No free polluting anymore: The impact of a vehicle pollution charge on air quality

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Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's
2013 AAEA & CAES Joint Annual Meeting, Washington, DC, August 4-6, 2013.

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Abstract

The paper analyzes the impact of a vehicle pollution charge (Ecopass), enforced at peak time, on nitrogen oxides concentration in Milan. Using hourly data on pollution concentration and a vector autoregressive model, I estimate the short and long run effects of the policy, the effects outside the Ecopass area and during off-peak time. Results suggest that Ecopass reduced pollution in the short run, but had no effect in the long run. The effect on zones outside Ecopass area is not homogeneous, suggesting substitution effects in some areas of the city. There is no systematic evidence of increased pollution levels during off-peak time due to Ecopass.

*I thank Anna Alberini, Robert Chambers, Pamela Jakiela, Wesley Musser, Marc Nerlove, David Newbery, and Rob Williams for their advice and comments. Participants to the Colorado Environmental Economics Workshop 2012 and the 2nd Northeast Workshop on Energy Policy and Environmental Economics provided very useful insights. I thank also Marco Bedogni and Guido Lanzani for their information on pollution and atmospheric data in Milan.

1 Introduction

In the recent decades, many cities throughout the world introduced restrictions to vehicle circulation to deal with increasing traffic levels and stricter environmental regulations. Such measures often encounter fierce opposition from part of the population due to the inconvenience they cause to drivers, and thus they need to prove themselves effective to justify their existence.

While the economic literature has discussed since long time the implications of road pricing (Walters, 1961, Vickrey, 1963, Keeler and Small, 1977, Newbery, 1988, 2005), it is only recently that economists started to analyze empirically the impact of existing policies (Eskeland and Feyziolu, 1997, Santos et al., 2000, Santos, 2004, Davis, 2008, Gallego et al., 2011, Lin et al., 2011). In this paper, I build on the existing literature and I explore a type of policy relatively overlooked so far.

The purpose of the paper is to examine the impact on nitrogen oxides concentration (NOx) of a vehicle pollution charge (Ecopass) introduced in the city center of Milan (Italy) from the beginning of 2008 to the end of 2011 and enforced during weekdays at peak hours. A pollution charge implies that polluting vehicles must pay a fee to enter in a certain area. The fee is proportional to the pollution class of the vehicle, meaning that highly polluting vehicles pay an high fee, but the cleanest vehicles can circulate without paying. The purpose of the policy was to disincentivize the use of more polluting, less efficient vehicles.

Ecopass was the first permanent city-level measure in Milan aimed to reduce pollution concentration and the first vehicle pollution charge ever implemented in a large city. It was also object of a couple of previous studies: Rotaris et al. (2010) produced estimates of pollution reduction at the source based on the number of vehicles entering in the Ecopass area before and after the introduction of the policy. Danielis et al. (2011) looked instead at the average yearly pollution trend within the Ecopass area. Both studies argue that Ecopass managed to reduce the pollution concentration in the city center.

With this paper I add three elements of novelty to the existent literature. First, I investigate the effects on air pollution of a new policy which is a combination of two widely diffused vehicle restriction policies. In fact, a pollution charge affects only highly polluting cars (like low emission zones), but imposes only the payment of a fee instead of forbidding circulation (like congestion charges). In the analysis I used a nine years time series dataset of hourly NOx pollution concentration from five pollution monitoring stations inside and outside the Ecopass area, taking into account the strong seasonality of pollution and the effect of atmospheric conditions and fuel prices.

Second, I analyze the spatial and temporal spillover effects of Ecopass: many critics of Ecopass claim that the policy simply shifted vehicle circulation - and hence pollution - in other areas of the city or in other hours of the day. This is a common critique to similar policies as well, and in case of Milan it has important implications also in terms of environmental justice, since in the city center pollution levels were already lower than the periphery and the estate values were generally higher. I also compare the short and the long term effect of the policy: since Ecopass fee is higher the more polluting is the vehicle, it can encourage drivers to switch to cleaner cars, changing the impact of the policy over time.

Third, I use a vector autoregressive model (VAR) event study approach. Several authors used this methodology to estimate the impact of an exogenous change in fiscal policy on various macroeconomic variables (Ramey and Shapiro, 1998, Edelberg et al., 1999, Blanchard and Perotti, 2002, Eichenbaum and Fisher, 2004), but this specific approach is relatively uncommon in environmental or energy economics. A VAR model is suitable in my particular situation, where I have long time series data but few monitoring stations in the Ecopass area. It also takes into account the persistence of pollution in the air even after several hours and allows to control for the interactions between pollution levels in different parts of the city.

Results suggest that Ecopass reduced NOx concentration in the city center, but only in the short run, while the effect disappeared in the long run. Concentration of NOx did not change in some areas outside Ecopass area, but increased in others, suggesting a spatial substitution effect. There is no evidence of increased NOx levels during off-peak hours compensating a pollution decrease in peak hours. A falsification test confirms that the results are not driven by regional factors unrelated to Ecopass, and that the spatial substitution effects are probably lower than what the analysis suggests.

The paper is organized as follows: section two describes the characteristics of the driving restriction policies adopted throughout the world and in which aspects Ecopass is different from them. Section three shows the pollution patterns in Milan, the source of the data used by the paper and justifies the choice of using NOx. Section four describes the empirical specification used in the paper. Section five shows the empirical results. Section six is the conclusion.

2 Vehicle pollution reduction policies

2.1 Policies outside Milan

In the last two decades several cities across the world introduced policies controlling vehicle circulation. In most of the cases their explicit goal is reducing congestion, pollution or both.

Congestion charges, which require all vehicles to pay a fee to enter the city, are one of the most popular and most diffused policies. Their popularity is due to two factors: first, they are a source of revenue for the city administration; and second, they are able to price both pollution and congestion externalities at the same time, potentially making it a better option in terms of welfare gains than policies (like high occupancy vehicle lanes) not charging drivers (Bento et al., 2013). They have been implemented or are on study in several cities, among which London, Stockholm, Oslo, Honk Kong, Beijing, Singapore, San Francisco and Santiago de Chile.

Driving bans are another widely adopted measure. Generally they are a partial vehicle ban based on the license plate number, and they have been implemented either permanently (Mexico City, Bogotá, São Paulo), during periods of pollution peaks (several European cities) or during other special events (Beijing during the Olympic games).

