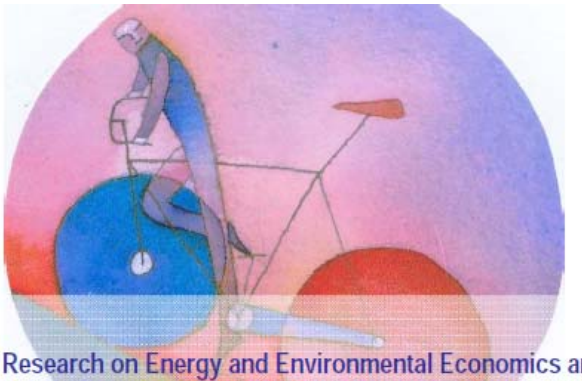

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URBAN ROAD PRICING: A COMPARATIVE STUDY ON THE EXPERIENCES OF LONDON, STOCKHOLM AND MILAN

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Abstract

Urban road pricing schemes have been designed in order to reduce externalities generated by traffic. Main impacts regard: time loss due to congestion, local pollution, noise; contribution to climate change caused by emissions of GHGs, pavement costs and road damages, increase in accidents risks, extra-fuel consumption, decrease in quality of life. Moreover road pricing schemes generate public revenues.

The paper performs a comparative evaluation of the three main experiences of urban road pricing in Europe: London (in operations since 2003), Stockholm (in operations since 2007, after a period of trial in 2006) and Milan (in operations since 2008, with a shift from pollution to congestion charge in 2012). Since their launch, the schemes have been adjusted in terms of amount of charge, area of application and other features.

The schemes have been able to reduce negative externalities generated by traffic, such as accidents, congestion and emissions, up to different levels. A comparative analysis of the three schemes is provided. Determinants of differences in the effectiveness of the schemes are evaluated with a particular focus on elasticity of use of private vehicles to charge.

The results can be useful to design well targeted congestion charge schemes and to assess their efficacy.

Keywords: Urban road pricing, Travel demand elasticity, Sustainable mobility

JEL Codes: H23, R41, R48, Q51, D12

(*main author)

1.The ratio of urban road charging

Negative externalities generated by mobility have been studied by economists since the XIX century (Newbery, 1998 and 1990). Main categories of externalities regard environmental impacts, accidents and congestion.

Environmental impacts refer to local air quality degradation due to traffic emissions - causing health consequences, reduction of life expectancy, reduction of real estate values and damages to cultural heritage -, noise - causing health consequences, stress and reduction of real estate values -, contribution to global climate change through CO_2 emissions.

Accidents involve material damages to vehicles and injuries and deaths to people.

Congestion is responsible for loss of time, economic productivity decrease, extra fuel consumption and frustration.

Externalities are particularly relevant in urban contexts, where there is a high density of people living, working and moving and a high relative scarcity of space (CE Delft, 2008).

Externalities can vary with respect to three main aspects: place where they are generated, time and type of vehicle (CE Delft, 2011) – Tab.1.

Mobility in dense, high populated and attractive areas, like city centres or main commuting roads, generates higher levels of congestion and other externalities than in scarcely populated and isolated areas.

Mobility in peak hours generates higher levels of congestion and other externalities than in daytime off- peak and night hours.

Private motorized traffic generates higher emissions than public transportation (on per capita basis) and non-motorized modes. Trucks give a higher contribution to congestion than cars and motorbikes.

Tab.1: Transport marginal extern costs in urban and non-urban areas in Europe in year 2008 (Euro/1.000 km) - our elaboration on CE Delft (2011)

	Urban Area	Non urban area	Difference
Car	87	44	49,4%
Motorbike	271	106	60,9%
Bus	44	24	45,5%
Train	19	12	36,8%

Road users impose (in different measure externalities to other road users) and bear (in different measures) externalities from other road users. So mobility is characterized by reciprocal externalities and congestion can be considered a "club good" (McKinnon, Sharon, Browne, Whiteing, 2010). But road users also impose unilateral externalities to residents. Recent studies assess the relevance of health consequences on people resident in proximity of congestioned areas and roads (Invernizzi et al., 2011).

Externalities generated by mobility are not limited to environmental impacts, accidents and congestion and include pavement costs and road damages, loss of house values, decrease in quality of life, environmental and social impacts in the production of fuels and in the construction of road infrastructures, social effects of transport infrastructure barriers, like roads and rails (Delucchi, 2000; Danielis, 2001).

Estimates of externalities generated by mobility in urban areas vary depending on the specific factors described. An average estimation for European cities amounts to 55,4 euros/year per person (CE Delft, 2008).

Overall in European cities, the adverse impact of traffic resulting in air pollution, noise, greenhouse gas emissions, delays and traffic accidents causes an economic damage amounting to 100 billion €

each year, corresponding to about 1% of the EU's GDP (European Commission, 2007; Erdmenger and Frey, 2010)

Externalities can be treated in various ways. Economics instruments have been proven particularly effective at this purpose. In the case of urban mobility park pricing has been widely introduced in cities and road pricing schemes have been introduced in a limited number of cities.

As Gervasoni and Sartori (2007) put in evidence (Tab. 2), different tolling schemes have been designed:

Tab. 2: Main targets of road pricing schemes (Gervasoni and Sartori, 2007)

Category	Primary goal	Financial benefits	Reduction congestion	Reduction pollution
Road Tolls	Increase revenues	***	**	*
Value pricing	Increase revenues and reduce congestion	**	***	**
High Occupancy Toll	Increase revenues	*	**	*
Travel distance based charging	Increase revenues, improve the equilibrium between demand and supply of mobility	***	**	**
Travel time based charging	Increase revenues, improve the equilibrium between demand and supply of mobility	***	**	**
Road Space Rationing	Reduce congestion within the urban area	-	***	*
Cordon-based charging/ Zonal Schemes/ Satellite-based road pricing schemes	Reduce congestion within the urban area	**	***	*

1. Road Tolls: fees for the use of the road network. Usually such instruments are used in order to finance the construction of roads, highways and bridges. Fees represent a tax for road users that make use of the service offered and cash flows are primarily invested in the infrastructure maintenance and improvement of the service;

2. Value Pricing: variable pricing schemes of the road network where the price depends on the timing of the day/of the month/of the year. Value pricing is used in order to decrease traffic during peak times in urban areas, hence the price to use the road network increases during periods of higher congestion. This type of road pricing may be used in order to increase revenues but also as a mean to change consumer preferences and to smoothen demand functions;

3. High Occupancy Tolls: allowances to vehicles to circulate in lanes reserved to public transportation under the payment of a price;

4. Travel distance based charging: tolls are proportional to the distance travelled;

5. Travel time based charging (or travel-delay based charging): tolls are proportional to the time spent in the network and the optimal tax is the one which minimizes total travel time;

6. Road Space Rationing: system based on credits which can be spent during a certain time period. Each player is given an endowment of credits, and after each entrance or after each kilometer driven, credits are deducted. Players that end up with a surplus may sell their credits to players in deficit;

7. Cordon-based charging: tolls are applied to a cordon and vehicles are charged in the inbound direction, outbound direction or both. These schemes have the advantage of being easy to implement but they may lead to a displacement of congestion, accidents and pollution as drivers are induced to reroute trips by travelling in untolled areas;

8. Zonal schemes: tolls are applied to vehicles circulating within a single perimeter. These schemes usually imply daily fees;

9. Satellite-based road pricing schemes: vehicles are charged for each kilometer driven, calculated by a GPS system or similar instruments. The schemes require the installation of on-board units in each vehicle. However as the area covered by the pricing scheme extends, it might be an optimal solution, as it allows the exploitation of large economies of scale.

Road charging has been experienced by a group of pioneer cities, starting from Singapore and, even if its diffusion is still limited, more and more cities are considering to adopt it[1]. The European Commission is pushing in this direction (European Commission, 2011 and 2013).

The aim, design of schemes, level of charges and results attained vary in factual experiences. The Curacao European funded project (Curacao, 2009) identifies several possible objectives of urban road user charging schemes:

1. Congestion Relief

2. Environment

3. Revenue Growth

4. Economic growth

5. Health

6. Liveability

7. Safety

8. Equity/Social Inclusion

9. Future Generations

Actual road pricing schemes charging private vehicles have been introduced by municipal authorities mainly in an attempt to price the externalities caused by traffic.

[1] In some cities, like Edinburgh, Manchester and New York, the attempt by local governments to introduce a charge failed because of citizens or political opposition.

These externalities, created by the fact that road users tend to disregard the impact they cause on others, lead to a gap between private costs, as faced by the decision maker, and social costs, as incurred by society at large, and they prevent the market to reach an efficient outcome. The introduction of a pricing scheme reduces these distortions and it hence results into a higher efficiency because journeys would then occur only when the benefits from driving outweigh the sum of the costs, which include all priced externalities (Newbery, 1988 and 1990).

Charges are not set at the efficient level that equals the marginal social damage, providing a full internalization of externalities, following pigouvian criteria (Pigou, 1920), mainly because of political reluctance and social acceptance difficulty in raising it up to over a certain level. Also the amount of charges is the same for all social groups (with the exception of exemptions and discounts for some categories) while a pigouvian approach would require differentiated charges depending on the damage caused.

In presence of a plurality of polluters and polluted, responsible and affected at different levels, efficiency can be achieved only if each polluter faces a personalized price that fully captures the harm generated. This means that when setting the toll both the cost curve and the demand curve of each actor should be known to the regulator. Unfortunately in a world of imperfect information such degree of differentiation is unachievable, and introducing a flat tax or a differentiated but not personalized tax, would never lead to the efficient market solution, leading to second-best solutions.

In this sense road charges are not a panacea: as the economic theory of "second best" suggests, they may cause distortions, as well as unwanted redistributive effects.

A relevant topic is the destination of revenues from charges. Road charging is often designed with a scope. In the case revenues are destined to road maintenance and improvement, there is a coincidence between payers and benefitters (as for toll bridges). In the case revenues are destined to improve public transit there is a subsidy from car drivers to users of public transport (implying a social choice to modify modal split).

So the assessment of road charging schemes requires a plurality of indicators, also targeted on the specific aims of the systems, as the Curacao project (2009) suggests:

Efficiency
1 Change in Average vehicle speed
2 Feeling about traffic conditions
3 Traveller perception of RUC system reliability
4 Change in number of vehicles entering the zone
5 Modal split
Equity
6 Level of user acceptance
7 Level of perception of fairness
8 Index of opinions from the different user groups
9 Index of opinions on ease of access
10 Level of user awareness
Environment
11 Change on CO_2 emissions
12 Change on CO emissions
13 Change on NOx emissions
14 Change on particulate emissions
Scheme Finances
15 Investment cost
16 Operational and maintenance system costs
17 Revenue from charges

18 Revenue from fees
Safety
19 Level of perception of security condition changes
Health
20 Level of perception of air quality into the zone
Liveability
21 Level of perception of on-street liveability
Land Use
22 Change in housing location
23 Change in activities' locations
24 Change in used parking places
25 Change in trips' destinations

In some cases, depending on local specificities, a charge requires dynamic variations in order to maintain its impacts. The effects of charges can attenuate over time, either because drivers "get used to the charges" and hence do not react to them anymore ("acquaintance effect"), or because the freed-up road space will be filled up by new groups of drivers, returning the amount of congestion to the same levels as before the charges ("rebound effect").

2. London, Stockholm and Milan: a comparison of three European road charge schemes

London, Stockholm and Milan have all adopted a cordon pricing scheme[2]. London and Milan set daily entrance charges, allowing for unlimited entrances, exits and travels during the time of charge application. Stockholm, instead, adopted a "pay as you drive" tariff (modelled after Singapore) to be paid at every single crossing of the area, differentiated for the time. In Milan entrance crossings are considered, in Stockholm entrance and exit crossings are considered, while in London all trips (even inside the cordon) are considered.

2.1 London[3]

System description

Congestion charging was first introduced into central London in February 2003 by Mayor Ken Livingston (Labour party). The charge, initially set at £5, was raised to £8 in July 2005, to £10 in January 2011 and to £11,50 (about €14,50) in June 2014 in order to maintain its efficacy. It is a daily charge for driving or parking a vehicle on public roads within the congestion zone between 7 am and 6 pm (originally, until 19 February 2007, between 7 am and 6.30 pm) Monday to Friday, excluding public holidays and weekends.

