Effectiveness of mobility limitation policies against long term approaches in reduction of emitted pollutants

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The case of Milan area

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Introduction and aims

This paper aims to analyse in numerical terms the effect of different policies, real and potential, in reducing total polluting emissions. Policies are evaluated in terms of total emissions avoided, but also in terms of effectiveness. This is done both considering the number of vehicles and the traffic excluded from consumption versus the emissions avoided. The study area is one of the most "car intensive" in Europe: the Milan metropolitan area.

A policy should be evaluated in terms of effectiveness, efficiency and equity. To be considered, it should reach at least the **effectiveness**, in this case represented by reduction in emissions. Every considered policy will have an estimation of avoided emissions.
Other issues are more relevant. Given that every limitation is, by definition, inefficient, nothing will be said about the surplus generation or losses caused by different policies, since this approach is out of this paper's aims and includes issues about area economy like the demand curve. In any case a sort of simplified "**efficiency**" for policies will be defined in next chapter and concerns the ratio between consumption or access to market admitted and emissions eliminated. For example, if a policy guarantees a reduction of 10% in emissions, but forces 30% of vehicles to remain at home, that policy is "inefficient", probably also in economical traditional terms.
Last issue, **equity**, will be considered only in very general terms, reflecting about who are the owners of more polluting vehicles.

This paper is only a first step to understand the problem, since a deeper approach should use a complex simulation model (Bedogni & Moroni, 2004) and consider explicitly the role of public transport, that in this work is simplified assuming, depending on cases, to have a residual capacity or to need a simple average increase in capacity.

Methodology

The question about the effects and efficiency of pollution policies requires a numerical approach. The way chosen is a disaggregate approach with no spatial dimension. A spatial based model is surely more precise and interesting, capable to catch the differences between city areas and congestion effects, but is out of this paper's aims. Some more information about such a project, with also the limits derived from Copert methodology, can be found in (Bedogni & Moroni, 2004).
On the other side, an aggregate approach, with no precise distinction on car technologies and unacceptable simplifications concerning avoided emissions, is simpler but inadequate to answer the question.

A disaggregate and non-GIS based model is a compromise between manageability and complexity, capable to evaluate different policies and answer the questions about

1. total emissions avoided by every action
2. effectiveness of the policy vs. the limitation imposed to traffic (vehicles.km).
3. effectiveness of the policy vs. the limitation imposed to vehicle use

Point 1 proposes a precise account of total emissions, using the fleet and the average car mileage together with Copert III coefficients. These coefficients, widely explored in literature and representing a standard for EU,

describe the unitary average emission for every pollutant and for every kind of road vehicle, basing on real driving cycles. The used ones are elaborated and described in (Beria, 2005).
The emission coefficient for *i*-pollutant is function of

$$ec_i = f(\text{vehicle type, engine, vehicle age, driving cycle, average flow speed})$$

Pollutants accounted are CO, PM, NOx, CH_4, VOC, FUEL, SO_2, CO_2.
Once coefficients are defined, the total amount, in ton/year, of pollution emitted is determined as follows:

$$TE_i = \Sigma_j (cv_j \cdot adm_j \cdot ec_i)$$

TE_i: total emissions for *i*-pollutant
cv_j: circulating vehicles for *j*-vehicle category
adm_j: average day mileage for *j*-vehicle category
ec_i: emission coefficient for *i*-pollutant

cv_j and adm_j are calculated for the base case and for simulated policies. These are determined as a percentage variation of base case. See chapter "policies considered" for an example.

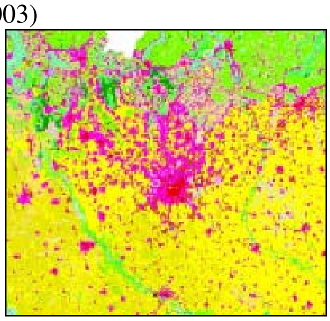
Point 2 and 3 allow a deeper analysis because represent the trade-off between the emissions avoided and the vehicles excluded from consumption. Since is clear and evident that the more km are forbidden, the less is the pollution produced, what cares is to underline which policies have best results in relative terms. This can be seen as a simplified definition of **efficiency**: the more a policy is "efficient", the less is the "cost", in terms of vehicles or traffic forbidden, spent to obtain the result. In other words "efficient" policies have a better use of scarce resource, in this case the traffic accepted.
This concept is applied in two cases: the **efficiency in terms of km admitted** and the **efficiency in terms of vehicles admitted**. Both are calculated as difference between the delta for total emission and the delta of vehicles (or vkm) admitted. If the value is positive, the emissions saved are more than traffic not produced. This is a positive fact: vehicles less polluting can drive more than worst vehicles or actions taken can improve the environmental performance of traffic, i.e. decreasing the congestion and related emissions.