Finally, low emission zones (LEZ) forbid circulation only to high polluting vehicles[1]. They are widely adopted in Europe, and especially in Germany, as a consequence of stricter air quality regulations approved by the European Union.

Despite their differences, any kind of vehicle restriction or road pricing faces strong opposition. Part of the opposition is caused by concerns about the real effectiveness of these measures on traffic and on air quality. These criticisms, and the interest in comparing the cost and the benefits of each policy inspired various lines of research on the topic.

In their study on the LEZ in Germany, Wolff and Perry (2011) suggest that LEZ reduced pollution concentration, even in nearby areas not directly regulated. Santos et al. (2000) and Santos (2004) simulate the impact of a congestion charge on traffic and pollution in eight British cities, finding a positive reduction of both with a stronger impact on traffic. Lin et al. (2011) study the impact of driving bans in Bogotá, São Paulo and Beijing, showing a positive reduction in pollution depending by the length of the ban. Also Gallego et al. (2011) examine the duration of pollution reduction, showing that the public transportation reform in Santiago de Chile and the partial vehicle ban in Mexico City caused a short time reduction in pollution, followed by an increase in the long run. The Mexico City case was examined also by Eskeland and Feyziolu (1997) and Davis (2008) study the Mexico City case as well, finding that the vehicle ban increased both overall gasoline consumption and car stock without any significant benefit to air quality.

The analysis of the past literature suggests that some of the examined policies have positive effects on air quality, while others are poorly designed and produce unintended consequences. Several factors, often related to the local context, contribute to the success or the failure of a specific road pricing scheme. It is then hard to find a solution fitting any situation, and even harder to predict *ex ante* the outcome of a new measure.

[1] The definition of a low emission zone is not univocal. In this paper, I refer to Wolff and Perry (2010): *A LEZ defines an area that a vehicle is allowed to enter only if it is classified as a low PM10 emitting vehicle. All high-polluting vehicles are banned from driving into the LEZ.*

2.2 The Ecopass pollution charge in Milan

Milan is the second largest city in Italy and capital of the Lombardy region, one of the richest and most productive Italian regions. The high population density, the high rate of economic activity and the geographical and atmospheric conditions make air pollution in Milan particularly pressing problem. In 2007 and in the previous years Milan exceeded the European pollution concentration limits for nitrogen dioxide (NO_2), ozone (O_3) and particulate matter (PM_{10}) (ARPA, 2007).

Since the pollution level in Milan kept being high, on January 2008 the city administration introduced a new entrance policy for the city center. The measure, called Ecopass, was a pollution charge, a combination of a LEZ and a congestion charge. Like a LEZ, it affected only polluting vehicles, and like a congestion charge, it did not forbid entrance to the city center but imposed the payment of a fee to drivers.

Ecopass was enforced between 7:30am and 7:30pm during weekdays, excluding most of the month of August. The fee increased with the emission of the vehicle according to a predetermined definition. Cleaner vehicles were exempt.

Ecopass was proposed for the first time in 2006, and went through a fierce political opposition before being finally approved. Several controversies arose before and after its introduction. At the end of 2007 the former Major of Milan, Mr. Gabriele Albertini, criticized the effectiveness of the policy, claiming that it would have created more congestion right outside the Ecopass area, and from there pollution would have been carried into the Ecopass area anyway[2].

Many people indeed expected that Ecopass would have just shifted traffic and pollution somewhere else but not reduce them overall. Another concern was that the city center was the least polluted area in Milan city and it was too small to produce an appreciable reduction in emissions.

A couple of studies look at the effectiveness of Ecopass in terms of pollution reduction and overall benefits. Rotaris et al. (2010) report a first assessment by the Milan Agency for Transportation, Environment and Territory (AMMA) suggesting that in the first eleven months (January 2008 - November 2008) PM_{10} emissions at the source inside Ecopass area decreased by 23%, NOx by 17% and CO^2 by 14% (AMMA, 2008*b*). These estimates rely on the comparison between the number and the type of vehicles entering in the after Ecopass was introduced and the vehicles entered in October 2007. A follow up study by Danielis et al. (2011) look at the number of days exceeding PM_{10} limit and the average annual PM_{10} concentration. Both trends show a decrease across time. However, the decrease for both series starts from 2006.

[2]From an interview published on the newspaper La Repubblica: [Ecopass] *will not produce any desired effect, because air shifts and all the congestion Ecopass will generate around the Bastioni* (Ecopass area) *will move to the city center* (La Repubblica, 2007)

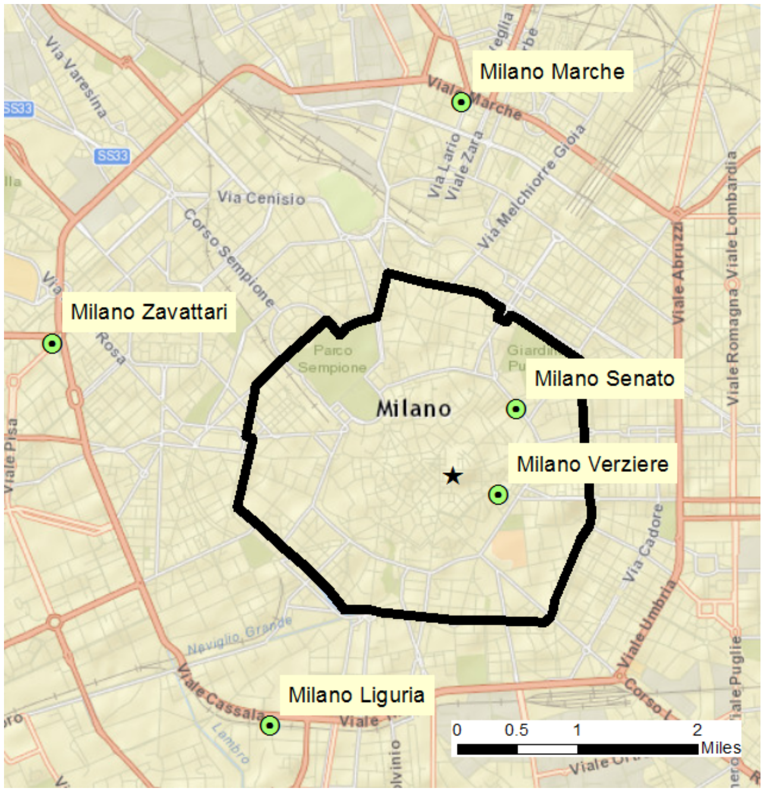

Figure 1: Map of pollution monitoring stations in Milan. The black line shows the boundaries of Ecopass area, the star is the main city square.

