MaaS Economics: Should we fight car ownership with subscriptions to alternative modes?

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1 Introduction

Mobility as a Service (MaaS) has gained popularity in recent years as a brand and an innovative concept towards sustainable urban transport provision. The concept proposes integration between various shared transport modes, thus delivering a comprehensive service for travellers including all phases of the door-to-door journey. The core aim behind integration is to replace individual car use, a major source of often under-priced and consequently welfare degrading negative externalities. Proponents of the MaaS concept often claim that a customer oriented integration of public transport and various shared modes can make individual car ownership unnecessary, which may lead ultimately to a reduction in car use, congestion, and harmful external costs.

The MaaS concept envisages integration between alternative modes in various ways. Information provision and the use of advanced telecommunication technologies, i.e. smart phones and other mobile devices, are key ingredients of the smooth transition between services provided by transport operators. From an organisational point of view, the engine of integration would be the MaaS operator, an agent that provides a two-sided platform for individual transport operators on the one hand, and travellers on the other hand who would perceive all available travel options in the city as a single mobility service.

Finally, and from the viewpoint of this paper most importantly, the majority of MaaS concepts propose that the unified service should be made available under a centralised tariff system, in which customers could access all alternative modes by purchasing subscriptions or predefined bundles of travel permits, often labelled as mobility packages. The aim is to

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make alternative modes more attractive, which may well be a legitimate goal if car use is under-priced. However, in microeconomic theory such techniques are considered under the umbrella term nonlinear pricing, and are normally identified as a form of second-degree price discrimination and an efficient form of revenue generation with mixed impact on economic efficiency (see a solid stream of microeconomics literature dating back to Brown and Sibley, 1986, Leland and Meyer, 1976, Littlechild, 1975, Oi, 1971).

Based on the relatively small but rapidly growing literature of Mobility as a Service, it seems the majority of research efforts are focused on predicting its impact on travel demand (Matyas and Kamargianni, 2018, Wong et al., 2018). Although travel demand is indeed an important indicator of the effectiveness of new policies, it does not uncover how the policy affects overall social welfare, especially when externalities are present in consumption. Interestingly, the MaaS literature often uses the terminology of profit oriented corporate management in the context of efficient policy design for urban transport provision, which is somewhat confusing, given that this industry is characterised by regulated natural monopolies and various externalities. For example, supply-side optimisation including pricing is frequently labelled as 'developing MaaS business models' in the related literature (Aapaoja et al., 2017). Socially optimal supply is rarely considered as a 'business model' in applied welfare economics, which suggests that dispite its popularity in industry, the MaaS concept is still detached to some extent from the mainstream transport economics literature.

2 Research Objectives

Adopting the usual steps of the microeconomic analysis of transport supply to the MaaS framework, one can identify four key gaps in the related literature. First, we know little about how a future MaaS operator should/will set the prices of subscriptions and mobility packages. Second, it is unclear how the available capacity in various transport modes (e.g. frequencies in public transport or the fleet size in shared modes) will react to the introduction of a completely new tariff system. Third, we do not know at this moment how new fare and capacity levels will affect (i) the net consumer benefit of urban transport provision, (ii) operational costs and public subsidies to public transport, and (iii) the magnitude of externalities generated by the transport sector as a whole. Fourthly, in general terms, it has not been proven yet that non-linear pricing of alternative modes is actually an idea that improves social welfare in transport markets.

This research uses the toolbox of welfare economics to investigate the efficiency of the nonlinear pricing techniques proposed in the MaaS concept. In particular, we intend to derive conclusions about

(1) the net welfare impact of unlimited-use subscriptions and bundled tariff products designed for the accelerated use of alternative modes;

(2) whether nonlinear pricing policies lead to a reduction in individual car ownership, and whether car ownership is proportional to congestion and the (in)efficiency of the transport system, when mild externalities may be generated during the use of alternative modes as well;

(3) how the MaaS operator's economic objective (e.g. welfare maximisation, profit maximisation, congestion minimisation, car ownership minimisation) will affect the net welfare impact on society of implementing nonlinear pricing in the MaaS framework.

The goal of this short paper is to report on the methodology and some of the early results of modelling efforts proposed to answer the research questions above. In subsequent sections we introduce a modelling framework in which car ownership, the choice of tariff products and mode choice are interdependent compontents of the demand system.

3 The model

Modelling Mobility as a Service is challenging, because it requires a number of extensions relative to traditional multimodal settings with public transport and car use. First, car ownership has to be an endogenous module, to be able to show the ability of MaaS tariff products to substitute the use of private vehicles. There are economic models for car ownership in the literature, but they are rarely mixed with interactions with other modes[1]. Second, nonlinear pricing in itself, within the public transport literature, is also significantly underrepresented, as most of the supply models in the literature consider only one (representative) usage dependent fare. A small branch of the literature hallmarked by Carbajo (1988), Jara-Díaz et al. (2016) and Hörcher et al. (2018) focus on the efficiency of travel passes when single tickets are also available, and find that this form of nonlinear pricing may be efficient in the hands of a private monopolist, but cannot increase social welfare if public transport use if subject to negative consumpation externalities such as crowding. Third, modelling shared transport services such as free-floating car sharing has not reached a consensual status in the literature so far, so several new assumptions have to be made to reproduce the basic features of car sharing in a MaaS supply model.

As part of this research we develop an analytical framework that models three levels of transport related decisions of the *representative* traveller:

I. Car ownership in the long run (index i);
II. Choice of tariff products, e.g. MaaS mobility packages, in the short run (index j);
III. Individual travel demand and mode choice in the very short run (indexed by m).

We formulate the demand model such that the expected consumer benefit of the representative use could be derived analytically, and thus consumer surplus could be compared with operational and external costs in subsequent analyses.