It's evident that the main difficulty is to obtain data with sufficient disaggregation and entrustability. In any case one must note that the total number of vehicles is quite irrelevant, since the following considerations about policies depends on classes relative percentages, an official and sure information, and annual mileage.

Notes about background and policies actuated in Milan area

The area analysed is Milan metropolitan area (Italy). It's characterised by a wide mid-density urbanisation zone, with some important urban sprawl problems and large use of private cars, surrounding the dense urban area with a massive attraction power and good mass transit services.

Fig. 1: Milan area sprawl (Betty et al., 2003)



The car use is more relevant and damage causing for the mobility in the ring area, starting from XXth century urbanisation to the farthest places of radial urban area. The historical centre, even if quite crowded, is proportionally less affected, even if its attraction power is the highest of the region, thanks to subway and transit systems and effective park pricing.

Policies historically applied in Milan area to contain the emissions, are both in the limitation approach and unitary emissions reduction, not only for traffic sector. Main actors, apart central state, are Regione Lombardia and Milan municipality.
First one guidelines are described in the *Libro azzurro* (RL, 2003) and include almost all tools like public and private fleet renewal, long term infrastructural investments, energy efficiency increase, new forests, monitoring actions. In front of these policies, Regione Lombardia has historically followed also a restrictive approach, imposing limitations in circulation during emergency periods.

Municipality actions are similar in wideness of approach: service and transit fleet renewal, incentives to methane and LPG, hydrogen experimentation, park pricing, public transport infrastructures. Guidelines can be found in (AMA, 2001).

Fundamental is to underline that the main and most visible actions taken during last years are the blocks and limitations. These are evidently **emergency actions**, but the fact is that they became periodic, seeming a structural policy.
TOTAL BLOCK. Usually during winter days, when concentration levels increase, total blocks of private circulation are imposed with about one week advance. Usually these blocks are on Sunday. One can underline that during weekends the use of private cars is more “compulsory” than during working days: the car in fact is often used to reach leisure places, usually not or badly linked by public transport with residential areas. This means that the cost of reaching leisure places tends to infinite, with some relevant equity problems.
PLATE BASED BLOCK. During pair days (Tuesday, Thursday and Saturday or pair dates) only cars with plate terminating with a pair number can circulate, and the opposite. Buses and usually also two wheeled vehicles are exempted. A decrease in traffic lower than 50% is observed. This is why second family cars, usually not used, get used and rush hours modify to overcome the block period.
DIESEL BLOCKS. Non actuated in Milan region, these actions should focus on prevention of PM and SO_2 emissions only.
NON-CATHALYSED BLOCK. Generally adopted policy during all winter time, avoid older and more polluting vehicles to drive. This is very effective to promote “voluntary” car substitution.

Fleet definition

No data with required disaggregation are available for Milan city or Milan circulating fleet, that is considerably higher than resident fleet. In demographic terms Milan municipality has 1.307.602 inhabitants with 863.792 cars, 99.735 duty vehicles, 3003 buses (AMA, 2002). The province counts about 3.7 million inhabitants (1996) owing a fleet of 2.279.010 cars, 189.233 duty vehicles, 273.504 motorcycles (ACI, 2003). Moreover one can identify another area, called “Area Urbana”, composed by Milan and by the 32 nearest municipalities. This hinterland area, quite dense, counted 2.460.000 inhabitants during 1995 (AMA, 2001).

To derive the **circulating fleet** in Milan metropolitan area, these hypotheses are assumed:

a. the fleet composition (COPERT classes) is the same of Milan Province (ACI, 2003);
b. the number of vehicles considered is the sum of Milan owned vehicles (AMA, 2002) and 434.000 province owned vehicles (calculated). Motorcycles and buses accounted are Milan owned only.
c. the average mileage driven for every class of vehicles is the one reported in (Saija, 2000), relative to Italy. Car mileage is updated as in (Beria, 2005).

The fleet derived is not presented here, but used in calculations. This number found and used is obviously an approximate estimation, but to obtain a better information one must use an extremely complex regional simulation model, that is over this paper’s aims. Note that the number of vehicles is quite irrelevant, since the following considerations about policies depends on classes relative percentages and annual mileage.

