

Parking Policy and Urban Mobility Level of Service – System Dynamics as a Modelling Tool for Decision Making

João P. R. Bernardino¹, Maurits van der Hoofd²

TIS.PT – Consultores em Transportes Inovação e Sistemas, S.A.

Parking policy is still the most directly available instrument for managing traffic demand in many cities. But policy design is subject to difficulties resulting from the complexity of the urban mobility system. This article presents a model framework, based on a system dynamics approach, aimed at assessing the effectiveness of parking policy and quantitatively identifying optimal design at an aggregate spatial level under a level of service maximization objective. An application to a city is developed and the results are discussed in view of their qualitative outcomes and quantitative validity and robustness. It is argued that system dynamics addresses several needs of modellers and decision makers regarding urban parking policy assessment, particularly if parking is used as a traffic management tool. The qualitative results of the model coincide with the prescriptions that would come from the economic theory, even with an objective function based on level of service instead of a broader indicator of efficiency. At the quantitative level, the validation testing of the model application with the available data provided positive indications and no case to reject that a quantitative accurateness useful for policy prescription could be attained provided that some data gaps are fulfilled. The necessary data for calibration seems to be possible to obtain by feasible local empirical observations.

Keywords: parking policy, system dynamics, urban mobility, traffic demand management

1. Introduction

Parking policy in cities is widely applied as a mobility policy instrument. It is applied as a demand management instrument directed not only at parking but also at traffic demand. However, questions arise as to how to optimally design parking policies to meet the objectives that justify its use, and whether parking policy is an effective and efficient instrument as compared to other available policy instruments.

Beyond theoretical considerations, the practical design and performance evaluation of parking policy is subject to technical constraints. In the particular case when parking policy is applied as a traffic demand management instrument, the analytical approach requires the understanding of the performance of the mobility system at an aggregate level. This either implies the use of very

¹ Av. Marques de Tomar 35-6, 1050-153 Lisbon, Portugal, T:+351213504400, F:+351213504401, E: joao.bernardino@tis.pt

² Av. Marques de Tomar 35-6, 1050-153 Lisbon, Portugal, T:+351213504400, F:+351213504401, E: maurits.vanderhoofd@gmail.com

extensively detailed models which are costly to build and parameterize, or more simple aggregate models which represent the behaviour of the system faithfully enough.

In the scope of the latter possibility, the modelling framework of system dynamics has characteristics that seem adequate to pragmatically assessing impacts. System dynamics is a modelling approach designed at understanding the behaviour of complex systems over time, dealing with internal feedback loops and time delays and thereby coping with the nonlinearity of systems. It is appropriate for modelling policy impacts at an aggregate level and is relatively simple and intuitive to use and communicate to policy makers and other non-technicians. Furthermore, it allows modelling long term impacts of the policy, like car ownership decisions.

There have been few cases of application of system dynamics modelling to the study and quantification of urban parking policy effects (e.g. Young et al., 1985, Sivasubramanian and Malarvizhi, 2010). A review of its appropriateness to supporting parking policy design has yet not been delivered. As a contribution to the assessment of the appropriateness of system dynamics as a tool to deliver quantitative impact assessment for the purpose of urban parking policy, this article provides a discussion and presents a case of application. The main goals of the model are to assess the effectiveness of parking policies in regulating urban mobility (including parking and circulation) and identifying optimal parking policy at an aggregate urban level. Effectiveness is measured through the quantification of the average level of service of mobility in the city. The validation and results of the quantitative application provide hints on its potential applicability for quantitative policy prescriptions.

2. Economic Objectives of Parking Pricing: A Review

Without proper policy intervention, the development of urban areas leads naturally to an excessive use of private transport from the social welfare perspective due to the presence of external costs. In line with the economic theory, for the system to function efficiently from a collective perspective, all external costs should be internalized by the users by facing a price for travelling equal to the social marginal costs caused.

In practice, perfect social marginal cost pricing is far from being fully attainable, for a set of reasons including technical viability, costs of implementation, transaction costs and information constraints. Alternatively, second-best solutions may be applied which, while not theoretically achieving optimal solutions, can still bring an outcome closer to it (see e.g. Rothengather, 2003). Parking pricing can be a first-best solution for parking space management, and is a possible second-best solution for traffic demand management.

The existence of scarcity of parking without the presence of an appropriate price holds three types of inefficiencies. Firstly, it does not allocate available supply efficiently, i.e. it does not attribute the resource to those parties that most value its use. Secondly, there is the phenomenon of cruising for parking. When parking places are fully occupied, additional parking seekers need to cruise around until they find a place. This is resource wasteful both to them and to the other road users who suffer additional congestion. A third and usually neglected type of inefficiency is the competition of users for parking places centred on arrival time. In the morning peak mostly, travellers have to adjust their arrival time to as early as free places are still available, implying wasteful time costs – or even sleep deprivation (Biddle and Hamermesh, 1990). Pricing for parking is appropriate to deal with these three types of problems, as they are all caused by the existence of scarcity of parking places.

The same does not fully occur with parking policy as a road traffic demand management instrument (see e.g. Verhoef et al., 1995). Although private vehicle trip choices with external costs have partial relation with parking time and parking place choices, their divergence could prevent parking pricing from being a reasonably efficient instrument. First best traffic demand pricing implies pricing according to distance, trip times and types of vehicle, and these are elements that

can be only remotely correlated with possible parking price formulations. For example, parking does not introduce any incentive to through traffic (Glazer, 1992).

At a time of emergence of new technological capabilities enabling theoretically more efficient demand management schemes, and perhaps a time where acceptability of road charging is becoming higher due to positive experiences worldwide and a changing mentality by citizens in relation to the car and other modes, it is especially timely to assess the effectiveness of parking policy approaches presently implemented, considering the various policy pathway alternatives available (Verhoef, 2001).

3. On System Dynamics for Urban Parking Policy Modelling and Design

System dynamics is a modelling approach characterized by its capability of representing aggregate systems and capturing the dynamic complexity of their evolution. It is also emphasised for its ability to deliver a comprehension of the systems structures (systems thinking) and for being a powerful communication tool (Serman, 2000). Its use for policy evaluation in the transport sector has been subject to crescent adoption and sophistication (e.g. Abbas, 1994, ASTRA, 2000, Raux, 2003, Fiorello et al, 2010).

Traditional static four-step traffic models, or dynamic micro-simulation models, are work intensive and have limited analytical scope in considering relevant mechanisms. The system dynamics approach, on the other hand, allows capturing the complexity of the system by considering dynamic effects. This need is pressed by a significant structural complexity of urban mobility systems, where short and long-run feedback effects take place involving multiple factors, due to which the assessment of policy effects is often not straightforward.