3 Pollution in Milan and other data

In province of Milan during 2007, right before the introduction of Ecopass, vehicles were responsible of 56% of particulate matter (PM_{10}) emissions, 62% of nitrogen oxides (NOx), 72% of carbon monoxides (CO) and 39% of ozone (O_3) precursors (ARPA, 2009, p. 16, 54). In Milan PM_{10}, NOx and O_3 regularly exceeded health limits before and during 2007 (ARPA, 2007, p. 38). Among these three pollutants, NOx concentration has been measured for a longer period and in more areas than PM_{10} and O_3. While PM_{10} is better known by the general public, NOx is very similar in terms of sources of emission and seasonal pattern.

Data on hourly NOx concentration between 2003 and 2011 come from the Lombardy Regional Environmental Protection Agency (*Agenzia Regionale Protezione Ambiente* - ARPA), a public institution which gathers and analyzes meteorological and environmental data. ARPA maintains a network of pollution monitoring stations in the whole region, including Milan, operating with the same measurement standards. Each station is classified by location type (urban, suburban, rural) and main source of pollution (traffic, industrial, background).

The pollution monitoring stations I consider in Milan are all urban, traffic type stations. These stations,

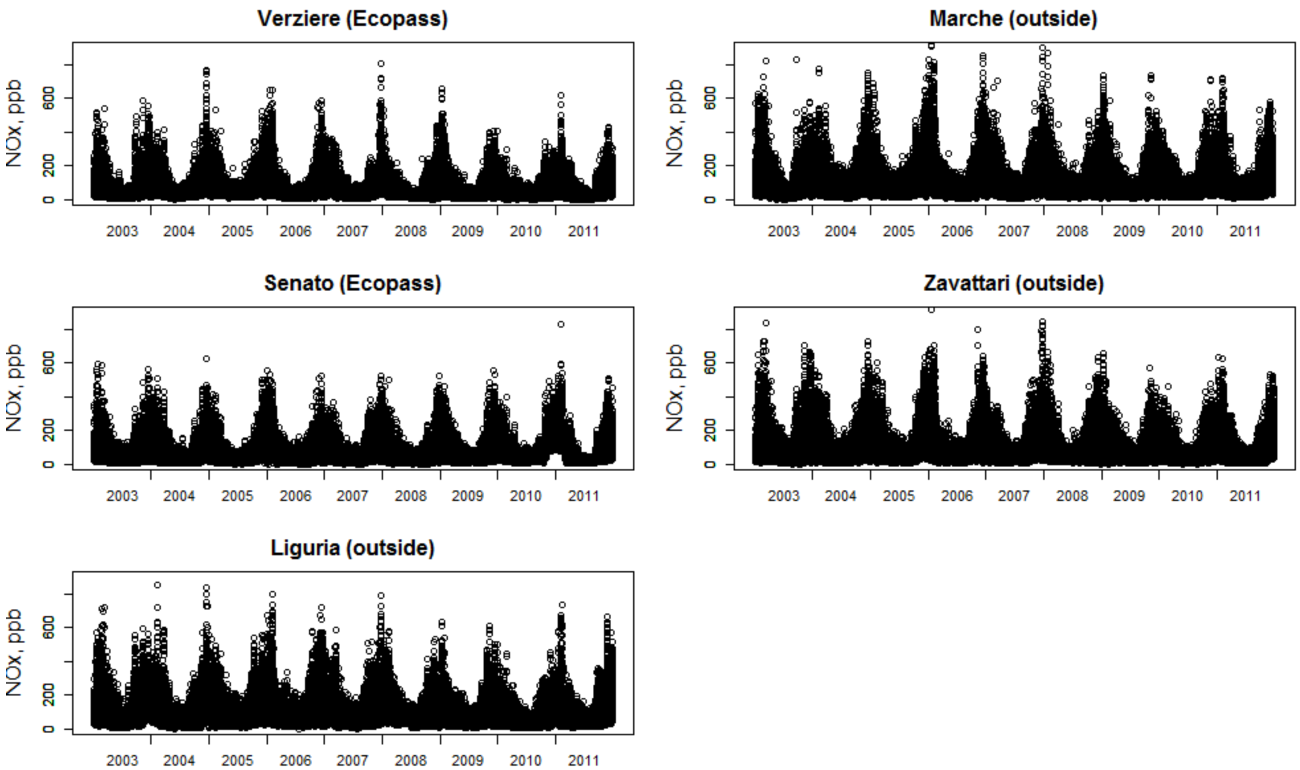

Figure 2: 2003-2011 NOx pattern by pollution monitoring station (parts per billion)

named from the street in which are located, are in high density areas and close to high traffic roads. Two stations are inside the Ecopass area (*Verziere* and *Senato*) and three (*Liguria*, *Marche*, *Zavattari*) are outside. These latter three stations are all in the same outer city ring (figure 1).

In figure 2 the seasonality of NOx concentration is pretty evident: NOx rises during winter months and declines in the summer. The overall pollution levels are lower around the two stations within the Ecopass area, *Verziere* and *Senato*, than around those outside.

Data on atmospheric conditions are collected by ARPA as well. There are more than one weather monitoring station in Milan, but the majority of them either do not measure some variables or they do not have data for the entire length of 2003-2011. Hence, I merged data from two weather stations on precipitation, wind speed, wind direction and humidity.

Since Ecopass has been occasionally suspended during interruption of public transport service and some special events, I have data on the exact hours and days in which Ecopass was effectively in force.

Finally, I have data on weekly real prices of gasoline and diesel, from the Department of Economic Development. In Italy, diesel vehicles are relatively common because fuel prices are lower than for gasoline. However, in

2008 there was a sudden increase in fuel prices, and this might have reduced driving during the introduction of Ecopass.

4 Estimation method

The paper must deal with some limitations with the data. A pollution charge has a direct effect on driving behavior, and through it an indirect impact on pollution. Facing a pollution charge to enter the city center, a driver decides whether paying the fee, taking public transport, buying a cleaner car exempt from the fee, not traveling at all, traveling in different areas of the city or traveling during the hours in which Ecopass is not enforced. These decisions have different impacts on pollution concentration and they are not necessarily time invariant. Unfortunately, detailed, disaggregated information on vehicle use and vehicle characteristics are not available.[3].