On the first level, car ownership is captured by i that can take two values: $i = 1$ if the representative user does own a car, and $i = 0$ if she does not. On the second level, we consider the choice of tariff product j, which can be either sticking to pay-as-you-go ($j = 0$), buying a rail pass ($j = 1$), buying a multimodal pass ($j = 2$), or choosing one of three *mobility packages* ($j \in \{3, 4, 5\}$) that enable a predetermined number of trips for a discounted price, normally cheaper than the same amount of consumption with usage dependent fees.

[1] De Borger and Mayeres (2007) is one of the exceptions, but their public transport model is rather stylised, both in terms of user costs and the tariff system considered; tariff products are not differentiated.

On the third level we consider three modes of transport: individual car use ($m = c$), public transport ($m = p$), and a shared mode ($m = s$), i.e. bike sharing or car sharing. Service quality in these modes is determined by the available road capacity, the frequency of public transport, and the average fleet size per geographical area in the shared mode. We assume that road capacity is fixed, but frequencies and the fleet size may be endogenous variables that the operators set to optimise with respect to their economic objectives. For technical reasons we introduce a fourth alternative on the level of mode choice, which represents the outside option of not travelling at all. In this case $m = 0$. The purpose of the outside option is to allow for aggregate travel demand to be elastic with respect to the user cost of available modes. This demand system is standard standard in the literature (see e.g. Basso and Silva, 2014).

We put this supply-side framework into the simplest possible network environment, the back-haul problem, to allow for the marginal user, operational and external costs of travelling to vary between demand-independent markets in all three modes. We believe this is a crucial property of real transport systems from a pricing point of view that cannot be appropriately reflected if supply in a model is optimised for only one representative OD-pair. We denote the two directions of the back-haul setting with variable d, where $d = a$ is the market with higher demand intensity, and $d = b$ is the 'off-peak' direction. The number of potential users in these markets are N_a and N_b, respectively.

3.1 Mode choice

Let us now describe the basic mathematical structure behind the model. This is a nested random utility discrete choice model in which utility on each of the three decision levels is determined by the sum of a systematic and a random component: $u^m_{dij} = v^m_{dij} + \varepsilon^m_{dij}$. In the following discussion we focus on the specification of the systematic part, while the random term captures, with type I extreme value distribution, unobserved heterogeneity in user preferences. As normally, we assume that the representative user selects the alternative providing the highest utility, which leads us to the well-known logit demand system.

The disutility of choosing mode m for a consumer with properties d, i, j is formulated as

$$
\begin{aligned}
v^c_{dij} &= A^c + \delta(\upsilon t^c_d + c + c^{park}_d),\\
v^p_{dij} &= A^p + \delta\Big[\upsilon_w f^{-1} + \upsilon t^p_0\Big(1 + \omega\frac{q^p_d}{fS}\Big) + \phi^p_j\tau^p_d\Big],\\
v^s_{dij} &= A^s + \delta[\upsilon\,(t_d + t^{acc}_d) + \omega_d + \phi^s_j\tau^s_d \cdot t_d].
\end{aligned}
\tag{1}
$$

These expressions require detailed explanation. All three utility functions contain an alternative-specific constant A^m, and user costs in monetary dymension are transformed into utils with parameter δ, the marginal utility of monetary payments, now assumed to be the negative of the marginal utility of income. In all three formulae δ is multiplied by the generalised cost of travelling.

In the car mode generalised cost includes the value of in-vehicle time (υt^c_d, where υ is the standard value of time and t^c_d is travel time bar car in direction d), and a monetary operational cost (c), and the cost of parking at the destination of market d. Congestion technology is based on the usual BPR cost function, i.e.

$$t_d^c = t_0^c \cdot \Big[1 + 0.15\Big(\frac{q_d^c + q_d^s}{K}\Big)^4\Big], \tag{2}$$

where t_0^c is free-flow journey time, and the degree of congestion depends on demand for private and shared car trips in direction d, q_d^c and q_d^s, respectively. Parking cost c_d^{park} is an exponential function of q_d^c, capturing in a simplified way competition for land. Road pricing is neglected in the model, as the the MaaS concept probably would not even exist if proper congestion charging was already a widely accepted regulatory policy.

The generalised cost of public transport in (1) includes three times. The first one is the cost of waiting time $\upsilon_w f^{-1}$, where υ_w is half of the value of waiting time and f is service frequency. The second is the in-vehicle travel time loss υt_0^p multiplied by a crowding dependent factor in which S is vehicle size, so that the fraction is density of users inside the vehicle. The third element is and the monetary fare paid. Specifically, τ_d^p is the fare itself, and ϕ_j^p is a binary variable which equals to one if someone holding tariff product j still has to pay a usage dependent fee for public transport trips. This specification is standard in the public transport literature.

In case of care sharing, on the other hand, we cannot rely on existing modelling practicies, as, to the best of our knowledge, analytical models in a context like ours have not been published in the literature so far. The utility function in (1) includes the cost of driving time loss, $\upsilon \cdot t_d$, which is equivalent to what private car drivers bear, plus an access time cost t_d^{acc} that captures the disutility of reaching a nearby shared vehicle by walk. The specification of t_d^{acc} is crucial from our perspective, as it determines how demand in of the two directions will affect the availability of cars in the opposite market. Let ρ denote the size of the shared car fleet, and σ represent the share of this fleet available for the potential users of market $d = a$ at the beginning of the morning period. Use $0 \geq \psi \geq 1$ as a variable representing time within the peak period. If $F_a(\psi)$ is the available fleet size for market a at time ψ, such that with a homogeneous distribution of travel demand over the peak,

$$F_a(\psi) = \rho\sigma + \psi(q_b^s - q_a^s) \tag{3}$$

then access time at this particular point in time can be expressed as

$$h_a(\psi) = h_0 + h_1 \frac{k}{F(\psi)} = h_0 + h_1 \frac{1}{\rho\sigma + \psi(q_b^s - q_a^s)}. \tag{4}$$