Aims

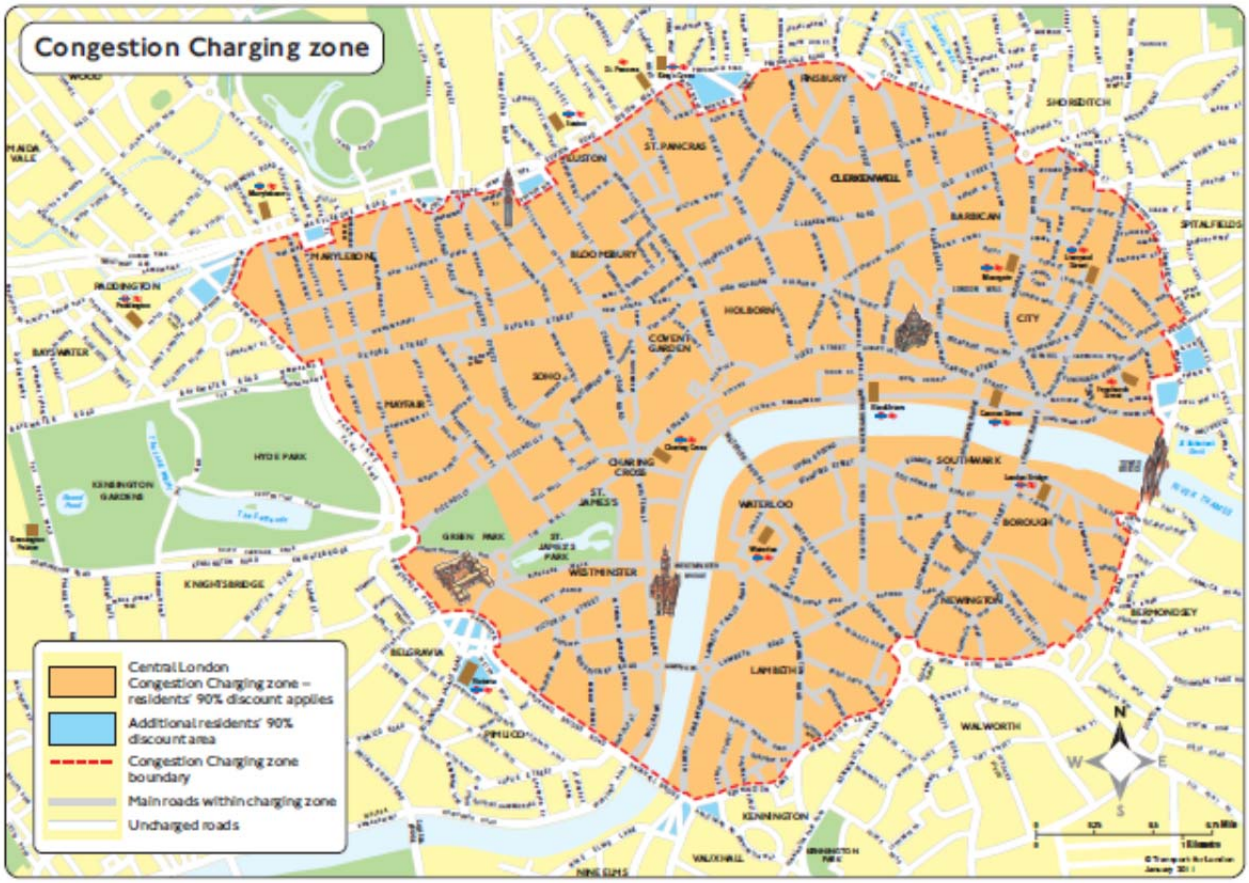
To reduce traffic and to raise revenues for re-investment in transport.

[2] Early adopters of toll systems to enter the city centre in Europe were the Norwegian cities of Bergen, Oslo and Trondheim in the early 1990s.
[3] Official website: http://tfl.gov.uk/modes/driving/congestion-charge.
See also case: http://www.c40.org/case_studies/londons-congestion-charge-cuts-co2-emissions-by-16

Area

Fig. 1 represents the central London congestion charging zone.

Fig 1: Central London congestion charging zone



London population is 7,5 million, while the Metropolitan Area population is 14 million. Greater London extends for 1.600 km^2.

The original central London congestion charging zone covered 21 km^2 in the heart of London (1,3% of the city surface, including over 150.000 inhabitants and attracting daily 1,1 million people), with a western boundary from Vauxhall, through Victoria, Marble Arch to the Edgware Road (Inner Ring road). In February 2007, the zone was extended by about 50% to include parts of west central London /Kensington and Chelsea, and included a free route (the original western boundary) through the centre of the enlarged zone. The extension stopped in January 2011 by decision of the new municipal government with Mayor Boris Johnson (Conservative Party).

Scheme Features

Access to the area is monitored by 170 access points equipped with cameras automatically reading the plates of vehicles. Drivers can pay the charge on the web, by SMS text message, by telephone, or via AutoPay, a system of automatic payment allowing a discount of £1 (which is the most popular channel, with 40% of transactions).

The payment of the charge should occur before midnight of the day of travel, or by midnight of the next day with an overcharge. The charge can be paid daily, weekly, monthly or yearly.

A penalty, the present amount of which is £ 130, applies to violators, reduced to £65 if paid within 14 days, and increased to £ 195 if not paid by 28 days of service.

Buses, taxis, private hire vehicles, alternative fuel vehicles that meet strict emissions criteria, motorcycles are exempt.

Vehicles used by residents of the zone can register for a 90% discount.

After a consultation from public and key stakeholders, in April 2013, some changes to the scheme were introduced. Among the innovations, starting 1 July 2013 the Ultra-Low Emission Discount (ULED)[4] replaced the former Greener Vehicle Discount (GVD)[5].

The congestion charge system is managed by Transport for London, which also manages the Low Emission Zone, the other economic instrument aimed at reducing truck emissions and improve air quality on a wider area, in a logic of policy integration[6].

Impacts

Five main impact areas are monitored: traffic reduction, environment and emissions, road safety, business and economic activities, revenues.

Among all four or more wheeled vehicles there was an 18% reduction in 2003 and a further 3% reduction in 2005, attributed to the change in charge from £5 to £8. Among cars and minicabs, there was a 33% reduction in 2003 and a further 3% reduction in 2005, giving a 36% reduction in 2006 over 2002. There were reductions in the numbers of both vans and HGVs of 11% in 2003 and 13% by 2006. There were increases in the numbers of uncharged vehicles. Licensed taxi movements increased by 17% in 2003 but fell subsequently so that by 2006 they were 13% higher than in 2002, and bus/coach movements were 23% higher in 2003 and 25% higher by 2006 (TfL, 2008 b) – Tab.3.

[4] To be eligible to the ULED, all vehicles emitting less than 75 gCO_2/km and meeting Euro 5 emission standards will get a 100% discount. Electric and Hybrid plug-in vehicles qualify for ULED independently by their emissions.

[5] On January 4, 2011, a ‘‘Greener Vehicle Discount’’ scheme was introduced that provides a 100% discount to all cars that emit less than 100 g/km of CO_2 and meet the Euro 5 standard for air quality. GVD vehicles registered before 28 June 2013 are entitled to the discount until 24 June 2016.

[6] In parallel with congestion charging, which mainly tacks on the problem of vehicle reduction, the London Low Emission Zone (LEZ) tool was put into place for the first time in 2008. It aims at tackling the issue of city air pollution, from public health perspective. Differently from congestion charge, LEZ has few exemptions, it operates 24 hours a day, every day of the year, and it has a much larger coverage to most of Greater London area (1.580km²). The implementation of LEZ is also enforced by cameras reading plates.
The direct impact of LEZ encourages the most heavily polluting vehicles driving in London to become cleaner, and since its introduction in 2008 LEZ has had an impact on pollution saving of 28 tonnes of Particulate Matter. The LEZ changes introduced in 2012 are expected to deliver around twice these reductions in air pollution.

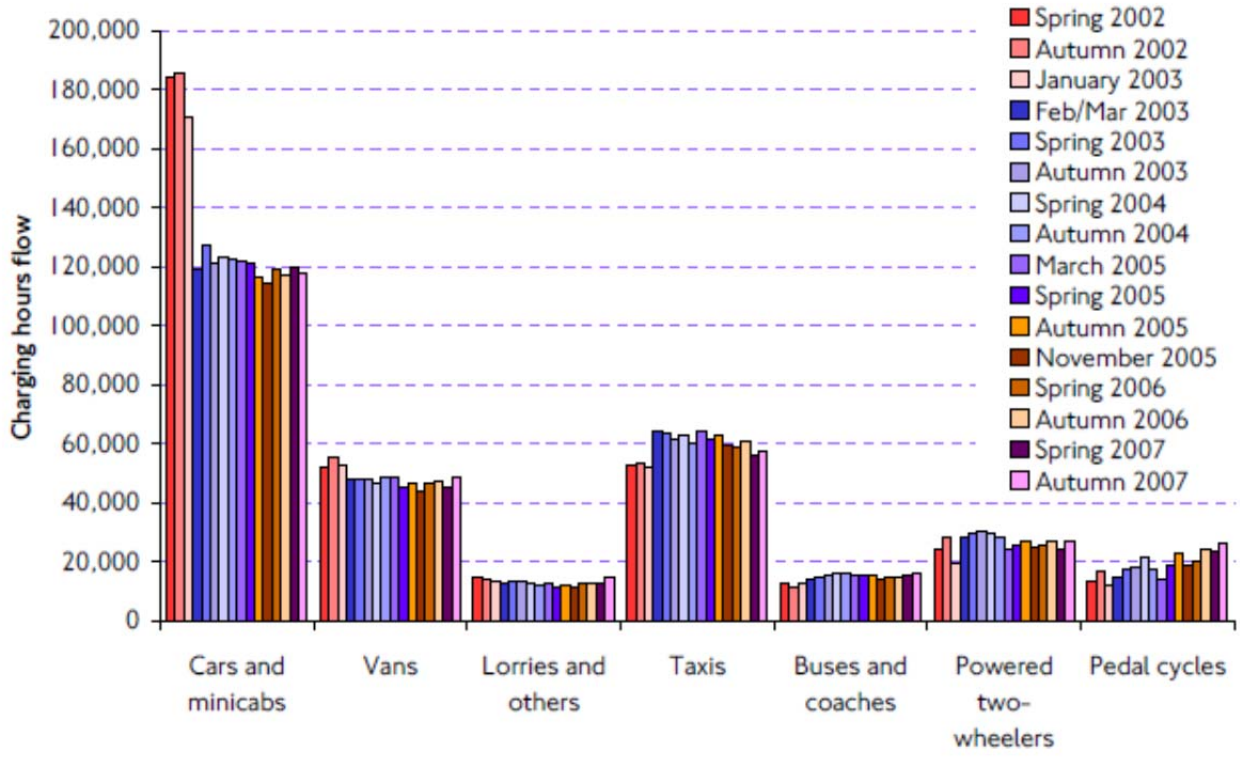
Tab.3: Year on year changes in traffic entering the Central London charging zone during charging hours (TfL, 2008 b)

Vehicle type	2003 vs 2002	2005 vs 2004	2006 vs 2002
All vehicles	-14%	-2%	-16%
Four or more wheels	-18%	-3%	-21%
Potentially chargeable	-27%	-3%	-30%
- cars and minicabs	-33%	-3%	-36%
- vans	-11%	-3%	-13%
- lorries and other	-11%	-4%	-13%
Non-chargeable	+18%	-4%	+16%
- licensed taxis	+17%	0%	+13%
- buses and coaches	+23%	-4%	+25%
- powered two-wheelers	+12%	-9%	0%
- pedal cycles	+19%	+7%	+49%

The introduction of congestion charge saw some 54.000 fewer vehicle movements in the zone during charging hours - a 14% reduction against the 2002 baseline. This data was monitored until 2008, at which time there was a 21% reduction compared to the 2002 baseline.