For the assessment of parking policy the system dynamics approach is also justified by the need to assess parking policy at an aggregate level. This need depends on the precise objective of parking policy, which can be used for parking demand management, for road traffic management, or for both. Where traffic circulation demand management is a goal of parking policy, an aggregate analysis at the urban level is essential because a relationship cannot be directly established between the precise object of pricing – the parking place, at a given time – and the precise intended object of policy intervention – traffic flows, at given links in given time intervals. Unlike road pricing, where pricing in a given section could at least theoretically be designed exactly to meet the optimal congestion level at that same link, the same cannot be done if the policy instrument is parking pricing. Traffic in an urban road section is generated from and to multiple areas, and refers to parking use at a wide time frame. Therefore, if applied as an instrument to manage traffic circulation in an urban area, parking policy must necessarily be conceived at aggregate rather than micro level both in space and time. An additional argument for using aggregate approaches is that pricing policy is only effective if agents are properly informed of the price of their choices. This implies a simple enough pricing system as opposed to a high level of disaggregation.

The use of the system dynamics approach may also be appropriate from a pragmatic policy making perspective. Local administrations commonly follow technically limited decision making processes both regarding parking price level as well as its segmentation across time and space. A methodology allowing the estimation of an optimal aggregate price or supply, within reasonable time and resources, in many cases constitutes a progress compared to common practices.

In summary, system dynamics may be an appropriate tool to assess effects of parking policy on the performance of urban mobility systems for several reasons: appropriate design and assessment of parking policy aimed at traffic demand management requires aggregate level analysis; system dynamics allows assessing dynamic effects not captured by common micro level traffic models; system dynamics modelling can be a useful communication tool to decision makers and technicians, and: system dynamics may be more cost-effective than other approaches.

However, it is a crucial matter whether system dynamics modelling could produce sufficiently reliable analyses and quantitative prescriptions for policy support. We present a case of application and discuss this issue on the basis of its results.

4. The Model

The model presented is aimed at studying the effects of parking supply and pricing policies on the level of service of urban transport systems. It characterizes the aggregate system at the level of urban public transport and private car, and allows assessing the effects of changes in the parking policy with corresponding changes on modal split and resulting travel speed and cost. As an indicator of aggregate level of service in the mobility system, average speed is used. It also considers the *Mohring effect* of a long-term positive influence of increasing demand on the volume of public transport services (Mohring, 1972).

The model is applied to the city of Lisbon, parameterized and calibrated with the available local empirical data.

4.1 Structure and mechanisms

The model structure is designed to cope with a set of crucial characteristics of the city and its transport system, most importantly the interdependence of flows between private and public transport, available types of parking (public, private), shares of traffic demand segments according to their potential use of parking, public transport segments according to infrastructure used, existence of road and parking congestion and public transport frequencies.

The policy inputs of the model are parking capacity and parking price. As the model aims to test aggregate level policies, these variables are defined at city-level, i.e. they represent the average state of the variable for the whole city.

At the system level the model includes aggregate variables and interactions directly or indirectly relevant to the evolution of the state of the quality of service indicators. Figure 1 outlines the main model interactions at an abstract level. Figure 2 maps relevant system variables and their qualitative inter-relations and illustrates how they lead to selected indicators of level of service.

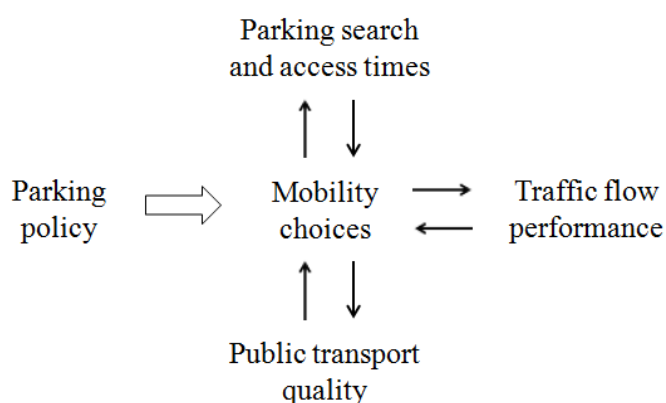
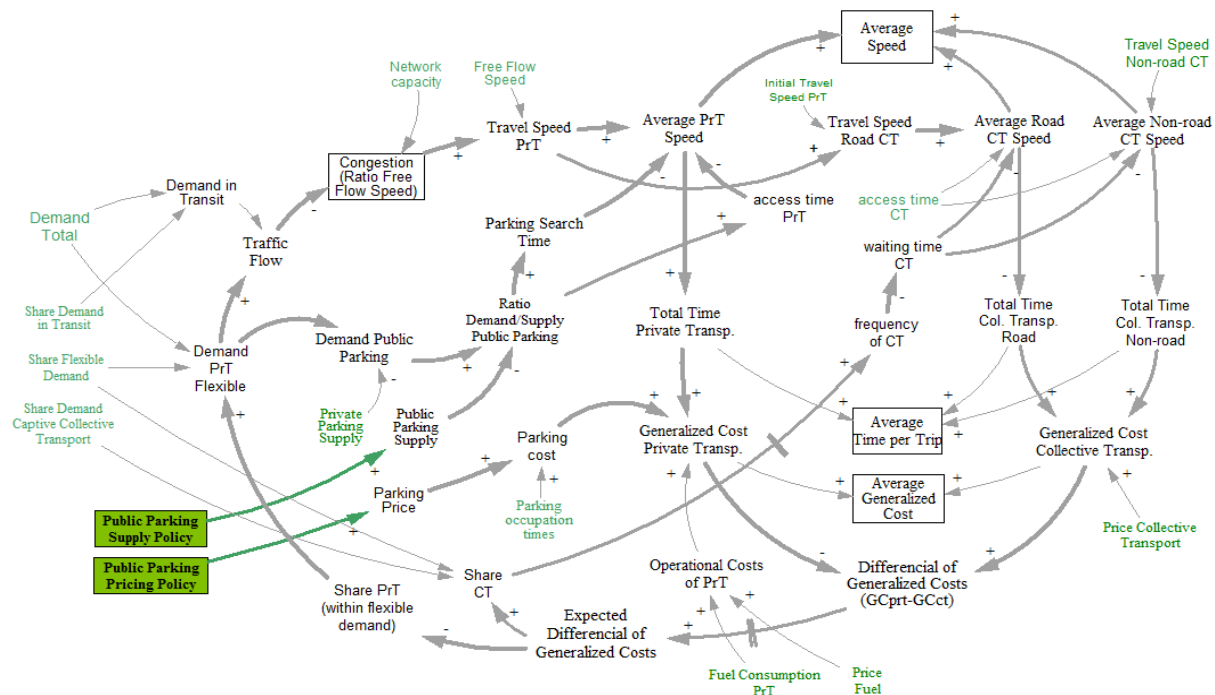


Figure 1. Outline of model interactions



Legend: Abbreviations: PrT – Private transport; CT – Collective (Public) transport; GC – Generalized cost

System dynamics symbols notation: \rightarrow : causal effect; + : positive effect between variables; - : negative effect between variables; || : causal effect with delay

Types of variables: green box – policy inputs; green – inputs; black - system variables; black with box - indicators