In the latest formula h_0 is the minimum access time when plenty of cars are available, and $h_0 + h_1$ is the longest possible walk time when there is only one available car in the origin zone concerned. Eventually, the *expected* access time is

$$t_a^{acc} = E[h_a(\psi)] = \int_0^1 \Big[h_0 + h_1 \frac{1}{\rho\sigma + \psi'(q_b^s - q_a^s)}\Big] d\psi'. \tag{5}$$

Unfortunately, this specification is not suitable to impose the contraint that by the end of the peak period, car sharing demand can never exceed the total number of available car. In case of direction a, this reads as $\sigma\rho + q_b^s - q_a^s \geq 0$. This constraint in built into the model through 'availability cost' ω_d in (1) which is activated when the constraint above is violated.

Finally, the last component of v_{dij}^s in (1) is the price of using car sharing. We consider that car sharing is normally priced on a travel time basis, so τ_d^s is a price per minute, while ϕ_j^s is once again a dummy variable that equals to one if tariff product j does not allow free access to car sharing.

3.2 Choice of tariff product and car ownership

On the second level of the decision tree the representative consumer selects one of the available tariff products j. To determine the attractiveness of a tariff product, we have to derive the expected utility of the mode choice situation for the user possessing tariff product j. Using the logsum approach,

$$E[u_{dij}^m] = \mu_{ij}^{III} \cdot ln\Big(\sum_m exp(v_{dij}^m/\mu_{ij}^{III})\Big). \tag{6}$$

Consumers travelling in direction d with car ownership state i attach the following utility to owning tariff product j:

$$V_{dij} = E[u_{dij}^m] + \delta\frac{T_j}{L} = \mu_{ij}^{III} \cdot ln\Big(\sum_m exp(v_{dij}^m/\mu_{ij}^{III})\Big) + \delta\frac{T_j}{L}, \tag{7}$$

where T_j is the price of tariff product j that we normalise by the length of its availability to a daily level. From V_{dij} we derive the market share of each tariff product as well as the expected utility in the choice situation of level II.

The decision on car ownership is eventually driven by utility gained with and without the availability of the private car in the mode choice situation. For car owners in market d, this is

$$V_{d1} = \alpha_1 + \mu_1^{II} \cdot ln\Big(\sum_j exp(V_{d1j}/\mu_j^{II})\Big) + \delta\frac{C}{ML}. \tag{8}$$

Notation: α_1 represents the constant (dis)utility of owning a car, an alternative-specific constant, the logarithmic term is the logsum on the tariff product level, C is the yearly monetary cost of car ownership net of operational costs, and M measures the number of tariff product periods in a year (practically speaking, the number of months in a year). Thus, we assume that car ownership decisions are re-evaluated on a yearly basis, but utility is normalised to a daily daily basis. Indirect utility for non-car owners (i.e. V_{d0}) is equivalent to (8), except that the car ownership cost disappears, and the logsum component has V_{d0j}'s in its argument.

3.3 Consumer surplus and social welfare

Based on the three-level nested logit specification detailed above, the expected utility of the representative traveller in market d, expressed in monetary terms using δ, is

$$U_d = -\frac{\mu^I}{\delta} ML \cdot ln\Big(\sum_{i\in(0,1)} exp(V_{di}/\mu')\Big) \tag{9}$$

per year. Note that the scale of expected travel utility is not meaningful in a discrete choice model, only changes in utility can be measured appropriately. Our aim is to derive the amount of consumer surplus (i.e. net user benefit) of providing alternative modes beside congestible road use. Let us define U_d^{ref} as the reference level of utility. This is derived by setting the price of alternative modes so high that no traveller is willing to use it; in this case U_d^{ref} is limited to the utility generated by road use in the absence of alternatives. Thus, the consumer surplus of public transport and car sharing provision becomes

$$CS(\theta) = \sum_d N_d(U_d(\theta) - U_d^{ref}), \tag{10}$$

in which θ, supressed in earlier equations for the sake of simplicity, denotes a vector of relevant supply-side variables such as the price of tariff products and the frequency of public transport.

Based on choice probabilities on the three levels of consumer decisions, one can derive derive for each mode, differentiating between travel directions:

$$q_d^m = N_d \sum_i \sum_j \pi_{di}\pi_{dij}\pi_{dij}^m, \tag{11}$$

where the choice probabilities π_{di}, π_{dij} and π_{dij}^m are standard logit expressions. System-level revenues from public transport and car sharing operations are

$$\begin{aligned} R(\theta) =& ML \cdot \Big[\sum_d \sum_i \sum_j N_d\, \pi_{dij}^p \phi_j^p \tau_d^p + \sum_d \sum_i \sum_j N_d\, \pi_{dij}^s \phi_j^s \tau_d^s t_d\Big] \\ &+ M \cdot \Big[\sum_d \sum_i \sum_j N_d\, \pi_{dij} T_j\Big]. \end{aligned} \tag{12}$$

In the first row of the revenue formula we have the payments from usage dependent public transport and car sharing fees, while the second row measures revenues from the sales of pass and mobility packages, if applicable. System profits is the sum of revenues in (12) and the operational costs of public transport and car sharing provision. For the sake of simpicity, we express these operational costs as a linear function of public transport frequency f and the car sharing fleet size ρ, so that the system profit becomes

$$\Pi(\theta) = R(\theta) - z^p f - z^s \rho, \tag{13}$$

where z_p and z_s are exogenous slope parameters.

