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Measuring the Cost of Congestion on Urban Area and the Flexible Congestion Rights

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Abstract

This paper presents a methodology to measure the cost of congestion in cities and to identify levers of action to manage traffic. The experimentation focuses on the ten largest Italian cities and considers the evolution between 2007 and 2008. By taking into account the cost of fuel, the cost of CO2 emission and of cost of time spent in traffic due to congestion, the methodology allows to assess the socio-economic cost of congestion as a proxy of the net reduction of GDP induced by traffic. It appears that the variances from a city to another and the evolution over a year can be significant: these differences point out that congestion is not an unavoidable consequence of urbanization and can be dealt with.

As a logical consequence of this measurement, the paper puts forward a proposal to address congestion in city through the implementation of a policy relying on the "pay as you pollute" principle: the flexible congestion rights. This incentive scheme would reflect the real externalities of car usage by considering the characteristic of the vehicles, of the journeys, and the effective use of public goods – roads and road related infrastructures. It would also provide rewards to environment friendly behaviors, while any surplus would be reinvested in the public transportation system. Thus, the mechanism would have the advantage of higher flexibility, making it more effective, equitable, and capable to win political resistance than more traditional road pricing schemes.

Keywords: traffic congestion, road pricing, flexible congestion right, externality, transport, mobility, urban planning

1. Introduction

Traffic is an issue in all major cities around the world, because the overall volume of vehicular traffic in many areas continues to grow faster than the overall capacity of the transportation system (Weisbrod, Vary & Treyz, 2003). Solving the problem of congestion (Note 1) is usually a top priority for city authorities, who note that congestion not only induces pollution, delays, and safety issues, but also decreases quality of life and imposes significant economic and social costs, to the local community but also to the local businesses (Weisbrod, Vary & Treyz, 2001), especially in rapidly growing cities. Since more than one century, the car has had a hegemonic influence on city shape and organisation. Paradoxically, individual car appears to be a very inefficient way of organising mobility in urban zones, not only in term congestion, but also considering the space they occupy (parking, roads, highways, bridges). Although different cities have developed diversified solutions for dealing with congestion, (enhancement of the public transport, reserved lanes, car and bike sharing), few have successfully neared a solution.Cities are facing a huge challenge in terms of capacity which implies to reconsider mobility to match the demand of sustainable transportation with the supply.

Two attitudes prevail when it comes to discussing congestion: on the one hand, the myth of the ineluctability of the problem which, following the arguments of most fatalists, is clearly beyond the ability of a single mayor: a sense of helplessness that leaves no other choices than that of turning on the radio and wait for the traffic jam to set you free; on the other hand, the syndrome of producing generic solution that are, most of the time, never based on objective evidence. Every policy considered either is too unpopular, too expensive or has proven ineffective (Arnott & Small, 1994). Helplessness and lack of information make us not only "losers" against traffic, but also lead us to make the promise of a society built on information less effective, and seriously reduce the potential of the technologies we can use.

This paper aims to give tools to tackle this issue. For this purpose, it introduces two innovative proposals:

1) An innovative tool to measure congestion, make comparisons both across space and time.

Myriad factors affect traffic flow, so the extent of congestion is still difficult to measure. Therefore, it is hard to determine scientifically just how well existing anticongestion policy are working (Downs, 2004). Measuring the cost of congestion will allow to draw comparisons between cities, in order to identify good practices and possible solutions to be transferred to other urban areas with comparable characteristics, while raising citizens 'awareness about the issue. Therefore, it would encourage good behaviors among citizens, but also good practices among policy makers. Not less interestingly, this methodology will enable to analyze evolution of congestion over time for each city. Thus, comparison could be drawn between political cycles, so that city authorities would be more accountable for the positive or negative consequences of their policies. Last but not the least, such an assessment would also encourage competition between cities and local authorities, so that those who would manage to reduce traffic would be rewarded (by the recognition of the improvement, a higher attractiveness of the territory, a re-election, the improvement of the quality of life…). Thus, it would foster innovation among local authority to manage traffic and mobility while putting the issue of congestion among the top priorities of policy makers.

2) The proposal of the "flexible congestion rights" which would provide an incentive / disincentive scheme based on the very measurement of the footprint of each car user and which appears both more effective, equitable and acceptable from a political point of view than traditional "road pricing", "congestion charge" solutions.

By assessing the cost of congestion in city, this methodology could be used as a benchmark to tailor a congestion charge on the basis of the "pay as you pollute" principle. Individuals would be charged for the use of the roads considering their real impact on the environment. This proposal consists in going beyond the current rigid models applied in London, Singapore, Stockholm or Milan where a fee is charged to car users on a daily basis, not only by applying a congestion charge but also through a system of incentives and rewards to encourage desirable patterns.

However, before developing these points further, it is necessary to recall few concepts of economic theory in order to comprehend the issue of traffic and the idea of road pricing, and their implication in terms of congestion.

1.1 Road Use and Externalities

Road space is a valuable and scarce resource (Newberly, 1990). In terms of the Public Good theory, road is rival in consumption (the consumption of the road by a user reduces its availability to others), and excludable when a road pricing scheme applies (Block, 1983). For that reason, road infrastructure is not a pure public good, and its use induces several externalities and social costs, among which:

1) Accident externalities: additional vehicles on the road increase the probability of other user (pedestrian and car users) to be involved in an accident. Accident probability also depends on the distance run, the speed, and driving time. These are usually treated as congestion cost (Newberly, 1990).

2) Road damages cost: damages caused by the passage of vehicles, and in particular heavy trucks, impose maintenance costs to the local community (Block, 1983; Newberly, 1988a).

3) Environmental externality: the more vehicles on the road, the greater greenhouse gas emission, the higher noise and vibration and the more important land use effect (consumption of land, destruction of wildlife habitat, water pollution) (Newberly, 1988b)

4) Traffic congestion: probably the most important externalities are induced by traffic congestion, as this phenomenon worsen the externalities mentioned above. Traffic congestion is defined as a condition of traffic delay because the number of vehicles trying to use a road exceeds the design capacity of the traffic network to handle it: additional vehicles on the road reduce the speed of other vehicles, induce delays, increase pollution, impact the quality of life, and decrease safety on the road (Weisbrod et al. 2003). Congestion can also be seen as an example of the "Tragedy of the Commons" (Note 2).

We can also mention the impact of delay on the attractiveness of the cities and on the overall performance of the local economy -- as delays impose significant costs in term of travel cost, additional business operating cost, and productivity (Weisbrod, et al. 1990) --, the effect of congestion on the public transportation efficiency, the implication on health, or the depreciation of vehicles.