Hence, this paper will focus on whether Ecopass managed to reduce pollution concentration (the indirect effect) and the spatial and temporal spillover effects on pollution. In the result section I will suggest a possible way in which Ecopass interacted with traffic and pollution using summary statistics on vehicle circulation.

The literature uses a set of different methodologies to assess the impact of a policy on air pollution, like difference in differences (Greenstone, 2004, Auffhammer et al., 2009, Wolff and Perry, 2011, Lin et al., 2011), regression discontinuity analysis (Davis, 2008) and propensity score matching (Greenstone, 2004). Most of the paper using the difference in differences or propensity score matching examine policies introduced at the national or state level. For a policy introduced at the city level, the pollution monitoring stations in the treated group are not enough.

Regression discontinuity is useful to measure the impact of a policy right after it is introduced. However, in the case of Ecopass there is no certainty ex-ante on when the charge affected pollution, so the focus of this paper is to compare the short versus the long term impact, if any.

I decided to exploit my highly disaggregated time series dataset using a vector autoregressive model (VAR), made popular by Sims (1980) and widely used in macroeconomics. VAR models are also frequently employed in energy economics (Crompton and Wu, 2005, Cologni and Manera, 2008, Marvão Pereira and Marvão Pereira, 2010), and in the analysis of carbon emissions dynamics (Bunn and Fezzi, 2007, Ang, 2007, Akbostanci et al., 2009), but not in other areas of environmental economics, like policy evaluation.

The basic structure of a VAR model is the following:

[3]The municipality of Milan gathered detailed data on vehicle transit in the Ecopass area only from 2008 and during a short period in November 2007.

$$y_t = B_0 + \sum_{n=1}^{N} \sum_{j=1}^{L} B_{nj} y_{nt-j} + u_t \tag{1}$$

Where $y_t = (y_{1t}, ..., y_{Nt})'$ is a $(N \times 1)$ matrix of n endogenous variables i.e. NOx concentration for N pollution monitoring stations considered at time t. B_0 is a $(N \times 1)$ vector of intercepts. B_{nj} is a $(N \times 1)$ vector of reduced-form coefficients for the jth lag of monitor n, with a maximum of L lags. Finally, u_t is a $(N \times 1)$ vector of white noise residuals.

In a VAR model, the past pollution concentration in any area affects the current pollution concentration in another or in the same area. That could be because pollution persists in the air across time or because there is some underlying relationship between the pollution in two different areas: for instance, commuters driving to the city center have to go through the periphery and vice-versa. Since all the pollution monitoring stations in Milan are close, such relationship is potentially strong.

I use a VAR event study approach to identify the effects of Ecopass on NOx concentration. Several papers use this methodology to estimate the impact of exogenous government expenditure shocks on other macroeconomic variables, using a set of indicator variables for the exogenous shocks (Ramey and Shapiro, 1998, Edelberg et al., 1999, Blanchard and Perotti, 2002, Eichenbaum and Fisher, 2004).

I divide the NOx observations in 2003-2011 period in four groups and I create four different indicator variables:

- I_1: The hours in which Ecopass was effectively enforced (peak hours)
- I_2: The hours, after the introduction of Ecopass, in which Ecopass was not enforced (off-peak hours)
- I_3: The hours, before the introduction of Ecopass, in which Ecopass would have not been enforced[4]
- I_4: The hours, before the introduction of Ecopass, in which Ecopass would have typically been enforced[5]

This classification allows to compare different times of the day (peak time and off-peak) before and after the introduction of Ecopass.

Equation (2) is the main specification, controlling for seasonality, weather and the effect of Ecopass:

$$y_t = B_0 + \sum_{n=1}^{N} \sum_{j=1}^{L} B_j y_{nt-j} + \sum_{k} \Gamma_k \gamma_{kt} + \Phi \text{ Trend}_t + \sum_{i=1}^{3} \Delta_i I_{it} + u_t \tag{2}$$

In which γ_{kt} is a set of time and weather variables, controlling for seasonality and atmospheric conditions[6].

A fifth-order polinomial Trend_t controls for unobserved dynamics of pollution in the time considered.

[4]This indicator includes weekends, the month of August, and the hours between 8pm and 7am during weekdays in the other months.

[5]This indicator includes the hours between 8am to 7pm, excluding weekends and the month of August.

[6]The set of control variables includes: indicators for month, day of the week, hour; interaction terms between day of the week and month, month and day of the week, day of the week and hour; values at t and $t-1$ of precipitation, humidity, wind speed, indicators for wind direction (north-west, north-east, south-west, south-east), weekly real gasoline price, weekly real diesel price.

The indicator factor I_{4t} is omitted, so that Δ_1 identifies the average NOx change during peak hours after the introduction of Ecopass, and $\Delta_2 - \Delta_3$ identifies the average NOx change during off-peak hours. In both cases, I compare the period 2003-2007 with the period 2008-2011.

The impact of Ecopass on pollution, however, might vary across time. In equation (3), I disaggregate the effect of Ecopass by year:

$$y_t = B_0 + \sum_{n=1}^{N} \sum_{j=1}^{L} B_j y_{nt-j} + \sum_{k} \Gamma_k \gamma_{kt} + \Phi \text{ Trend}_t + \sum_{i=1}^{2} \Delta_i (I_{it} \times year_t) + \Delta_3 I_{3t} + u_t \tag{3}$$

Where $year_t$ is a set of indicator variables for years between 2008 and 2011. In equation (3) then, the average NOx change after Ecopass during peak and off-peak hours in each year with respect to the average peak and off-peak NOx concentration in 2003-2007. Again, the yearly change during off-peak hours is given by $\Delta_2 - \Delta_3$.

In order to disaggregate the effect of Ecopass by hour, I use the following specification:

$$y_t = B_0 + \sum_{n=1}^{N} \sum_{j=1}^{L} B_j y_{nt-j} + \sum_{k} \Gamma_k \gamma_{kt} + \Phi \text{ Trend}_t + \sum_{i=1}^{2} \Delta_i (I_{it} \times hours_t) + \Delta_3 I_{3t} + u_t \tag{4}$$

Where $hour_t$ is a set of indicator variables of the hours of the day.

4.1 Identification and exogeneity of Ecopass

One important condition for identification is that Ecopass is an exogenous shock on pollution, and its introduction was not a response of an unusually high pollution concentration.