Figure 2. Detailed model structure

The essential structural features of the model are described:

- Demand segmentation: three types of demand segments are considered, according to their flexibility towards the use on different modes and to their need to use parking. They are *Demand in transit* (or through traffic), captives of public transport, and demand potentially using parking (*Flexible demand*).
- Modal choice: demand choices of mode of transport depend on the relative generalized costs – variable trip costs plus time costs – between modes. It is considered that only demand potentially using parking is affected by parking policies. By segmenting demand according to whether it is affected by parking policy we are able to better assess the impact of such policy on demand choices and the mobility system.
- Parking scarcity effects: as demand for public parking approaches parking capacity, both parking search time – the time spent by the driver looking for a parking place – and access time – walking time from parking location to final destination – increase.
- Road congestion: average speed depends on the daily traffic flow level of private transport.
- Public transport types: A distinction is made between road public transport and off-road Public Transport. The former is affected in speed by road congestion while the latter is not.
- Expectations: It is assumed that demand has an information gap regarding changes in the system. Therefore travellers adapt choices to changes in level of service gradually in time.
- Frequency of public transport: In the medium term public transport operators adapt service frequencies to demand and frequency affects waiting time for public transport.
- Travel distances: To account for heterogeneity of demand, modal split is differentiated in different groups of travel distances (similarly to Raux, 2003), particularly: short, medium and long distances.

- Private parking price and demand: It is assumed that private parking supply is lower than total demand for parking and that private parking providers level their price according to public supply and price levels in such a way that the occupancy rate of private parking is invariant. These assumptions imply that public parking supply and pricing policy has the ability to determine aggregate demand for parking (for a detailed analysis on public relative to private parking provision see Calthrop and Proost, 2006).

Some of the most relevant external inputs of the model, i.e. variables not controlled in the simulation, are Demand, Travel Distances, Parking Times, Public Transport Price and Fuel Price.

The fundamental dynamics of the model can be described in the following loop: transport users select modes of transport according to their generalized costs; the share of private transport influences traffic volume, which causes a certain level of congestion, defining the average speed of private and road public transport, and ultimately the generalized costs of road transport that base transport user choices. When the system is in equilibrium, generalized costs do not vary in each iteration. If the system is not in equilibrium, the demand will progressively adapt choices as the users adjust expectations on costs.

The congestion effects entail a balancing feedback loop when there are changes in the system: e.g. an increase in private transport use will cause an increase of congestion related time costs, contributing to a reduction in private transport adoption. This feedback loop represents a widely stylised characteristic of transport systems (in the system dynamics literature see for example Sterman, 2000). Similarly to traffic congestion, the dynamics of parking search and access time form a balancing loop by which increasing (decreasing) costs contribute to bring down (increase) demand and ultimately the time costs. A difference in the dynamics of these loops is that the former affect both private and public transport while the latter affect only private transport. These feedback loops take place mostly in the short-run.

The other relevant effect represented in the model is the medium-term increase of public transport frequency with public transport demand (also known as the Mohring effect): when public transport demand increases (decreases) frequencies increase (decrease) in the medium-term, contributing to a further increase (decrease) of demand, consisting of a reinforcing feedback loop.

Additionally to the crucial issue of the general advantages of the use of an aggregate model to study parking policy effects described in the previous section, we highlight three particularities of this model that are of particular relevance for studying parking policy effects. The first one is the segmentation of demand according to the need for parking. By isolating demand that is directly affected by parking changes it is potentially possible to obtain a more real account of the policy effects. The second aspect is that it segments public transport supply according to its proneness to being affected by parking policy changes, particularly through congestion. Thirdly, this model has the characteristic of integrating into a single model the various mobility system performance aspects related to parking, including besides congestion also parking search time and access time from the parking location to the destination.

4.2 Application

The model is applied quantitatively to the city of Lisbon. A local characterization of the city, the parameterization and calibration of the model and the approach regarding the objective function of the policy are described.

4.2.1 Local characterization

Lisbon is a city with half a million inhabitants that is the centre of a metropolitan urban area of about five times that population. The Lisbon area contains the largest share of employment in the region and attracts a mass of workers who live in the surrounding area.

The traffic situation in Lisbon is characterised by considerable road congestion in the morning peak, as a consequence of high private car use for commuting. About 400,000 vehicles enter Lisbon daily, while 180,000 of those are transit traffic without an origin or destination in the area³. Since bus services often have to use the same infrastructure as private vehicles, road congestion also leads to slower speeds for bus transport. Official public parking places in the area are around 200,000.

4.2.2 Functions, parameterization and calibration

The parameterization and calibration of the model is mostly based on data about the Lisbon mobility system provided by the “Lisbon Mobility Plan” (CML, 2005). Several major inputs could be parameterized or calibrated on the basis of available data, like public parking supply, demand for public parking, total and type disaggregated demand, average travel speeds of bus, tram and metro, modal split shares, parking price or CT prices. Other parameters and relations were defined on the basis of the opinion of the authors based on their knowledge of the situation of Lisbon.

The most important causal relationships are the congestion time degradation functions. For road traffic congestion, a traditional BPR curve (Singh, 1999) is used to represent the relation between aggregate traffic flow and average speed in the network:

$$\bar{s}(Q_a) = \frac{\bar{s}_0}{1 + \alpha \cdot \left(\frac{Q_a}{C_n}\right)^\beta} \quad (1)$$

with

\bar{s} - Average speed in the road network

\bar{s}_0 - Average free flow speed in the road network

Q_a - Average traffic flow (vehicles/day)

C_n - Parameter for aggregate network capacity

α, β - Parameters

Parameters C_n , α and β , or a different functional form, could in principle be calibrated to the real case of Lisbon, provided availability and proper analysis of data based on traffic models. In our model C_n has been calibrated to match the initial values of the average speeds of private transport and of on-road public transport.

Modal split between private and public transport is defined in the model using a logit function, where λ is a parameter and $\Delta GC_{PrT,CT}$ is the difference in generalized cost between private and public transport. For simplicity it assumes a fixed share between on-road and off-road public transport was assumed.

$$share_{PrT} = \frac{1}{1 + \exp(-\lambda \times \Delta GC_{PrT,CT})} \quad (2)$$

³ A recently opened link on the circular road (“CRIL”) outside the city borders may have changed this reality in a significant way.

Parameter λ defines the rigidity of demand towards differences of generalized cost between the two modes. In our model λ has been calibrated in relation to the real observed shares of private and public transport given the average computed generalized costs of each mode.

Other crucial time degradation relations are those related to parking search time and walking access time. The relation between parking demand and supply and parking search time is described by a functional form similar to the exponential type⁴ (see Figure 3). A similar time degradation function describes the relation between the ratio of parking demand to parking supply and the access time from the parking spot to the point of destination. Existing and further research work could be used to further calibrate these relations more accurately.