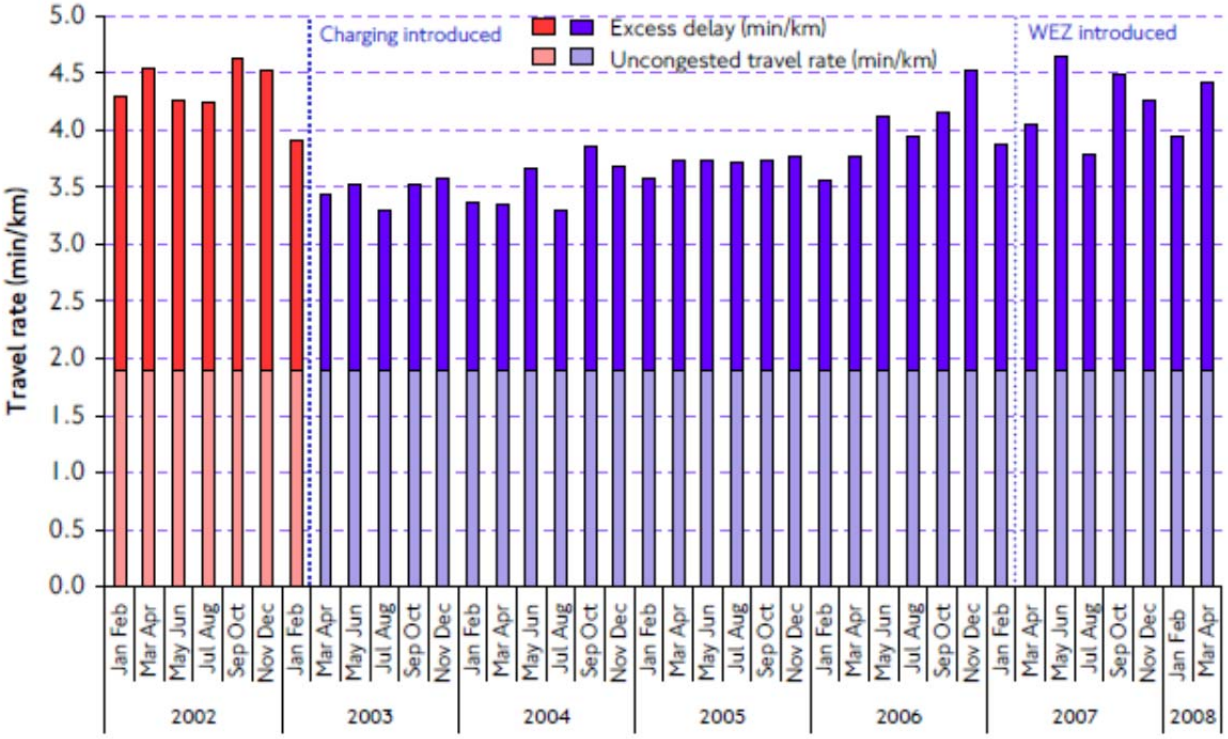
More recent traffic flow data collected by TfL illustrates the continuing trend of falling traffic flows in Central London, where traffic flows have reduced by 21,9% since monitoring was set up in 2006/07 and continue to fall (over 4% in 2013 versus 2012, in contrast with pan-London traffic increase) - (TfL, 2014) - Tab.4.

Tab. 4: Traffic entering the central London charging zone (across all inbound roads), Charging hours, 07:00-18:00, 2002 to 2007 (TfL, 2008)



Data on congestion don't always follow data on reductions of motorized trips, as Tab. 5 shows.

Tab. 5: Congestion in the original central London charging zone during charging hours. Moving car observer surveys (Tfl, 2008)



After the first 12 months of the Congestion Charge scheme, measurements of congestion within the charging zone indicated average reductions in congestion of 30% since congestion charging was introduced. The level of congestion on roads bounding the zone also decreased (TfL, 2004)[7].

Congestion (measured in excess time to travel 1 km) in the original charging zone has been assessed against a selected 'representative' value for conditions in 2002 of 2,3 minutes per kilometer. 2003 and 2004, the years immediately following the introduction of the original scheme, saw average reductions in congestion of 30% against the representative 2002 baseline. The average reduction for the 2005 calendar year was 22%. 2006 and 2007 however saw accelerating loss of the original congestion benefits. Average congestion in 2006 was just 8% below pre charging levels. Average congestion in 2007 was identical to representative pre charging values. This is in spite of sustained reduction in the volume of traffic circulating within the original charging zone (TfL, 2008).

Congestion reduction has been significantly reversed by "*road space reallocation to improve conditions for pedestrians, cyclists, public transport and the urban realm*". In other words, lanes were surrendered for buses and bikes, footpaths widened at intersections, reducing road capacity. The charge was used to reduce demand, and enable the network to be altered to promote modal shift. Whether this has further supported reducing congestion through mode shift or exacerbated conditions for those with little choice (e.g. freight) is debatable (TfL, 2008).

TfL considered that "the general trend towards increased congestion was a long-standing one dating back perhaps two decades or more. Furthermore, as network conditions in the central zone had materially changed, with a proportion of the road network capacity made available by the scheme given over to other policy priorities, and an accelerated utility services renewal programme significantly impacting on traffic operation, comparison of prevailing conditions against a static pre charging baseline was increasingly inappropriate. Projecting forward likely conditions in central London in the notional absence of a scheme, TfL therefore concluded that traffic in the central London zone was still benefiting from comparable levels of congestion relief, in relative terms, to those seen shortly after the introduction of the scheme in 2003" (Tfl, 2008).

Another interesting indicator is "travelled kilometers" by motorized vehicles inside the area. After a sharp decrease in the first year, values have stabilized (Givoni, 2011) – Tab. 6.

[7] For an early assessment see also Leape, 2006.

Tab.6. Traffic within the congestion charging zone during charging hours (millions vehicle-km driven, annualized weekdays) - Givoni (2011).

Type of vehicle	2002	2003	2004	2005	2006
Cars and minicabs	0.77	0.51	0.47	0.47	0.49
Vans	0.29	0.27	0.26	0.25	0.26
Others	0.07	0.07	0.07	0.07	0.07
Potentially chargeable, total	1.13	0.85	0.80	0.79	0.82
Licensed taxis	0.26	0.31	0.29	0.3	0.29
Buses and coaches	0.05	0.07	0.07	0.07	0.07
Pedal cycles	0.07	0.09	0.09	0.10	0.10
Others	0.13	0.13	0.13	0.14	0.13
Non-chargeable, total	0.51	0.60	0.58	0.61	0.59
All vehicles	1.64	1.45	1.38	1.40	1.41

TfL's Second Annual Monitoring Report gives an estimated breakdown of the reduction in car driver movements into the charging zone. This suggests that around 70% of the total reduction is accounted for by conventional responses to travel cost increases – transfer to another mode, to other destinations or reducing trip frequency – with the other 30% being responses which are more specific to the congestion charge – diverting around the charged area or making the trip outside charging hours (TfL, 2004).

The main response by car drivers is a switch to public transport - around 40.000 daily movements. Bicycle trips have also increased by 83% across London.

In spite of the harsh debate, the London Congestion Charge affected a limited number of people. In fact the mode share for car trips into central London in the AM peak was only 9,8% in 2002 and was 6,6% in 2007. The most important mode for commuting into central London is rail (not underground) with 44,1% mode share in 2007 (a rise of 42,2% in 2002). On top of that, Tfl (2008b) suggests that only half of cars pay the full charge, some 30-40% are exempt or receive 100% discounts and around 10% receive residents' discounts – Tab.7

Tab. 7: Central London Congestion charge zone car trips by payment category (TfL, 2008 b)

Source	Full charge	Fleet	Residents discount	Selected partner	100% discount	Evader
LTS Calibration of CCS Response Jan 2007 data	41%	5%	12%	N/I	39%	3%
Halcrow analysis: Feb – Mar 2007 data	53%	4%	9%	1%	30%	2%

A brief description of other impacts is summarized.

Bus speed increased only in the first year and then decreased. In 2008 buses in the charging zone were 8% slower than before charging was introduced in 2002. This is due to the fact that buses run on reserved bus lanes, so they didn't take advantage of private vehicles traffic reduction, while they were slowed by the increase in service and number of passengers.

Accidents also decreased with a reduction of between 40-70 road traffic casualties per year.

NOx emissions have fallen by 13% and total PM10 emissions have fallen by 15%. This effect is partly due to business as usual substitution of older cars with lower emission ones. A 16% reduction in road transport CO_2 emissions was estimated within the original charging zone, amounting to 30.000 tonnes annually. The London-wide CO_2 reduction is estimated at around 100.000 tonnes, ~1% of London's total road traffic CO_2.

It is relevant to underline that, in contrast with a common opinion, there was no significant effect on retail in central London and there was no effect on property values (TfL, 2005).

Costs and Revenues

Initial set up investments amounted to £160m, with annual operating costs of £90m. The additional costs for the extension to the western zone amounted to £140m for investments and £43m for annual operating costs.

In the first five years average gross revenues per year amounted to £138m (plus 22 m by fines). They increased up to £227 m in 2012.

All surplus is spent on projects for transportation, including: bus network operations, roads and bridges, road safety, walking and cycling.

2.2 Stockholm[8]

System description

The charge consists in a toll cordon around the inner city, thereby reducing traffic through the bottlenecks located at the arterials leading into the inner city.

The cost of passing the cordon (in any direction) on weekdays is SEK 20 (about € 2) during peak periods (7:30-8:30, 16:00-17:30), SEK 15 during the shoulders of the peaks (30 minutes before and after the peak periods) and SEK 10 during the rest of the period 6.30-18.30. The total charge per day is capped at SEK 60.

When the congestion charging scheme started in 2006, an initial trial period of 18 months was proposed. In practice, the trial period lasted 7 months, from January to July 2006, and after a referendum in September 2006 – imposed by opponents to the charge - where the majority of

[8] See official website for Stockholm trial: http://www.stockholmsforsoket.se/
See case: http://www.toolsofchange.com/en/case-studies/detail/670/

Stockholm citizens voted in favour, turning the initial opinion, the permanent implementation of the congestion tax was approved and the charge permanently reintroduced by August 2007[9].

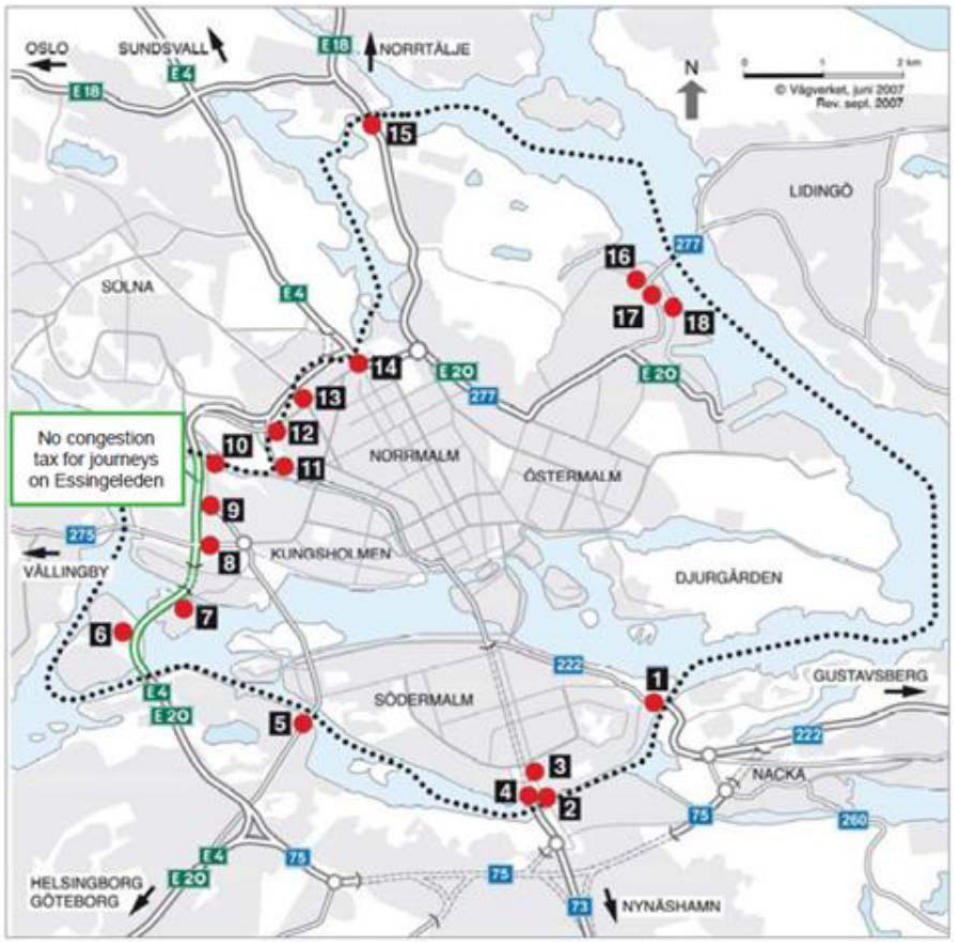
Aims

To reduce congestion in the inner city especially during the peak hours, thus, the congestion fee is differentiated depending on time, and to improve the environment.

Area

Fig. 2 represents the Stockholm congestion charging zone.

Fig. 2: Stockholm congestion charging zone



[9] The trial was forced through by the small Green party in exchange for its support for a national social-democratic government, in the face of public opposition and despite a promise of the social-democratic mayor in Stockholm not to introduce congestion charges. This ignited a heated debate, making public attitudes even more negative to congestion charges than before. But once the trial started in January 2006, the congestion reductions turned out to be enormous, and public opinion shifted quickly. The referendum resulted in a narrow majority in favour of keeping the charges (similar referenda organized in some towns in the surrounding of Stockholm showed a prevalence of opponents). After the referendum, public support continued to increase, eventually reaching around 70% support in 2011. No political parties want to abolish the charges anymore, and the debate has shifted from the system's existence to how it can be improved and how the revenues should be used.