Policies considered

The analysed policies are described below, giving also the assumptions used to run the model. Following table summarises the effect of policies on the three aspects to be provided as input to the model.

Table I: policies considered and effects simulated

policy	*emission reduction due to…*		
	lower mileage	*lower congestion / higher speed*	*lower unitary emissions*
1: total area block	V	V	x
2: plate based limit.	V	V	x
3: diesel block	V	V	x
4: non-Euro block	V	V	x
5: duty vehicles block	V	x	x
6: central area block	V	x	x
7: general park pricing	V	V	x
8: fleet renewal	x	x	V

First column refers simply to mileage: some policies causes a limitation in car use and less vkms directly signify less emissions.
The second aspect concerns the speed: in case of congestion (and the considered area is widely congested), a decrease in circulating vehicles increase significantly the speed. We assume (and emission coefficients are calculated consequently) that in normal case, at 8.30am, the average car and light duty vehicles speed is 25 km/h (AMA, 2001). If considerably less vehicles (at least 25% less) can circulate, we assume that new speed is 30 km/h. Both coefficients sets can be found in (Beria, 2005).
Third cause of pollution decrease can be the use of cleaner cars. This can be obtained by physiological or forced renewal towards alternative cars.

Policies are described as a percentage of vehicles admitted and traffic admitted compared to base case.

Table II: example of policy 1 hypotheses

category	*vehicles admitted*	*vkm driven per vehicle*
buses	100%	+20% to consider an obvious increase in supply
any other class	5% to consider that somebody can drive or drives even if not allowed	as usual (100%)

- **case 1 - total area block**: to every vehicle, except buses, is forbidden to circulate. These radical actions are usually taken during weekends, when traffic is lower and different, with no business trips. The model is run for an average day, like if total blocks were during working days, as sometimes happened. Average speed during block increase 30 km/h.
- **case 2 – plate based limitations**: Only pair or non pair cars can circulate. Buses and usually also two wheeled vehicles are exempted. The obvious effect should be a 50% reduction in vkm (45% to assume a 5% not allowed vehicles running), but is observed that some unused cars, usually the older ones, are used in substitution, typically the second family car. The effect on the emissions is that older cars runs statistically more km than usual (assumed: 150%). Assumed average speed during block days is 30 km/h.
- **case 3 – total diesel block**: total block limited to diesel vehicles would be effective to reduce PM. On the other side, other pollutants remain almost the same (CO, CH_4, VOC). Speed during block is 30 km/h.
- **case 4a – non-euro car block**: a more clever policy would be to avoid the use of old and more polluting cars instead of the whole fleet with no distinction. The simulated policy consider the limit of Euro normative. Speed during block is 30 km/h.
  Note that cars from Euro II on, are a bit less efficient in terms of fuel economy and CO_2 (mainly due to increase in ancillary systems, like air conditioning). This effect is accounted in the model.
- **case 4b – non-euro vehicles block**: following similar prescriptions of case 4a, in this case every non-euro vehicle is forbidden to travel. This policy is more radical and hits mainly economic activities like commerce and goods distribution. Speed during block is 30 km/h.
- **case 5 – duty vehicles block**: since main polluters are duty vehicles and especially the heaviest ones, this policy simulates a total duty vehicles block. Total vehicles admitted are just a little less (-9%), so the speed is assumed to remain the same, 25 km/h.
- **case 6 – central area block**: this policy should need a simulation model, to estimate the effect of the block of part of the municipality area only. Experiences of such a block, not applied in Milan, suggest a –30% in total traffic, with no limitations in vehicles categories. Average speed constant to 25 km/h since probably part of the traffic remains at the borders of precluded area.[1]
- **case 7 – generally adopted park pricing**: central area park pricing in Milan has been existing for years and showed a reduction in vehicles circulating. For simplicity's sake one can assume that extending the park pricing to the whole city would reduce of 15% the total of vkm produced and increase the average speed of all vehicles.
- **case 8a and b – finalised car fleet substitution**: the main cause of pollution in cities is the existence of older vehicles, more polluting. An effective policy should tend to remove these vehicles promoting newer and cleaner ones. A large number of different policies can be proposed: renewal of fleets with Euro IV models or with methane cars or with hybrids. Only two will be simulated in this case, since the effect would be quite similar compared to first 7 policies: substitution with Euro IV (8a) or natural gas (8b) of 20% of Euro I cars or older.
- **other policies:** other policies could be analysed with the same categories, but result less interesting in Milan area, since many of them are already existing (electrification of public transport, bus substitution, mobility management).