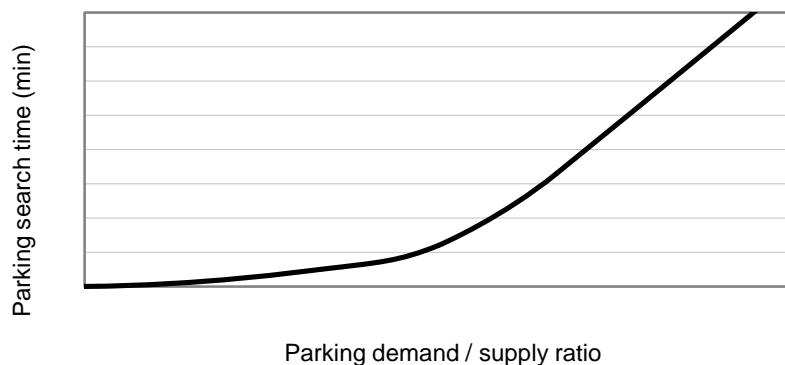


Figure 3. Function of parking search time in relation to demand / supply ratio

In relation to the effects on the frequency of public transport, it is assumed that in the medium term operators keep a constant occupancy rate and therefore frequency is linearly proportional to the demand for public transport, while waiting time for public transport is inversely proportional to frequency.

The remaining relations between variables are simple linear relations not described here in detail. An appendix to this paper describes all variables used, their computation functions, values and sources of parameterization⁵.

4.2.3 Objective function

Due to the various difficulties and uncertainties towards a correct specification of prices according to the social marginal cost principle, there is a need to find other ways to decide a correct pricing level. In this, the optimization of level of service indicators at the urban level seems to be the most reasonable and viable candidate⁶. For the purpose of this case of application, level of service is defined by the average (door-to-door) trip speed. Other indicators considered are average time per trip, average generalized cost per trip and congestion (real speed / free flow speed ratio). The optimization for each policy vector (parking price, parking supply) is realized iteratively.

⁴ An average park search time of 3,3 minutes is assumed when demand equals supply, in line with reported empirical results by Shoup (2006).

⁵ In order to have access to the Appendix please contact the corresponding author.

⁶ An undesirable distortion on the appropriateness of this measure would happen if the policies led to an overall reduction of demand, causing reduction of congestion (and therefore improving level of service) but with costs related to the suppression of trips. On the other hand, relevant effects towards the appearance of additional trips also arise from the improvement of level of service itself, both in private but mostly in public transport. As a simplification, the model assumes a constant aggregate demand.

4.3 Model validation

It has not been an ambition of this particular model to obtain accurate quantitative predictions. Such aim would require additional data in relation to what was already available for Lisbon. However, the validation results suggest that it has a potential to adjust sufficiently well to reality with that aim, if additional data is available and proper calibration to the local characteristics is realized.

4.3.1 Structure assessment

In relation to structural assumptions of the model, they feature stylised mechanisms of urban mobility systems and it seems that they are not subject to significant uncertainty. For example, it is clear enough that average road travel times decrease with private demand level, that an increase in parking price reflects on the perceived costs of car use and consequently on its demand level, or that the flow of on-road public transport is negatively affected by traffic of private transport. The same qualitative triviality could be mentioned of any of the model relations in question. Therefore the challenge seems not to lie with the nature and direction of relations, but with their quantification.

4.3.2 Parameter assessment

In terms of parameter assessment, the model adjusts fairly well to known parameters in equilibrium under the state of aggregate mobility demand and supply characteristics described in the Lisbon Mobility Plan. Particularly, it was possible to develop a consistent equilibrium with approximate values for the given public parking supply, demand for public parking, total and disaggregated demand by type, average travel speeds of bus, tram and metro, modal split shares, parking pricing and public transport pricing. To achieve an outcome consistent with the given reality, unknown parameters have been calibrated to deliver the empirically given values, particularly the network capacity (C_n) and the demand choice rigidity parameter (λ).

The fact that these parameters are unknown allows for such flexibility in their calibration, but the values calibrated are not necessarily consistent with the reality. Although they adjust well to the given state in Lisbon, it remains to be known whether they deliver realistic behaviour when changes to the system are inputted. A full validation of the model would therefore require additional testing of its responses to changes in inputs affecting costs of different modes. The key model components in relation to reactions to input changes are the mode choice function, the congestion function and the parking search and access functions. In the following section we provide a sensitivity analysis to some of the relevant parameters.

The differential analyses produced in the results section provide relevant extreme conditions testing by radically constraining parking supply or increasing its price. The outcomes are within a range of plausibility in terms of trip speeds and transport mode choices.

4.3.3 Sensitivity to key parameters

We provide an indication of the model robustness to three key parameters through a sensitivity analysis. The variables in question are the network capacity parameter (C_n), the congestion function parameter β and the mode choice rigidity parameter (λ). These were selected for being crucial parameters for the reaction of the model to changes in inputs, but their selection should not exhaust a full analysis of robustness for future analyses⁷.

Important trade-offs in the model depend on the time costs incurred by the pressures of private transport demand on the road network and the parking infrastructure, as determined by the congestion function parameters. The precise amount of those costs in relation to demand

⁷ Within the TOOLQIT project, sensitivity to fuel prices was also analysed but we didn't include their presentation in this paper since they were not essential to the arguments presented here.

intensity is crucial input for the outcomes within the mobility system. This item analyses two of the three congestion parameters included in the road congestion function, β and C_n . The test performed in both cases refers to the speed losses incurred from defining a price based on a wrong parameter assumption. Given the speed s^* obtained with a price policy designed with certain parameter assumptions, we calculate its percentage deviation Δs_{opt} from the maximum speed s_{max} that would be achievable through the optimal price calculated with real parameter values. The following equation defines this analysis:

$$\Delta s_{opt} = \frac{s^* - s_{max}}{s_{max}} \quad (3)$$

The analysis allows anticipating consequences for policy of wrong model assumptions. The impact of wrong β assumptions seem to be minor in relative terms. For example, the simulation of a negative deviation of 30% to the expected β level results in a relatively small sub-optimal speed deviation of 0.6%. On the contrary, wrong assignment of the parameter for aggregate network capacity (C_n) causes relevant errors in price setting with strong undesirable implications on the achieved equilibrium (see Figure 4). For example, the existence of a C_n 20% lower than the simulated value would result on an average speed 2.4% under the optimum level. Nonetheless, it is noteworthy that an adoption of wrong assumptions to such high extent is unlikely under any soft check-up with reality. For example, a negative deviation of parameter C_n in 20% causes a variation in average travel private transport vehicle speed of 26%, which would hardly match a calibration with real data.