1.2 Measuring the Cost of Congestion

The model allows, as we shall see, to convey to the same unit of measurement (currency) the three main components of congestion costs that entails:

1) The value of time lost in the car

2) The energy bill determined by the cost of fuel needed to power the vehicles

3) The cost of CO2 emission produced.

This methodology was tested on the ten largest Italian City in 2009, with data from 2007 to 2008 (Vision & Value, 2009). The results show important figures: the traffic induced a 27 million euro cost per year borne by the 8.5 million inhabitants the sample encompasses. However, these figures underestimate the real impact of congestion in terms of cost as several factors could not be taken into account in the study (such as the depreciation of car, or pollutants other than CO2).

A city-dweller of Rome spends on average 227 hours a year in his car, and 68% of such time he is in congestion.

The model shows that the improvements are not marginal, even from a year to another, and this evidence together with the differences observed between cities, allow to conclude that traffic congestion is not inevitable.

1.3 Road Pricing

Because of the externalities, many economists have recommended to rationalize the use of roads through the implementation of a road pricing – or a congestion charge – in order to correct and internalize these costs. Several cities have set up such a policy: Stockholm, London, Singapore or Milan for instance impose a charge to road users in certain zones of the city. In less than one year, the City of Milan has managed to reduce the number of vehicles entering in this zone by one third (an average of 46 133 vehicles a day), the number of car accidents by 28%, and the carbon dioxide emissions by 22% (compared to January to June 2011) because of the implementation of the Area C, a congestion charge policy that entered into force in January 2012 (Note 3).

The new technology of electronic tolls no longer requires motorists to stop at tollbooths, and therefore, they prevent additional congestion from occurring (Sandford, 1988). An electronic number plate can be given to drivers, which signals the presence of a vehicle to a recording computer. Singapore was the first city in the world to implement an electronic toll collection system for the purpose of congestion pricing in September 1998 to discourage usage during peak hours. It consists in ERP gantries located at all roads with high traffic with camera to capture the license plate numbers of vehicles entering the area where the charge applies. A device known as an In-vehicle Unit (IU) is affixed on the front windscreen, in which a stored-value card, or CashCard, is inserted for payment of the road usage charges. This solution encountered considerable success (Goh, 2002): its introduction results into an immediate reduction of 24 700 cars during the peak time and a rise of traffic speed by 22%.

Furthermore, many argue that road pricing is the best method of dealing with congestion, and that it would have far-reaching implication for the sustainability of public transport, for the investment in urban infrastructure and a positive impact on quality of life (Newberly, 1990). Moreover, by reducing delay and improving transport efficiency, it would have a positive impact on the local economy and would help city be more attractive (Weisbrod, et al. 2003).

1.4 The "Polluter Pays" Principle Applied to Road Pricing in Urban Area

The "polluter pays" is a principle for creating a market to internalize these social costs and assigning liability to users. Applied to road pricing in urban area, it consists in applying a charge that reflects the real footprint of road-users and setting up incentive to encourage good behaviors. The charge should therefore take into account the characteristics of the vehicles (footprint, emission per kilometer, electric cars or trucks), the characteristic of the trip (duration, speed), the time the road is used (peak hour, holiday, week-end, nights), and the space (distance from congested areas). The idea is completed by the provision that any revenues (deducted the cost of operating the system) would be tagged to better (cheaper or more) public transportation.

This is what *Vision and Value* refers to as the "flexible congestion right".

This pricing scheme offers several advantages. As already mentioned above, road pricing is a suitable and optimal tool to internalize most of the external effect of road use. Such a pricing scheme would reflect the real impact of vehicles on their environment. Furthermore, it would reveal the true economic cost of road use so that intermodal competition would be fairer. By connecting road prices with congestion cost, the perceived cost of driving in non-urban areas could probably fall whereas the same in urban areas would increase (Newberly, 1990).

As explains Downs (2004), distortions arise partly because individual drivers and businesses do not have to face the true social cost of their private decision about where and when to travel and how to influence the travel of other. Last but not the least, such a charge would engage people directly, making them aware of the issues, and forcing them to make informed choices about road use. By providing accurate information to drivers on route capacities (through the pricing scheme, see last section), expected travel costs would be reduced (Arnott, de Palma, Lindsey, 1991). Furthermore, the flexibility of the scheme would be, in fact, much more compatible than rigid pricing technologies (like the ones in place in London or Milan) to directly involve citizens into establishing pricing, exemptions, incentives and change them when situation evolve. Public choice and active public participation would be then brought to the forefront of the debate on sustainability (Drewes, Nielsen &Gjesing Hansen, 1997).

However, its application implies the need for monetary valuation of the damages caused to the environment (Newberly, 1990) in order to set up a fair and equitable pricing. To do so, Vision and Value conducted an experimentation which aims at setting up a methodology to assess the cost of congestion in cities through the estimation of the cost of CO2 emission, the cost of fuel and the cost of timelost because of traffic congestion in the ten largest Italian cities in 2007 and 2008.

2. Methodology

Vision and value developed an innovative approach to the issue of urban mobility with a view to assess the cost of congestion in cities. Therefore, we focused on the extra costs (the extra consumption of fuel, the extra time spent in traffic, and the extra CO2 emission) induced by the reduction in speed below 30 km/h due to the increasing demand for the use of road (we therefore assumed that the cost of fuel, time and CO2 emission induced by traffic when running at a higher speed are the "normal" costs of traffic, and are not taken into account in our analysis). The study used a model that may not only provide a systematic measurement of the costs of congestion in cities, but also the identification of the precise levers to be used in order to reduce these costs.

2.1 Collection of Data and the Model

The experimentation focuses on the ten most populated Italian cities: Bari, Bologna, Florence, Genoa, Milan, Naples, Palermo, Rome, Turin, Venice (the Italian "so-called" metropolitan cities); and considers two weeks respectively in October 2007 and October 2008 (to which we added the Christmas week in Rome, Milan and Naples to see how the situation evolves accordingly to the way people consume in this specific time of the year). In particular, the figures encompass data related to different days of the week and time of day (morning: 7:00-10:00, median 10:00-16:00, afternoon 16:00-21:00, and night 21:00-7:00), from Monday to Friday.

