A System Dynamics Model of Mobility Vouchers for Implementing Urban Road Pricing

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1 ABSTRACT

Urban road pricing policies are increasingly seen as a promising tool for promoting a more sustainable urban mobility. One of the main objections raised against pricing is that less affluent people is discriminated. The assignment of an initial endowment of mobility rigths to all citizens can provide a response to this criticism. Furthermore, the cost of additional mobility rights (mobility vouchers) can be differentiated according to several dimensions like the quality of public transport form the zone of residence or the vehicle type (size, emission class, etc.) so that road pricing is better sized in relation to the trip conditions. Finally, a voucher-based pricing approach would introduce the possibility of trading mobility rights, allowing low mobility segments of population (often correspondent to lower income inhabitants) to receive a compensation. Technologies now allow for introducing and managing this kind of complex pricing schemes. The municipality of Genova (Italy) is currently studying the feasibility of a mobility voucher system. In order to simulate the impacts of the application of the mobility vouchers approach, a strategic model was realised.

The Genova Mobility Vouchers (GMV) model is an application of the System Dynamics methodology and was implemented in the VENSIM software. The choice of the set up a System Dynamics model has two main justifications. First, this methodology is capable of modelling feedback effects and simulate adaptation over time rather than just provide an estimation of an equlibrium in a future time point. Second, the structure of a System Dynamics application is inherently open to further developments, addition of new modules, etc. The GMV model has been set up with a specific objective and to provide a given set of results, but having in mind the chance of extending its structure, especially in the direction of a more detailed simulation of trips and of the land-use impacts of the policy.

The model simulates eight different population groups, identifying various combinations of income and working conditions. The reaction to the application of the road pricing schemes is simulated in terms of variations of the travel behaviour of the individuals with respect to the reference mobility pattern. On the one side, the pricing policy is simulated by setting the price of the additional mobility vouchers according to how and where the car trips are undertaken (e.g. vehicle type, trip length, time of the day, etc.) as well as by defining the number of free vouchers available for each individual in age. On the other side, there are many elasticity parameters, segmented by population group and zone, which produce the responses of the model to the application of the policy. On the basis of the number of free trips allowed and the cost of the additional ones, each population profile will react in different ways. Population groups who are planning a total number of trips per week which is lower than the number of free vouchers will not pay anything and will be entitled to re-sell the remaining credits to the central clearing office. For the other groups, i.e. those willing to make more trips than the free ones allowed by the policy, the model will simulate the distribution among the available different reactions. The trips exceeding the endowment of free vouchers can be: undertaken by purchasing an additional vouchers or shifted on public transport or shifted on motorcycles or suppressed. The application of the pricing schemes gives rise to feedback effects in the model. In particular, the renewal of the fleet and the motorisation rate is dependent on the differentiation of pricing between vehicle types, while the reduction of congestion may induce more people to use car despite the pricing.

The model computes a number of indicators that illustrate the overall impacts of the policy from different points of view. The first group of indicators concern the transport side (number of trips, mode split, traffic performance, etc.), in order to analyse the impact of the policy on the mobility in the area. The second group of indicators make reference to the households budget. On the one side, households are expected to pay for additional mobility vouchers, but on the other side some low-mobility demand segments are expected to sell unused free vouchers. So, the outcome in economic terms is different across population groups. The third group of indicators is still concerned with the economic aspects of the policy, namely with the revenues for the local authority. The model provides the information on total revenues as well as the share of each demand segment. Finally, the model allows the user to analyse the impacts of the policy on the air quality in the urban area and on the greenhouses gas emissions.

The model has been applied to test several alternative pricing schemes. The results of the simulations allow to highlight the impact of a mobility voucher scheme in comparison to a pure road pricing measure, showing that impacts on the mobility may well be significant in term of reduced congestion, whilst the economic burden of the policy is better distributed across population segments.