[1] this case is obviously imprecise: it's evident that it's false that 100% vehicles are admitted. All vehicles can run, but not in the place they want to go. As told before, a simulation model would be useful.

Results

The first level of analysis considers the absolute value of prevented emissions: for every approach, how much pollution isn't emitted?

On a deeper level one may question about the trade-off between emissions saved and traffic or vehicles excluded from consumption. Obviously, if a policy saves a large amount of emissions blocking many vehicles, is less "efficient" than another one preventing the same emissions but with less limitations, as explained in "methodology" chapter.

Given this, the decision maker approach should be the following:

a. how many emissions do I want to save?

b. which policy is more efficient and fair to reach this level

Saved emissions

Following table summarises the calculated emissions and consumption for the different policies considered. Values are expressed in tons per day.

Table III: absolute values of pollutants not emitted

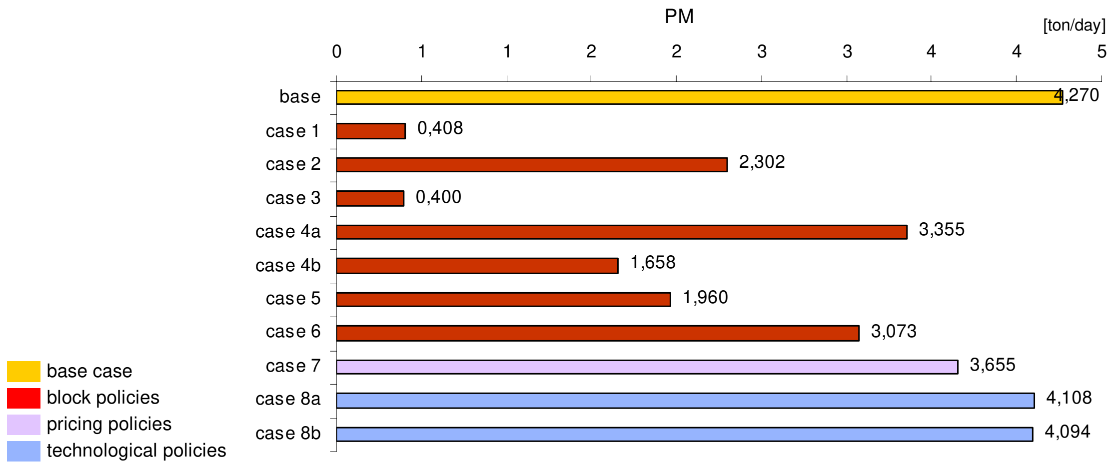
	vkm/day total	vehicles admitted	CO	PM	NOx	CH4	VOC	FUEL	SO2	CO2
						[ton/day]				
base	52.580.630	1.389.829	453,5	4,270	74,5	2,313	50,1	5.780	0,246	18.291
case 1	3.040.522	72.579	20,8	0,408	9,6	0,152	3,0	425	0,027	1.345
case 2	28.849.781	696.540	238,4	2,302	44,5	1,287	28,6	2.989	0,130	9.457
case 3	33.343.266	1.068.994	374,3	0,400	35,4	1,798	37,9	3.316	0,026	10.502
case 4a	43.728.130	1.025.707	228,5	3,355	55,3	1,215	23,5	4.589	0,215	14.526
case 4b	40.428.014	970.820	206,2	1,658	36,6	1,003	18,5	4.037	0,164	12.781
case 5	45.385.521	1.260.926	420,3	1,960	44,4	2,029	43,1	4.620	0,141	14.625
case 6	36.967.889	1.389.829	317,9	3,073	54,5	1,638	35,3	4.107	0,178	12.998
case 7	45.066.665	1.389.829	333,0	3,655	65,9	1,798	39,1	4.677	0,208	14.800
case 8a	52.580.630	1.389.829	409,3	4,108	70,3	2,052	44,1	5.746	0,245	18.186
case 8b	52.580.630	1.389.829	398,9	4,094	70,2	2,018	43,8	5.623	0,240	17.714

As one can see, policies from 8 to 1 are more and more restrictive in terms of traffic admitted and partially also in terms of vehicles admitted. In other words in policy 1 only 72.000 vehicles of 1.3 millions run, while last four policies doesn't limit the use of any vehicle.