The data were collected through GPS devices embedded in cars for insurance purpose (and that were collected by an Italian firm called Octo Telematics). The sample encompasses 257 400 cars equipped with this GPS technology. The geographical area for each city was defined by the rectangle that includes the entire province, including the municipalities that constitute a conurbation. The measurements refer to an area defined by conventional latitude and longitude. The data consists of 1) the percentage of cars provided with this specific GPS device that were in motion during this period; 2) the duration of trips; 3) the speed and thus 4) the percentage of the cars and of the time travelling in congestion.

For the purposes of this study, congestion is defined as the time spent in a car that runs below 30 km/h. Therefore, we assume that the costs of traffic when travelling above 30km/h are the normal cost of traffic associated to a normal speed. Then, we focus on the cost of congestion, not to be confused with the total social cost of traffic referred to as the cost of road use.

The extrapolation of these basic data to the entire system was done using the following formula:

$$\frac{\textit{Vehicles equipped with GPS travelling in the Province}}{\textit{Number of vehicles equipped with GPS in the Province}} \times \textit{Number of vehicles in the Province} \quad (1)$$

Given the total population, the total car fleet for each city and assuming the sample was representative, the survey then allows to assess: a) the average distance (km) travelled per trip, b) the average speed (km/hour), c) the average duration of trips, d) the fuel consumption, d) the CO2 emissions, e) the percentage of time/ Km spent in congestion. This measurement allows to quantify, per citizen and per city:

1) *The cost of time spent in the car* which is a function of average speed, km traveled and opportunity cost of time (which is a function of average income per capita and therefore varies by city).

2) *The cost of fuel* which is the number of travelled miles which multiplies the average consumption of fuel in liters per km at the recorded average speed multiplied again by the average price of a liter of fuel.

3) *The cost of CO2 emission which is* a function of the average number of miles covered per car, the amount of CO2 (in tons) produced per km, and the average price per ton (calculated considering the price of certificates of CO2 in future markets).

If the first two categories of costs correspond to costs paid by the very car users, the third is a pure "externality" which is borne by everyone but the person who produces the cost. By considering this latter, the model goes beyond the methodology used by the Texas Transport Institute (2000) that assessed the cost of congestion in 75 metropolitan areas in the US in 2000 by taking into account the extra time lost and the cost of fuel (Note 4).

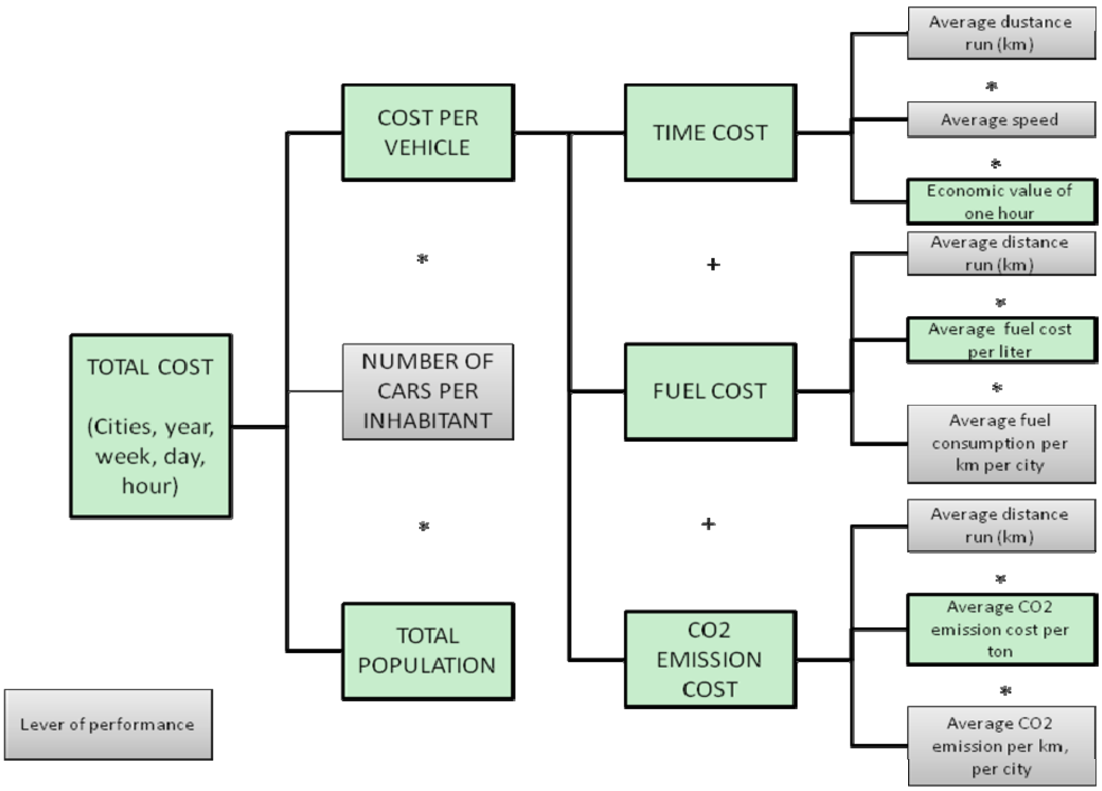


Figure 1. The model

Source: Vision & Value

The analysis provides two main results which can be useful for making policy choices on the basis of better information:

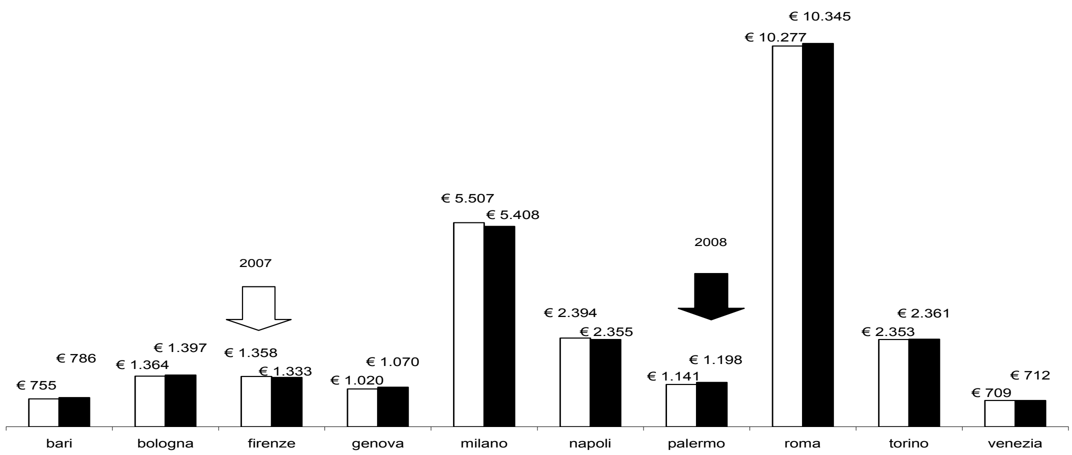
1) It allows comparison in space (amongst different cities) and in time (the differences of performance of the same city between different years): this can be useful to measure the impact of different organization model although the gaps may be explained by different characteristics;
2) It also provides a picture of the situation through levers, determinants; a larger gap on a certain factor may lead a certain city to concentrate its efforts in filling that particular gap.