The City of Stockholm has around 0,8 million inhabitants, and is the central part of the Stockholm County, with a total of 1,9 million inhabitants.

The congestion tax area of Stockholm is about 30km² out of the entire city surface of 188km² (about 16% of the city surface). 280.000 inhabitants live inside the area.

Before the congestion charges (2005), the cordon around the inner city was crossed by around 530.000 vehicles and 800.000 transit passengers each day.

Scheme Features

Thanks to topography, 18 control points with cameras are sufficient to monitor access.

In order to access the area and pay the charge a vehicle needs to register. A bill is sent to the owner at the end of each month and can be paid by internet or bank debt ("Autogiro"). Tax must be paid into the Swedish Transport Agency's congestion tax account no later than on the last day of the month following the notification month. In case the congestion charge is not paid in time a surcharge of SEK 500 applies.

Exempt traffic has varied across years. Taxis were exempt during the trial, but not when the system became permanent.

"Clean cars" (alternative fuel cars, including ethanol, biogas, hybrid and electric vehicles) were exempt in a first phase. In 2007 it was decided that they would not be exempt anymore if registered after 1 January 2009, while, if registered before, they would be exempt only until 2012. Their share grew from 2% in 2006 to a peak at 14% in 2009.

Motorcycles are exempt. Foreign vehicles are also exempt.

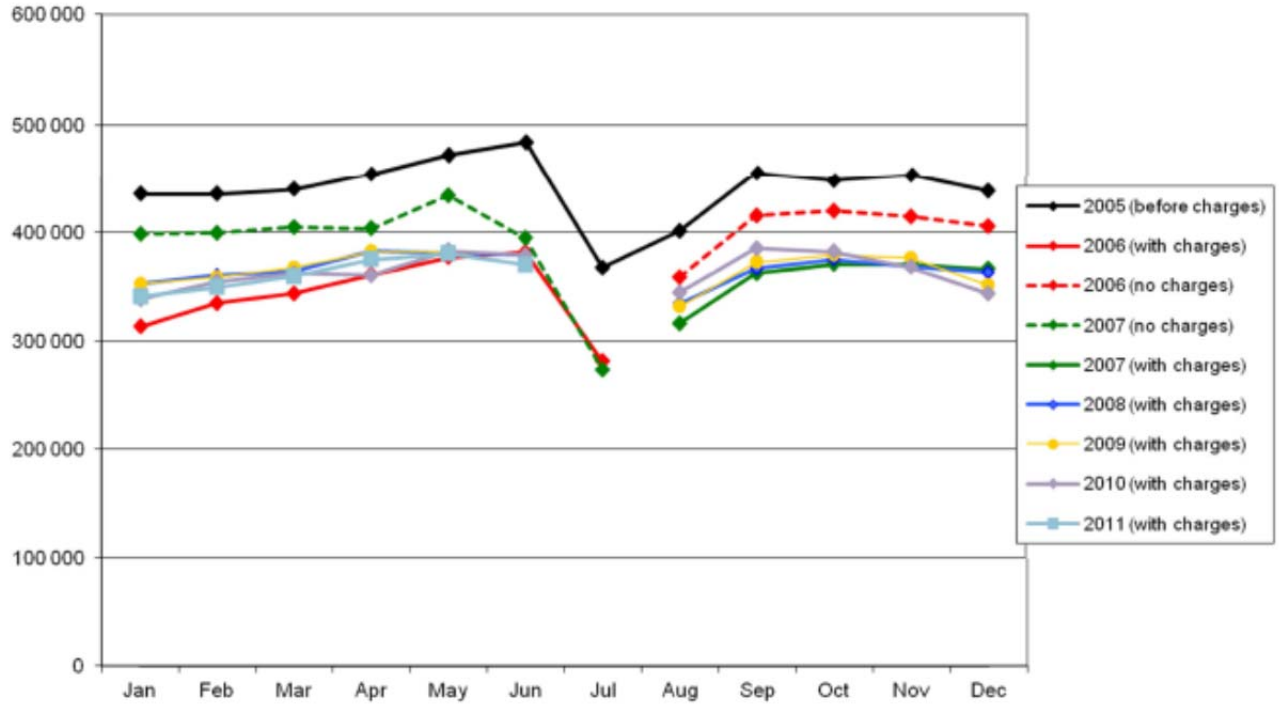
There is no charge for vehicles that pass two different control points within 30 minutes, one of which must be a control point at Gasverksvägen, Lidingövägen or Norra Hamnvägen.

Overall exempt traffic has varied in the range 24-29%.

Impacts

In January 2006, first month of application of the charge, traffic decreased by 29% to 300.000 vehicles per day crossing the area. Increase to 400.000 vehicle per day, a reduction by 20% with respect to baseline is due to both initial overreaction and seasonal traffic variations. At the end of July 2006 the trial terminated, but some effects remained mainly because of change of habits induced by the trial. The traffic effects have proved persistent in the years since - Fig. 3 and Tab. 8.

Fig. 3: Average number of passages across cordon (weekdays 6-19). 2005-2011 (Börjesson M, et alii, 2012)



Tab. 8: Average number of passages across cordon (weekdays 6-19). 2005-2011 (Börjesson M, et alii, 2012)

Compared to 2005	Jan	Feb	Mar	Apr	May	Jun	Jul[4]	Aug	Sep	Oct	Nov	Dec	Average
2006	-28%	-23%	-22%	-21%	-20%	-21%	-24%	-11%	-9%	-6%	-9%	-7%	-21% (Mar-Jun)
2007	-9%	-8%	-8%	-11%	-8%	-18%[6]	-26%[5]	-21%	-20%	-17%	-18%	-17%	-19% (Aug-Dec)
2008	-19%	-17%	-17%	-16%	-19%	-22%	-	-17%	-19%	-16%	-19%	-17%	-18% (excl. Jul)
2009	-19%	-18%	-16%	-16%	-19%	-24%	-	-17%	-18%	-15%	-17%	-20%	-18% (excl. Jul)
2010	-22%	-19%	-18%	-21%	-19%	-22%		-14%	-15%	-15%	-19%	-22%	-19% (excl. Jul)
2011	-22%	-20%	-18%	-17%	-19%	-23%							-20% (excl. Jul)

The exempt traffic (in terms of number of exempt passages) amounted to 28% in 2006, 24% in 2007, 26% in 2008, 29% in 2009, 27% in 2010, 25% in 2011 (Borjesson et alii, 2012).

During the trial the impact on commuting trips by car across the cordon was a 24% reduction; 99% switched to transit and 1% switched route to avoid the cordon. The impact on non commuting trips by car across the cordon was a 22% reduction; most changed destinations or decreased trip

frequencies. Commercial traffic decreased by approximately 15%, switching route or changing trip[10].

Regarding other impacts, PM10 emissions in the area decreased by 13% and CO_2 by 14% (Anas, Lindsey, 2011).

Costs and Revenues

Investment costs amounted to 1.900 mSEK.

Yearly operational costs amount to 220 mSEK.

On the basis of an agreement between the City and the National Government, the charge revenues were funding parts of a major transport investment package, where the national government also made a major funding commitment (202 mSEK). The charge revenues were earmarked for the road investments in the agreement, while the substantial rail investments were claimed to be paid for with money from other sources.

Annual revenues amount to about 763 mSEK.

2.3 Milan[11]

System description

In 2008, Milan introduced a cordon pricing scheme in the city center, by which all vehicles entering the area 7.30 am to 7.30 pm Monday to Friday had to pay a pollution charge, proportional to their emission class, correspondent to € 0, 2, 5 or 10 per day. The scheme, called "Ecopass", was in force until the end of 2011. In January 2012 it was replaced by a congestion charge scheme, called "Area C", characterized by a flat charge of € 5.

[10] It is notable that traffic didn't return to the same figures, after the end of the trial. Other factors, such as fuel prices, changed too little to cause such a relatively large traffic decrease. Apparently, some car users developed new travel habits during the trial – habits persisting even after the charges were abolished. One hypothesis is, however, that some drivers were pressed by the charges to search for travel alternatives, and found such alternatives that were indeed more suitable for them, once they were tested. Another hypothesis is that some drivers were forced to invest in alternative travel options (e.g. buying a motorcycle), which could not be changed back without new transaction costs. (Börjesson M, et alii, 2012).

[11] See the official web site: http://www.comune.milano.it/portale/wps/portal/!ut/p/c1/04_SB8K8xLLM9MSSzPy8xBz9CP0os_hAc8OgAE8TIwMDJ2MzAyMPIzdfHw8_Y28jQ_1wkA6zeD9_o1A3E09DQwszV0MDIzMPEyefME8DdxdjiLwBDuBooO_nkZ-bql-QnZ3m6KioCADL1TNQ/dl2/d1/L2dJQSEvUUt3QS9ZQnB3LzZfQU01UlBJNDIwT1RTMzAySEtMVEs5TTMwMDA!/?WCM_GLOBAL_CONTEXT=/wps/wcm/connect/ContentLibrary/elenco+siti+tematici/elenco+siti+tematici/area+c

See also ICLEI case study: www.iclei.org/casestudies

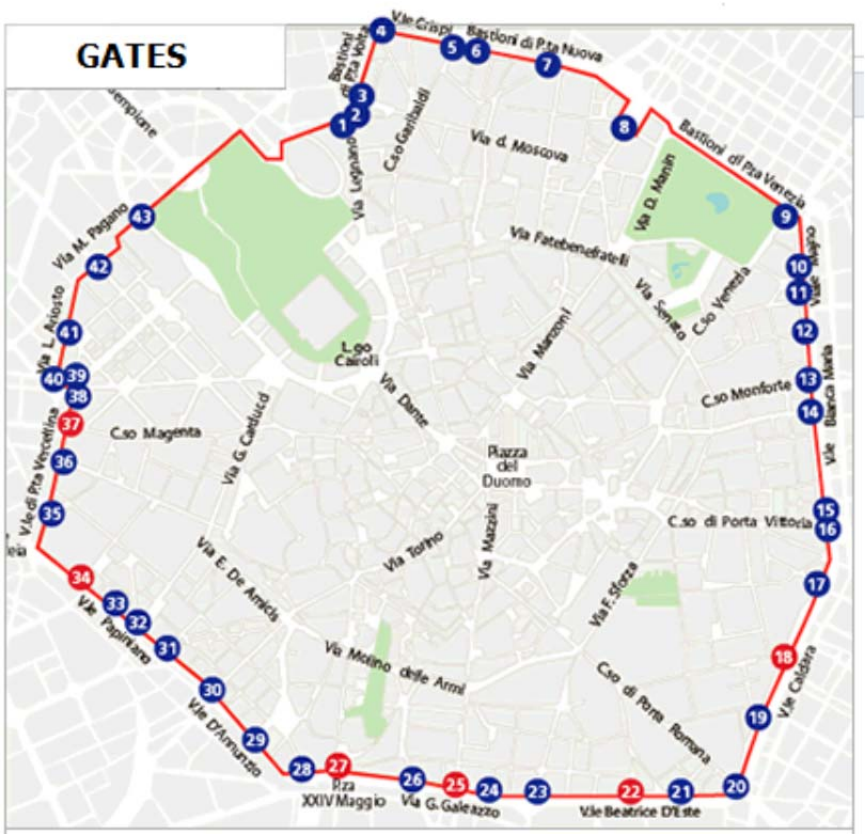
Aims

To reduce both congestion and air pollution.

Area

Fig. 4 represents the Milan congestion charging zone.

Fig. 4: Milan Ecopass / Area C zone



Milan is the capital of Lombardy, northern Italy. The city has a population of about 1.3 million. The Metropolitan area, being instituted, has a population of 3 million. The city is the core of a wider "city region" area which extends beyond Lombardy, with a population of about 10 million.

The cordon toll area is 8 km^2 covering 4,5% of Milan Municipality historic urban district "Cerchia dei Bastioni" and 6% of urban population (about 90.000 people). The area attracts daily about 500.000 people.

Scheme features

Traffic emissions are the main responsible of poor air quality in Milan and Lombardy, also because of geo-climatic conditions adverse to particulate dispersion.

The program of the center-right coalition who won local elections in 2006 envisioned a "pollution charge" to be paid by most polluting vehicles to access the city center. On 1 January 2008 the system, called Ecopass, entered in force, aiming of reducing PM10 concentrations, in the framework of a sustainable mobility package. Ecopass was a daily charge, operating 7.30 am to 7.30 pm Monday to Friday, proportional to vehicles' PM10 tail emissions.

The system started as a 1 year trial and was extended for the years 2009, 2010 and 2011.

The 43 toll entrance gates were controlled by an electronic system of cameras, reading the license plates of the vehicles accessing the area. Amount of charges is described at Tab. 9.

