The effect of road pricing on traffic composition: evidence from a natural experiment in Milan, Italy

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Abstract

The paper aims to estimate the effect of road pricing on the composition of traffic. By considering the case of Milan, where a charge to enter the city center was introduced in 2008, and by relying on an unexpected and temporary suspension of the tax, we analyse the effect of the policy on flows of vehicles classified by type of engine. We have found that road pricing shifted users from Euro 0-3 vehicles to GPL, bi-fuel and hybrid vehicles. However, environmental benefits of the policy were reduced by a substantial increase in the usage of motorbikes. This evidence calls for a consideration of behavioral reactions of road users when evaluating ex ante the social profitability of road pricing schemes.

Keywords: Road pricing, Traffic composition, Natural experiments, Milan.

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1 Introduction

The internalization of external costs of transportation is one of the most relevant issues policy makers and scholars have been dealing with in recent years. In the cities, congestion and air pollution are among the most relevant sources of externalities, increasingly tackled through the adoption of road pricing schemes. The London Congestion Charge, introduced in 2003 and then modified to extend the treated area, is probably the most known and studied example (Banister, 2003; Givoni, 2012; Ison and Rye, 2005; Prud'homme and Bocarejo, 2005; Quddus et al., 2007; Santos and Bhakar, 2006; Santos and Fraser, 2004; Santos and Shaffer, 2004). Other examples of such policy are Hong Kong (Ison and Rye, 2005), Singapore (Santos, 2005), Stockholm (Eliasson et al., 2009), several Norwegian cities (Ieromonachou et al., 2006), Milan (Percoco, 2013; Rotaris et al., 2010).

The effectiveness of these measures has received little attention and most of the studies argue for limited benefits from road pricing in terms of social welfare variation (Mackie, 2005; Prud'homme and Bocarejo, 2005; Raux, 2005) or pollution abatement (Eliasson et al., 2009; Percoco, 2013).

In this paper we study the effect of road pricing in Milan on traffic composition in the city center. The rationale for analysing this type of outcome relies on the dependence of the effectiveness of of those policy instruments on the types of vehicles circulating in the charged area and also on behavioral responses of road users. Second best road pricing schemes (as it is often the case in reality) may provide users with incentives to use certain types of vehicles to avoid the payment of the charge or to pay less. Therefore, the outcome of the policy crucially depends on the extent of this behavioral response. To the best of our knowledge, empirical evidence on this point is very limited. By using stated preferences surveys, Ubbels and Verhoef (2006) and Vritic et al. (2010) have highlighted the relevance of behavioral responses of Swiss and Dutch car users respectively when evaluating road pricing options.

This paper contributes to the literature on the empirics of road pricing by estimating the effect of the congestion charge in Milan (the so-called Area C) on flows of several typologies of vehicles classified on the basis of the type of engine. By using daily data for 2012 and adopting a regression discontinuity framework, we estimate the effect of road pricing by exploiting an exogenous variation in its application given by a 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. By observing change in the composition of traffic during those 50 days with respect to the previous and next days during which the charge was applied, we are allowed to infer the impact of Area C on traffic flows in Milan. In other words, since we are not allowed to study the effect of the introduction of road pricing because of the lack of data before January 2012, we make use of the aforementioned natural experiment of its temporary suspension to infer the impact of the charge.

Through our econometric analysis, we found that the introduction of the charge shifted users from Euro 0-3 vehicles to bi-fuel and hybrid vehicles. However, environmental benefits of the policy are reduced by a substantial increase in the usage of motorbikes of an order of magnitude of +21%.

The paper is organised as follows. In Section 2 we provide some background information on road pricing policies in Milan, whereas in Section 3 we present the methodology we have used to evaluate the effect of Area C . Section 4 contains results while Section 5 concludes.