2.2 The Limit of the Model

The model does not consider other less computable factors that may be relevant for the analysis such as the security cost (Jones-Lee, 1990) -which could be approximated by considering the insurance costs that cover injury and damage-, the cost of maintenance and expansion of the infrastructure, the depreciation of vehicles, the costs of pollutants other than CO2, the impact of motorcycles, and the costs imposed to future generations that the cost of energy may not price correctly. Furthermore, the model does not include the costs of other public services which may be impacted by congestion, or the consequence on health. It is conceivable, therefore, that the figures provide a lower representation than the effective overall cost of congestion.

3. Results

The model allows different level of analyses. First of all, the data allow to draw a comparison of the macro-cost of congestion (cost of time, CO2 emission and fuel consumption combined) between 2007 and 2008 for each city (see graph 1).



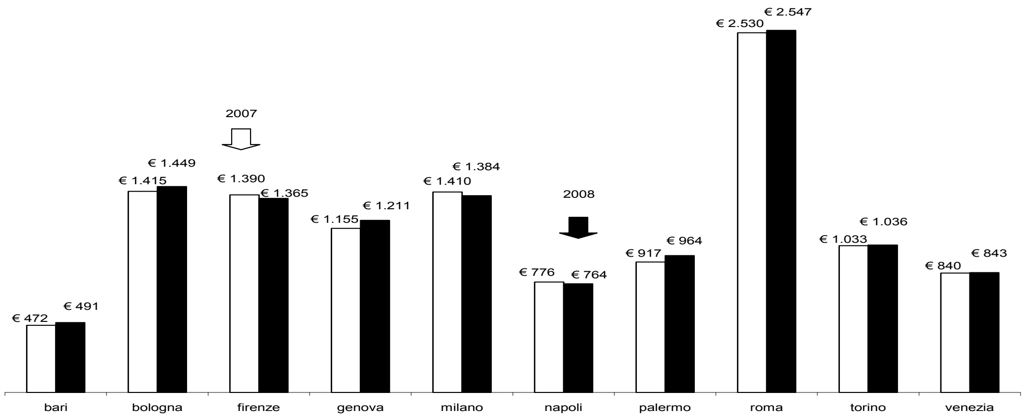
Graph 1. Total cost of congestion, million Euros, 2007 and 2008

Source: Vision & Value on Octo Telematics, ACI, MISE, Istat and ICE data

The congestion cost amounted to 27 billion euros per year for around 8.5 million people living in the ten most populated cities of Italy. This figure represents about 2% of the GDP, and is rather impressive, considering that the model did not take into account several parameters such as the cost of pollution other than CO2, the public services, or the depreciation of car, as mentioned before.

Rome seems to dominate the overall standings. It accounts itself to almost 40 % of the total cost, although the population represents less than 30% of the overall population the sample represents. With more than 10 billion euros per year, the Italian capital bears a charge which overtakes the cost incurred by the second, third and fourth Italian city (in term of population; respectively Milan, Naples and Turin) combined.

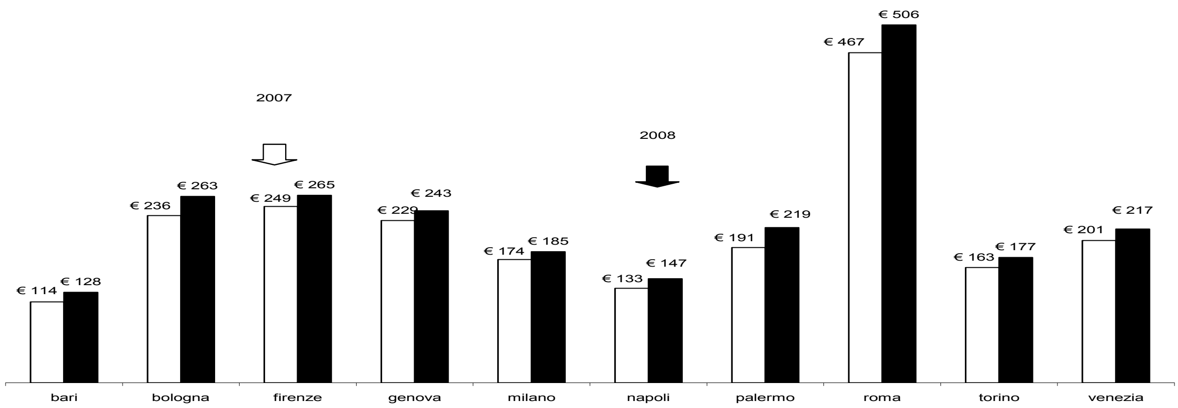
If we divide the total cost by the number of inhabitants for each city (see graph 2), the figures remain similar. The cost of traffic congestion in the capital amounts to approximately 2500 euros per person, including children, the elderly and all those who do not use the car in the calculation. This represents more than 7000 euros per household (considering an average of three people per nucleus), which is twice the cost recorded in Milan, although the income per habitant is almost twice higher than in the capital. Moreover, Rome records a slight increase in 2008, while the cost borne by Milan slightly declined. However, if we consider the inflation (an average rate of 2% per year in Europe), this drop illustrates quite an improvement of the situation. The inhabitants of Bari are the lucky ones, followed at a distance (which is relatively surprising) by Naples. In general the ranking shows more favorable values for the cities in the South (which is a little bit of a surprise) although this does not necessarily reflect the correlation between incomes and traffic, as we have seen when putting alongside Milan -- that seems to have better performance -- with Rome.



Graph 2. Cost per inhabitant, in Euro, 2007 and 2008

Source: Vision & Value on Octo Telematics, ACI, Ministero Sviluppo Economico (MISE), Istat, Intercontinental Exchange (ICE) data

Clearer figures arise from the data on fuel cost. In fact, if the above parameters are influenced by a number of hypotheses on the opportunity cost of an hour spent in the car, data on the cost of gasoline and diesel that motorists of the ten largest cities consume is less susceptible to interpretation (see graph 3).