Tab. 9: Class vehicle category PM10 (mg/Km) Charge (Euro)

Class	**Category of vehicle**	**Daily charge (€)**	**PM 10 Emission factors**
Class 1	Low emission vehicles (LPG, methane, hybrid, electric)	free	
Class 2	Petrol Euro 3+ Diesel Euro 3+ with particulate filter installed before sale Diesel Euro 4 with particulate filter installed after sale	free	≤ 10 mg/km
Class 3	Petrol Euro 1 and Euro 2	€ 2	≤ 10 mg/km
Class 4	Petrol Euro 0 Diesel cars Euro 1, 2, 3 (and 4 without particulate filter) Diesel commercial vehicles Euro 4 without particulate filter Diesel commercial vehicles Euro 3	€ 5	> 10 mg/km ≤ 100 mg/km
Class 5	Diesel cars Euro 0 Diesel commercial vehicles Euro 0, 1, 2	€ 10	> 100 mg/km

The key assumption to design the system was that the responsibility for emission externalities varies among vehicle categories.

Class 1 and 2 vehicles were exempt from the charge, class 3 vehicles charge was € 2, class 4 charge was € 5 and class 5 (in large majority commercial vehicles) charge was € 10.

Overall potentially tariffed vehicles amounted to 50% of circulating vehicles (apart exempt ones), but a temporary exemption was also set for diesel cars Euro 4 without particulate filter (covering about 10% of circulating vehicles) which was prorogated over time. So actual chargeable vehicles in the base year, before implementing the charge, were 41,8%. Charged vehicles in the first month of implementation amounted to 25,3% of vehicles entering the area and progressively dropped to about 10% in 2011.

The original idea was that the rules could be made stricter dynamically, charging class 2 – but this never happened because of political opposition by parties.

The system allowed for few exemptions, the main regarding public transportation vehicles, taxis, vehicles transporting disabled, motorcycles.

Residents in the area had the option to buy yearly permits at a price corresponding to one tenth of daily entrance.

Other multiple discounted tickets could be bought (first 50 entries with a 50% discount, successive 50 entries with a 40% discount, no discount after 100 entries), but showed scarcely popular.

In the first year the system showed very efficient in reducing congestion and in reducing car emissions, thanks to both traffic reduction and substitution of older polluting vehicles with new cleaner ones. Then the effect on congestion progressively decreased because of car substitution. The effect on emissions would also soon decrease, as attrite emissions in the area resulted higher than tail emissions.

As the local government was not willing to update the system, a citizens committee led by the first proponents of the charge, called *MilanosiMuove*[12], promoted a referendum, under the Municipality rules for public participation, with five questions of which one regarded the future development of Ecopass. The question asked for the evolution to a congestion charge: *"Would you like to extend the charged zone to the whole city and to all vehicle categories to fund policies for sustainable mobility?"*

The voter turnout was 49% and the result was clearly in favor of changing the cordon pricing: 80% positive answers and 20% negative answers.

The vote happened in coincidence with new municipal elections, won by a left coalition, in June 2011.

As result, the pollution charge "Ecopass" was replaced by the congestion charge "Area C" in the same central area. The new system entered into force on January 16, 2012 for a trial period and turned permanent since April 2013.

Under Area C scheme vehicles entering the area between 7:30 and 19:30 (since 20 September 2012 until 6 pm on Thursdays) have to pay a € 5 daily charge.

Gasoline vehicles – Euro 0 and Diesel vehicles – Euro 0, 1 and 2 are prohibited the access to the area.

Exemptions have been extended to utility vehicles. Commercial vehicles are allowed to a discounted ticket of € 3. More recently another discounted ticket of € 3 has been allowed to cars parking in private parking lots.

Residents are allowed 40 free entrances per year after which any additional entrance will cost € 2.

The payment of the charge must be done by midnight of the next day of access to the area. A fine of about € 80 is applied to violators. In 2014 it has been decided to apply a reduced fine, if paid by 2 weeks.

Impacts

Main results of the Ecopass and Area C schemes regard congestion reduction, public transport speed increase, air quality improvement.

Traffic inside the tolled area as of 30 June 2011 was reduced by 16,2% with respect to 2007, before the Ecopass was implemented.

Road accidents within the tolled area were reduced by 21,3% in the same period.

[12] www.milanosimuove.it

Traffic composition in the tolled area improved as the number of most polluting vehicles (class 3, 4 and 5, the tolled ones) decreased by 70% by 2011 with respect to base year 2007 and number of "ecological" vehicles (class 1) increased sixfold.

In 2012, after the launch of Area C, the traffic reduction has been even greater, corresponding to a further reduction of 30,1% with respect to Ecopass last year (2011).

Road accidents were further reduced by 23,8% in 2012 with respect to 2011.

Public transport use, measured as the number of passengers exiting subway stations inside the tolled area, increased by 12,5%. In addition, the average speed of public transport increased by 11,8%.

It is estimated that the Ecopass scheme reduced the area's total PM10 emissions by 15% compared to the prior period without the Ecopass. These estimated PM10 emissions were reduced by another 18% after the first year of the Area C toll system in 2012 compared to 2011 levels.

Main traffic results are summarized in Tab. 10.

Tab. 10: Road charges effects as reported by AMAT (2009, 2010, 2010b, 2012b)

		Ecopass				**Area C**	
Year	**2007**(4)	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Average number of vehicles entering	90.582 (of which 77.540 passenger)	71.729 (of which 62.120 passenger)	75.097 (of which 65.332 passenger)	73.103 (of which 64.072 passenger)	80.799 (of which 72.378 passenger)	55.670 (1)	56.478 (1)
Charged	*38.081*	*16.322*	*12.255*	*12.224*	*11.431*	*n.a.*	*n.a*
Not charged	*52.501*	*55.407*	*62.842*	*60.879*	*69.368*	*n.a.*	*n.a.*
Average number of accesses (2)	159.328	136.136	n.a.	n.a.	131.898	90.849	92.175
Traffic inside Area. Variation compared to 2007 (3)		-20,8% -19,8% for passenger cars	-17% -15,7% for passenger cars	19,3% -17,4% for passenger cars	-10,8% -6,7% for passenger cars	-38,8% (1) -31,1% compared to 2011	-37,6% (1) -30,1% compared to 2011

(1) Our estimate applying the same variation as number of accesses.
(2) Notice that the total number of entrances differs from the number of individual vehicles entering (that may enter more than once in the area).
(3) Excluding exempt vehicles.
(4) average of 10 days period 26-30 October and 12-16 November 2007.
(5) Provisional data

The composition of traffic entering the Ecopass area changed drastically over time with respect to the composition of immatriculated vehicles in Milan – see Tab. 11. The change was characterized by the increase in non charged classes and a decrease in charged classes.

Tab. 11: Composition of traffic (passenger cars) circulating in Milan (AMAT, 2012)

	2008	2009	2010	2011
Class 1	1,7%	3,1%	4,2%	5,3%
Class 2	48,1%	52,9%	50,1%	52,5%
Class 3	25,2%	21,2%	20,2%	19,4%
Class 4	23,8%	21,7%	24,5%	21,9%
Class 5	1,2%	1,1%	1,0%	0,9%

A large effect on composition of vehicles entering the Ecopass area has happened since the first year. Tab. 13 shows a reduction of 60,5% of passenger chargeable vehicles in the first year. A strong reduction of 47,5% applies to commercial vehicles.

Tab.13: Composition of traffic entering Ecopass area in 2008 (AMAT, 2009)

		Commercial vehicles	Personal transport automobiles	Total
Vehicles belonging to classes subject to charge	**Accesses pre-Ecopass**	9.738	28.341	38.079
	Accesses December 2008	5.116	11.206	16.322
	Variation (n.)	**- 4.622**	**- 17.135**	**- 21.757**
	Variation (%)	**- 47,5%**	**- 60,5%**	**- 57,1%**
Vehicles belonging to classes not subject to charge	**Accesses pre- Ecopass**	3.302	49.199	52.501
	Accesses December 2008	4.493	50.914	55.407
	Variation (n.)	**+ 1.192**	**+ 1.715**	**+ 2.906**
	Variation (%)	**+ 36,1%**	**+ 3,5%**	**+ 5,5%**

The long term effect of Ecopass is showed in Tab. 14, referred to the class composition variation in the last year (2011) with respect to base year (2007) for passenger cars – Tab. 14 commercial vehicles – Tab. 15 and all vehicles entering the area – Tab. 16.

Tab.14: Composition of traffic (passenger cars) entering Ecopass Area in 2011 (AMAT, 2012)

	Reference pre-Ecopass	2011	Variation #	Variation %
Class 1	1.102	6.064	4.962	450,3%
Class 2	48.097	57.738	9.641	20,0%
Class 3	11.124	2.243	-8.881	-79,8%
Class 4	17.206	6.328	-10.878	-63,2%
Class 5	12	5	-7	-58,0%
Total vehicles	**77.540**	**72.378**	**-5.163**	**-6,7%**
Total vehicles - paying classes	**28.341**	**8.576**	**-19.765**	**-69,7%**

Tab.15: Composition of traffic (commercial vehicles and buses) entering Ecopass Area in 2011 (AMAT, 2012)

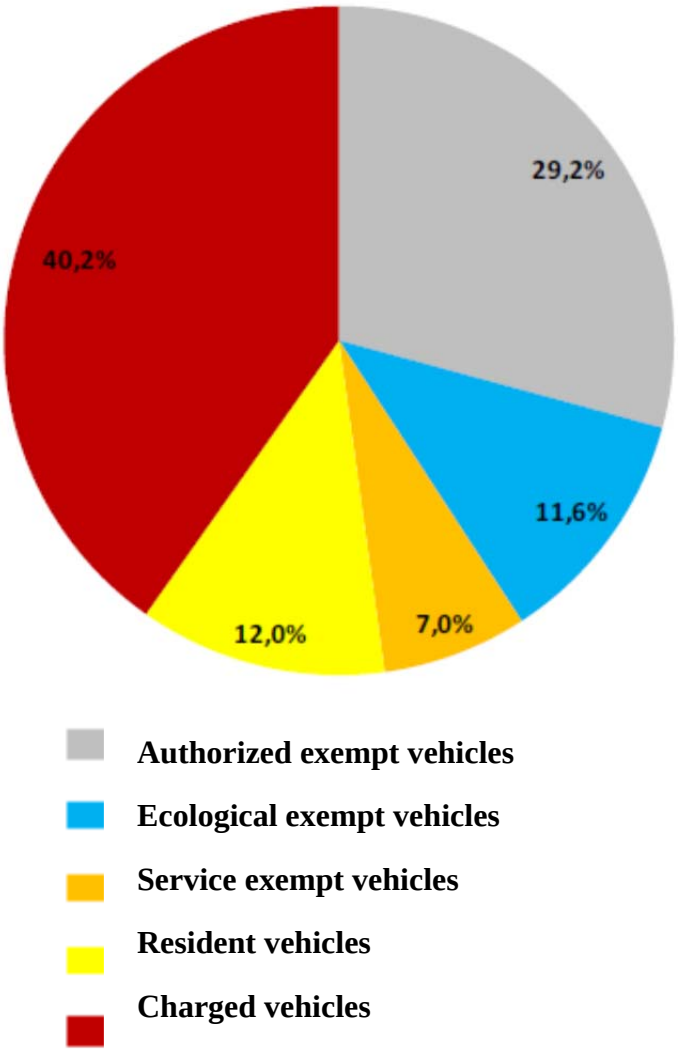
	Reference pre-Ecopass	2011	Variation #	Variation %
Class 1	92	1.284	1.192	1295,8%
Class 2	3.210	4.282	1.072	33,4%
Class 3	815	110	-705	-86,5%
Class 4	5.962	2.381	-3.580	-60,1%
Class 5	2.961	362	-2.600	-87,8%
Total vehicles	**13.040**	**8.419**	**-4.621**	**-35,4%**
Total vehicles - paying classes	**9.738**	**2.853**	**-6.855**	**-70,7%**

Tab. 16: Composition of total traffic entering Ecopass Area in 2011 (AMMA, 2012)

	Reference pre-Ecopass	2011	Variation #	Variation %
Class 1	1.194	7.348	6.154	515,4%
Class 2	51.307	62.020	10.713	20,9%
Class 3	11.939	2.353	-9.586	-80,3%
Class 4	23.167	8.709	-14.458	-62,4%
Class 5	2.973	367	-2.606	-87,7%
Total vehicles	**90.580**	**80.797**	**-9.783**	**-10,8%**
Total vehicles - paying classes	**38.079**	**11.429**	**-26.650**	**-70,0%**

With the passage to Area C, while more vehicles are chargeable, exemptions have increased. Note that only 40,7% of vehicles entering Area C are fully charged. 12% are owned by residents in the area, 71,7% of which has made less than 40 entries in the year – so being exempt – Fig. 5.