Finally, we need an aggregate measure of social welfare, to be able to express the net benefit of service provision, considering both consumer costs and benefits, and the costs and revenues generated on the operator's side. This social welfare metric is simply the sum of the consumer surplus and profit functions defined above.

$$W(\theta) = CS(\theta) + R(\theta) - z^p f - z^s \rho. \tag{14}$$

4 Policy simulation

In this preliminary phase of this research we assume that the entire system is regulated by a single entity, the MaaS provider. That is, we neglect potentially very complicated interactions between the MaaS provider and the operators of individual modes that may in reality lead to an uncertain bargaining process. Consider that supply and the system's performance can be evaluated on the bases of various economic criteria, including (1) welfare maximisation, (2) profit maximisation, (3) congestion minimisation and (4) car ownership minimisation. In the long run we plan to apply an optimisation algorithm to derive optimal supply according to these objectives. In the current stage of the research project we limit the investigation to the introduction of MaaS tariff products beside pay-as-you-go pricing, and th evaluation of their performance at various tarifflevels according to the four objectives above.

We use the modelling framework to simulate five pricing policy scenarios. That is, we compare the performance of the following pricing schemes:

(1) Flat fares only, with undifferentiated directions, $\tau^p = \tau_a^p = \tau_b^p$ and $\tau^s = \tau_a^s = \tau_b^s$;
(2) Flat fares combined with an unlimited-use public transport pass;
(3) Flat fares combined with an unlimited-use pass for all alternative modes (multimodal pass);
(4) Flat fares combined with 3 mobility packages;
(5) Direction-differentiated pricing, without any MaaS tariff products.

Scenarios 2 and 3 are straightforward; unlimited-use pass usage requires a one-off entry fee T_j, after which the marginal monetary cost of travelling drops to zero for L trips. By contrast, mobility packages enable a predetermined number of public transport and car sharing trips, for a discounted price relative to the cost of the same consumption with pay-as-you-go fares. Package $j = 3$ includes many public transport trips with fewer car sharing, package 4 has many car sharing combined with fewer public transport, while package 5 is contains modest amount of both modes. These settings are summarised in Table 1 as well.

Table 1: Specification of mobility packages

	Trip allowance in each mode (m)	
Package ID (j)	Public transport (p)	Car sharing (s)
3	0.5 L	0.25 L
4	0.25 L	0.5 L
5	0.25 L	0.25 L

We calibrate the model to represent a reasonable urban transport setting. We have $N_a = 9000$ and $N_b = 1000$ potential users, so demand is heavily unbalanced, just in case of a typical radial transport corridor of a monocentric city. L and M are set to 30 and 12, respectively, so we model yearly car ownership decisions with monthly tariff products. Road capacity and public transport frequency are set to have a significantly congested initial equilibrium combined with non-negligible crowding on the public transport alternative. Parameters of the demand model are set to reproduce around 40% mode share for both individual car use and public transport, 10% for car sharing with a fleet size of $\rho = 300$ shared vehicles, and 10% of the population does not travel at all at the initial equilibrium.

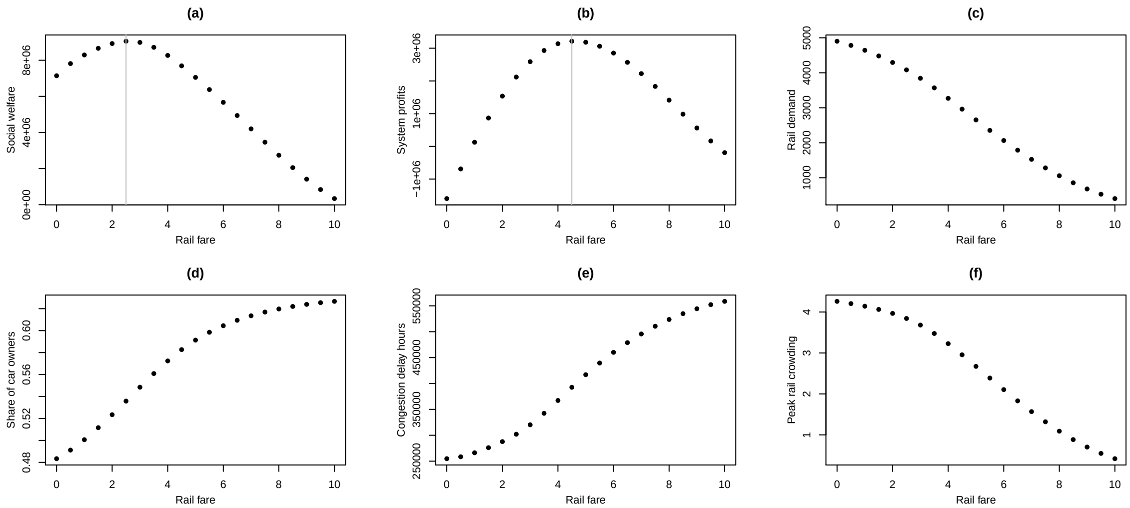

Figure 1: Scenario 1 – Impact of flat fare level on system performance.

5 Preliminary results

This is an ongoing research project. However, we can present some of the preliminary results that are already valuable due to the insights they allow for. Let us begin the analysis with Scenario 1, i.e. the case of flat fares in both alternative modes.