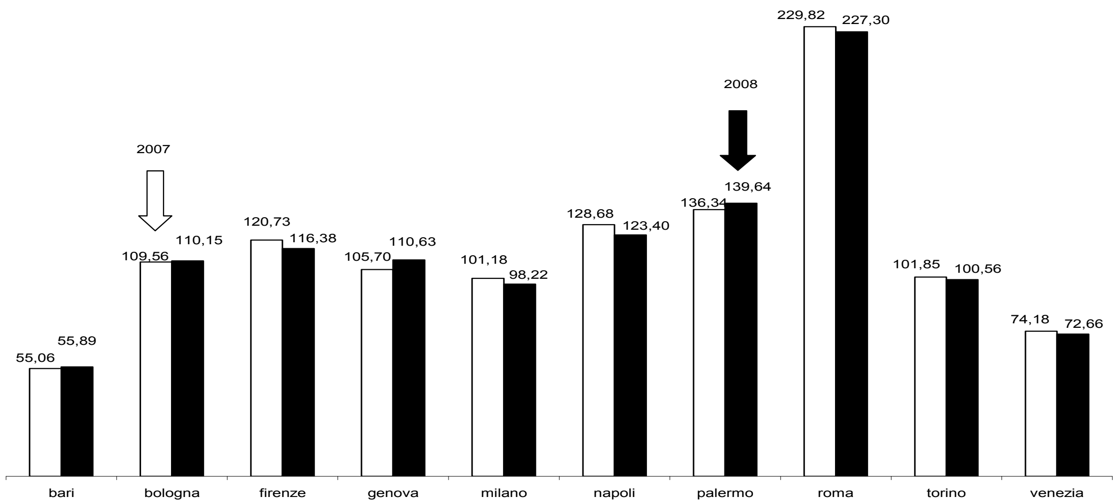


Graph 3. Fuel cost per inhabitant, in Euro, 2007 and 2008

Source: Vision & Value on Octo Telematics, ACI, MISE, and Istat data

Once again, the citizens of the capital pay the highest price - more than 500 euros, almost three times than the bill paid by a city-dweller from Milan. In fact, the data indicate that not only inhabitants of Rome travel more miles, but also that their car fleet is less efficient from an energy point of view.

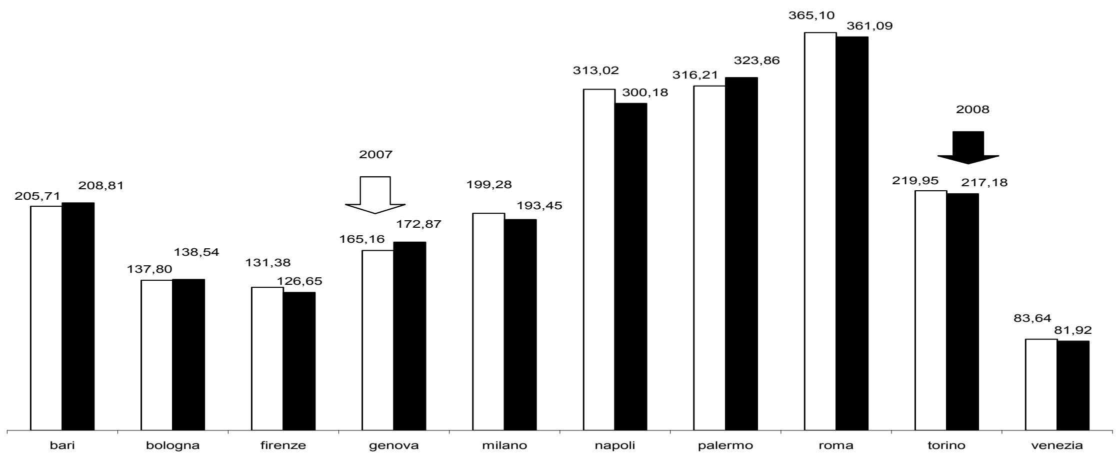
The graph 4 considers the overall time spent in car for all the inhabitants of the ten cities.



Graph 4. Time spent in car per inhabitant, in hour, 2007 and 2008

Source: Vision & Value on Octo Telematics

The overall time spent in a car per citizen recorded a slight improvement between 2007 and 2008 everywhere except in Genoa, while it was stable in Turin, Bologna and Bari. Again, this confirms the differences we pointed in the previous graphs. Rome records values that more than double those of Milan. The situation is better in Bari (and Venice, which is, however, a rather special case).



Graph 5. Time spent in motion per automobile and per year, in hour, 2007 and 2008

Source: Vision & Value on Octo Telematics' data

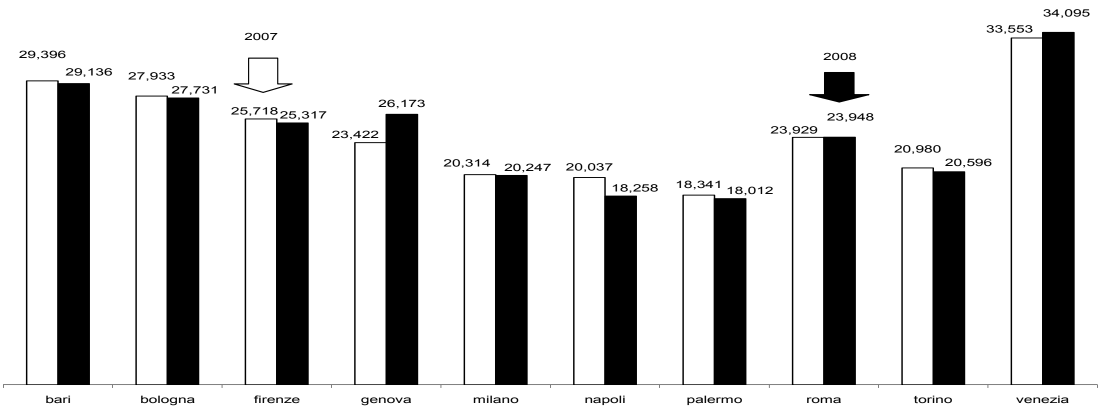
The graph 5 highlights the estimated average time a car is in motion over a year. Rome is, again, at the first place of the ranking, but the distance has greatly reduced: Palermo and Napoli are in a much better situation and, also, the difference compared to Milan is slighter. In fact, the data emphasize the problem and introduce an important parameter: the number of cars per inhabitant (0.67 in Rome compared to 0.58 in Milan, see table 1) that explains part of the disadvantage of the Italian Capital City.