Obviously first policies give lower total emissions, simply because less are the vehicles running.

Following chart represent the results for PM.

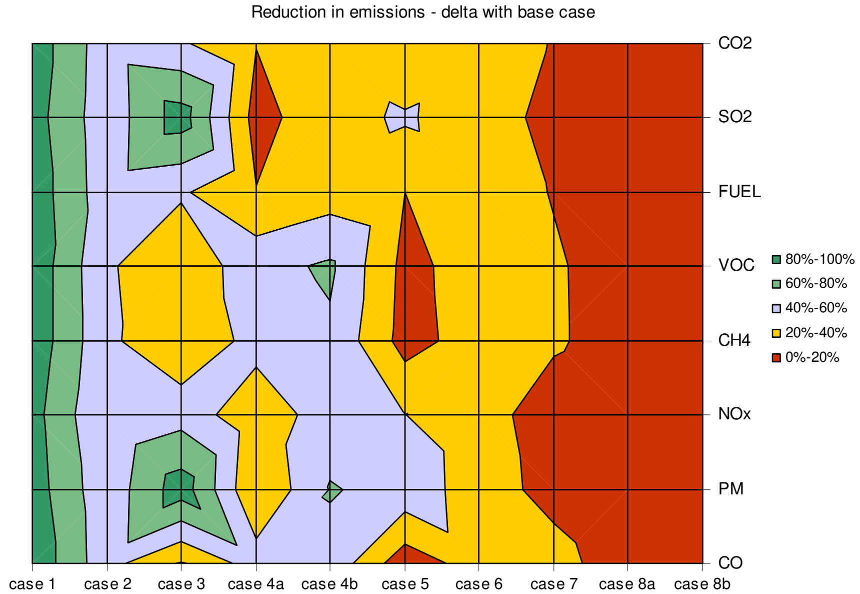
Fig. 2: PM reduction



Policy 3, total diesel block, is extremely effective to reduce PM emissions, but also policies 4b (non-euro total block) and 5 (duty vehicles block) give good results, reducing about one half. The result of policy 4a, non-euro car block, shows clearly that the main responsible in relative terms of PM emissions is duty traffic.

To have a complete overview of all results, next surface chart shows all pollutants wit colours depending on percentage of absolute reduction.

Fig. 3: policies absolute effect (delta)



Excluding extreme policies (1,2,7,8), policy 3 (total diesel block) is very effective against many pollutants, with lower results for VOC and CH4 only. On the other side policy 5 (duty vehicles block) performs good results for SO_2 only.

Efficiency in terms of km admitted

In terms of reductions relative to how many traffic is allowed to circulate, policies are described in following chart.

Fig. 4: policies effect relative to km admitted

	CO	PM	NOx	CH4	VOC	FUEL	SO2	CO2
case 1	1%	-4%	-7%	-1%	0%	-2%	-5%	-2%
case 2	2%	1%	-5%	-1%	-2%	3%	2%	3%
case 3	-19%	54%	16%	-14%	-12%	6%	53%	6%
case 4a	33%	5%	9%	31%	36%	4%	-4%	4%
case 4b	31%	38%	28%	34%	40%	7%	10%	7%
case 5	-6%	40%	27%	-1%	0%	6%	29%	6%
case 6	0%	-2%	-3%	-1%	0%	-1%	-2%	-1%
case 7	12%	0%	-3%	8%	8%	5%	1%	5%
case 8a	10%	4%	6%	11%	12%	1%	0%	1%
case 8b	12%	4%	6%	13%	13%	3%	2%	3%

completely unefficient (<-20%)
unefficient (-20% / -2%)
indifferent (-2% / 2%)
efficient (2% / 20%)
very efficient (>20%)

Total and partial blocks (policies 1 and 2), even if very effective in absolute terms, shows a relative performance varying from indifferent to lightly inefficient. This is due to the generality of the action: all vehicles, independently from their environmental behaviour, are blocked.
Policies 3, 4 and 5 are based on limitations finalised and punctual to some vehicle categories, hopefully the more polluting. The effect is various: diesel block is very efficient for PM and SO_2 reduction eliminating only emitters, but negative for CO, CH_4 or VOC. Policy 4b and partially also 4a are always positive, thanks to the fact that they block only the most polluting categories.

Policies 6 and 7 actuate a "geographical" block, limiting emissions only in more affected and congested areas. The effect in terms of vkm is indifferent for #6, but more interesting for #7, lowering emissions even if with a light effect on traffic forbidden.
More interesting are policies 8, promoting car renewal. Effects are always positive or indifferent, and this with no effect on traffic (100% allowed). Moreover the effect in absolute terms is lighter, but permanent.