Fig.5: Traffic composition entering Area C in 2013 (AMAT, 2014)



Costs and Revenues

Investment costs for Ecopass mainly regarded the installation of cameras and the system software and amounted to about 7 million €. The cost was limited thanks to sunk costs and in particular to the pre-existence of a technology advanced traffic management centre. The operational costs of both the Ecopass and the Area C schemes amount to about 14 million € per year, directly funded by the scheme's revenues.

Annual revenues decreased from 12,061 million € in 2008, to 9,609 in 2009, to 5,021 in 2010, to 5,905 in 2011 in the Ecopass period.

Concerning Area C and considering the period between January to June 2012, the revenues are equal to 11,2 million €. In subsequent years Area C revenues amounted to about 30 million €.

An even higher amount of revenues refer to traffic sanctions of system violators.

Revenues are mainly destined to increase in public transport service.

3. Elasticity to charge

Price elasticity can be measured in any point of the demand function with the following equation:

$$\varepsilon = \frac{\%\Delta Q}{\%\Delta p}$$

where Q is the quantity demanded and p is the price, which can be computed in each point of the demand curve by taking the inverse of the slope of the demand function and multiplying it by p/Q.

An alternative measure to point elasticity is arc-elasticity, which measures elasticity between two points on a curve, and is calculated as follows:

$$\varepsilon = \frac{\Delta Q}{\Delta p} * \frac{(p_1 + p_2)/2}{(Q_1 + Q_2)/2}$$

Referring to Q as traffic and p as congestion charge, Q_1 is traffic at time 1, after the introduction of the charge, Q_0 is traffic at time 0 before the introduction of the charge (baseline), p_1 is the amount of charge and p_0 is 0. If the charge has varied over time the elasticity can be measured in correspondence of the difference price variations, where p_1 is the new amount of the charge and p_0 the old amount of the charge.

In case of cost increase and traffic reduction, the arc elasticity value results slightly higher than the point elasticity value. In case of cost reductions and increased traffic the arc elasticity value results slightly lower than the point elasticity value.

Demand elasticity is always negative because of the inverse relation between quantity and price in the demand curve. We will consider its value in absolute terms.

To assess the contribution of a congestion charge to traffic reduction is quite complex[13].

First of all a rational traveler should consider the full cost of a trip, or at least all the components of the variable costs involved in a trip to take a decision about travelling. At this purpose the cost of a trip includes at least gasoline and parking tariffs - not to consider the value of time. So elasticity of traffic (demand) to the whole cost of a trip should be measured, where a congestion charge is just one of the components contributing to the cost.

[13] Even the apparently simple measure of the deterrent effect of a congestion charge (its ability to reduce traffic) is not so easy to perform. One could hypotize to calculate it assessing the difference in trends of traffic in the charged area against the non charged area (to be considered as characterized by a Business As Usual trend), but this wouldn't be correct as congestion charging contributes to reduce traffic also in external areas. The deterrent effect of a congestion charge scheme also depends on exemptions and discounts, penalties and other specific rules. So the effect on total traffic can be very different from the effect on chargeable traffic.

In theory travelers should be indifferent to which component of the whole cost of a trip varies. In this case we should expect that the value of elasticity of traffic to the price of a single component, like gasoline, is the same as elasticity to any other component, like a congestion charge. There is a vast body of literature on demand elasticity with respect to fuel prices, parking fees, public transport fares, costs of accidents and insurance and other costs of driving (see for example the literature reviews: Goodwin, 1992; Oum, Walters and Yong, 1992; TRACE, 1998). Fewer works deal with tolls and road charges.

Estimates of elasticity of traffic to price of gasoline are provided at Tab. 17.

Tab. 17: Summary of elasticity values of traffic to gasoline price from the literature (TfL b, 2008)

	Short Run - soon after price change		Long Run - within 3 to 5 years	
	Car trips with respect to fuel price	Car km with respect to fuel price	Car trips with respect to fuel price	Car km with respect to fuel price
Graham and Glaister	-0.16	-0.16	-0.19	-0.26
Goodwin, Dargay and Hanly	-0.1		-0.3	
Toner and Mackie				
- Fowkes et al 1991	-0.1		-0.3	
- Goodwin 1992	-0.15		-0.3 to -0.5	

Typical values of elasticity of traffic – measured either in number of car trips or in travelled km – to gasoline price are between -0,1 and -0,15 in the short period and between -0,19 and -0,3 in the long period. TfL (2008 b) estimates National Transport Model Elasticities of car traffic with respect to Fuel Costs (increase of 10%) between -0,17 and -0,24.

In reality a congestion charge seems to weight more than the increase in gasoline price or other costs in the perception of drivers. We expect elasticity values of traffic to road charges to be more similar to elasticity values of traffic to tolls.

In the road toll systems analysed in economic literature, the typical elasticity values range is between -0,20 and -0,50 (see Wuestefeld and Regan, 1981, White, 1984, Goodwin, 1992, 2004, Jones and Hervik, 1992, Harvey, 1994, Hirschman et al., 1995, Mauchan and Bonsall, 1995, Gifford and Talkington, 1996, Burris et al., 2001 and 2003, Matas and Raymond, 2003). In some of the studies elasticity was analysed in the short and the medium-long terms, showing evidence of a general trend towards an increase of 20%-50% (Odeck and Bråthen, 2008; Fonti, 2012).

In our specific analysis on elasticity of traffic to urban road charges, some preliminary considerations are due.

It is necessary to define the variable indicating the quantity of traffic *Q*. Available data for congestion charges can regard number of trips, number of entries or crossings the cordon area, travelled kilometers, a congestion index. Unfortunately to use one or another is not always equivalent, as in some cases evaluations based on traffic, access to the charging area or congestion in the area involve different trends.

In fact after the first period on introduction of a charge, local governments can decide to take advantage of reduced congestion to reserve part of the road space to uses in favour of non motorized traffic (pedestrian space, bicycle lanes, etc.), so reducing road capacity with a further alteration of original conditions.

More in general the compresence of other policies and measures targeted to traffic reduction can make it difficult to distinguish the effects attributable to congestion charging.

Even the definition of a baseline quantity of traffic Q_0 is difficult as it doesn't exist a "standard day". Traffic flows vary by months and by several specific day conditions (meteorology, road works, presence of big events, etc.)

Moreover it is almost impossible to isolate the effect of a congestion charge on traffic from other factors. Many external factors influence traffic in a period. Among them: economic activity factors (like per capita income, population dynamics and employment rate) and behavioral factors (like number of persons per car), infrastructural factors (like availability of transit).

Many factors also influence the real price of a trip (like inflation, price of gasoline and other costs of car use, price of public transport, fiscal regulation regarding the deductibility of the charge). Croci, Melandri, Molteni and Zadorozhna (2012) build an interesting index measuring the ratio between public and private transportation (including cost of gasoline, park price and congestion charge) and find it to be one of the explanatory variables of greenhouse gas emissions by urban traffic.

Most factors don't have a relevant influence in the short term, while their influence grows in the long term. So it is possible to measure a short term and a long term elasticity with a different degree of accuracy[14].

The elasticity formulas introduced anyway provide a rough measure, as it attributes the whole impact of traffic variation to the introduction or the variation of the charge

A more accurate measure of elasticity requires to consider all the factors incident on traffic variation in the period between time 0 and time 1, to describe a model where traffic (Q) is a dependent variable and considered factors – among which the congestion charge - are independent variables and to measure the influence of each variable on traffic variation. This requires the availability of time series of traffic and considered independent variable.

Even if some of these factors have been included in previous econometric analysis, a comprehensive framework is still lacking.

In this paper only a comparison of rough measurements of elasticities will be provided, with the risk of overestimate their values.

[14]"There are two reasons why the long-term effects might be *smaller* than the short-term effects. First, there might be a "acclimatization" effect: after a while, people might get used to the charge and consider it less important when making their travel choices. This effect could be especially important if it is, at first, a little difficult to pay the charge – and the extra "cost" of actually making the payment might decrease over time. Second, the freed-up road space may induce new traffic – travellers with high values of time, or travellers making car trips not crossing the cordon. There are also a number of reasons why the long-term effects might be *larger* than the short-term effects. There are more possibilities to adjust travel behaviour in the long run. Over time, people continually reorganize their lives, relocate place of residence or work, become familiar with new destinations or change other habits, and in this process they will take the permanent charges into account. "(Börjesson et al., 2012)

Note that, in coherence with the different indicators and goals of the systems, by traffic reduction we intend reduction of number of charged trips in London and Stockholm, while we intend reduction of number of charged vehicles in Milan (equivalent to number of charged trips as the average number of entries for vehicle is constant). In London both trips across the area and inside the area are included, in Stockholm all trips crossing the cordon (in entrance or in exit) are included and in Milan only trips in entrance to the area are included.

3.1 London

Surveys were performed in London to estimate travel behaviour reactions of different categories before and after implementing the western extension. Ex ante stated and ex post revealed preferences regarding the travel behaviour in the original central London charging zone are here reported – Fig. 6, 7 and 8.

Fig.6: Comparison of anticipated and reported behaviour – non resident drivers (Tfl, 2008). Charging hours equivalent, 2006 and 2007.

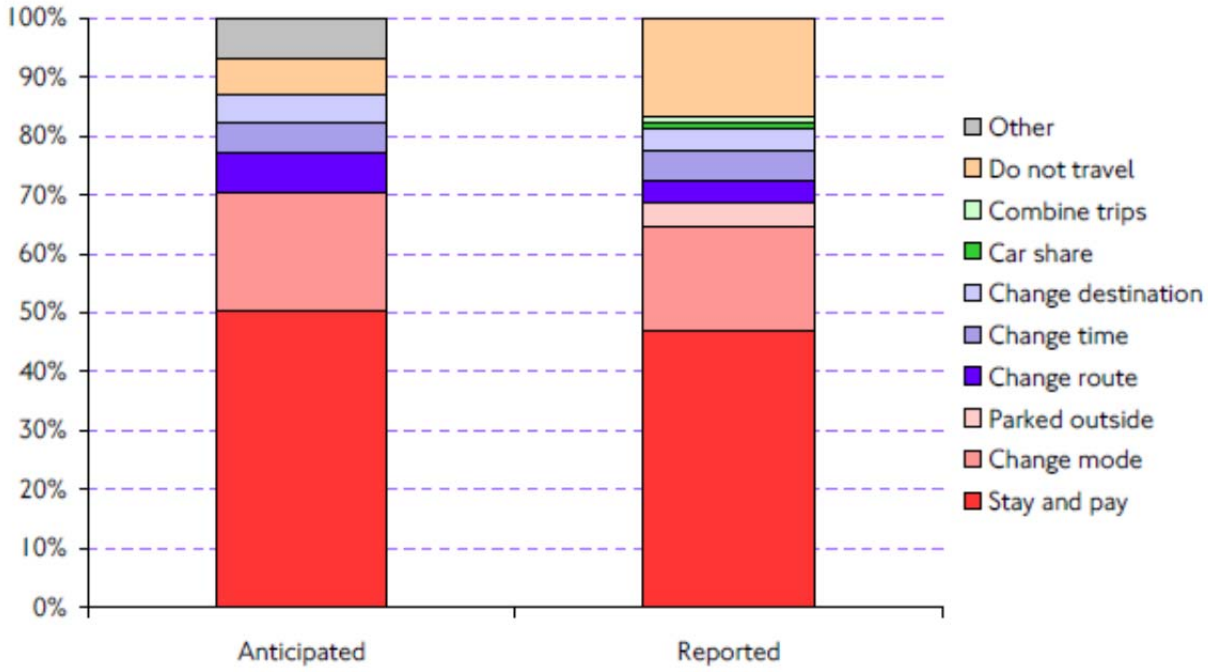


Fig.7: Comparison of anticipated and reported behavior – resident drivers (Tfl, 2008).

Charging hours equivalent, 2006 and 2007.