There are two reasons why the introduction of Ecopass can be considered an exogenous shock: first, the timing of Ecopass is more linked to political dynamics than to actual observation of pollution concentration. Second, there is no evidence of an increase in pollution in the city center across years which might have push towards tougher pollution control.

On the first point, a pollution charge has been proposed for the first time in 2006 by one of the Mayor candidates of the time, Ms. Letizia Moratti. Once in office, it took her more than one year to start Ecopass, mainly due to the political opposition within her coalition (Appendix A).

The other reason of the exogeneity of Ecopass is that there is no evidence of a rise in yearly pollution concentration in the years before the introduction of Ecopass which might have induced the city council to approve a pollution charge. Table 1 shows the results of a simple VAR equation in the 2003-2007 period with time controls, weather variables and indicators for the year. There is no evidence of an increase of NOx concentration across time.

The introduction of a pollution charge in Milan should be then considered more like the result of the necessity

Table 1: VAR model with year trend, 2003-2007

	Dependent variable:			
	NOx (part per billion)			
	Verziere	Verziere	Senato	Senato
2004	0.439*	0.719***	−0.060	−0.344
	(0.260)	(0.270)	(0.261)	(0.262)
2005	1.048***	0.746**	−0.677**	−0.785***
	(0.276)	(0.292)	(0.282)	(0.279)
2006	0.616**	−0.016	−0.376	−0.306
	(0.261)	(0.270)	(0.260)	(0.263)
2007	0.432	−0.008	−0.841***	−0.370
	(0.287)	(0.306)	(0.296)	(0.289)
Time controls	Yes	Yes	Yes	Yes
Weather controls	No	Yes	No	Yes
Observations	59,646	39,904	39,904	59,646
R^2	0.897	0.914	0.934	0.915
Adjusted R^2	0.896	0.912	0.932	0.915

*p<0.1; **p<0.05; ***p<0.01
Note: Standard errors in parenthesis. Change with respect to year 2003

to deal with a long term problem in a period with a sufficiently sensible political environment. Ecopass can be hardly linked to specific fluctuations in pollution levels[7].

4.2 Unit root test

Table 2 shows the results of some widely used unit root tests: the augmented Dickey-Fuller test (ADF), the Phillips-Perron test (PP) and the Elliot, Rothenberg and Stock test (ERS). The tests use 25 lags, but tests run with a lower number of lags obtain similar results.

The tests overwhelmingly reject the hypothesis of a unit root for all the time series. The intuition behind this result is that it would be very unusual that all the NOx persisted in a certain area for more than few hours. Considering that my data range from 2003 to 2012, it is reasonable to assume that NOx emitted in 2003 does not last until 2012.

[7] Actually, the city and the regional administration put in place some measures which are activated during temporarily high pollution levels. These interventions include the ban of high polluting vehicles during peak hours or total car ban on Sundays. These measures, which can be rightly considered endogenous, are generally too sparse and limited in time to produce permanent effects, and they are not taken into account in this paper.

Table 2: Unit root test with constant

	Verziere	Senato	Liguria	Marche	Zavattari
ADF_τ	-19.39	-18.64	-21.62	-21.15	-22.27
ADF_γ	188.04	173.71	233.80	223.65	247.92
PP (Z-τ)	-47.20	-44.68	-56.15	-48.01	-48.48
ERS	-16.67	-16.38	-16.75	-16.83	-18.56
Inside Ecopass area	Yes	Yes	No	No	No

p-values for ADF_τ: -3.43=0.01, -2.86=0.05, -2.57=0.1
p-values for ADF_γ: 6.43=0.01, 4.59=0.05, 3.78=0.1
p-values for PP (Z-τ): -3.43=0.01, -2.86=0.05, -2.57=0.1
p-values for ERS: -2.57=0.01, -1.94=0.05, -1.62=0.1

5 Results

5.1 Lag choice and overparametrization

The data used in this paper are quite different to those traditionally used in time series analysis, being a large number of hourly observations. Since the temporal unit is smaller than those typically available in macroeconomics papers, the number of lag terms used is likely to be higher than those commonly used in VAR models.

The VAR model in this paper has a maximum lag of $L = 25$. The number of lags is obtained using the Schwarz Criterion (SC) (Schwarz, 1978).

Using other criteria, like the Akaike Information Criterion, brings to far higher lags. There are three reasons why this paper employs specifically the Schwarz Criterion.

First, the Schwarz Criterion is more consistent than the Akaike Information Criterion, suggesting the same value of L even when using different specifications.

Second, a comparison between different information criteria made by Geweke and Meese (1981) shows that the estimated value of L by the Schwarz Criterion converges in probability to the true value. The asymptotic probability of overparametrization does not vanish instead with the Akaike Information Criterion.

Third, a lag term up to 25 means that the VAR model takes into account the pollution fluctuations at any hour of the day.

5.2 Results from VAR models

Table 3 shows the results based on equation (2). The effect on pollution after Ecopass (Δ_1) among the stations inside the Ecopass area is negative, as expected, but is only significant for *Senato*. For the three stations outside Ecopass area, the results show an increase in pollution (*Liguria* and *Marche*), or no statistically significant effect (*Zavattari*).

Table 3: Regression results for equation (2)

	Dependent variable:				
	NOx (part per billion)				
	Verziere	Senato	Liguria	Marche	Zavattari
Ecopass (Δ_1)	-0.816	-1.286^{*}	3.414^{***}	2.408^{**}	-0.711
(2008-2011)	(0.679)	(0.686)	(1.019)	(0.985)	(0.915)
No Ecopass (Δ_2)	-0.578	-2.884^{***}	1.803^{*}	3.463	-0.887
(2008-2011)	(0.724)	(0.731)	(1.086)	(1.050)	(0.975)
Off-peak (Δ_3)	-0.626	-1.170^{***}	1.300^{**}	1.235	-2.004^{***}
(2003-2007)	(0.384)	(0.388)	(0.576)	(0.557)	(0.517)
F test (p-value) $\Delta_2 = \Delta_3$	0.941	0.009	0.606	0.018	0.202
Inside Ecopass area	Yes	Yes	No	No	No
Observations	43,346	43,346	43,346	43,346	43,346
R^2	0.906	0.924	0.879	0.909	0.913

*p<0.1; **p<0.05; ***p<0.01

Note: Standard errors in parenthesis. Change with respect to peak time in 2003-2007.