Table 1. Number of automobile per inhabitant

Cities	2007
Bari	0.51
Bologna	0.58
Florence	0.65
Genoa	0.49
Milan	0.58
Naples	0.56
Palermo	0.56
Rome	0.67
Turin	0.61
Venice	0.51

Source: Vision & Value on ACI and Istat's data

The graph 6 introduces another essential parameter and presents a ranking that is almost reversed: the average speed in the morning peak time, calculated from Monday to Friday.

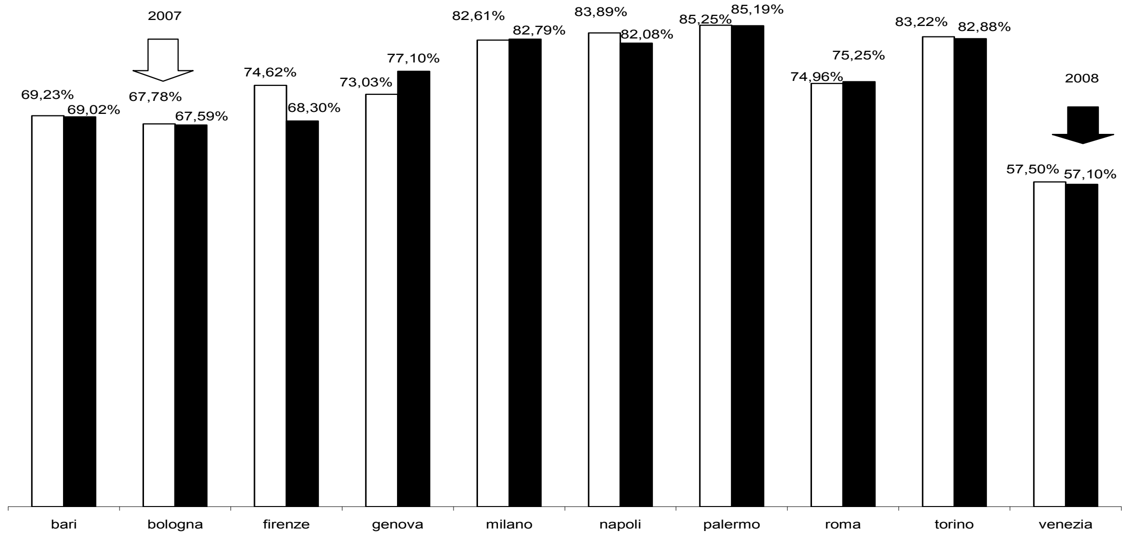


Graph 6. Average speed during morning peak (km/hour) from Monday to Friday, 2007 and 2008

Source: Vision & Value on Octo Telematics' data

Bologna, Florence and Bari record better levels while the situation is worst in Milan, Naples, Palermo and Turin. Genoa recorded the greatest improvements. Rome is in an intermediate position.

This outcome is confirmed by the following graph that indicates the average time spent in congestion (when running below 30 km / h) during the morning peak.



Graph 7. Percentage of time spent in congestion during in morning peak (from Monday to Friday) 2007 & 2008

Source: Vision & Value on Octo Telematics' data

The overall percentage of time spent in congestion during peak hour in the morning is very significant. Traffic is even practically at a standstill in Naples, Torino and Milan more than 80% of the time.

These figures enlighten the importance of another factor which enables to explain the big gap in terms of hours spent in car: the size of the road infrastructure and the distribution of the (commercial and business) centers. Rome encompasses twice more roads (in term of kilometers) than the city of Milan and the way main services and offices are distributed forces people to travel much more: a yearly average of more than 10 000 km are travelled by a citizen of Rome, whereas less than 5000 km in Milan (see table 2: Average distance run per driver and per year). This stresses that part of the solution of the traffic issue relies on the city planning itself, and in the distribution of the services when compared with the location where families and individuals live.

Table 2. Average distance run per driver and per year (Km)

Cities	2007	2008
Bari	5 871.73	5 998.52
Bologna	4 127.36	4 221.30
Florence	3 675.25	3 570.45
Genoa	4 709.98	4 595.18
Milan	4 661.91	4 547.06
Naples	3 804.10	4 860.17
Palermo	6 022.78	6 359.10
Rome	10 119.65	10 022.25
Turin	4 802.77	4 782.38
Venice	3 116.58	3 089.52

Source: Vision &Value on Octo Telematics and ACI's data

The table 3 introduces a new result: a different estimate of the time lost due to congestion (at any time of the day) in each city. It is a different notion from the total number of hours spent in the car travelling at a speed below 30 km. We assumed that the conditions of the traffic during the night could be used to illustrate a traffic-less situation (Note 5). The formula used for the assessment is the following:

$$(KM_{\text{time of the day } X} / Speed_{\text{night}}) - (KM_{\text{time of the day } X} / Speed_{\text{time of the day } X}) \quad (2)$$

The third column shows the difference in average speed compared to the night time. In the fourth column, the table highlights the number of lost hours due to the traffic for each city per time slot. The figures encompass data related to different days of the week and time of day (morning 7:00 to 10:00, median 10:00-16:00, afternoon from 16:00 to 21:00, and night from 21:00 to 7:00) from Monday to Friday. The last column represents the percentage of time spent in the car that is determined by the congestion.

Table 3. Average speed difference and lost time due to congestion per time slot

Cities	Time slots	Average speed difference (km/h)	Time spent in car (hour)	Time spent in congestion (%)
Bari	Morning	0.63	5387	2.18 %
	Median	0.32	4869	1.11 %
	Afternoon	0.37	5492	1.27 %
Bologna	Morning	7.03	69 607	20.10 %
	Median	4.98	72 740	14.24 %
	Afternoon	7.55	120 108	21.60 %
Florence	Morning	6.45	66 482	20.05 %
	Median	4.36	74 056	13.55 %
	Afternoon	6.58	117 393	20.44 %
Genoa	Morning	5.89	54 426	20.10 %
	Median	3.63	54 361	12.40 %
	Afternoon	5.20	83 739	17.75 %
Milan	Morning	6.87	297 687	25.28 %
	Median	4.18	286 434	15.37 %
	Afternoon	5.87	416 040	21.59 %
Naples	Morning	3.98	130 122	16.56 %
	Median	3.45	206 127	14.38 %
	Afternoon	4.50	271 141	18.72 %
Palermo	Morning	6.45	129 667	26.03 %
	Median	6.08	209 736	24.52 %
	Afternoon	6.54	222 946	26.38 %
Rome	Morning	8.44	743 174	26.07 %
	Median	4.91	678 081	15.18 %
	Afternoon	6.89	970 503	21.28 %
Turin	Morning	4.11	114 289	16.39 %
	Median	3.23	133 999	12.87 %
	Afternoon	4.64	223 671	18.51 %
Venice	Morning	7.46	32 938	18.18 %
	Median	4.69	35 775	11.44 %
	Afternoon	6.21	43 315	15.14 %

Source: Vision and Value on Octo Telematics and ACI's data

This table shows that, as we expect, the percentage of time spent in traffic is globally lower from 10:00 to 16:00. Venice, Turin and Naples recorded value below 20%, Rome, Milan and Palermo have value above 25%, while other cities have intermediate position. Traffic jam is more important in Milan and Rome during the morning and the afternoon, when people return from work. Turin, Naples, Bologna and Florence recorded a higher traffic during the afternoon (Note 6).