Panels (c) to (f) in Figure 1 are meant to illustrate that the model mechanics with the current set of parameters are in line with realistic expectations: the relationship in panel (c) is a proper downward sloping demand curve, panels (d) and (e) tell that car ownership and car use are both inversely elastic with respect to the public transport price, and crowding in the rail mode ranges between zero and 4 passengers per square metre depending on the fare level we set. Due to the presence of crowding externalities, the socially optimal fare is above zero, despite substitution with congestible and under-priced road use. Congestion delay in plot (e) is computed as the additional travel on a yearly basis that drivers lose above the free-flow travel time if congestion was completely eliminated. Panel (a) shows that welfare is maximised at around $\tau^p = \$2.5$, but a welfare maximising operator would raise this fare to as high as around \$4.5. The plot of the car sharing fee shows similar relationships in terms of interdependencies with car ownership: with cheap car sharing residents do not own that many cars, but the congestion level increases due to mode shift towards car sharing.

Next, we turn to the introduction of travel passes for only one alternative mode, public transport. We fix the flat fares, both τ^p and τ^s, to their welfare maximising levels, and vary the price of the pass in Figure 2. Travel pass usage becomes attractive under around $T_2 = \$80$, which is equivalent to making $L = 30$ trips per month with single tickets only. Below this pass price, car ownership diminishes (panel b) and a mode shift begins to take place towards increased rail use (see panel d) with strong impact on rail crowding in panel (f). Figure 2 reveals a less anticipated consequence of pass sales, however. Panel (c) shows that in the interval $T_2 \in (80, 40)$, congestion actually increases. This is a counter-intuitive result, because one would expect that cheap travel passes should attract drivers to public transport.

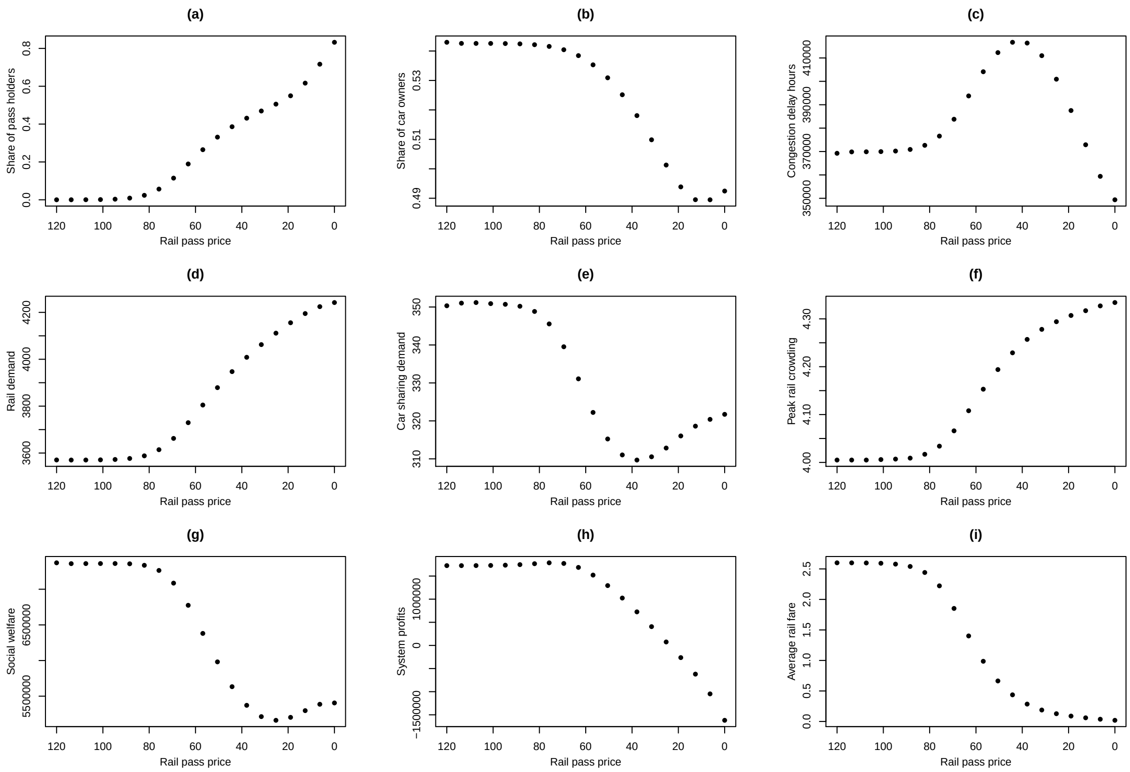

Figure 2: Scenario 2 – Impact of the price of public transport passes on system performance.

We looked deeper into the simulation results to find the explanation for this phenomenon. Let us split public transport users into two groups: travel pass users ($j = 2$) and single ticket users ($j = 1$). As passes become cheaper, more and more passengers decide to buy this subscription, and their public transport increases, as expected. On the other hand, for those – less frequent – public transport users who stick to single tickets, rail becomes significantly less attractive, because τ^p is constant but the level of crowding increases due to pass holders. As a consequence, a considerable part of $j = 1$ consumers switch to more driving. At a relatively low market penetration of the rail pass this effect is so strong, that congestion actually increases, despite the fact that the average price of a public transport trip decreases (see panel i). To sum up, the cause of the adverse outcome is that pass holders push single ticket users out of the public transport mode through crowding.

Partly due to increased congestion, and partly due to the overconsuming behaviour of pass holders, social welfare is maximised if rail passes are actually not introduced at all (panel g). This result is in line with earlier findings in Hörcher et al. (2018), where mode choice was neglected, by overconsumption in the presence of crowding externalities was a sufficient reason in itself to make the availability of passes welfare degrading. From a profit generating point of view, it is barely visible in panel (h), but profits somewhat increase at a modest level of pass ownership. That is, a profit oriented MaaS operator is likely to be more willing to introduce travel passes, due to the revenue generating potential of nonlinear pricing (Anderson et al., 1992).