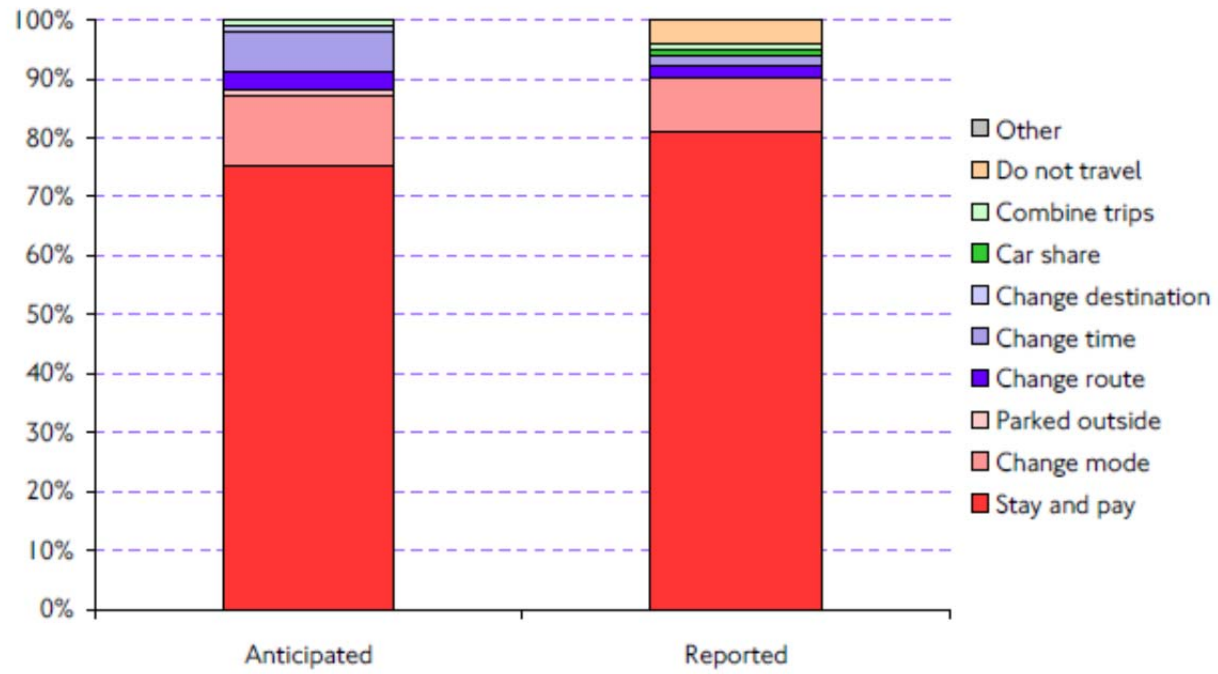
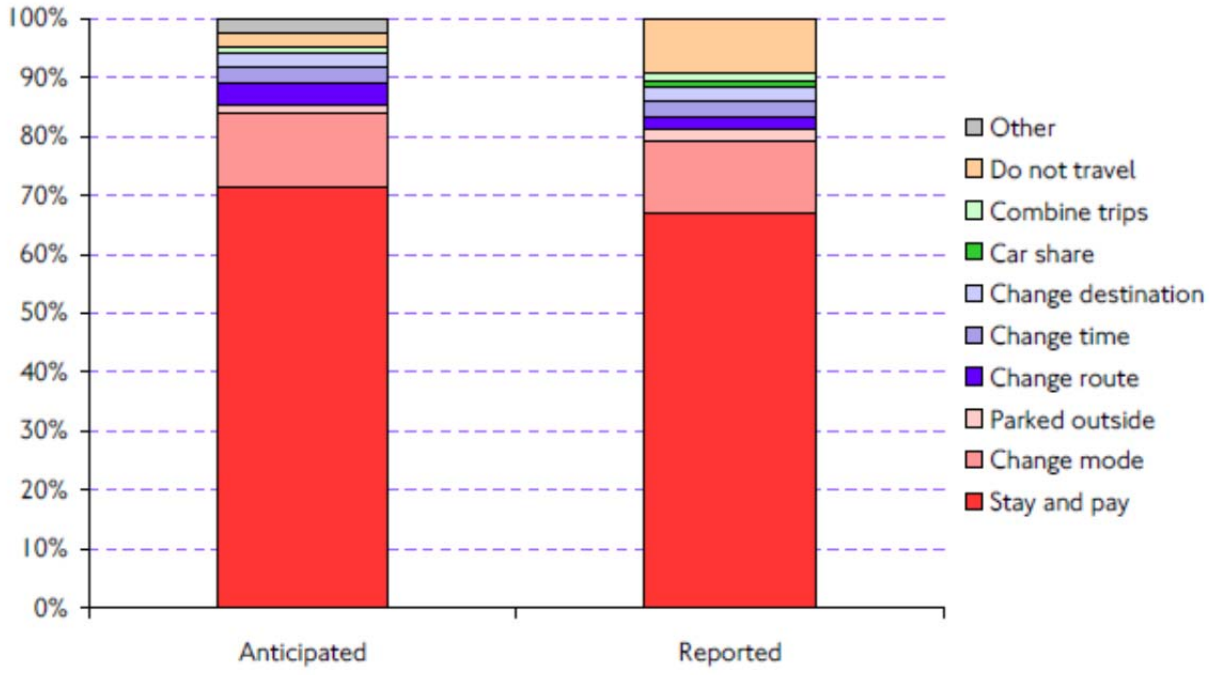


Fig.8: Comparison of anticipated and reported behavior – overall resident and non drivers (Tfl, 2008).

Charging hours equivalent, 2006 and 2007.



Comparisons between ex ante and ex post results show a high reliability of the survey.

As expected behaviours of non residents and residents (allowed a 90% discount) are different.

After the introduction of charging, just under half of the nonresident drivers chose to continue to make their trip by car and pay the cost of the charge.

About a fifth of resident drivers reported a change to their trip in some way to avoid paying the charge, despite the 90% resident's discount.

Overall 68% of sampled drivers reported that they chose to stay and pay for their 'most recent' trip, 12% changed to an alternative mode, 9% chose not to make the trip at all and the remainder made other choices, such as changing the time, route or destination of their trip.

The deterrent effect is relevant. In 2008 Tfl reports a reduction of 37% in number of trips of chargeable vehicles which change mode, destination or frequency and a reduction of 53% of all chargeable cars and private minicab trips. At the time the charge amounted to £8.

Tab. 18: Net car trip response to £8 charge (Tfl, 2008 b)

Car Trips	CCZ
All car and minicab trips	-36%
All car and minicab trips which change mode, destination or frequency	-25%
Chargeable car and minicab trips	-53%
Chargeable car and minicab trips which change mode, destination or frequency	-37%

Tfl provides estimates of elasticity of traffic to cost of travel, as a response to the charge.

The central elasticity estimates, for the arc elasticity, of the change in mode, destination and trip frequency among chargeable car trips in response to the change in money costs (fuel cost and the charge) are: -0,47. Variations in assumptions about the numbers and lengths of trips made by cars into the charged areas give elasticity ranges of -0,40 to -0,51. Elasticities measured across all car and minicab trips, including those not eligible for the charge, are smaller. The central estimates are -0,29 (TfL, 2008 b) – Tab.19.

Tab. 19: Elasticities results (TfL, 2008 b)

Area	Elasticity wrt to money cost: fuel	parking	gen cost time	Assumptions: trip length km	trips per day	other	Elasticity chargeable car trips only: £0 - £5	£5 - £8	£0 - £8	all car trips: £0 - £5	£5 - £8	£0 - £8
CCZ	✓			17	2.5		-0.55	-0.16	-0.47	-0.35	-0.09	-0.29
	✓			17	2		-0.48	-0.15	-0.42	-0.30	-0.09	-0.26
	✓			20	2.5		-0.61	-0.18	-0.51	-0.39	-0.10	-0.32
	✓			15	2.5		-0.51	-0.16	-0.44	-0.32	-0.09	-0.28
	✓			20	2		-0.53	-0.16	-0.45	-0.33	-0.09	-0.28
	✓			15	2		-0.45	-0.15	-0.40	-0.29	-0.08	-0.25
	✓	✓		17	2.5	parking charges averaged across all car trips	-0.89	-0.25	-0.72	-0.57	-0.14	-0.45
	✓			17	2.5	charge cost = £5 plus 0.5*actual charge	-0.43	-0.39	-0.44	-0.28	-0.22	-0.28
	✓	✓		17	2.5	charge cost = £5 plus 0.5*actual charge plus parking charges	-0.68	-0.56	-0.67	-0.43	-0.32	-0.42
	✓		✓	17	2.5	non-business car value of time = £10.8 per hour	-3.18	-0.54	-2.12	-2.02	-0.31	-1.34

Santos and Fraser (2006) provide an estimation of elasticity of congestion charge for cars of -0,27. This estimation derives from higher estimation of elasticity of "generalized cost" of travel (including other cost determinants beyond congestion charge) to demand trips for cars amounting to -0,96.

An early analysis of the LCC found that just over half of the deterred car trips shifted to public transport, around a quarter diverted around the charging zone, 10% shifted to taxis, and 10% were either rescheduled outside charging hours or canceled (Leape 2006, quoted by Anas, Lindsey, 2011).

3.2 Stockholm

For Stockholm, Börjesson et al. (2012) show that elasticity of traffic to charge increased from -0,70 in 2006 to an apparently stable value of around -0,85 in 2009 and onwards. If only private trips were considered, excluding taxis and commercial traffic, which are less sensitive to the amount of charge, the charge elasticity becomes -1,27 in 2006, increasing to just below -1,9 in 2009-2011 – Tab. 20.

The elasticity of traffic to charge for chargeable vehicles is calculated adjusting for external factors (employment in Stockholm County, fuel price, car ownership resulting relevant) - where travel costs are in real terms - with 2005 as base year. Note that the median length of trips crossing the cordon was 13 km, both before and after the trial in 2006, according to travel surveys carried out before and during the trial. Controlling for increases in fuel price, the average marginal driving cost has stayed constant at €0,15/km. Hence, the median trip cost excluding the charge is € 13·0,15 = € 1,95.

Tab. 20.: Changes to the charge in real terms, and changes in elasticity across time, 2006-2011 (Borjesoon et alii, 2012)

	2005	2006	2007	2008	2009	2010	2011
Inflation (compared to 2006)			2.21%	5.77%	5.43%	6.77%	9.01%
Company cars (share of all cordon passages)		23%	23%	23%	23%	23%	23%
Clean cars (share of all cordon passages)		3%	9%	12%	14%	12%	10%
Company cars that are not "clean cars"		21%	16%	14%	12%	13%	15%
Real charge reduction factor due to company cars			0.89	0.90	0.92	0.91	0.89
Real charge reduction factor due to tax deductability			0.95	0.95	0.95	0.95	0.95
Real charge adjustment factor (total)		1	0.82	0.81	0.83	0.80	0.78
average charge, real terms		**1.28**	**1.06**	**1.04**	**1.06**	**1.03**	**0.99**
average total trip cost, real terms	1.95	3.23	3.01	2.99	3.01	2.98	2.94
Reduction of non-exempt traffic, adjusted for external factors (from table 2)		-29.7%	-27.5%	-28.1%	-30.7%	-29.8%	-29.8%
Elasticity		**-0.70**	**-0.74**	**-0.77**	**-0.85**	**-0.83**	**-0.86**

The last row compares the elasticity across years. It has increased from -0,70 in 2006 to an apparently stable value of around -0,85 in 2009 and onwards and shows a light but constant increase over time.

3.3 Milan

The difference in charge amounts (no charge, €2, €5 and €10, depending on vehicle emission factors) determines a renounce on the use of the private vehicle according to the corresponding charge level.

The Ecopass charge categories have been selected following a criterion of potential to deter private vehicle use. The evaluation was based on a survey of Stated Preferences (SP) that took place in fall 2006.

Around 2.200 interviews were made to drivers at the 58 main entrance points of the city between 7 am and 9 pm a weekday to assess the reaction of people to a proposed implementation of a road charge.

Various aspects might have influenced the results of the analysis: first of all interviewed drivers were not told where the pricing scheme would have been implemented; secondly drivers were not informed that the charge could have varied based on the contribution to pollution of each vehicle, finally the survey has been conducted at the municipality boundaries and only drivers not residing in Milan were interviewed[15].

For each proposed charge amount, the proposed alternatives were:

A Confirm the use of car and pay the charge

B1 Park&Ride outside the charged area

B2 Public transport

C1 Car pooling

C2 Motorcycles or bicycle

C3 Renounce to the trip

The outcome was examined taking into account its reliability, in terms of distance between the real preference and the declared one, and the possibility of declaring a renounce to the use of the car in protest to the idea of a charge. Linking elasticity to profession or reason for the journey to the city, it is possible to conclude that a vast majority of the interviewed did provide coherent answers, encouraging the use of elasticity to predict the effects of Ecopass. Through this procedure it was possible to estimate the expected renounces to the use of the car to enter the Ecopass area for each of the applicable level of charge.