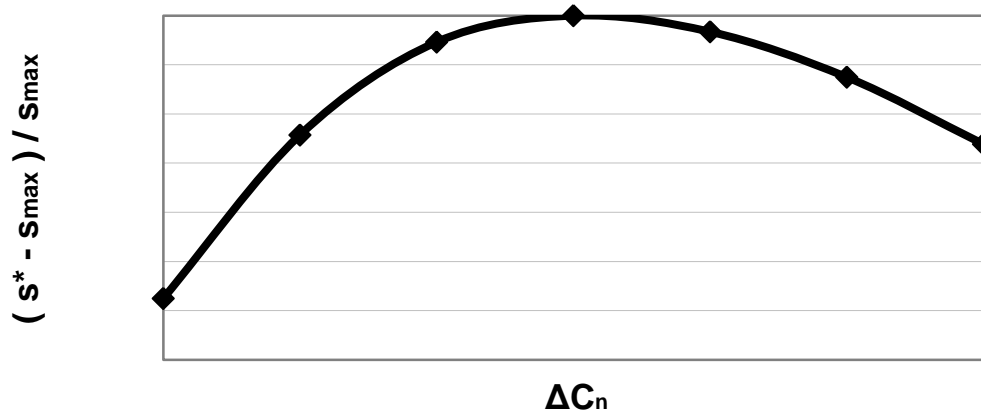


Figure 4. Sensitivity analysis on deviations to optimal average speed from variations congestion parameter C_n

The functional form and parameters defining modal split behaviour is key to understanding the impact of the policies at a quantitative level. A specific calibration of the function used in relation to observed outcomes in the mobility system would be necessary for an assessment with sufficient quantitative accurateness for adequate policy design. This has not been addressed in this work, however to provide an indication on the robustness of the results in relation to the function used in this model we develop a sensitivity analysis of parameter of the mode choice rigidity parameter λ . The results show non negligible effects of deviations of the mode split parameter on the effectiveness of pricing policy. For example, a deviation in rigidity of demand caused by a variation of λ of minus 20% would result in a 0.8% speed loss⁸.

⁸ The variation in λ corresponds to a similar percent variation (20%) of the elasticity of demand to generalized cost. It should be noted that the correspondent elasticity to generalized costs (~ -0.25) is significantly conservative relative to empirical values of elasticity to fuel price found in the literature (e.g. Goodwin et al. 2004). This conservative value calibrated for λ should be partly the result of the fact that no fixed utility premium was

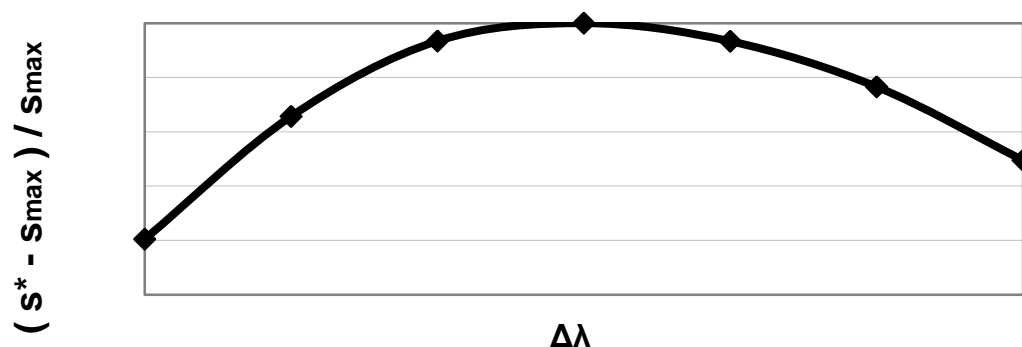


Figure 5. Sensitivity analysis on deviations to optimal average speed from variations modal split parameter λ

4.4 Results

4.4.1 Policy alternatives

The model was simulated for several alternatives of public parking supply and pricing. Two alternatives were simulated for testing either a decrease or an increase in parking supply in relation to the present situation. Two other alternatives were simulated with different parking prices, the first with free parking and the second with the parking price that optimizes average speed in the network. These four alternatives compare to a business as usual scenario which assumes that the present policies are kept. The inputs characterizing the alternatives are presented in Table 1:

Table 1. Policy alternatives inputs

| ALTERNATIVES | Supply (# places) | Price (average) (€/place.hour) |
|----------------------------|----------------------|-----------------------------------|
| 0. Business as Usual (BAU) | 203,800 | 1 |
| 1.1 Low Parking Supply | 163,040 -20% | 1.00 0% |
| 1.2 High Parking Supply | 244,560 +20% | 1.00 0% |
| 2.1 No Pricing | 203,800 0% | 0.00 -100% |
| 2.2 Optimal Pricing | 203,800 0% | 2.75 +175% |

The results are used to analyse the effects of the tested policies on the targeted indicators. Average trip speed could be improved up to 2.7 km/h on average in relation to the “business as usual” scenario by increasing parking price by 175%. Increasing parking supply could slightly improve average trip times. The opposite result would happen with a lower parking supply.

Figure 6 and Figure 7 show respectively the evolution of average speed in the road network and parking search time for each of the alternatives. Table 2 outlines the average values for the indicators at equilibrium. The results for each alternative are described in more detail below.

considered in favour of private transport relative to public transport, as only time and monetary cost issues were considered in the generalized cost function. A possibly too high value of time (based on Maibach et al., 2008) compared to the demand segments that use parking for longer times (which mostly excludes trips with greater value of time like business trips and goods delivery) is another aspect that might contribute to the difference.