Is this picture more positive when we expand the availability of travel passes to more than one mode? Figure 3 does not indicate significant differences. An exception is that car sharing demand now moves in the opposite direction, as cheap access to car sharing implies it naturally. The impact of multimodal passes on car ownership is slightly stronger, which may look like a positive property for the first sight. Unfortunately, the adverse impact on total congestion delay on the other hand is even stronger than in case of the rail pass, which is convincing, given that car sharing now contributes to congestion additively. Based on these observations it is not surprising that the welfare effect of multimodal passes is not positive at all. In fact, we replace the set of welfare optimal flat fares in Scenario 1 with a tariff product that increases both rail crowding and rail congestion, inducing overconsumption relative to marginal social cost pricing in both modes.

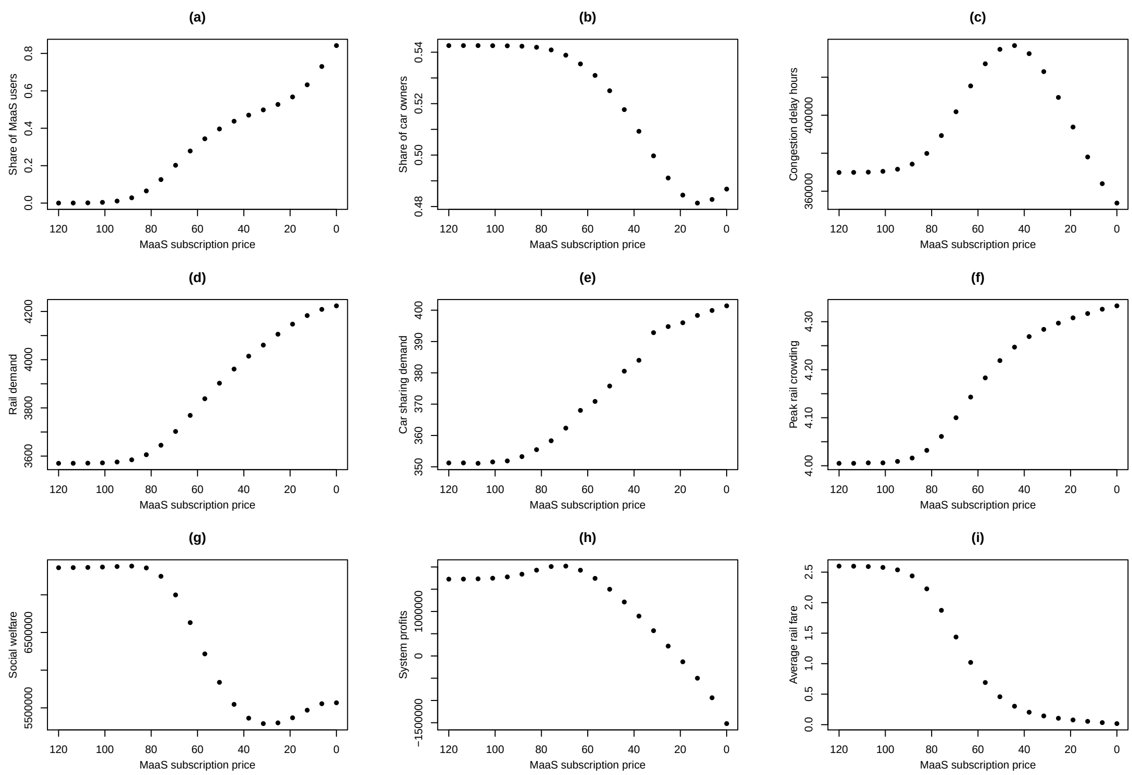

Figure 3: Scenario 3 – Impact of the price of multimodal passes on system performance.

Let us now move on the case of mobility packages in Scenario 4. In this case passengers can choose between three alternative tariff products with different levels of consumption offered in each bundle (see Table 1). To make this scenario suitable for simple numerical analysis, we vary the level of discount offered for package holders, i.e. the multiplier applied when the price of a mobility package is determined relative to pay-as-you-go payments for the same amount of trips. For example, when the multiplier is 80%, then $T_3 = 0.8 \cdot 0.75 L\tau_a^p$. (Actually we added access to car sharing 'for free', but this can be amended in subsequent phases of this research project.)