2 Background: road pricing in Milan[2]

Milan has one of the highest rates of car ownership in Europe. More than half of population use private cars and motorcycles, ranking second only after Rome, and among the highest in the world (Percoco, 2010). The city also has the third-highest concentration of particulate matter among large European cities, both in terms of average annual level and days of exceeding the European Union PM10 limit of 50 micrograms per cubic meter. Due to its lingering air pollution problems and associated health problems, in 2007, and for a trial period, the city banned 170,000 older cars and motorcycles that do not pass strict environmental emission standards. In January 2008 the Ecopass program was launched within a designated restricted traffic zone

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[2] This section relies on information in Percoco (2013).

corresponding to the central “Cerchia dei Bastioni” area of 8.2 km2 (figure 1). The amount of the charge depended on the vehicle’s engine emissions standard and fees vary from €2 to €10 on weekdays from 7:30 a.m. to 7:30 p.m. Free access to the ZTL was granted to motorbikes, to several types of alternative fuel vehicles and to conventional fuel vehicles compliant with the European emission standards Euro3 and Euro4 or better. Residents within the restricted zone were exempted only if driving higher emission standard vehicles while owners of vehicles with older more polluting engines a discount only if they buy an annual pass that can go up to €250 depending on the vehicle’s engine emission standards. Enforcement was carried out through digital cameras located at 43 electronic gates, with fines for offenders varying between €70 to €275.

[Figure 1]

An estimated 98,000 vehicles were entering the restricted area before the Ecopass came into force (AMMA, 2008a). According to an evaluation conducted by the Milanese Agency of Mobility and the Environment in December 2008, during the first month traffic inside the ZTL fell to 82.2 thousand vehicles, and for the first eleven months the average traffic flow was 87.7 thousand vehicles . This represents 12.3% fewer vehicles entering the ZTL, while outside of the Ecopass area traffic decreased by 3.6%. Meanwhile, surface public transportation service grew by 1,300 additional daily runs, carrying an average of 19,100 additional daily passengers, an increment of 7.3% for this eleven month period. For the morning rush hour during the same months the number of congested kilometers in the interior traffic network fell by 25.1% and average travel speed improved 4.0%, translating into 9.3 million euros saved by year. Traffic accidents inside the ZTL also fell by 20.6% (AMMA, 2008c). A comparison of the type of vehicles entering the ZTL by engine standard with respect to the months of October and November 2007 found that there has been a change in the composition of the fleet entering the restricted area, with a sharp reduction of older vehicles with lower emission standard engines. The number of vehicles subject to the charge fell by 56.4%, representing an average reduction of 21,274 vehicles per day, with a greater variation among auto drivers when compared to commercial vehicles. The number of exempt vehicles grew by 4.3%, for an average increase of 2.248 vehicles a day. The Milanese Agency of Mobility and the Environment report shows that during the first eleven months of the Ecopass program the number of days exceeding the permitted level of Diesel particulate matter of 50 mg/m3 fell to 83 days, in contrast to the period January to November 2002 to 2007, when the average number of days exceeding this limit was 125 days. This study also found that between January and November (excluding August when the charge was temporarily suspended), all traffic related emissions were lower. PM10 decreased by 23%, particulate matter decreased by 18%, NH3 fell 47%, NOX was reduced by 15%, and CO2 emission were cut by 14% (AMMA, 2008c). By conducting a cost-benefit analysis similar in spirit to the one proposed by Prud'homme and Bocarejo (2005), Rotaris et al. (2010) find that social welfare variation associated to the introduction of the tax is slightly positive and amounting to 6 million euros per year. 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. Area C started as an 18-month pilot program with the objective to reduce traffic, to promote sustainable mobility and public transport, and to decrease the levels of pollution. Area C was definitively approved on 27 March 2013, but was temporarily suspended 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 Milan. This event is of particular interest for our research since we will use this natural experiment to assess the extent of the shift for different types of vehicles.

Under Area C all types of vehicles were charged with the sole exceptions of electric, bi-fuel, GPL and hybrid vehicles and motorbikes. All Euro 0 fuel vehicles and Euro 0-3 diesel vehicles were not allowed to enter the city center, whereas all other vehicles are charged. This provides an incentive for road users not willing to pay the charge to use cleaner vehicles or motorbikes. Therefore the temporary suspension of Area C is a temporary removal of those incentives and constitutes an important occasion to evaluate how the shift across types of vehicles may be affected by road pricing.

