International Transport Forum

Pricing and Efficient Public Transport Supply in a Mobility as a Service Context

Discussion Paper

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Roundtable

Daniel Hörcher
Imperial College London

Daniel Graham
Imperial College London

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The International Transport Forum

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International Transport Forum
2 rue André Pascal
F-75775 Paris Cedex 16
contact@itf-oecd.org
www.itf-oecd.org

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Introduction

Mobility as a Service (MaaS) is a collection of ambitious policy proposals fostering integration between collective and shared transport modes.

The MaaS concept reforms the industrial organisation as well as a range of specific supply policies in urban transport, primarily in the fields of information provision and pricing.

- Industrial organisation is affected by MaaS due to the proposed establishment of a new actor in the integrator's role, and a series of new collaboration channels between public and private service providers who may otherwise have conflicting institutional or corporate objectives.
- In terms of pricing, the MaaS concept proposes the introduction of new tariff products such as subscription-based mobility packages and other incentives to improve the popularity of sustainable transport modes.

The successful implementation of MaaS requires thorough justification in order to gain support from the wider public and eventually the relevant decision makers. The majority of the existing academic literature of MaaS evaluates its propositions with demand modelling tools. That is, various demand models had been established and calibrated with stated or revealed preference data to evaluate whether MaaS-related policies would achieve the desired shift in travel demand, i.e. an increase in the use of public transport and shared modes, and preferably a reduction in private car use and ownership. However, demand effects do not necessarily reflect the true impact of a policy on society, as various users, operational and external costs, as well as the benefit that the service delivers for users, might not fully correlate with the level of demand. The authors of this paper argue that MaaS policies should be appraised and optimised with the objective tools of welfare economics, in line with the usual practice of investment appraisal where benefit-cost analysis techniques are the predominant means of project selection and evaluation.

This paper focuses on the pricing policies proposed in the MaaS framework specifically. Microeconomic theory suggests that pricing provides the ideal incentive for consumers if the charges reflect the *marginal social cost* of travelling. This theorem has been adopted as the user pays principle to transport policy within the European Union and several other countries. In the context of public transport, the "marginal cost" of a trip turns out to be a broad term that includes a wide range of social welfare effects. The first goal of this article is to introduce the most relevant determinants of the optimal price schedule in public and shared modes.

Second, the paper presents the results of a microeconomic modelling exercise in which subscription and usage dependent pricing techniques can be evaluated with endogenous car ownership and commuting mode choice. The analysis reveals that subscriptions induce welfare losses for two reasons. (1) Subscription holders do not make payments prior to incremental trips, and therefore some of their trips have negative net welfare effect. (2) Non-subscription holders experience increased crowding in public transport and lower vehicle availability in shared modes, and therefore they tend to rely on their private cars more. These results raise questions about the economic efficiency of subscription-based tariff products in the MaaS framework.

The rest of the paper is concerned with additional pricing related aspects of the MaaS framework. Attention is paid to the economic objective of the MaaS provider: depending on whether this agent is a publicly or privately owned firm, its pricing strategy and the overall efficiency of MaaS provision might diverge substantially. The paper addresses further policy questions in connection with the redistributional (equity) effects of MaaS pricing as well as speculations about the consequences of the ongoing Covid-19 pandemic.

What makes pricing efficient in public transport?

The theory of pricing in transport economics is based on the observation that travel demand is sensitive to the monetary fare paid, and therefore it can be used as an incentive or disincentive for travelling. Regulating demand is important when certain costs or benefits of mobility are not taken into account by the individual traveller, for example when travel flows generate externalities borne by other members of society. If such externalities are not taken into account by individuals, then

- some of the realised trips will be *wasteful* on the level of society, as their social cost exceeds social benefits, while
- some of the *useful* trips with a positive net social benefit might not be realised, because the individual traveller does not perceive a part of the external benefits.

Thus, economic theory suggests that pricing is efficient if the monetary fare paid by the individual user equals the sum of all costs and benefits of her trip that other members of society bear or enjoy. This sum might also be called the external welfare effect of travelling. Any deviation of the monetary fare from the external welfare effect of travelling leads to an inefficient allocation of resources devoted to mobility.