2 A MOBILITY VOUCHER SYSTEM FOR THE MUNICIPALITY OF GENOVA

The mobility voucher system is based on the concept of sustainable mobility load on urban network (see Viegas, 2001 for a theoretical analysis of the principle); the main steps for applying this system are:

1) the identification of the sustainable level of mobility load on the urban network;

2) the definition of the "budget" of urban mobility for the mobility individuals, distributing the sustainable mobility load among all the individuals: the mobility vouchers are the measure of this "budget";

3) the creation of pricing exchange mechanisms between the individuals, in order to allow the system to reach the equilibrium which satisfies all mobility needs;

4) the definition of rules for consuming the vouchers.

The level of sustainable mobility load has to be defined from the local administration, according to the policies which application is pursue (e.g. congestion sustainability, environmental sustainability, energy consumption sustainability, etc.). Depending on their mobility habits, people could have needs higher or lower than the common mobility budget assigned: as a reaction, exchange mechanisms develop in the system, regulated through a sort of bank where vouchers are bought by the individuals or returned with monetary benefit in case they have been unused.

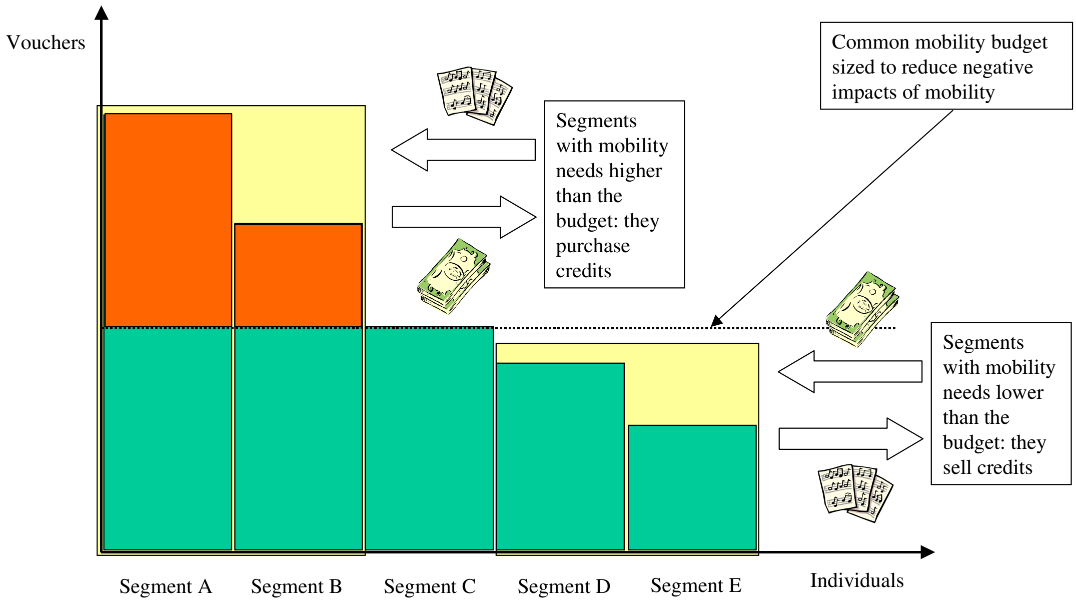

Fig. 1: reaction of individuals in front of the mobility vouchers system

- The definition of the tariff for buying additional vouchers and its differentiation is the most important aspect of the mobility voucher system, because it leads to the policy measures which the Administration pursues.

3 THE GMV AGGREGATED MODEL

3.1 The structure of the model

The municipality of Genova (Italy) is currently studying the feasibility of a mobility voucher system, for which an aggregated simulation model has been set up to assess the impacts. The Genova Mobility Vouchers (GMV) model is an application of the System Dynamics methodology and was implemented in the VENSIM software. The model is necessarily a synthetic representation of the real world, a number of assumptions were required to translate the complexity of the mobility and of the policy into a workable tool. First of all, the model is aggregated as it is not simulated demand on a link basis and it does not include a detailed origin-destination matrix. Instead, the analysis is made on the total number of trips generated from each zone and directed to the urban area of Genova, the only one where the mobility voucher policy is supposed to be applied. Therefore, only trips generated in or destined to Genoa are modelled, whereas mobility within or between other municipal districts are excluded. Figure 2 below summarises the way the GMV model simulates the impacts of a pricing policy implemented together with a mobility voucher system.