A F-test on the significance of the effect during off-peak hours before and after the introduction of Ecopass ($\Delta_2 - \Delta_3$), shows results that are quite in line with the results during Ecopass hours: *Verziere* and *Zavattari* shows no statistically significant difference, *Senato* and *Marche* a significant decrease and increase respectively, and *Liguria* an insignificant increase.

Table 4: Regression results for equation (3)

	Dependent variable:				
	NOx (part per billion)				
	Verziere	Senato	Liguria	Marche	Zavattari
Ecopass (Δ_1)					
2008	−2.807***	−2.812***	3.555***	0.480	0.388
	(0.820)	(0.829)	(1.231)	(1.190)	(1.105)
2009	2.189*	−1.160	8.567***	5.006***	3.782**
	(1.219)	(1.232)	(1.829)	(1.768)	(1.643)
2010	0.426	−3.714**	9.105***	2.075	3.340
	(1.778)	(1.797)	(2.669)	(2.580)	(2.397)
2011	3.932*	−0.359	11.550***	1.400	6.230**
	(2.310)	(2.335)	(3.467)	(3.352)	(3.114)
No Ecopass (Δ_2)					
2008	−0.861	−3.297***	1.839	1.887	−1.216
	(0.824)	(0.833)	(1.238)	(1.196)	(1.111)
F test (p-value) $\Delta_2 = \Delta_3$	0.795	0.006	0.598	0.547	0.417
2009	1.700	−3.581***	6.342***	5.484***	1.841
	(1.211)	(1.224)	(1.818)	(1.757)	(1.632)
F test (p-value) $\Delta_2 = \Delta_3$	0.044	0.043	0.003	0.012	0.014
2010	0.196	−5.056***	6.854***	2.340	1.269
	(1.757)	(1.776)	(2.637)	(2.549)	(2.368)
F test (p-value) $\Delta_2 = \Delta_3$	0.621	0.027	0.031	0.656	0.156
2011	2.894	−2.917	11.550***	3.594	5.519*
	(2.282)	(2.307)	(3.426)	(3.312)	(3.076)
F test (p-value) $\Delta_2 = \Delta_3$	0.117	0.450	0.002	0.471	0.013
Off-peak (Δ_3)	−0.662*	−1.183***	1.233**	1.218*	−2.053***
(2003-2007)	(0.384)	(0.388)	(0.576)	(0.557)	(0.517)
Inside Ecopass area	Yes	Yes	No	No	No
Observations	43,346	43,346	43,346	43,346	43,346
R^2	0.906	0.925	0.879	0.908	0.913

*p<0.1; **p<0.05; ***p<0.01
Note: Standard errors in parenthesis. Coefficients measure the change with respect to peak time in 2003-2007.

Table 4 shows the effect disaggregated by year, providing more insights on potential spillover effects. The effect on pollution after the introduction of Ecopass (Δ_1) is negative in 2008 at both stations inside the Ecopass area. With respect to the average NOx concentration during peak hours before Ecopass, it is a -3.6% for *Verziere* and a -3.5% for *Senato*. Note that, apart 2008 in *Verziere*, results show a NOx change in the same direction during off-peak hours after Ecopass, rejecting the hypothesis of intertemporal substitution of pollution due to Ecopass.

All the stations outside the city center shows some positive significant coefficients (mostly during 2009) for peak hours. Again, apart 2008 in *Liguria* (+3.6%), such changes are matched with statistically significant changes in the same sign during off-peak hours. I will show in the next section that both of them are likely to be caused at least partially by regional trends not related specifically to Milan or Ecopass.

Table 5: Regression results for equation (4), Ecopass hours only

	Dependent variable:				
	NOx (part per billion)				
	Verziere	Senato	Liguria	Marche	Zavattari
8am	−1.515	1.927*	2.742	6.197***	5.666***
	(1.143)	(1.154)	(1.713)	(1.657)	(1.539)
9am	−0.903	1.748	6.370***	2.835*	0.930
	(1.147)	(1.158)	(1.719)	(1.663)	(1.545)
10am	−2.388**	−0.184	6.462***	4.122**	−1.240
	(1.151)	(1.162)	(1.726)	(1.670)	(1.551)
11am	−1.180	0.801	5.012***	0.157	1.124
	(1.154)	(1.165)	(1.730)	(1.674)	(1.555)
12pm	0.343	−0.546	5.858***	1.373	3.280**
	(1.154)	(1.166)	(1.730)	(1.674)	(1.555)
1pm	−0.976	−2.746**	4.885***	1.475	1.148
	(1.154)	(1.165)	(1.730)	(1.674)	(1.554)
2pm	0.601	0.227	3.761**	4.107**	0.797
	(1.151)	(1.162)	(1.725)	(1.669)	(1.550)
3pm	1.067	−1.995*	3.875**	1.168	2.008
	(1.153)	(1.164)	(1.728)	(1.672)	(1.553)
4pm	−1.881	−3.416***	1.895	1.392	0.933
	(1.152)	(1.164)	(1.727)	(1.671)	(1.552)
5pm	−1.242	−5.540***	2.439	0.710	−1.691
	(1.143)	(1.154)	(1.713)	(1.658)	(1.540)
6pm	−1.124	−2.378**	1.025	2.885*	−2.265
	(1.143)	(1.154)	(1.713)	(1.658)	(1.540)
7pm	−0.305	−2.660**	−0.065	2.903*	−1.945
	(1.143)	(1.154)	(1.713)	(1.657)	(1.539)
Observations	43,346	43,346	43,346	43,346	43,346
R^2	0.906	0.925	0.879	0.909	0.913

*p<0.1; **p<0.05; ***p<0.01
Note: Standard errors in parenthesis. Coefficients measure the change with respect to peak time in 2003-2007.

Table 5 shows the effect per hour after the introduction of Ecopass. For *Verziere*, the effects are not statistically significant - apart 10am - suggesting a somehow uniform decrease throughout the day. *Senato* has a strong decrease in NOx during the late afternoon.

For stations outside the Ecopass area, the increase in pollution is more common during the morning and early afternoon. There is no clear match in terms of hours between the decrease in pollution inside the Ecopass area and the increase outside.

The increase in pollution at 8am might be a consequence (to be explored further in future versions of the paper) of intertemporal substitution at the policy threshold (Ecopass starts at 7:30am).