This principle is well known under the term *"marginal cost pricing"* (MCP), which is a slightly misleading terminology, given that it hides the presence of potential benefits discussed later on in details in this section. The principle has been adapted to transport policy as well: the *"user pays principle"* is one of the key policy objectives of the European Union (EU) transport policy since the 1990s.

The critical challenge of the implementation of marginal cost pricing in public transport is the complexity of calculating the marginal welfare effect of travelling. Public transport trips induce a wide range of welfare effects, and the academic literature that addresses the related theoretical and quantitative problems is still in development. Existing evidence suggests that the relevant costs and benefits of greatest magnitude derive from the following features of public transport provision:

- *Scale economies*: public transport has the beneficial property that both users and the operator are better off if the scale of operations increases. The scale of operations applies to both network size and the frequency of services on a given network. Scale economies stem from the fact that waiting time decreases with increased service frequency, and the time required to reach the closest stop/station also decreases with increased network size. In operational costs, savings can be realised by running larger vehicles and maintaining a larger fleet of vehicles. Thus, it is efficient to incentivise demand with low fares to reduce the average walking and waiting time for passengers, as well as to reduce the average operational cost.
- *Substitution for car use.* If the MCP principle is violated in car use, i.e. certain externalities remain unpriced in that mode, then public transport may have to be provided at a lower price to compensate for the distortions in the private mode by inducing mode shift. This argument is well

known and accepted in policy making. However, it is less clear what level of fare reduction can be justified by the external costs of car use. This is a context-dependent quantity, which depends on (i) the gap between car externalities and the existing taxes (e.g. fuel and road taxes) on car use, and (ii) the degree of substitution between the two modes. If either of these two parameters is small in magnitude, then large reductions in public transport fares are not justified on the grounds of economic efficiency.

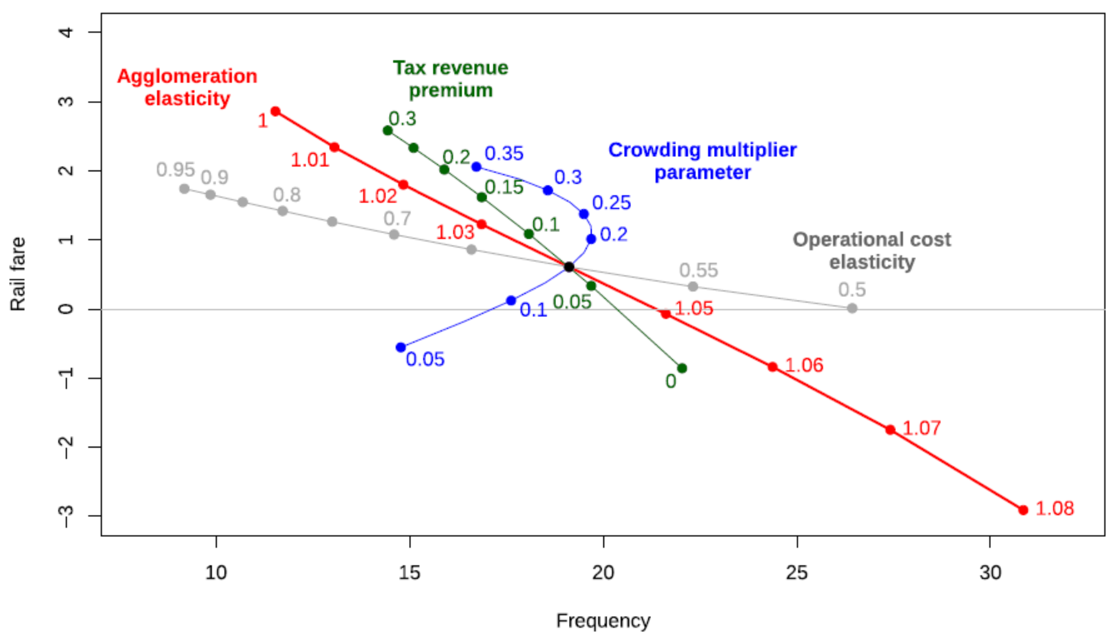
- *Crowding externalities.* Crowding inside vehicles and stations causes disutility for passengers. Recent developments in the literature enable the quantitative measurement of the disutility: evidence suggests that heavy crowding may double the perceived cost of travel time (Hörcher, Graham and Anderson, 2017). It is important to note that crowding is also an externality, as one passenger's disutility is caused by another passenger's travel decision (Tirachini, Hensher and Rose, 2013). This effect increases the optimal fare, as trips on a crowded public transport vehicle, especially in peak hours, have a negative external impact on social welfare.
- *Costly public funds.* The governments responsible for public transport provision normally face severe budgetary restrictions, and therefore their ability to cover the financial loss of transport provision might be limited without raising additional taxes elsewhere in the economy. In this case, the fare may have a partial revenue-generating role as well. The impact of this effect on the optimal fare is once again positive, and its magnitude depends on the local government's ability to raise taxes.
- *Agglomeration economies.* Empirical evidence shows that accessibility and connectivity within an urban area improves the productivity of workers and local firms (Graham and Gibbons, 2019). Some of the benefits of productivity are external to the actual commuter. In other words, improving the connectivity of a location in the urban area provides productivity benefits for those workers who are actually not using the transport infrastructure. This positive externality moves the optimal fare downwards, as lower fares have a positive impact on connectivity and thus productivity.