Road pricing in Milan has been the subject of several papers. The aforementioned paper by Rotaris et al. (2010) has proposed a cost-benefit analysis in which the Ecopass passed the test by about 6 million euros. However, the analysis was carried out by using descriptive statistics, in which the identification of the policy effect was particularly weak. To deal with this issue, Percoco (2013) has proposed the use of a regression discontinuity design to analyse the effect of the Ecopass on the concentration of pollution. It was found that the charge decreased significantly the concentration of some pollutants (especially carbon monoxide and particulates) but only in the short run, while one week after its implementation, pollution returned to its pre-treatment levels. Finally, Percoco (2012) made an attempt at estimating the effect of road pricing on housing price by using a difference-in-difference approach, finding that the charge significantly decreased home prices in the treated area and hence indicating that the negative effect of an increase in transport costs offsets the benefits from a reduction in external costs such as congestion and pollution).

3 Methodology and data

In our research, we aim to exploit the exogenous variation in the treatment (the Area C) imposed by the temporary suspension of the charge. To study this event, we adopt a regression discontinuity design.

More formally, let y_0 and y_1 denote the counterfactual outcomes without and with treatment T, let x be the forcing variable and consider the following assumptions:

A1. E(y_g| T,x) = E(y_g| x), g=0,1

A2. E(y_g| x), g = 0,1 is continuous at $x = x_0$

A3. P(T=1|x)≡F(x) is discontinuous at $x = x_0$, i.e. the propensity score of the treatment has a discrete jump at $x = x_0$.

Following Imbens and Lemieux (2008) the goal is to estimate the parameter ρ on treatment of this form:

$$y_{t,T} = \theta + \rho T_t + f(\tilde{x}_{t,T}) + \eta_t \tag{1}$$

where $y_{t,T}$ is in our case the flow of vehicles of a given type at time t whose treatment status is T (i.e. during the suspension or not), θ is a constant, $\tilde{x}_{t,T}$ is the forcing variable properly normalized. In our case $x_{t,T}$ is a time trend normalized with respect to July 25, that is we consider a variable in the form $x_{t,T} - x_0$ so that at $x_{t,T} = x_0$ we have that $\tilde{x}_{t,T} = 0$ and $f(\tilde{x}_{t,T}) = 0$. Consequently, ρ expresses the impact of the treatment at $x_{t,T} = x_0$. The $f(\tilde{x}_{t,T})$ term is a p-th order parametric polynomial whose parameters are allowed to differ on the left and the right of the cut-off point (Angrist and Pischke, 2009) in order to account for non linearity and thus be sure that the jump is not due to an unaccounted non-linearity, while distinct sets of parameters allow different trend functions. Lastly η_i is an error term.

Our data cover daily vehicle access in the city-center of Milan (i.e. in the charged area) for 2012 by type of vehicle. In this respect, we have information on nine typologies of vehicles classified according to the type of engine:electric cars (type 1), GPL, bi-fuel and hybrid cars (type 1b), Euro 1-4 fuel and Euro 4 diesel cars (type 2), Euro 0 fuel and Euro 1-3 diesel cars (type 3); electric vans (type 1); GPL, bi-fuel and hybrid vans (type 1b), Euro 1-4 fuel and Euro 4 diesel vans (type 2), Euro 0 fuel and Euro 1-3 diesel vans (type 3) and motorbikes. These information are complemented with data on weather cnditions in terms of average temperature, total rainfalls, average pressure, average wind speed, average humidity. The rationale for considering these variables as potentially relevant in explaining traffic intensity is that they can affect the propensity to use given types of vehicles (e.g. motorbikes). All data are collected, maintained and distributed by Agenzia per la Mobilità, l'Ambiente e il Traffico (AMAT) and have been extensively checked by researchers to ensure quality and reliability.

It should be mentioned that traffic daily data have been collected only starting from January 2012, so that it is not possible to use similar information to evaluate the introduction of the Ecopass in 2008. Furthermore, only data aggregated in the aforementioned 9 categories are publicly available.