The data can highlight other figures when focused on specific period. For instance, we tried to assess how traffic is worsened during the week before Christmas in three cities. The results are summarized in the table 4.

Table 4. Lost time due to increasing congestion during the week before Christmas (percentage, number of hours, and Euros)

City	Time slot	Speed difference (km/h)	Time spent in car (hours)	Time spent in congestion (%)	Cost of time spent in congestion (million euro)
Milan	Median	3.28	342 277	14.10 %	4 153 612
	Afternoon	3.51	411 250	16.84 %	4 990 608
Naples	Median	1.49	113 669	7.65 %	661 965
	Afternoon	3.02	287 381	16.08 %	1 423 190
Rome	Median	2.00	294 234	7.38 %	3 505 773
	Afternoon	3.44	732 517	13.57 %	6 513 990

Source: Vision & Value on Octo Telemactics and ACI, Istat's data.

The cost of congestion due to Christmas shopping amounts then to about 20 million euros, in only one week and three cities (and without taking into account the cost of fuel and CO2 emission).

So far, the data have confirmed the scale of the problem, especially if we compare the figures and values to the budget of an administration or that of a family. However, the real outcome of this study is the cross-city comparison and the evolution over the years that show that the problem is not unavoidable. Therefore, it can help policymakers identify areas of action in order to manage traffic.

4. Discussion

The experimentation enables to figure the determinants of congestion for each city. Furthermore, the results show that congestion is not an ineluctable consequence of urbanization, and that it can be reduced through different levers. Moreover, by estimating the social cost of congestion, this methodology can also help draw a policy based on the "pay as you pollute" principle and to raise people' awareness to shift mobility patterns. This section aims at introducing the concept of "Flexible congestion right".

The deployment of Intelligent Transport Systems in which information and communication technologies are applied represents an opportunity in the field of mobility to set up a policy based on the "polluter/payer" principle (Harrison et al. 1986). Tailoring the charge to individual users would engage people directly, making them aware of the issues, and forcing them to make informed choices about car usage (Drewes et al. 1997). The solution therefore would be not only equitable (car drivers – i.e. individual or owning companies - would pay for the amount of pollution and disruption inflicted to their fellow citizens) but also effective from the point of view of congestion and traffic management, by shifting accountability and responsibility towards vehicle users, bringing public choice and active public participation to the forefront of city sustainability and climate management.

However the fulcrum of proposals like the flexible congestion rights is to make what is seen as an unpopular proposal to be accepted by public opinion (Arnott, 2001). Boris Sandford (1988) pointed out that "Hong Kong's experiment with electronic road pricing showed that the technology was completely feasible. However, the government was unable to implement the scheme due to strong opposition from a public that perceived it as an invasion of privacy and a tax increase". In fact, the difficulty to win consensus may be largely explained by prejudices that the flexibility of the scheme may overcome, and not just through the traditional strategy of effective communication. The debate on congestion charge is a very effective example of how fundamental the involvement of citizens in the development of these policies is (Hau, 1990), and of how important are forms of participation that go beyond the traditional participatory forms, such as the elections of political representatives.

If the idea of congestion charge has been controversial - as illustrated by the failure of its implementation in the cities of Hong Kong and New York -, few would deny the partial and yet concrete benefits that it produced (reduction of traffic and time lost, wider mobility, lower fuel consumption and greenhouse gases emission, an improved quality of life, and even attractiveness and economic growth). The next frontier would be, however, of a different kind:

- Not only a charge (for whom pollutes the most) but also rewards (or rights to be spent for getting further services like free entries at museums, for whom pollutes the least) to orienting individual behaviours towards desirable patterns (for instance individuals that leave cars for embracing biking) (Note 7); and
- Incentives and disincentives much more flexibly linked – thanks to GPS technologies - to the quantity of externalities that a certain individual produces (thus linked to actual usage of roads, size of the car, as for the "flexible congestion" right proposal) (Note 8);
- Allocation of the entire revenues that the scheme may generate (once the cost of operating the system and the above incentives are deducted) to provide more, higher quality or cheaper public transportation so that public finance are kept neutral and the position of citizens as a whole stays the same.

Two experimental transportation projects developed by Balaji Prabhakar (Note 9), engineering professor at Stanford, were tested in 2012 in Singapore and in the Silicon Valley that have proven the benefits of a rewards-based solution to shift driving patterns, through gaming. In Singapore, more than 17,500 citizens were enrolled in this six-month pilot program that ended in July 2012 (just over 1,825 in the Stanford project). The principle was the following: participants were encouraged to avoid rush-hour traffic to earn credits they could trade for chances to win a prize in cash. One kilometer travelled by train corresponded to one credit; any kilometer traveled by rail during the hour before or after the morning peak (7:30 to 8:30 a.m.) allowed to earn three credits. The outcome of this experimentation shows that "using carrots" – in that case game - "rather than sticks" - congestion charge – help adopt desirable patterns since more than 10% of Singapore commuters have shifted off-peak.

The proposal is therefore to overcome the current rigid models of congestion charge in application in Milan, London and Singapore with a pricing policy that is rather flexible, more rational and more efficient. Specifically the need is to make the price a function of four variables (as shown in the graph below):

1) The characteristics of the vehicle: the price scheme should reflect the impact of the car on the environment and traffic. The CO2 emission per kilometre of each vehicle should be taken into account, so that low emission car ownership could be encouraged and rewarded. Another very important determinant of the flexible congestion charge could also be the size of the vehicle, since large cars shrink the space available for circulation (Newberly, 1988a). One possible strategy could be to exempt vehicles below a certain size or, even, to reward those who agree to use alternative individual mode of transport (for example, bicycles, with or without motor). The result is the creation of a direct incentive to buy small vehicles, and indirectly, to produce smaller cars adapted to circulate in the city thanks to an increasing demand for smaller vehicles.