5.3 Falsification test

A potential problem with the specification used in this paper is that the effect of Ecopass might be confounded with other factors affecting directly or indirectly pollution levels and overlapping with Ecopass.

Ecopass was the only city-wide permanent traffic measure adopted in 2008. However, the regional administration enforced some additional environmental regulations. Ecopass also overlaps with some other phenomenon which could have had a wider effect, such as the economic crisis.

To test that the results in the previous section are not caused by other events than Ecopass, I used pollution and weather data of a different city, with the same regional regulation and similar pollution levels than Milan city center.

I use data from three pollution monitoring stations (*Garibaldi*, *Goisis*, *Meucci*) in the city of Bergamo (Lombardy)[8]. Bergamo is around 51 km (31 miles) far from Milan. According to the ARPA classification, both cities are within the A1 zone, meaning that they are both highly urbanized areas, with high levels of pollution, similar atmospheric conditions and with good availability of local public transport. Any regional environmental legislation has effect on the whole A1 zone, thus affecting both cities at the same time.

Figure 6 shows that there is no statistical significant decline in pollution in any of the three station at any year after the introduction of Ecopass. During years after 2008, it shows an increase.

The falsification test suggests that the results for 2008 are likely to be valid, while the results after 2008 might be biased upwards.

[8]Differently than Milan, only *Garibaldi* is classified as urban, traffic station. *Goisis* is a suburban, background station and *Meucci* is a urban, background station.

Table 6: Regression results for equation (3), falsification test (Bergamo city) for Ecopass hours

	Dependent variable:		
	NOx (part per billion)		
	Garibaldi	Meucci	Goisis
	(1)	(2)	(3)
Ecopass 2008	0.055	−0.580	0.824*
	(0.703)	(0.575)	(0.447)
Ecopass 2009	1.427	1.638**	−0.539
	(1.020)	(0.835)	(0.648)
Ecopass 2010	1.620	2.169*	−0.099
	(1.518)	(1.243)	(0.965)
Ecopass 2011	3.753*	3.917**	1.486
	(1.950)	(1.597)	(1.240)
Observations	51,509	51,509	51,509
R^2	0.943	0.924	0.889

*p<0.1; **p<0.05; ***p<0.01
Note: Standard errors in parenthesis. Coefficients measure the change with respect to peak time in 2003-2007.

5.4 Discussion about results

The analysis of aggregate data on vehicle entering Ecopass area after its introduction (AMMA, 2008*a*, 2009, 2010) gives a possible explanation of the results. Ecopass had very few modification across its existence, and the classes of vehicles required to pay the fee remained essentially the same.

Table 7 shows that on average right before Ecopass 41.80% of the vehicles were polluting vehicles (paying the fee). After the introduction of Ecopass, the number of polluting vehicles entering the Ecopass area decreased by more than 50%. However, more cleaner vehicles (not paying the fee) started enter and that increased the total number of entering vehicles. Even if the statistics refer to different month ranges, it provides a possible explanation on the underlying mechanisms behind the effects of Ecopass on pollution: the fee was initally high enough to incourage drivers not to enter, but eventually drivers switched to cleaner vehicles - potentially, but not necessarily, due to Ecopass - and hence the reduction in NOx was only temporary.

The impact on zones outside the Ecopass area is not homogeneous across stations: in 2008 *Liguria* shows an increase in NOx levels, while *Marche* and *Zavattari* show no significant effect. This suggests that, at least in 2008, some spillover effects took place. This is consistent with the fact that the number of entrances into the Ecopass area initially decreased, and suggests that some drivers changed their route.

I did not consider the possibility of anticipation effects (Ramey, 2011): the idea of a pollution charge came up a couple of years before its introduction. It is then possible that some owners of polluting vehicle switched to

Table 7: Statistics on vehicle entrances into Ecopass area

	Average daily vehicle entrances			
Time	Paying	Not paying	Total	% paying
Oct-Nov 2007	38,079	52,501	90,580	41.80%
Jan-Nov 2008	16,805	54,749	71,554	23.04%
Jan-Jun 2009	13,216	62,138	75,354	17.55%
Jan-Jun 2010	11,569	64,545	76,144	15.28%

cleaner vehicles before Ecopass was officially enforced. If so, my results would underestimate the real Ecopass impact since part of the effect occurred during the 2003-2007 period.

6 Conclusion

The paper presents an analysis of the effect of a vehicle pollution charge (Ecopass), introduced in Milan during 2008, on NOx concentration. Data on pollution levels are between 2003 and 2012, including two pollution monitoring stations inside the Ecopass area and three outside.

I use a VAR event study approach, which takes into account the persistence of pollution in the air and pollution leakage from other areas, controlling for seasonality, weather variation and real fuel prices. I also perform a falsification tests to make sure that my results are not caused by a regional trend.

Results shows that, inside the Ecopass area, the pollution charge managed to improve air quality - with respect to 2003-2007 - during the first year of its application (2008), reducing NOx concentration by around 3.5%, but the effect disappeared afterwards. Aggregate data on vehicle transit suggests that at the beginning owners of polluting vehicles entered the Ecopass area less often due to the fee, but they started entering again once they replaced their vehicles with cleaner ones.

The evidence on NOx concentration outside the Ecopass area is mixed. In some zones results show no change in air quality, in other they show a worsening. A falsification test using a control city suggests that at least part of the increase in NOx is driven by regional factors and not by substitution effects.

There is no evidence of a systematic average increase in pollution at off-peak time after the introduction of Ecopass. It might be possible, however, that drivers entered the Ecopass area more often in the hours immediately before or immediately after the enforcement period of Ecopass (7:30am-7:30pm). I plan to examine this issue in future extensions of this paper.

The analysis has some limitations. First, the VAR event study approach cannot guarantee by itself a causal relationship between the introduction of Ecopass and the change in NOx levels. Identification relies on the fact that the falsification test showed that the decline in pollution in 2008 is not a result of a regional trend, and that Ecopass was the only major vehicle restriction policy introduced in that period.

Second, even assuming that the identification strategy is correct, a reduced form model cannot formally disaggregate the various factors affecting NOx concentration (change in vehicle quality, change in modal transport). The paper tries to provide an intuitive explanation looking at aggregate data on traffic inside Ecopass area, but this should not be considered the main focus of the analysis.

The paper can be extended in many directions: the main priority is to analyze the impact on certain off-peak hours, the presence of anticipation effects and the impact of Ecopass on the vehicle stock and the comparison between Ecopass and a congestion charge introduced in 2012 in the same area.