[Table 1]

Table 1 reports descriptive statistics for traffic variables and shows an apparently surprising result, that is the number of vehicles during the suspension of Area C is lower all across typologies. This seems in contrast with our prior that during the suspension traffic intensity should have been higher, so that we can use such event to estimate the impact of road pricing on travel demand. However, it should be noted that the suspension took place during the summer, i.e. during a period of low traffic. This implies that our time series are affected by seasonality, a feature which needs to be taken into account in the econometric specification.

4 Results

Our event study approach needs to be framed in the context of the type of data we use. In particular, statistics in table 1 reported counterintuitive statistics and this fact was considered to be due to seasonality. In equation (1), our parameter of interest, ρ, identifies a deviation from the time trend in $f(\tilde{x}_{t,T})$. However, in the case of seasonal time series, to identify a time trend and its deviation correcly, we need to control for seasonal effects, which, in our case, are month- and day-specific. Our baseline econometric specification therefore is:

$$y_t = \alpha + \sum_{s=1}^{5} \beta_s \left(trend\right)^s + \rho suspension_t + \delta \mathbf{weather_t} + \varpi \mathbf{seasonality_t} + \varepsilon_t \qquad (2)$$

where the dependent variable is the number of vehicles of one of the typologies in the dataset entering the city center (i.e. the charged area) at time t, *trend* is a time trend considered up to a 5-th order polynomial to account for potential nonlinearities around the treshold, *suspension* is a dummy variable taking the value of 1 for days of suspension and 0 otherwise, **weather** is a vector of weather controls. As stated above, our data are affected by seasonality, so that in specification (2) we have included a vector of variables, **seasonality**, to deal with this important issue. In particular, in this vector, we include fixed effects for the month and the day of the week. α,$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \rho, \gamma, \delta, \varpi$ are parameters to be estimated, whereas ε is an iid error term. Parameter ρ is our parameter of interest since it measures the variation of the dependent variable due to the suspension of the Area C. Equation (2) is hence estimated by OLS.

Table 2 reports the results of the analysis only in terms of estimates of ρ, whereas all other parameter estimates are not reported for the sake of space. In particular, we have estimated equation (2) by type of vehicles and for the total number of vehicles. The table reports results for a baseline specification (Panel A) and for other robustness checks, namely, excluding 15 days before Area C was introduced in January 2012 (Panel B), considering only data for the 50 days before the suspension, 50 days of suspension and 50 afterward (Panel C), and accounting for auto-correlation in the dependent variable (Panel D).

[Table 2]

Results of baseline regressions point at a reduction of type 1 and type 1b cars by 11 and 2,688 vehicles respectively. Type 3 cars increased by 862 units, whereas type 2 cars do not seem to react to pricing as no significant change is detected. As for commercial vehicles, estimates of coefficient ρ indicate that users shifted from type 1b (GPL, bi-fuel, hybrid) to more pollutant vehicles by 236 units and that further trips with type 3 vans were generated since the magnitude of the coefficient is 363. Furthermore, road users reacted to the suspension by reducing motorbike usage, although the total number of vehicles in the city center remained unchanged since estimates of ρ in model (10) are not statistically different from zero.

Results in Panel B are obtained by excluding the first 15 days of 2012, i.e. the ones in which Area C was not implemented yet. They confirm substantially estimates of the baseline regressions.

As results may be driven by the fact that suspension lasted for only 50 days, whereas, the charge has been in place for 300 days, in Panel C we consider a sample of 150 days (50 of suspension and 50 days before and after the suspension). Also in this case, results are unchanged, although point estimates are slightly smaller than baseline estimates.

Finally, to account for potential serial auto-correlation in traffic variables, specification in Panel D add two lags of the dependent variable as further regressors. In this case, which is the most restrictive case, estimates are qualitatively (i.e. in terms of sign and significance) unchanged although coefficients are considerably smaller and of lower statistical significance. Point estimates indicate a reduction in GPL, bi-fuel and hybrid cars by 1,435 and a marginally significant increase of cars with Euro 0-3 engines. As regards commercial vehicles, we found a shift from type 1b to type 3 vehicles. Furthermore, a reduction by 3,109 motorbikes in the city center is detected.