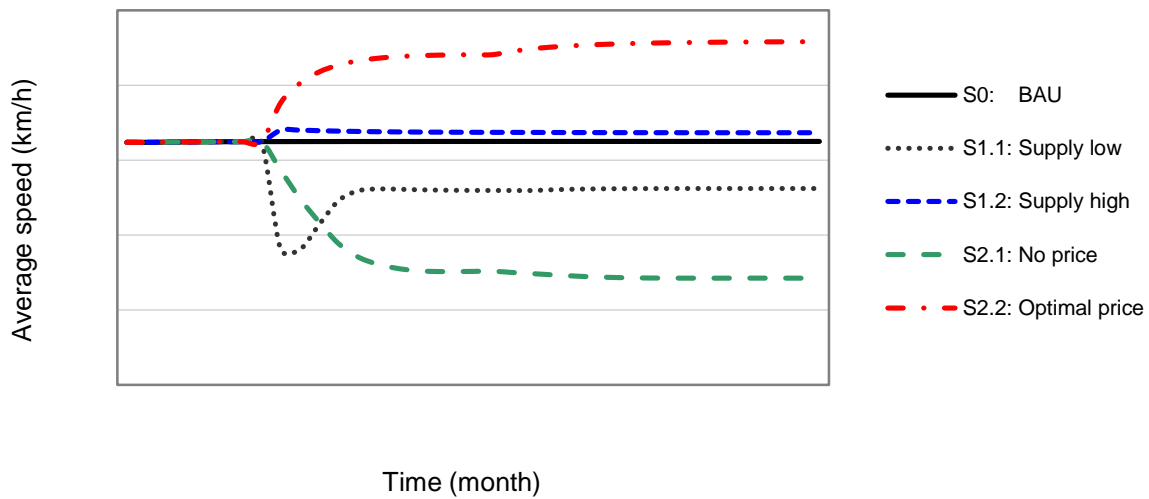


Figure 6. Average speed results

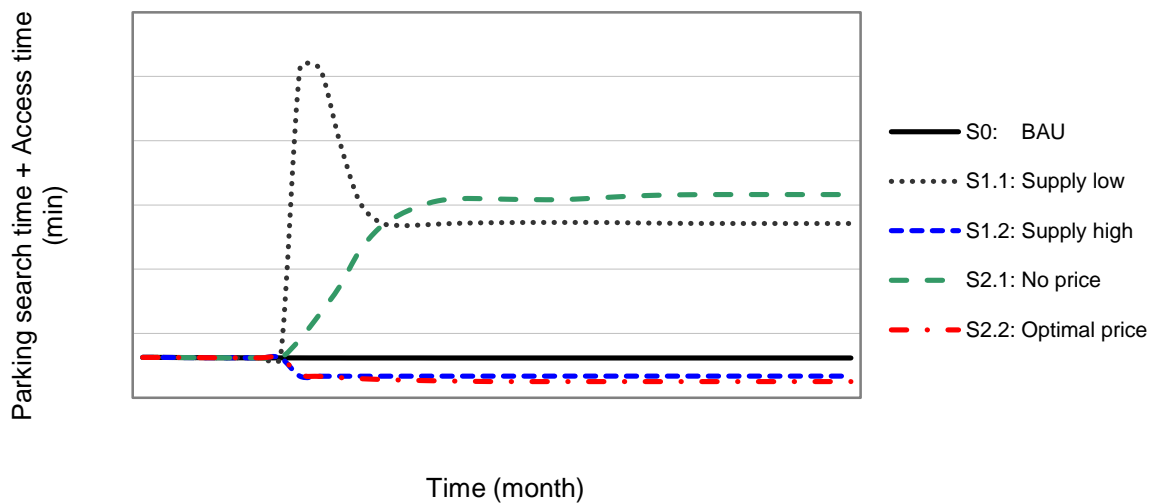


Figure 7. Parking search time results

Table 2. Indicator values at equilibrium under different policy alternatives

| ALTERNATIVES | | Average Speed (km/h) | Average Time per Trip (minutes) | Average Generalized Cost per Trip (€) | Congestion (real / free flow speed ratio) |
|----------------------------|---------------|----------------------|---------------------------------|---------------------------------------|---|
| 0. Business as Usual (BAU) | S=1 P=1 | 21.5 | 43.7 | 9.8 | 0.60 |
| 1.1 Low Parking Supply | S=0.8 P=1 | 20.2 | 46.4 | 9.9 | 0.63 |
| 1.2 Higher Parking Supply | S=1.2 P=1 | 21.7 | 43.3 | 9.8 | 0.59 |
| 2.1 No Pricing | S=1 P=0 | 17.8 | 52.7 | 9.6 | 0.48 |
| 2.2 Optimal Pricing | S=1 P=2.75 | 24.2 | 38.9 | 9.9 | 0.85 |

A short-term adaptation to the new policy circumstances occurs in the first about 6 months after the policy introduction due to the expectations and information factor. In the longer-term, a small variation in the indicators can be observed due the variations in public transport frequencies following changes in demand. The initial discontinuities in the low supply policy alternatives are due to the fact that the model assumes an instant change in the provision of infrastructure which leads to a sudden change in the mobility performance indicators. Since the mobility choices depend on the generalized costs observed in the previous periods, the demand only starts to adapt after the second period after the policy is introduced. Since our focus has been on assessing policy effects in equilibrium, a more realistic representation of short-term behaviour was not among the aims of this work.

Decreasing public parking supply capacity has a negative effect on circulation conditions, increasing trip times. This negative impact is stronger in the short-run because the travellers do not immediately incorporate changes in the travel costs into their travel decisions. This adaptation of expectations progressively takes place in the months following changes in generalized costs, which results in a partial recovery of average speed due to a gradual transfer of travellers from private to public transport.

The results of a higher parking supply alternative supply contrast with those of a lower supply. Circulation conditions slightly improve on balance due to lower parking search and access walking times achieved. This benefit is sufficient to offset a road congestion increase derived from a higher share of private transport.

The alternative with no parking pricing produces the worst results for circulation conditions. The attraction of more private transport demand causes both an increase of road congestion and parking search and access times. The time losses more than offset any time benefits acquired by the demand shifting from public to private transport. In the medium term, a further decrease of average speed is observed due to a reduction of public transport frequencies caused by a decrease of its demand, causing additional degradation of level of service, following a negative *Mohring* effect.

In the price optimization alternative, where average speed is maximized, the optimal price is about 175% times higher than the present level. Such price policy allows both to reduce congestion and parking search and access times to levels that manifestly decrease travel times. At this level, because the parking price is optimal towards travel speed, we know that marginal price effects on factors that improve average speed are equal to marginal price effects on factors that reduce average trip speed. A positive *Mohring* effect is observed in the medium term, conducting to further level of service improvement.

4.4.2 Detailed analysis of policy effects

This section shows in detail the variation of results for a spectrum of possible parking policies.

The variation of parking price allows to highlight that the use of pricing is essential to get the best performance in the mobility system. In this model, the losses in average trip speed incurred by not applying a price would amount to 26%. A curious outcome is that the performance achieved is better with very high prices than with a zero price alternative; the time burdens caused by excess private transport demand at null price are higher than the time losses caused by excessive modal shift in the high price alternative. Another interesting result is that there is an interval of possible pricing at which the level of service achieved is quite stable. Deviations from optimality of plus or minus 30% the optimal level do not produce losses of more than 2% in travel speed. In a mobility system well illustrated by this model, politicians aiming at optimizing the level of service of the urban mobility system but constrained by issues of public acceptability would prefer keeping the price at the lower level of that interval, although this could overlook other possible objectives like reducing air pollution or freeing public space.

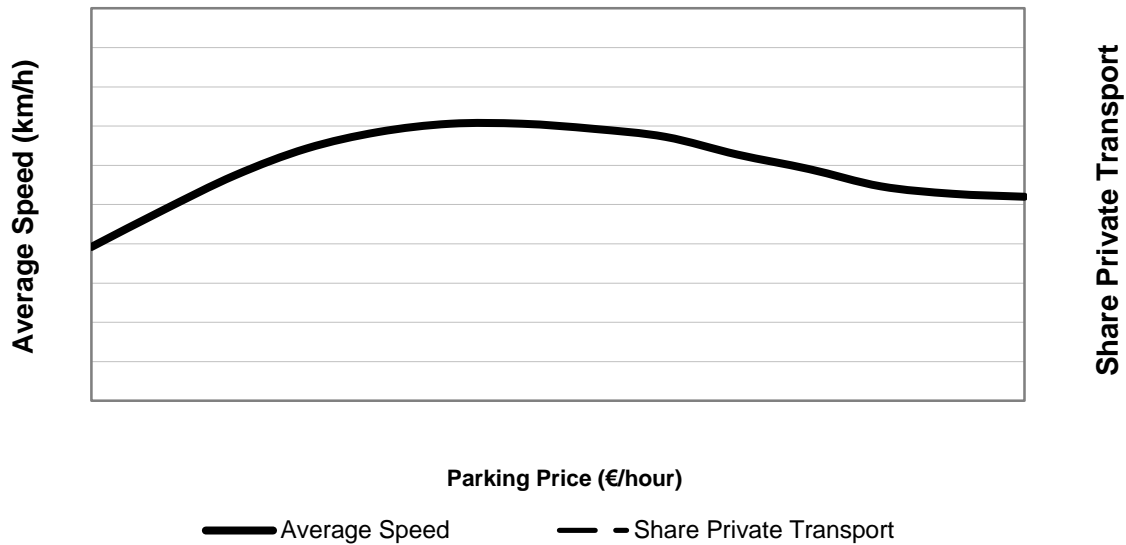


Figure 8. Effects of parking price on average speed and share of private transport