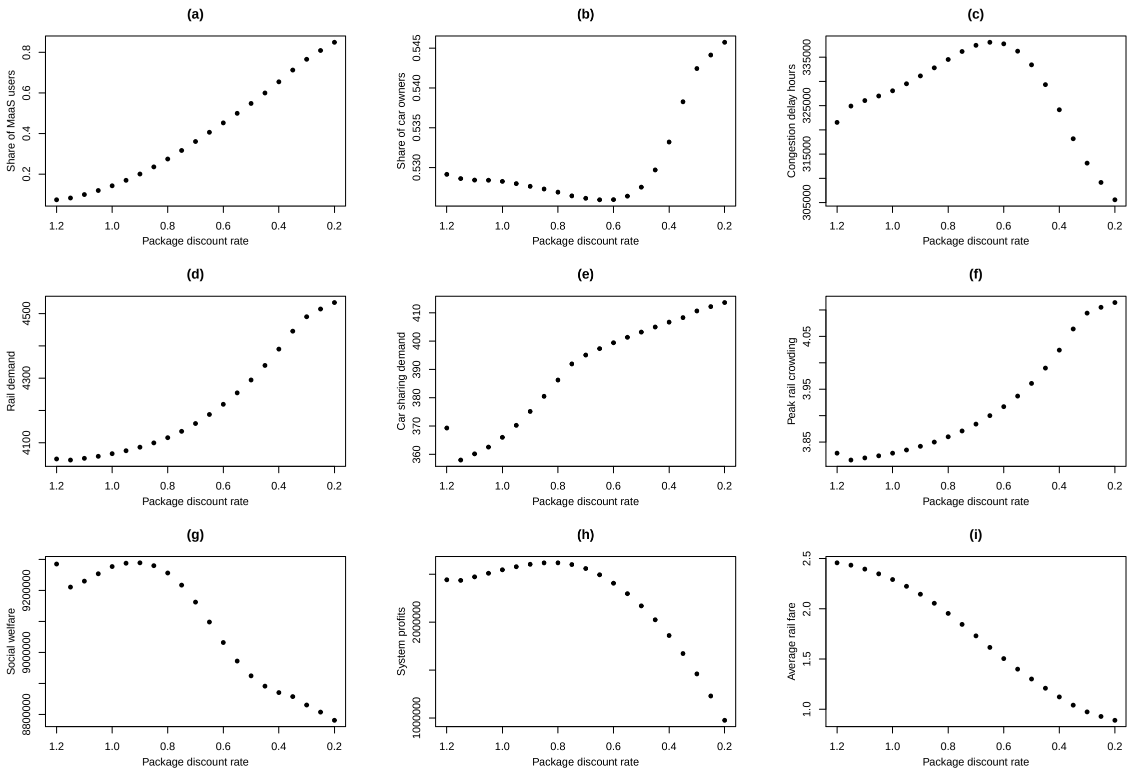

Figure 4: Scenario 4 – Impact of the discount level of mobility packages on system performance.

Simulation results in Figure 4 show that the impact of mobility packages on system performance somewhat differs from what we saw in scenarios 2 and 3. Mobility packages achieve mild reduction in car ownership until the discount rate of around 60%, but then ownership tends to increase again sharply. The impact on congestion delay is the opposite, surprisingly: congestion slightly increases in the high region of mobility package prices, and then starts to decline with more significant discounts. Nevertheless, the impact of bundling on aggregate social welfare creates ground for somewhat more optimism. Panel (g) in Figure 4 shows that the welfare maximising discount level is in the range of 90%, where around 20% of the population possesses one of the three mobility packages. In the current stage of the project we cannot give a precise explanation for this. It is certain, however, that congestion mitigation is not the reason why mobility packages improve welfare, as opposed to what the MaaS literature often suggests, because congestion actually increases at the welfare maximising discount level. It is more likely that the benefits of variety, a positive consequence of product differentiation in the presence of heterogeneous preferences (Anderson et al., 1992) brought in by the random component in the logit demand model, is what could explain the success of mobility bundles.

From a profits point of view, we observe in panel (h) that a private monopolist as MaaS operator would offer more discount (around 80%) than a welfare oriented service provider. Underpricing mobility packages is harmful for society, because crowding, congestion as well as social welfare are less beneficial in this case.

Finally, let us briefly discuss our results for Scenario 5, MaaS tariff products or any other forms of nonlinear pricing are excluded, but peak and off-peak usage fees can be differentiated. In Figure 5 we plot system performance metrics against the level of discount in the off-peak direction, i.e. $\tau_b^p/\tau_a^p = \tau_b^s/\tau_a^s$. The result of this policy is very straightforward. Off-peak discounts lead to monotonous reduction in car ownership and congestion delay, with a parallel increase in the popularity of alternative modes. The socially optimal level of off-peak discounts is 40%. Note that system profits, on the other hand, monotonously decline with the introduction of cheaper travelling off-peak. This may imply that private operators are normally not prone to offer such discounts, as long as peak fares must be kept constant. In fact, profits can be increased when off-peak discounts are combined with fare hikes in the peak.

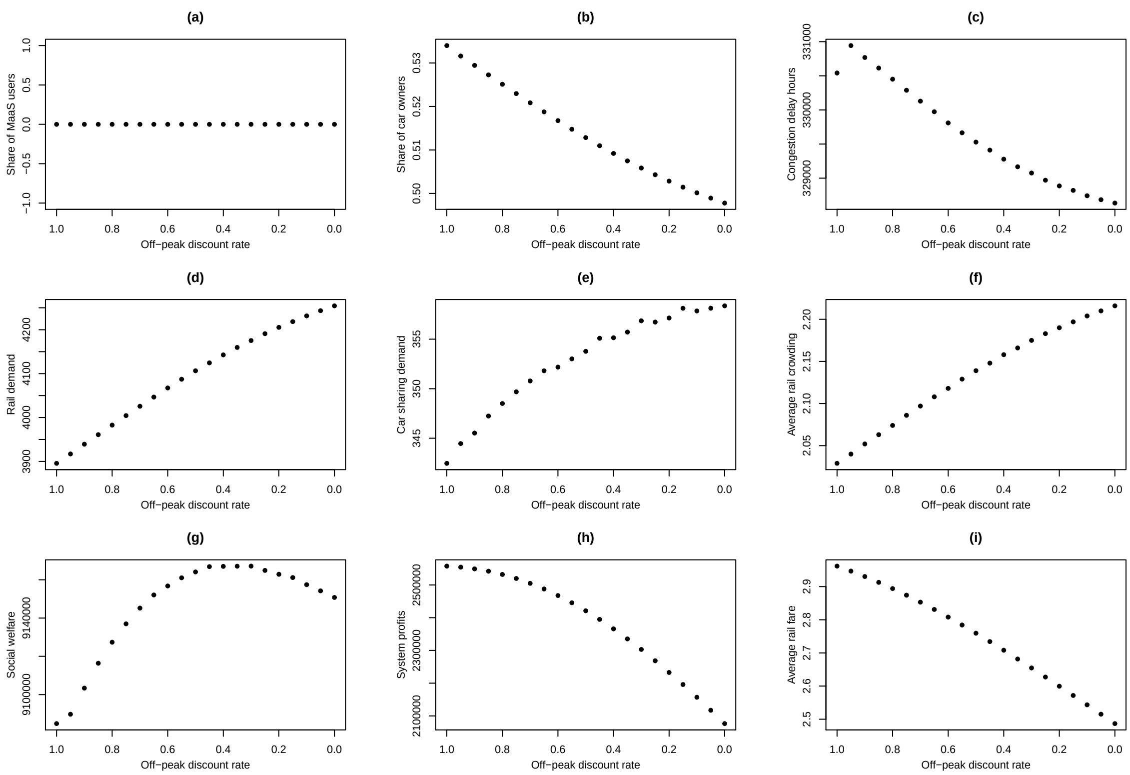

Figure 5: Scenario 4 – Impact of off-peak discount of single tickets on system performance.