To sum up, our findings point at a substantial shift among types of vehicles due to the introduction of the congestion charge. In particular, according to our baseline specification, the suspension of Area C reduced the usage of bi-fuel and hybrid cars by 17% with respect to the yearly average and increased the number of Euro 0-3 cars by 13%. Similarly, GPL, bi-fuel and hybrid commercial vehicles decreased by 9.6% and Euro 0-3 vehicles increased by 20%. Interestingly, motorbikes reduced by 21%, whereas the total number of vehicles circulating in the city center has remained unchanged as corresponding coefficients were never found statistically significant.

Econometric results hence point at a marginal effectiveness of the charge in reducing congestion as traffic remained constant (hence road users are more willing to shift to unpriced vehicles or to pay the charge than to leave the car) and also environmental benefits are questionable since Area C, according to the estimates from the natural experiment of the temporary suspension, increased substantially the usage of motorbikes, although a small increase in the usage of ecological vehicles was also found. This result is in line with the findings of Percoco (2013), in which road pricing schemes in Milan were found to have had negligible impact on pollution concentration.

5 Conclusion

In this paper we have studied the effect of road pricing on traffic composition in Milan. By exploiting the exogenous source of variation in the application of Area C and by controlling for a number of confounding factors, we have argued that the road pricing scheme has had limited impact in terms of congestion and environmental quality because of the behavioral response of road users. In fact, we have found that the policy did not produce a reduction in the number of vehicles entering the city center, while increasing the number of motorbikes and in part of GPL, bi-fuel and hybrid cars.

The approach we have used, i.e. regression discontinuity, provides local estimates of an Average Treatment Effect whose transferability properties are notably unknown. This implies that our results can hard be generalized to other cities and contexts. However, the evidence presented in this paper points at a potential ineffectiveness of road pricing schemes when road users have incentives to shift across types of vehicles. This further implies that behavioral responses should be taken into account when evaluating ex ante the potential costs and benefits of a congestion or pollution tax.