Three curves were derived, showing the will to continue to access the city by car in function of an extra cost, corresponding to:

Obtained data (from interviews);

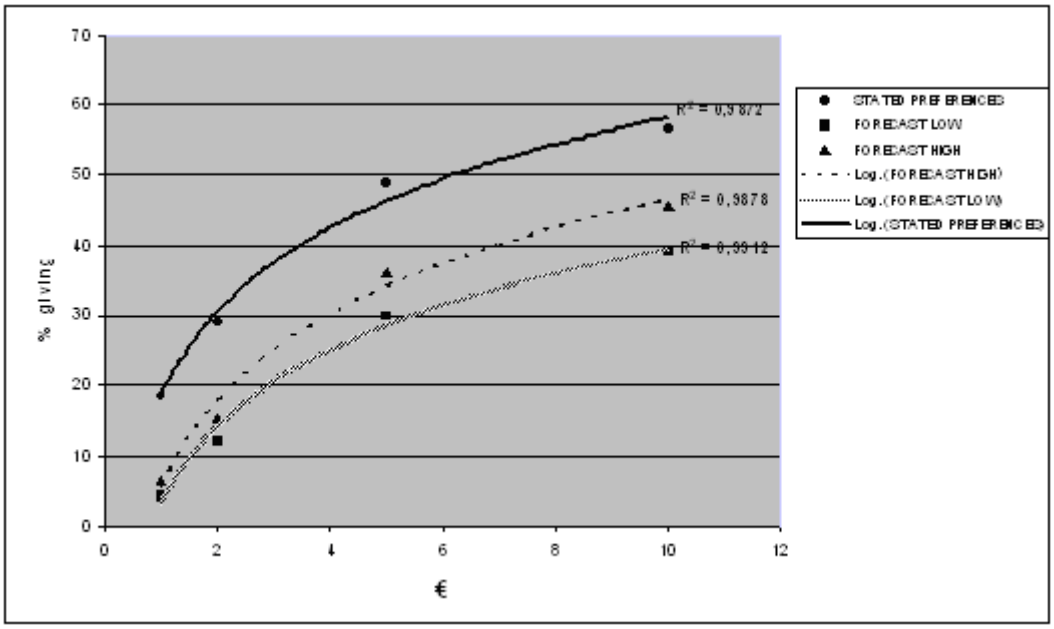
A maximum Forecast (High);

A minimum Forecast (Low).

[15] This was part of a wider sample interviewed on travel behaviours of commuters, which are responsible of half the traffic in city.

Elasticity of traffic to cost of charge can be derived from the curves[16].

Fig. 9: Stated preferences in the renounce to use of cars as a function of level of charge in Milan (Croci, 2008)



An average elasticity is estimated by AMAT -0,40 value. AMAT used the subsample of drivers directed within the Bastioni ring to measure elasticity only for drivers entering what later on became the Ecopass area. The average elasticity drops to about -0,24. However inference might be affected by the small sample size (around 300 observations).

The distribution among different possible alternatives to car use was estimated – Tab. 21.

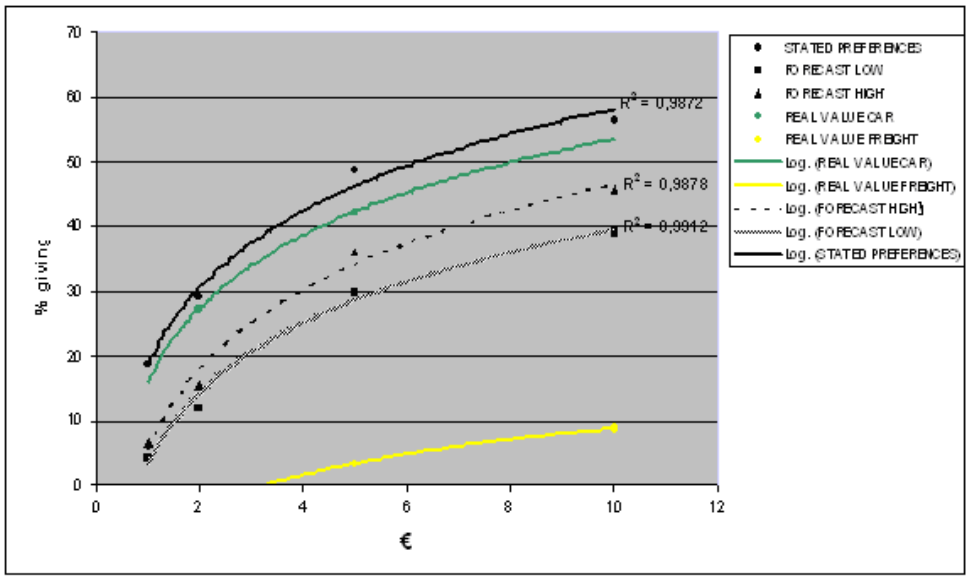
Tab. 21: Modal shift distribution for travellers renouncing to the use of cars (AMAT, 2008)

Car Pooling	Switch to Local Public Transport		Switch to two wheelers (Motorcycle and Bicycle)	Renounce to journey
	park&ride	LPT		
6%	74%		7%	13%

Stated preferences were compared with revealed preferences obtained by real behaviours of car drivers after the first 9 months of Ecopass with the results showed in Fig. 10.

[16] Elasticity is calculated per type of employment and per motivation of entrance in the Ecopass area. Results show that students fall in the high elasticity class, with an elasticity level of -1,1 while retired people, housewives and unemployed are medium-elastic (-0,56). Businessmen and entrepreneurs instead, as expected, fall into the low elasticity class, with elasticity estimates around -0,25. Similarly travel trips result being much less elastic than pleasure trips, with elasticity of -0,39 and -0,65 respectively (Fonti, 2012).

Fig. 10: Stated preferences in the renounce to use of cars as a function of level of charge in Milan (Croci, 2008)



A charge of €2 causes a renounce of 27% of drivers to enter the Ecopass area. A charge of €5 a renounce of 43%. For commercial vehicles, the renounce rate is not relevant when the charge amounts to €2; at €5 the renounce is around 3%, reaching almost 9% when the charge is € 10.

The deterrent effect resulted higher than expected. Renounce to private car use rates were close to the ones obtained with the Stated Preferences survey, but it is also possible to observe a renounce among commercial heavy duty vehicles.

In this paper we provide a new measure of arc elasticity of Ecopass for passenger cars referred to year 2011 (the last one for Ecopass) using more recent AMAT data. We estimate a long term value of -0,66 for class 3 and -0,46 for class 4. It is not possible to provide a measure for class 5 as too few passenger cars fall into class 5[17].

Values for commercial vehicles show lower values (between -0,15 and -0,17).

Unfortunately we cannot provide a short term measure of elasticities for Ecopass, because of lack of data, but we can affirm that elasticity grows over time. Lack of data also prevents a reliable estimate of traffic elasticity of charge under Area C.

Unexpectedly elasticity decreases passing from class 3 to 4. A possible interpretation is that class 3 vehicles owners are wealthier and change cars more often than class 4 (in class 5 there are almost exclusively commercial vehicles).

[17] Fonti (2012) provides slightly different values of elasticities: -0,6 for class 3 and -0,41 for class 4 in 2011. She also provides average elasticity values for the whole Ecopass period (2008-2011): -0,44 for class 3, -0,37 for class 4, -0,58 for class 5. The values show quite stable over time.

4.Conclusions

The three largest European urban road pricing systems started during a decade (first London in 1998, then Stockholm in 2006, finally Milan in 2008).

All of them are cordon charges, where cameras automatically control access to central areas. The dimension of areas varies from 8 km^2 in Milan, to 21 km^2 in London (not considering the temporary western extension) to 30 km^2 in Stockholm.

Baselines are expressed in different variables. Before implementing a congestion charge system there were about 150.000 car trips in entrance to the charged area in Milan, 400.000 trips inside or entering the area in London and over 400.000 crossings (either in entrance or in exit) the area in Stockholm, during charging hours. In spite of the variety of indicators, traffic conditions in the area are comparable.

All charged areas are core areas for the cities and metropolitan areas and served by an extended and dense transit network.

The main aim for all systems is reducing congestion. A secondary aim is to reduce air pollution (this aim was prevalent in the first phase in Milan).

In all systems a flat rate is imposed: at present it amounts to £11,50 in London (€ 14,50), SEK 20 in Stockholm (€ 2) and € 5 in Milan. In the first phase in Milan charge was differentiated (€ 0, 2, 5 and 10) on the basis of PM10 emission factors.

Charges are on daily basis in London and Milan and on number of accesses in Stockholm (with a daily maximum of SEK 60). In London circulation in the area is charged, while in Milan access to the area is charged and in Stockholm crossing of the area is charged.

Charges operate only in the daytime (11 hours a day in London, 12 hours a day in Stockholm and Milan).

All systems present several exemptions and reduced charges for specific typologies of vehicles (public transport, “clean vehicles”, residents). The exemption was lifted for “clean vehicles” in Stockholm. The majority of vehicles is exempt or charged at discount in London and Milan.

Similar technologies are in place, using cameras automatically recognizing car plates.

Stockholm and Milan started as trials and were then confirmed. All the systems evolved during time in various aspects like the area (London), the amount of charge (London and Milan), exemptions (London, Stockholm and Milan) and other aspects. In the case of Milan there was a major change in the structure of the scheme itself, shifting from a pollution charge to a congestion charge.

Political and public debate were relevant factors in setting up and decide permanency of the systems. In the cases of Stockholm and Milan a referendum was a key factor at that purpose.

In all cases, even when polls showed citizens were not in favour when the charge was announced, after implementation the majority of citizens turned in favour.

The ratio operating costs / revenues amount to 39% for London (in 2008; falling from initially 65%), 28% for Stockholm (in 2010) (Erdmenger C, Frey K, 2010); over 100% for Ecopass and 65% (increasing from initially 46%) for Area C, Milan. Cost benefits analysis, not analyzed in this paper (see among others OECD, 2010, Danielis, Rotaris, Marcucci, Massiani, 2012), report high surplus benefits due to the reduction of externalities generated by traffic.

In all cases a robust increase of public transportation was announced and implemented in coincidence with the introduction of the charge and a substantial part of revenues are invested for sustainable mobility (in Stockholm indirectly through an agreement with national governments).

In all cases the following trend effects, though in different measures, are demonstrated: traffic reduction and modal shift, mainly through increase of passengers of public transport. A huge pollution emission reduction happened in Milan and a relevant one in Stockholm, while the effect was negligible in London. In Stockholm and Milan also accidents reduction, and speed increase in public transportation were experienced (while in London it doesn't seem to exist a connection with accidents, while bus speed decreased). In all cases traffic reduction happened also in in the area surrounding the charged one. No negative effects were registered on retail and real estate values in the area.

All cases show a high deterrent effect of the charge, as measured on travel behaviour changes referred to all traffic and in particular to chargeable traffic. In London a £8 charge drove to a 53% reduction of fully chargeable traffic in 2007. In Milan the effect has been even stronger: after the first year (2008) Ecopass reduced chargeable passenger traffic on average by 60,5% and in the last year (2011) by 79,8% and 63,2%, respectively for a € 2 and € 5 charge[18].

The demand elasticities of car travel in response to a congestion charge are considerably higher than the values in response to fuel costs in literature[19].

Lack of data and different methodologies in monitoring and evaluating data limit our analysis. Nevertheless it is possible to make a comparison of passenger cars elasticities to charge in the three cities. Elasticity is here considered with reference to chargeable trips (not to all vehicles). The introduction of the charge can actually affect also non chargeable trips, because of better alternatives in public transport and alternative mobility and imitation of virtuous behaviours. Elasticity here is considered only for passenger cars. We expect lower elasticity values for commercial vehicles which are less sensitive to the charge, as put in evidence in various analysis.

Variations in system rules and contribution of external factors are not completely taken into account, leading to a low accuracy of estimates. Still results are relevant and coherent with similar studies.

For London, Transport for London (2008) estimates an elasticity of -0,47. For Stockholm Börjesson et a.i (2012) provide an estimation of elasticity from -0,70 in 2006 to -0,85 in 2009 onwards. For Milan, our own measures indicate an elasticity referred to the Ecopass system varying between -0,46 and -0,66 (for different classes of emissions of vehicles). In all cases there is no evidence of a decrease of elasticity over time.

These values are systematically higher than elasticity to fuel price and even to traditional tolls for roads and bridges.

Data on congestion show different trends, because local governments in some cases decided to use the road space freed from cars for other social or sustainable mobility purposes (bike lanes, pedestrian areas, etc.).

[18] As previously stated, this unexpected difference, leading a lower charge to cause a higher reduction needs to be further investigated. A possible explanation is the lower income of drivers of class 4 vehicles, who are less eager to change car.

[19] A charge represents a much larger change in cost than a 10% increase in fuel cost (which normally considered in literature). For London a charge of £8 is equivalent to a 191% cost increase in fuel cost (TfL, 2008 b), considering average trips of 17 km.

Urban congestion charging, though limited to pioneer experiences, confirms its ability to reduce congestion in an effective way.

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