The optimization of price under different public parking supply levels reveals that, after a certain amount of supply, the optimal price and speed are approximately constant. Up to that supply level it is beneficial to increase supply. The theoretical logic of this result is that after there is enough parking supply as to eliminate scarcity of parking space conducting to search and access time losses, no further effect on the system is obtained from additional parking supply. On the other side, under increased scarcity of supply higher prices are necessary to avoid inefficiently high search and access times.

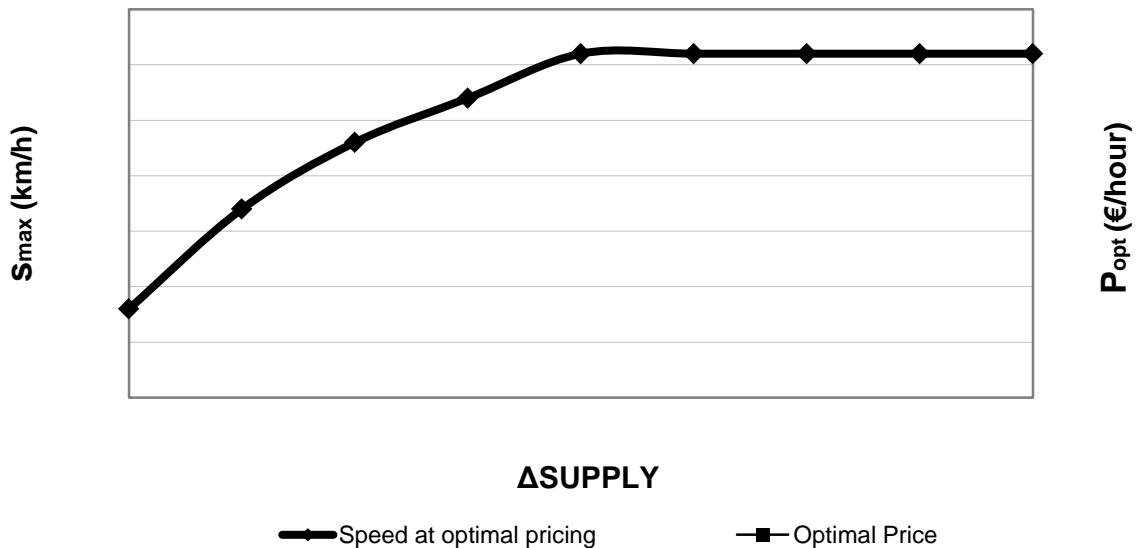


Figure 9. Optimal price under different variations of parking supply to the BAU scenario

4.4.3 Variations for different public transport types

Public transport sharing road infrastructure with private transport is an important characteristic of different urban areas concerning the effects of congestion on public transport performance. Apart from the baseline simulation with a 40% share of road public transport, two extreme cases

of 0% and 100% were tested. As intuitively expected, the higher is the share of road public transport over off-road public transport, the higher the optimal price, since road public transport benefits from the reduction of road congestion. Depending on the infrastructure type of the public transport system, optimal price may vary between 2.45 and 3.25 €/hour. An interesting corollary from this result is that the introduction of measures to segregate infrastructure between public transport and private transport (like bus lanes) allows to reduce optimal parking price, which could be a powerful public argument for politicians aiming at higher public transport segregation from road.

Table 3. Effects of share of road over total public transport demand on optimal price and speed

| Share public transport sharing road with private vehicles | P_{opt} | S_{max} |
|---|-----------|-----------|
| 0% | 2.45 | 25.1 |
| 40% | 2.75 | 24.2 |
| 100% | 3.25 | 22.9 |

5. Discussion

This section provides a discussion on results, their robustness and transferability, and technical strengths and limitations of the model and the system dynamics approach applied to urban parking policy design in general.

5.1 Synthesis of model application results

The simulations suggest that parking pricing may be used to obtain significant mobility performance improvements, including parking demand management and traffic demand management, with results pointing to potential benefits in the average trip speed up to the order of 35% to the system in question in relation to a policy alternative without pricing. The optimal average price level and the overall benefits it brings depend on several assumptions and city characteristics. In relation to parking supply, results underscore that it seems to be a rather ineffective policy if used as a standalone demand management instrument. Moreover, there is a level of supply after which the provision of more parking is useless (as potential benefits in parking search times are exhausted) and that reductions of supply below that level do not produce significant influence on the performance of the system as long as they are matched by appropriate pricing. The explanation for this outcome is that the optimal price for traffic congestion regulation limits the amount of traffic irrespective of the provision of surplus parking space.

The qualitative results are in line with the economic theory which states that the system has a more efficient performance if there is a price set regulating both parking scarcity and traffic congestion. It is significant that this outcome occurs despite the fact that the objective function indicator applied here is average (door to door) trip speed instead of a broader indicator on economic efficiency (see discussion below).

5.2 Robustness and transferability

To believe that the results of the application of such a model can be deemed realistic, not only must we assume that its structural assumptions are correct but also we need to have sufficiently reliable data to calibrate parameters. This application gives no case to reject that both conditions are possible to attain to a useful level of accurateness. It was possible to calibrate the model to represent the aggregate characteristics featured by the available data on key variables of the

transport system in Lisbon, although this was made easier by the existing degrees of freedom related to unknown parameters that could be calibrated.

Important elements of the model that were not sufficiently calibrated through empirical data, such as the congestion function, the modal split function and the parking search and access time functions, could conceivably be calibrated through empirical studies of the local reality and other literature not covered here. The necessary data for calibration of congestion and parking search and access time seems to be possible to obtain through relatively straightforward measurements of load and performance measures for sets of representative links or sites in the urban area. Existing traffic models could also provide a good basis for adjusting aggregate congestion curves⁹. Adjustment of parking cruising time curves dependent on parking demand and supply relations could follow empirical work like that produced by Shoup (2006) or rely on local mobility enquiries. For calibration of mode split behaviour there are diverse and widely applied methods that could be applied at local level or obtained from the relevant literature (e.g. Goodwin et al, 2004). In all cases, data available for short time spans would have to be conveniently converted into meaningful relations on a daily basis, since the aggregate model works with average daily figures.

