figure: Accidents in the charged area



# Extention 2: The effect on the housing market

Estimate the parameter $\rho$ on treatment of this form:

$$y_{it} = Treated_i + \rho Post_t + \gamma Post_t \cdot Treated_i + f(\tilde{x}_t) + \varepsilon_i \tag{5}$$

where:

$y_{t,T}$ is the (log) average housing rent in period $t$ in area $i$

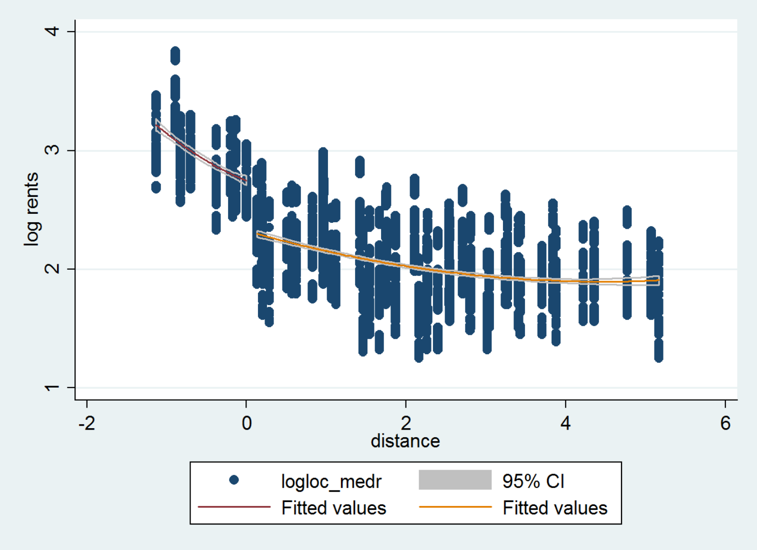
$\tilde{x}_{t,T}$ is the forcing variable properly normalized (a spatial trend from the Duomo centered at the border of the charged area). $f(\tilde{x}_{t,T})$ is a 5-th order parametric polynomial trend

*Post* is the treatment variable. It measure the average impact in the whole city London

$Treated_i$ is a dummy taking the value of 1 for monitoring stations within the treated area.

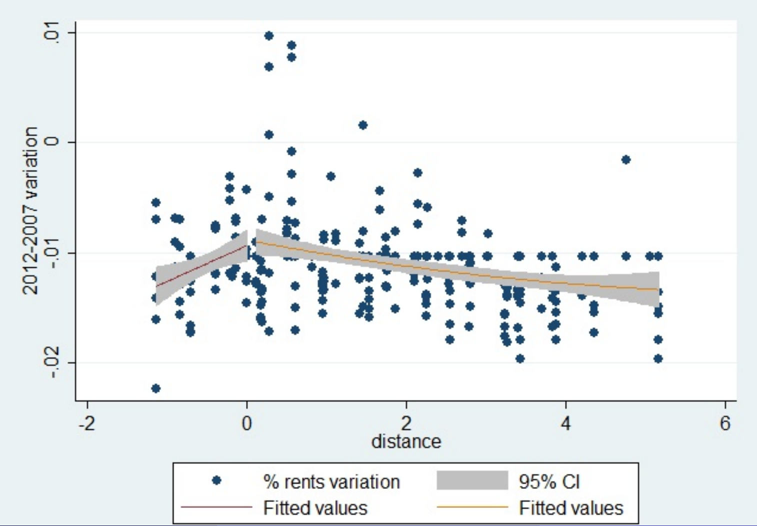
Adjustment for seasonality, housing types, preservation status.

Figure: Housing rent: levels



# Data

Figure: Housing rents: temporal differences



# Descriptive statistics

Table: Descriptive statistics

| Zone | N | Mean rent (€ $\times$ month /sq.m) | Standard Dev. |
|---|---|---|---|
| Central | 720 | 19.42 | 6.15 |
| Semi-central | 864 | 10.19 | 2.96 |
| Peripheral | 2,088 | 7.45 | 2.30 |
| Suburban | 288 | 7.05 | 2.00 |
| Whole city | 3,960 | 10.19 | 5.66 |

# Results

Table: Baseline results

| Average (log) rents at constant prices | (1) | (2) | (3) |
|---|---|---|---|
| Policy [T(i)×D(i)] | 0.00749*** | 0.00749*** | 0.00749*** |
| | (0.00230) | (0.00230) | (0.00230) |
| Distance from the trated area (km) | -0.0907*** | -0.0907*** | -0.0907*** |
| | (0.0132) | (0.00863) | (0.00861) |
| Inside the treated area [D(i)] | 0.628*** | 0.628*** | 0.598*** |
| | (0.0556) | (0.0364) | (0.0718) |
| Treatment period [T(i)] | -0.00613*** | -0.00587*** | -0.00613*** |
| | (0.00124) | (0.00124) | (0.00124) |
| Time trend | -0.0120*** | -0.0120*** | -0.0120*** |
| | (0.000125) | (0.000125) | (0.000128) |
| Preservation | | Yes | Yes |
| Type | | Yes | Yes |
| Interaction type*preservation | | Yes | Yes |
| Interactions treatment*pres.*type | | | Yes |

# Robustness checks

Different types of polynomial in the spatial distance

Geo diff-in-diff vs diff-in-diff

Pooled OLS vs Random effect

Restriction of the sample

# Discussion

Previous results are different with respect to Percoco (2014) who found a decrease in housing prices by 1.2-1.8%

1. Inefficiency in housing markets. The implied rate of return from this evidence and Percoco (2014) is 4%, wherease the user cost estimated by Catter et al. (2004) for Italy is 1%.

2. Road pricing increases the user cost more than rents (through externalities reduction): $P = \frac{R}{r}$; Var r=90-445% for residents (50-250 euros for annual payments); Var R=0.75%.

3. Mis-specfication in Percoco (2014)

# Concluding remarks

- Limited effectiveness of RP schemes: "Diversion" is the word.
- The evil is in the details: problems of design.
- Policy implications:
  - not only elasticity of traffic to transport cost, but also cross-elasticity
  - spatial dimension is relevant
- Future (current work):
  - (long run) welfare analysis for London
  - Effect of RP on congestion
  - Ecopass and health

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Thank you for your attention!

- "Heterogeneity in the reaction of traffic flows to road pricing: a synthetic control approach applied to Milan", Transportation, forthcoming.
- "The impact of road pricing on housing prices: preliminary evidence from Milan", Transportation Research A, 2014, 67(September):188–194.
- "The effect of road pricing on traffic composition: evidence from a natural experiment in Milan, Italy", Transport Policy, 31(January):55–60.
- "Is road pricing effective in abating pollution? Evidence from Milan", Transportation Research D, 2013, 25(December):112–118.
- "Heterogeneity and the political economy of road pricing", Journal of transport economics and policy, revise & resubmit.
- "Housing rent and road pricing in Milan: evidence from a geographical discontinuity approach", joint with F.M. D'Arcangelo, submitted.
- "Environmental effects of the London Congestion Charge: a regression discontinuity approach", submitted.