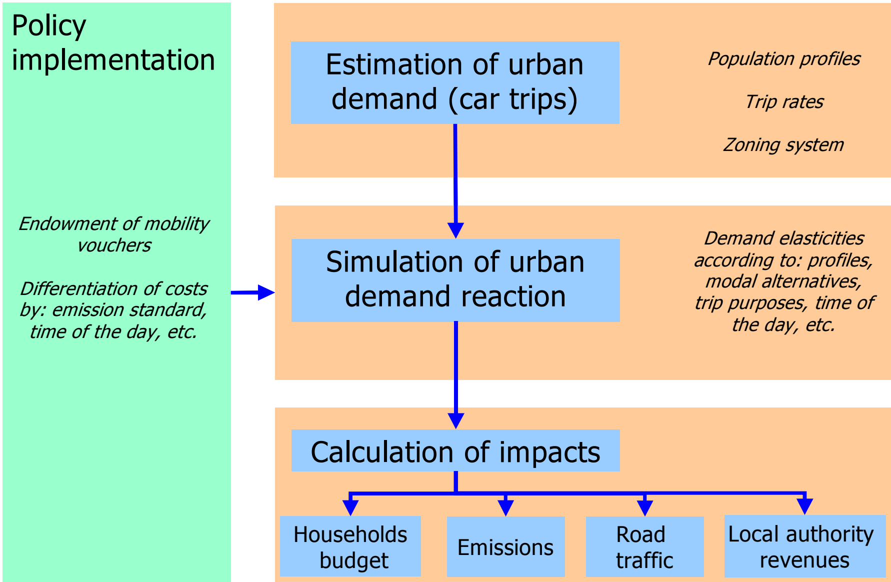

Fig. 2: Main simulation steps of the GMV model

First, the model estimates the total number of trips generated within the study area in the reference case (no pricing policy applied). The estimation is made by applying trip rates by purpose to the number of inhabitants in each zone. Trip rates are different across population groups and zones, in order to reflect the observed variability of personal mobility.

The second step consists of the simulation of the reaction of the urban demand when a pricing policy is applied. The reaction is simulated in terms of variations of the travel behaviour of the individuals with respect to the reference mobility pattern. On the one side, the pricing policy is simulated by setting the price of the additional mobility vouchers according to how and where the car trips are undertaken (e.g. vehicle type, trip length, time of the day, etc.) as well as by defining the number of free vouchers available for each individual in age. On the other side, there are many elasticity parameters, segmented by population group and zone, which produce the responses of the model to the application of the policy. On the basis of the number of free trips allowed and the cost of the additional ones, each population profile will react in different ways. Population groups who are planning a total number of trips per week which is lower than the number of free vouchers will not pay anything and will be entitled to re-sell the remaining credits to the central clearing office. For the other groups, i.e. those willing to make more trips than the free ones allowed by the policy, the model will simulate the distribution among the available different reactions. The trips exceeding the endowment of free vouchers can be: undertaken by purchasing an additional vouchers or shifted on public transport or shifted on motorcycles or suppressed.

The application of the pricing schemes gives rise to feedback effects in the model. In particular, the renewal of the fleet and the motorisation rate are dependent on the differentiation of pricing between vehicle types. On the one side, individuals are encouraged to replace vehicles for which the cost of voucher is higher. Therefore, the revenues of the system are reduced. On the other side, when individuals start to suppress car trips, some are encouraged to get rid of their car, so reducing the car ownership rate and the overall motorised mobility, reinforcing the impact of the system. Another negative feedback effect concerns the reduction of congestion, which may induce more people to use car despite the pricing.