Whether parameterization relies on solid data or is estimated through subjective opinion, it is relevant to assess the risk related to parameter uncertainty. To minimize risks of misprediction, any available resources to obtain better data should focus primarily on parameters with higher sensitivity on results.

Analyses on the influence of variations of specific parameters also allow providing indications on the transferability of results of a model application to another. The example of the share of road public transport over non-road public transport points out how results can differ from city to city, depending on specific characteristics.

5.3 Technical strengths and limitations

5.3.1 On aggregate VS micro analysis

Using an aggregate urban model features advantages and disadvantages. The main disadvantage refers to its inability to account for local micro phenomena, both spatially and dynamically. This limitation is particularly important when the goal of parking policy is parking demand management, because the scarcity of parking places is a much defined by local area circumstances in space and time. To account for these in detail, system dynamics modelling should be complemented by micro level analysis.

In contrast, the use of parking policy as a road traffic demand management instrument must be designed in an aggregate rather than local perspective, since the physical relationship between network congestion and parking use is disperse. Therefore, in the field of road network demand management, an aggregate modelling approach may be the most appropriate analytical tool.

The best approach in designing parking policy directed both at parking demand management and road network demand management is to complement aggregate modelling with local parking scarcity assessment. However, local administrations often take decisions on parking policy based more on political than technical concerns¹⁰. This may occur for various reasons, like concerns of political nature, low regard for technical capabilities or scarcity of budget or time for

⁹ Later to the development of this work, aggregate congestion functions have been calibrated to different simulations of the traffic model used for the Lisbon Mobility Plan within the project DEMOCRITOS (Grant Agreement no. 233744 funded under the 7th Framework Programme of the European Commission) – see Fermi et al, 2011.

¹⁰ For example, in Lisbon, until recently the parking price was set at the same level in all covered areas of the city, revealing limited technical insight taking part in the price decision.

their use. It may be thus be too optimistic to expect the departure to large-scale technical policy analyses. As a first step, the use of more aggregate models seems to be an appropriate approach, since they are capable of giving a wide insight, while they are comparatively more economical.

5.3.2 *On economic efficiency*

The notion of economic efficiency applied to mobility implies that the use of the available resources should produce the highest value to citizens. Given the approach applied here of evaluating the performance of the urban mobility system by the average trip speed, one may question if it is adequate from the perspective of economic efficiency.

Improving average speed of all trips is apparently a good indicator, but the way in which it is achieved may not be fully in line with the aim of value maximization, since the value of mobility depends not only on the time spent to access the point desired, but also on the value put by the travellers on that time. Mobility management policy should ideally take into account the value of time of individuals, but parking policy does not succeed to do it when applied as a traffic demand management instrument. By pricing parking only, it excludes or over-considers segments of demand depending on the time of their parking time use. Some segments of demand do not use parking at all (through traffic) while others use it all day; the first are totally excluded from the parking pricing system, while the second are possibly overburdened.

As a consequence of this imperfect relationship between object of price and the fundamentals of value, the goal of economic efficiency is sub-optimally addressed. In the case of parking policy, the effect may be that subjects with very high value put on travel time may still be excluded from the use of private transport, while some subjects with low value to travel time (or with a good transport alternative at hand) may remain on it. Therefore, even if parking policy is effective in increasing travel speed at constant aggregate demand, theoretically it may still be economically harmful if the market distortions it introduces produce higher costs. This calls for prudence when interpreting the results of model, particularly in assessing optimal policy. The fact that the policy affects only part of the demand suggests that the optimal parking pricing policy from the economic efficiency perspective is below the optimal policy prescribed by the maximization of average speed.

The model could be extended to account for these market distortion phenomena. This would be possible particularly by considering different demand segments according to their value of time. Such a model upgrade may also be useful to compare the efficiency of parking pricing with other traffic demand management instruments like road charging.

5.3.3 *Other caveats*

In the present modelling exercise parking policy was analysed as a standalone policy, i.e. effects of other possible demand management instruments were absent. It is common that cities have other demand management instruments in practice, and optimal parking policy should be assessed in coordination with them.

Cruising time costs were considered as additional time lost by individual drivers but no additional traffic congestion effects caused by the cruising effect were considered. Time costs derived from the order of appearance effect were not considered either. Their consideration would make the overall costs of absence of regulation more severe and optimal price would converge at a higher level.

The assumption that public parking policy is able to determine the market price of parking is valid in situations where private parking supply is lower than demand. In the situation where the private sector is able to supply all the existing demand, the public sector is not able to influence traffic demand through public parking pricing and supply.

6. Conclusions

The emergence of new technological possibilities is putting in question the present use of parking-based policy instruments as a response to urban problems of road congestion and pollution. From the political perspective, it becomes more relevant than ever to assess the ability of parking to solve mobility problems in an effective and efficient way.

Given that congestion taking place in particular road links is generated from traffic with multiple origins and destinations, parking policy as an instrument to manage road traffic demand in an urban area must necessarily consider the aggregate behaviour of mobility flows. On the other hand, because the mobility system is complex and the actual effects of policies are not always self-evident, along with the need to offer meaningful and costs-effective analytical approaches to policy makers, raise the need of using practical modelling approaches. The system dynamics modelling approach seems to gather these ingredients.

This paper presents a system dynamics modelling framework and a case of application aimed at the assessment of effectiveness of urban parking policy design at an aggregate level, particularly parking supply and parking pricing. The model has a structure similar to other stylised dynamic models of urban mobility but includes specific adaptations to cope with parking related behaviour and to compute specific indicators to measure policy efficiency. Due to existing technical difficulties in assessing economic efficiency, the objective function used for policy assessment has been the aggregate level of service, particularly average trip (door to door) speed for all transport modes considered.

Even with this difference in objective, the qualitative results of the model coincide with the prescriptions that would come from the economic theory. The maximization of level of service is obtained with a price for parking, and parking supply increments beyond the optimal level of demand produce limited benefits. Even if trips by private transport are on average faster, the time gains related to traffic congestion and parking search and access time outweigh the time losses of demand shifting to public transport.

At a quantitative level, we discussed if this type of model could produce assessments sufficiently accurate for policy prescription, particularly for parking pricing aimed at traffic demand management. The case of application parameterized and successfully calibrated the model with available local data, but for a full check on the quantitative validity of the model further calibration with additional data would be required, particularly in relation to the key functions of congestion, modal choice and parking search and access times. Within the possible model calibration and validation, the case of application has shown no reasons to reject that a useful level of quantitative accurateness could be attained provided the additional necessary data. Such data, in relation to the key functions identified, seems to be possible to obtain through empirical observations at the local level, use of existing traffic simulation modelling or realization of enquiries. If this is the case, the approach may be recommended for technical support to practical policy prescription in cities.

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