6 Conclusions

This paper introduces a simple modelling framework in which car ownership has an endogenous decision mechanism, and travellers can select various travel products for the use of alternative modes, including unlimited-use travel passes and bundles of travel permits. The aim of the paper's policy analysis is to investigate how such MaaS-related subscriptions affect the performance of the multimodal transport system, including car ownership rates, road congestion delay, aggregate social welfare and financial profits. We find that unlimited-use travel passes cannot generate social welfare as they induce overconsumption in both the crowded rail and congestion road transport modes. The reason behind their adverse effect on road congestion is that infrequent public transport users, who do not buy a pass even at a reasonable price, tend to be diverted to driving due to crowding induced by pass holders. We find that congestion increases as a results of the introduction of mobility packages as well, but, presumeably due to beneficial product differentiation, social welfare can impove at a 90% discount level. By contrast, differentiated pricing, i.e. off-peak discounts, lead to monotonous improvement in all metrics of service performance.

The magnitude of welfare changes depend heavily on model parameters, indeed, so our results above cannot be generalised for any geographical areas. However, it is certainly true that the introduction of travel subscriptions, no matter if they are for unlimited use or a predetermined amount of trips, limits the possibility of price differentiation between transport markets subject to unequal marginal travel costs for society. The concept of Mobility as a Service is built on the availability of advanced IT solutions. MaaS offers a perfect opportunity to promote differentiated pricing in urban transport. It is therefore surprising that so many proponents of Mobility as a Service advocate trip bundling and subscriptions instead of differentiated pricing, thus pushing tariff policy in the opposite direction to what the principles of economic efficiency would prescribe. We hope this research can contribute to policy dialogues surrounding the MaaS concept and convince the community of transport researchers and professionals that differentiated pricing is the right direction to exploit the full potiential of Mobility as a Service.

References

Aapaoja, A., Eckhardt, J. and Nykänen, L. (2017), Business models for MaaS, *in* '1st International Conference on Mobility as a Service'.

Anderson, S. P., De Palma, A. and Thisse, J.-F. (1992), *Discrete Choice Theory of Product Differentiation*, MIT press.

Basso, L. J. and Silva, H. E. (2014), 'Efficiency and substitutability of transit subsidies and other urban transport policies', *American Economic Journal: Economic Policy* **6**(4), 1–33.

Brown, S. J. and Sibley, D. S. (1986), *The Theory of Public Utility Pricing*, Cambridge University Press.

Carbajo, J. C. (1988), 'The economics of travel passes: non-uniform pricing in transport', *Journal of Transport Economics and Policy* pp. 153–173.

De Borger, B. (2001), 'Discrete choice models and optimal two-part tariffs in the presence of externalities: optimal taxation of cars', *Regional Science and Urban Economics* **31**(4), 471–504.

De Borger, B. and Mayeres, I. (2007), ‘Optimal taxation of car ownership, car use and public transport: Insights derived from a discrete choice numerical optimization model’, *European Economic Review* **51**(5), 1177–1204.

Hörcher, D. and Graham, D. J. (2018), ‘Demand imbalances and multi-period public transport supply’, *Transportation Research Part B: Methodological* **108**, 106–126.

Hörcher, D., Graham, D. J. and Anderson, R. J. (2018), ‘The economic inefficiency of travel passes under crowding externalities and endogenous capacity’, *Journal of Transport Economics and Policy* **52**(1), 1–22.

Jara-Díaz, S., Cruz, D. and Casanova, C. (2016), ‘Optimal pricing for travelcards under income and car ownership inequities’, *Transportation Research Part A: Policy and Practice* **94**, 470–482.

Jittrapirom, P., Caiati, V., Feneri, A.-M., Ebrahimigharehbaghi, S., Alonso González, M. J. and Narayan, J. (2017), ‘Mobility as a Service: A critical review of definitions, assessments of schemes, and key challenges’.

Kamargianni, M., Li, W., Matyas, M. and Schafer, A. (2016), ‘A critical review of new mobility services for urban transport’, *Transportation Research Procedia* **14**, 3294–3303.

Leland, H. E. and Meyer, R. A. (1976), ‘Monopoly pricing structures with imperfect discrimination’, *The Bell Journal of Economics* pp. 449–462.

Littlechild, S. C. (1975), ‘Two-part tariffs and consumption externalities’, *The Bell Journal of Economics* pp. 661–670.

Matyas, M. and Kamargianni, M. (2018), ‘The potential of mobility as a service bundles as a mobility management tool’, *Transportation* .

Oi, W. Y. (1971), ‘A disneyland dilemma: Two-part tariffs for a mickey mouse monopoly’, *The Quarterly Journal of Economics* **85**(1), 77–96.

Small, K. A. and Rosen, H. S. (1981), ‘Applied welfare economics with discrete choice models’, *Econometrica: Journal of the Econometric Society* pp. 105–130.

Wong, Y. Z., Hensher, D. A. and Mulley, C. (2018), ‘Emerging transport technologies and the modal efficiency framework: A case for mobility as a service (MaaS)’.