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A The Ecopass pollution charge

Before 2008, the city administration and the Lombardy region introduced occasional car bans for part of the vehicle fleet. Starting from 2006, the regional administration banned from October to April of each year the oldest (and most polluting) vehicles within the areas most exposed to pollution, including Milan.

These occasional measures were too limited in time or involved a small share of the vehicle fleet to be effective in reducing pollution. The Mayor of Milan at the time, Ms. Letizia Moratti, proposed the introduction of a pollution charge during her electoral campaign, in May 2006, when air quality was perceived as one of the mayor issues to address (Corriere della Sera, 2006*b*). Ecopass was supposed to be introduced between late 2006 and mid 2007. However, immediately after the elections, the project was blocked by harsh disagreement within the city council majority and with the President of Lombardy (Corriere della Sera, 2006*a*). Part of the coalition of Mayor Moratti even threatened to challenge the decision in front of an administrative court (Corriere della Sera, 2007*b*).

Ecopass was officially approved by Milan city council the 23th November 2007 (Corriere della Sera, 2007*c*). Two factors allowed eventually the approval of the bill introducing Ecopass: the political initiative of Mayor Moratti and Edoardo Croci (Councillor for traffic) against their own coalition, and the threaten for Italy to be fined by the European Union due to its constant high level of PM_{10} concentration in several Italian cities, among which Milan (Corriere della Sera, 2007*a*).

The payment was required only once a day and increased with the pollution class of the vehicle according to a standard European vehicle classification[9]. Hence, the entrance fee could vary from 10 Euros to 2 Euros (table 8). Discounted multiple entry tickets and discounted yearly passes for residents in the Ecopass area were also available. Within the same pollution class, fees were higher for diesel vehicles than gasoline vehicles. The reason is that diesel vehicles without particulate filter are a much higher source of PM_{10} than the gasoline counterparts.

Ecopass was enforced within one of the inner city rings, called Circle of Bastions (*Cerchia dei Bastioni*), an area of about 8 km^2 (3 $miles^2$). There are 36 entrances to the Circle accessible by private vehicles, and all of them were monitored by closed circuit television, registering the license plate number of entering vehicles (figure 3). Drivers could pay on a dedicated website, by mobile phone, buying a ticket in participating stores or through direct debt. If the driver did not pay the fee in 24 hours after his entrance, he was fined at the address linked with the license plate.

Ecopass started on the 2nd of January 2008 and ended the 31st of December 2011. It was enforced only during weekdays from 7:30am to 7:30pm, with the exception of August. The policy changed only once, on the

[9] The European vehicle classification assigns a class to each vehicle from *Euro 1* to *Euro 5*. The lower the number, the more polluting is the vehicle. *Euro 0* is the classification of the vehicles before European standards took place. Diesel and gasoline vehicles of the same class emit different amounts of pollutants.

Vehicle class	Ecopass fee
Euro 0 gasoline	5€/day
Euro 1 gasoline	2€/day
Euro 2 gasoline	2€/day
Euro 3+ gasoline	Free access
Euro 0 diesel	10€/day
Euro 1 diesel	5€/day
Euro 2 diesel	5€/day
Euro 3 diesel	5€/day
Euro 4 diesel without filter	5€/day after June 2010
Euro 4 diesel with filter	Free access
Euro 5 diesel	Free access

Table 8: Ecopass fees by vehicle pollution class

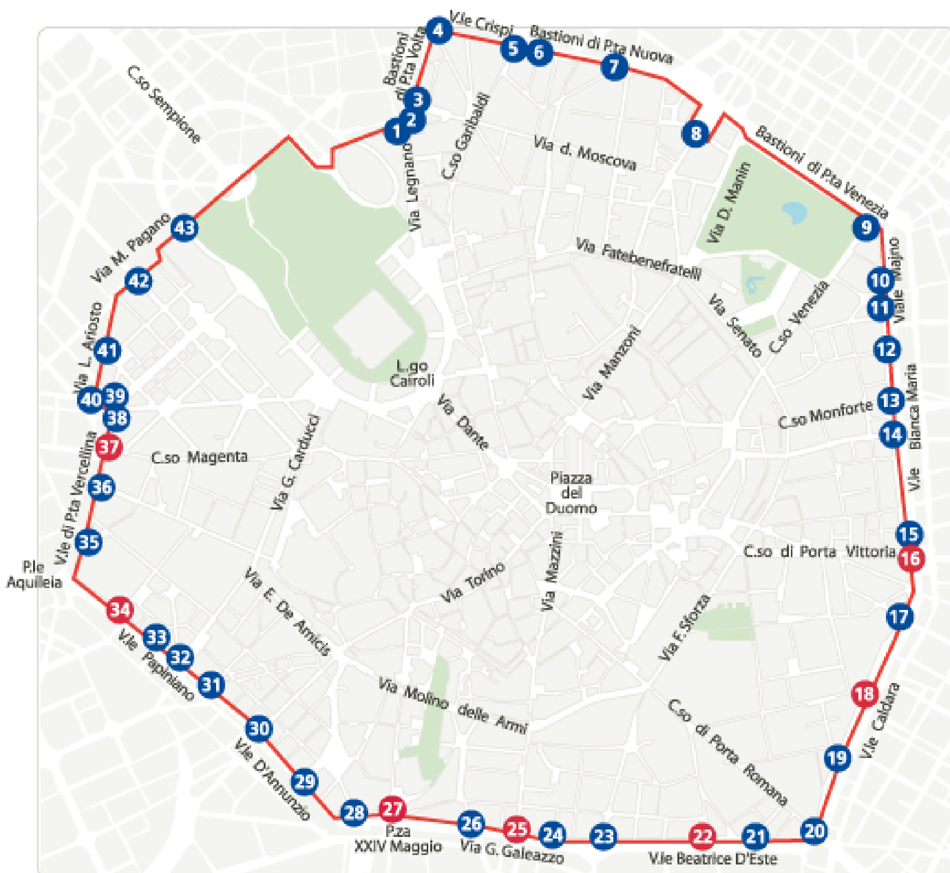

Figure 3: Map of Ecopass area and its entrances

1st of June 2010, requiring the payment from a certain class of diesel vehicle without particulate filter. At the end of 2011, a new city administration abolished Ecopass, switching to a congestion charge scheme.