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Figure 1: The charged area

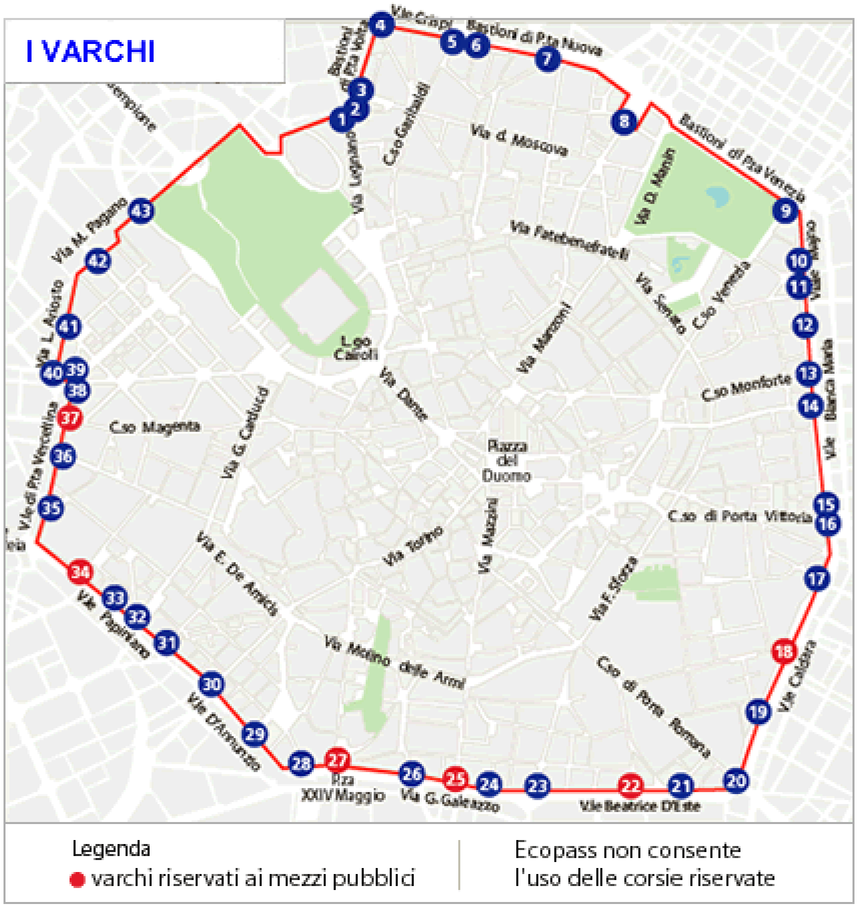

Table 1: Descriptive statistics

	Whole sample	Out of suspension	During suspension
Cars type 1	35.44	37.29	23.72
	(19.18)	(19.14)	(14.98)
Cars type 1b	15,534	16,417	9,948
	(4,936)	(4,367)	(4,694)
Cars type 2	91,565	94,970	70,044
	(19,858)	(15,209)	(30,053)
Cars type 3	6,651	6,786	5,801
	(1,773)	(1,736)	(1,782)
Vans type 1	9.306	9.794	6.220
	(6.746)	(6.869)	(4.942)
Vans type 1b	2,457	2,582	1,672
	(1,296)	(1,285)	(1,085)
Vans type 2	9,149	9,450	7,245
	(4,326)	(4,249)	(4,362)
Vans type 3	1,759	1,766	1,717
	(613.9)	(566.9)	(859.6)
Motorbykes	33,485	34,786	25,264
	(19,676)	(19,751)	(17,210)
Observations	365	315	50

Notes: Each column reports mean and standard errors (in parentheses). Type 1 cars are electric cars; type 1b cars are GPL, 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 GPL, 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: ***: $p<0.01$; **: $p<0.05$; *: $p<0.1$.

Table 2: The effect of a temporary suspension of Area C on traffic composition

	(1) Cars type 1	(2) Cars type 1b	(3) Cars type 2	(4) Cars type 3	(5) Vans type 1	(6) Vans type 1b	(7) Vans type 2	(8) Vans type 3	(9) Motorbykes	(10) Total
Panel A: Baseline regressions										
Suspension	-11.10**	-2,688***	4,662	861.6**	-1.425	-235.7***	159.4	363.0***	-7,087***	-3,978
	(4.343)	(267.7)	(3244)	(288.9)	(1.134)	(41.64)	(241.5)	(90.28)	(747.6)	(4,366)
Observations	365	365	365	365	365	365	365	365	365	365
R-squared	0.589	0.770	0.611	0.692	0.697	0.849	0.832	0.747	0.835	0.710
Panel B: Only after Area C										
Suspension	-11.03**	-2,687***	4,750	866.2**	-1.457	-237.4***	150.3	360.3***	-7,142***	-3,953
	(4.315)	(254.2)	(3996)	(341.4)	(1.079)	(47.53)	(284.8)	(104.1)	(794.3)	(5,406)
Observations	350	350	350	350	350	350	350	350	350	350
R-squared	0.571	0.774	0.617	0.682	0.699	0.854	0.839	0.755	0.835	0.715
Panel C: Equal time window										
Suspension	-10.66	-2,548***	6,421	966.4*	-0.768	-226.1***	143.1	341.6***	-6,513***	-426.0
	(6.283)	(349.6)	(4898)	(416.8)	(1.427)	(41.67)	(243.2)	(102.8)	(1,155)	(7,104)
Observations	150	150	150	150	150	150	150	150	150	150
R-squared	0.744	0.903	0.769	0.635	0.783	0.897	0.892	0.814	0.870	0.846
Panel D: Accounting for autocorrelation										
Suspension	-8.574	-1,435**	3,437	642.0*	-0.782	-166.8***	85.13	142.5***	-3,109**	1584
	(5.946)	(550.2)	(3350)	(311.7)	(1.260)	(49.74)	(176.6)	(27.55)	(1,164)	(4,679)
Observations	150	150	150	150	150	150	150	150	150	150
R-squared	0.751	0.930	0.840	0.689	0.799	0.912	0.918	0.876	0.902	0.907

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. In Panel B we exclude all observations before the introduction of Area C. In Panel C we consider only data 50 days before and after suspension. Specifications in Panel D have two year lags of the dependent variable as further explanatory variables. Standard errors are clustered by month of the year. Type 1 car are electric cars; type 1b cars are GPL, 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 GPL, 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: ***: $p<0.01$; **: $p<0.05$; *: $p<0.1$.