2) Distance in space from peak hour: some areas are more exposed to congestion than other, therefore, the characteristic of the journey should be considered so that road users would be dissuaded from driving in certain zones. To be more specific, one possible strategy could consist in taking into account the whole urban area (and not only the city centre) and to differentiate the price per zone, in order to decrease the demand for the use of most congested roads. Such a differentiation in the price would inform drivers on route capacities and help them make better choices and therefore would help reduce congestion and its cost (Arnott, de Palma & Lindsey, 1991).

3) Distance in time from peak hour: in order to encourage the use of public transportation and good behaviours among car users the congestion charge should depend on the time and date of the journey. The differentiation between night and peak hour, working day and holiday/week-end, season of the year should be considered in order to orientate the demand for the use of the road towards less congestion.

4) Duration of the journey: the congestion charge should reflect the time vehicles are in motion. One of the backwards of the current models of congestion currently in force is that they apply a daily fee. The flexible congestion right would instead differentiate parked vehicles from vehicles in motion. Regarding the journey, this pricing scheme should reflect the distance run, the average speed, and the duration of each journey to keep with the polluter-pay principle.

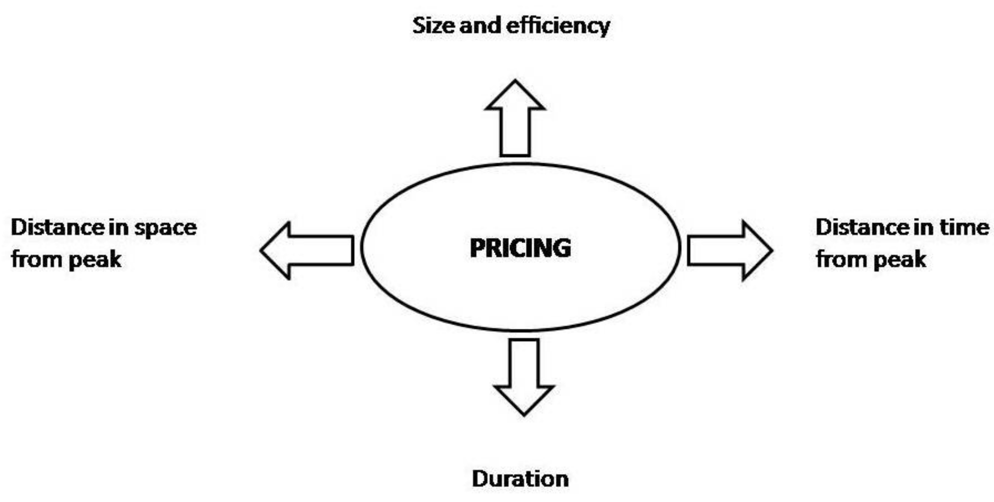


Figure 2. The Flexible congestion pricing scheme

Source: Vision & Value

Such a flexible pricing would enable to lower traffic, reduce the carbon impact of personal car transportation on congested roadway, and increase transportation system efficiency while avoiding the need to add capacity. Furthermore, a polluter-pay based policy would increase public acceptance of road charging, and, by providing smart incentives linked with reward/loyalty programs for using more efficient modes of transportation, would encourage a modal shift from personal to public transportation.

5. Conclusion

Road pricing appears to be the best method of dealing with congestion: economists have for long stressed that a shift to road pricing would induce a fall in the demand for the use of the most congested roads. Furthermore, a charge based on the "pay as you pollute" principle seems even more accurate to solve the issue of traffic congestion at the city level. By reflecting the real impact of car use on the environment, it would engage citizen directly. Moreover, it would have far-reaching impact on the efficiency of public transportation, for the finance of urban infrastructure, for the quality of life, and the attractiveness of the cities.

However, such a charge implies to assess accurately the foot print of cars and individuals. The methodology we introduced in this paper allows to estimate the social cost of congestion in urban area. The experimentation enables an estimate of the social cost of externalities of road use in currency: the cost of time, the cost of CO2 emission, and the energy bill. By doing so, the figures allow to identify the main determinants of congestion for each city, depending on the characteristics of the fleet, of the infrastructure, of the driving patterns per time slots. The results are showing impressive figures: more than 27 billion Euros per year, only in the ten largest Italian Cities which represent 8.5 million inhabitants. However, the study also lead to the conclusion that traffic congestion is not an unavoidable consequence of urbanisation and can be dealt with through an intelligent road pricing scheme such as the flexible congestion rights.

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Notes

Note 1. We refer to congestion as the situation where cars travel at a speed below 30 km/h. We will not therefore include in our calculation the costs associated to travelling in conditions that we assume to be "normal".

Note 2. "The tragedy of commons" refers to the concept introduced by the ecologist Garrett Hardin in the so-called article published in the journal *Science* in 1968. The phenomenon is therein explained as followed: "*the depletion of a shared resource, such as road, by individuals, acting independently and rationally according to each one's self-interest, despite their understanding that depleting the common resource is contrary to their long-term best interests*"

Note 3. See the presentation of Pierfrancesco Maran, Councilor responsible for Mobility, City of Milan [powerpoint slides]: http://www.visionwebsite.eu/UserFiles/Maran.pdf

Note 4. According to the Texas Transport Institute, congestion amounted to 68 billion USD in 75 metropolitan areas in the US in 2000, or 505 USD per person.

Note 5. The hypothesis that the speed of the night corresponds to the speed in the absence of congestion is an approximation: In fact, average speed may differ even during the night due to differences in urban layout, coordination of traffic lights ect.

Note 6. Interestingly, we note that the average speed run in Bari is similar during the day and night time. This is probably due to an inappropriate choice in time slots.

Note 7. See also the theory of Nudge (Sunstein, Cass, Thaler, & Richard, 2008). *Nudge: Improving Decisions about Health, Wealth, and Happiness*. Yale University Press.

Note 8. Full description of the proposal is available at this link: http://www.visionandvalue.com/insights/Traffic_less_Cities_FlexCongCharging.pdf

Note 9. See also "Cities Bet They Can Curb Traffic with Games of Chance" Josie Garthwaite, for National Geographic News, Published June 15, 2012 retrieved from http://news.nationalgeographic.com/news/energy/2012/12/120615-commuters-games-to-reduce-traffic/