Finally, in the third step the model computes a number of indicators that illustrate the overall impacts of the policy in different domains: transport, economy (households budget and local authority revenues), environment.

3.2 Sample results

The figure 3 below summarises some results obtained from the simulation of different charging schemes using the GMV model. In particular, in addition to a Business as Usual scenario (BAU), three different types of scenarios have been simulated:

- A pure road pricing according to the London scheme: all vehicles charged the same;
- A pure road pricing according to the Milan scheme: charge differentiated by Euro category;
- Alternative schemes with a different number of vouchers and a different price of additional vouchers.

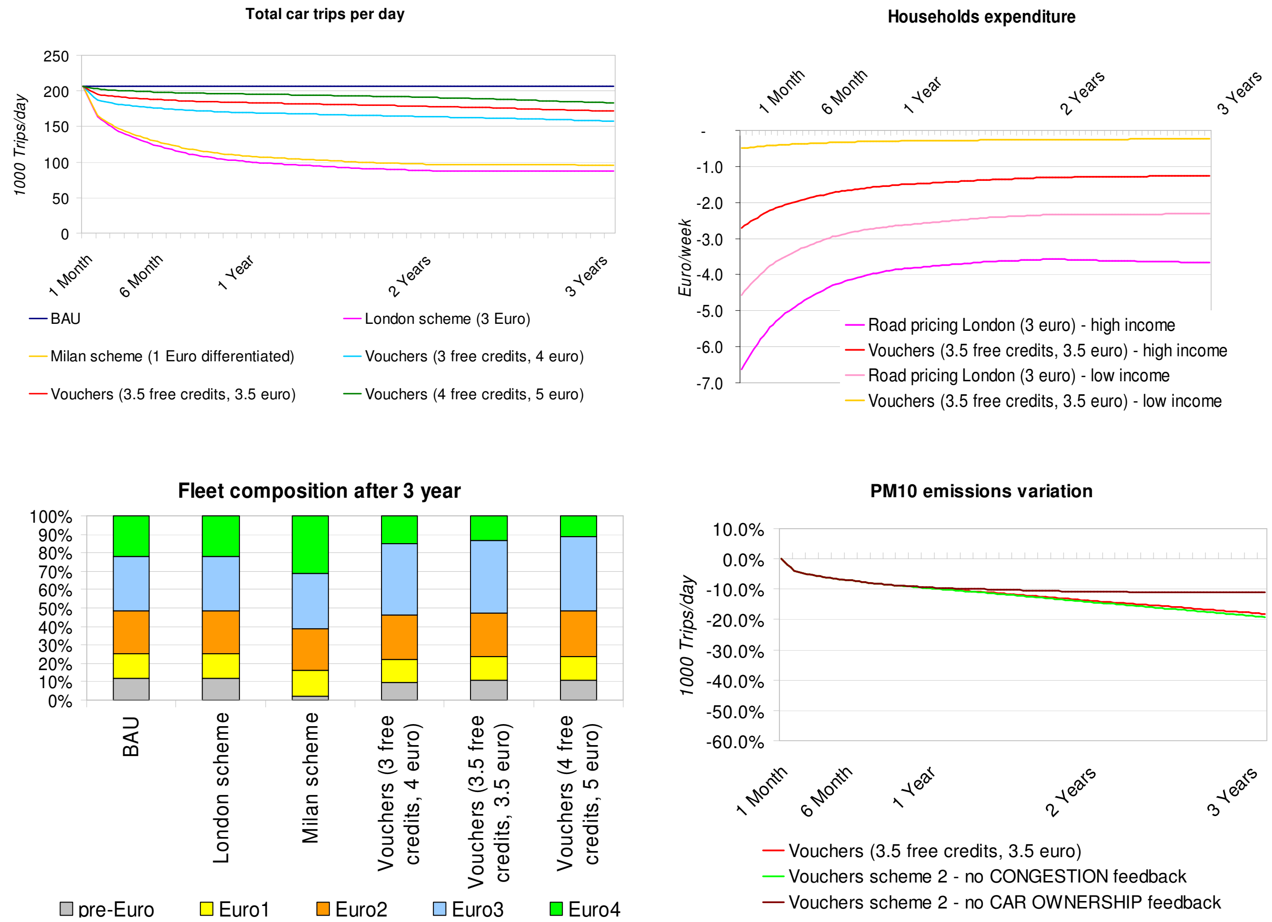

Fig. 3: Sample results from the GMV model

From the results of the simulations some preliminary conclusions can be drawn:

- A voucher system can reduce car traffic (and therefore congestion and pollution) to a significant extent, even if the potential of a pure road pricing scheme cannot be reached. However, the financial burden of the policy is better distributed among different groups. For instance, a "London-type" scheme costs to low income households about 160 Euros in the first year, while a voucher scheme able to reduce traffic by 25% costs less than 40 Euros in the same period to this group of households (and individuals with very low use of personal car can even get some money).
- The revenues of a voucher scheme are necessarily lower than if a pure road pricing is applied, but the difference can be not so high and, again, the source of the revenues can be better distributed, improving the accpetability of the scheme. For instance, a "Milan-type" scheme yields about 33 Million Euros per year of which 59% from high income users, while a voucher scheme with 3 free permits and a price of 4 Euro for each additional voucher can yield 24 Million Euros of which 78% from high income users.

- The differentiation of charges across user groups do not change significantly the aggregate results (total revenues, total reduction of trips, etc.) but allows the local authorities to better calibrate the distribution of costs and benefits, so the policy maker has more degrees of freedom .
- Simulating the impact of the pricing scheme on the car ownership and the feedback on the number of car trips changes significantly the results of the simulations: about 35% of the reduction of trips is explained by this effect. Further researchs are needed, but as far as this result can be confirmed, it is a very relevant indication that a charging scheme can induce structural impacts on the mobility habits. Instead, the opposite feedback effect of reduced congestion on car trips seems to be quite small.

4 CONCLUSION

The GMV model is a system dynamics model dealing with the simulation of urban road pricing schemes based on the principle of mobility vouchers. The tool has been designed and tested for studying the application of mobility vouchers in the municipality of Genova (Italy). Even if the GMV is an aggregated model, some interesting conclusions could be drawn from the simulation of several alternatives schemes. Namely, the simulations suggest that mobility voucher schemes are able to produce relevant reductions of traffic and to yield revenues allowing the public authorities to control how to allocate the costs of the policy. Even if the effectiveness of a mobility voucher system is lower than a pure road pricing measure, the degrees of freedom for the policy maker can help to increase the acceptability of introducing a charge for the use of cars.

The current version of the GMV model has been designed to provide aggregate results. There are future objectives for further refining and developing the tool. More specifically, there are three developments lines where more work would be needed:

- First, the elasticity parameters of the model have been calibrated using the results of a direct survey in the area. However, for budget reason, the size and the quality of the survey were not fully satisfying and a full set of elasticities could not be estimated. There is therefore room for improving the model parameters, which in some cases are now questionable. In the same line, also the estimation of the size of the population groups can be improved if more data is available.
- Second, a more detailed representation of transport demand would greatly improve the model, both in terms of the variety of results and in terms of their precision. Actually, the very aggregate definition of demand in the current version of the model makes results per zone not very reliable and limited to those variables depending on the composition of the demand originated in each zone. The objective in this line is twofold: on the one side, to include a full origin-destination matrix instead of just the total number of trips generated. On the other side, to link the tool to a network transport model, in order to simulate link-based results and, ideally, also link-based tolling schemes.
- Third, the model currently deals mainly with short-term impacts on the transport side, but a road pricing scheme is expected to induce further effects in the longer terms on land use. Another objective for the development of the model is to include re-localisations of households or to establish a linkage with a land-use model, in order to widen the scope of the tool and provide more realistic forecasts in the longer term.

5 REFERENCES

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