Efficiency in terms of vehicles admitted

Another way to read the results is to compare the relative performance to the number of vehicles that cannot run, because explicitly excluded by the policy. This aspect is the more limiting, since a part of customers cannot drive and use his vehicle at all. This is even more inefficient in terms of welfare loss than vkm limitation.

Fig. 5: policies effect relative to vehicles admitted

	CO	PM	NOx	CH4	VOC	FUEL	SO2	CO2
case 1	1%	-4%	-8%	-1%	-1%	-2%	-6%	-2%
case 2	-2%	-4%	-10%	-6%	-7%	-2%	-3%	-2%
case 3	-6%	68%	29%	-1%	1%	20%	66%	20%
case 4a	23%	-5%	0%	21%	27%	-6%	-13%	-6%
case 4b	24%	31%	21%	26%	33%	0%	3%	0%
case 5	-2%	45%	31%	3%	5%	11%	33%	11%
case 6	30%	28%	27%	29%	29%	29%	28%	29%
case 7	27%	14%	11%	22%	22%	19%	15%	19%
case 8a	10%	4%	6%	11%	12%	1%	0%	1%
case 8b	12%	4%	6%	13%	13%	3%	2%	3%

- completely unefficient (<-20%)
- unefficient (-20% / -2%)
- indifferent (-2% / 2%)
- efficient (2% / 20%)
- very efficient (>20%)

Analysis is quite similar to last one, but with more extreme effects. Policies 1 and 2 are clearly negative: they obtain a great absolute decrease, but the price is paid indifferently by every driver, with evident welfare loss.
Case 3, 4 and 5 are, once more, contradictory depending on which pollutant is considered. In this case is evident that non-euro car block (4a) is significantly worst than non-euro general block (4b).
Differently than before, policy 6 is extremely efficient regarding vehicles admitted: no limitations in who can drive are imposed, so the result is always very positive. Similar policy 7 result.
Once again policies 8 are a bit more "modest" in absolute and relative terms, but always positive and permanent.

Conclusions

Carried analysis allows to derive some relevant conclusions, even if the study should made more precise some aspects (see next chapter for further extensions).
General limitation policies, seen with great unfavour by citizens and economical actors, are very effective in absolute terms only, since for the day they are taken, prevent a great amount of pollution. The unovercoming limit is that they can be used for emergency and short periods only[2] and that the "cost" inflicted to economy and mobility freedom is enormous.
Lighter polices finalised to eliminate more polluting vehicles only, are the most effective in short term. Policies like non-euro blocks, especially if including duty vehicles too, are extremely effective: 4b emissions are reduced from 30% to 63% (depending on pollutant), but blocking only 30% of vehicles and 23% of total traffic. These policies forces also the substitution of old vehicles, even if with some distributive problems (probably older vehicles are owned by poorer classes).
Long term actions should in any case be taken to solve the problem at the roots, mainly promoting or forcing the use of less polluting vehicles or reducing the car use, like in policies 8 and 6 or 7. These actions are the only ones capable to became structural, giving a permanent benefit.

[2] the effect in terms of pollution concentration and health effects is out of this paper's aims. One can say that spot decrease in pollution emission doesn't give any useful effect on pollution concentration.

Some words must be spent about equity issues. As told before, effectiveness is not the only target of a pollution control policy. Since both pollution and limitations in circulation represent a cost, internal or external to the market, efficiency should be reached. Some policies, generating or preventing costs, present some relevant unfairness since costs are not paid by the same classes that generates it. Some aspects of this should be explored wider:

a. Generalised blocks limit the circulation of every vehicle, independently from the damage caused, so little polluters pay the same cost of inactivity paid by great polluters.
b. Blocks done during weekend days hit all these trips done with the car simply because the car is the only way to reach leisure places. The utility of car use during weekends for a person living and working in Milan city is higher than during working days, when mass transit offers an alternative.
c. Blocking older cars is effective and efficient, but statistically affects lower social groups (students, poor classes, migrants, …), simply because they can't afford a new car.

Possible extensions

Many extensions can be proposed to reach better and more sure results for this study.

a. implement a more rational and articulated policy assessment procedure;
b. treat the problem in terms of external costs, voluntarily not touched in this work;
c. create a spatial model to answer at the same question.

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