Are all these determinants of the optimal public transport supply equally relevant in practice? Hörcher et al. (2020a) investigate this question in a numerical exercise. They model a standard commuting rail service with 30 minute travel time that runs in parallel with a congestible road corridor. Total commuting demand has a positive impact on urban productivity and thus on wages through agglomeration economies, but crowding may emerge on the public transport service and deficit financing requires costly public funds in the model. They derive the social welfare maximising service frequency and monetary fare. This optimisation is repeated several times by varying major model parameters to see whether they have a substantial impact on supply. These major parameters of interest are (i) returns to scale in rail operational costs with respect to service frequency, (ii) passengers' sensitivity to crowding (i.e. the crowding multiplier), (iii) the social cost of tax revenue generation (i.e. the tax revenue premium), and (iv) the degree of agglomeration economies measured by the elasticity of productivity with respect to total commuting demand. All parameters are varied over the range of regular estimates in the empirical literature.

The results of this sensitivity test are depicted in Figure 1. In the initial supply regime, the model parameters were set to their most typical estimates in the literature: the operational cost elasticity is 0.6, the crowding multiplier is 0.15, the tax revenue premium is 6.6% and the agglomeration elasticity is 1.04 – these lead to the optimal rail fare of just below USD 1 and a service frequency of 18 trains per hour. This is depicted as the initial supply regime in the centre of Figure 1. Then the four input parameters are varied one by one to reveal the sensitivity of the optimal supply with respect to them. The optimal fare reacts to variations in the input parameters as intuition suggests. For example, with milder scale economies, weak agglomeration economies, very costly public funding and high crowding sensitivity, the optimal fare should be higher than in the initial setup. Theoretically, a fare very close to zero cannot be excluded either, especially if commuters' crowding sensitivity is relatively low, the government's budget constraint is relaxed, but commuting generates very significant agglomeration benefits.

The key finding of Figure 1 and the underlying simulation is that all four major input parameters are significant determinants of the optimal public transport supply, quantitatively. That is, none of them can be neglected in practical decision making, and local variations in the input parameters should be measured and taken into account in policy design. Pricing has an important role in balancing agglomeration and scale economies related benefits with the crowding and financing related costs of public transport provision.

Figure 1. The sensitivity of optimal public transport supply with respect to four major model parameters



Source: Hörcher et al. (2020a).

For the direct adaptation of these findings in pricing policy, one needs to consider that all parameters above might feature significant heterogeneity among the population of commuters. For example, car congestion and public transport crowding varies both spatially and temporally, and their effect on the optimal pricing policy is also heterogeneous. The agglomeration effect of travelling depends heavily on the trip purpose: commuting trips might have a strong impact on urban productivity while leisure-related travel might not. This hints that in the ideal world of first-best public transport provision, a regulator would compute the net welfare effect of each trip performed in the network, and assign a dedicated price proposition to each traveller. Such fully disaggregated policies are hard to administer both technologically and institutionally. However, it is also likely that flat/uniform pricing is unable to adapt to the variance of the optimal financial incentive, thus leading to inevitable losses in resource allocation. Little is known about which of these effects would be the most and least subject to heterogeneity, which highlights the importance of empirical efforts in future research.

Non-uniform tariff structures in urban transport

The previous discussion, in line with the vast majority of the academic literature, has limited the reader's attention to only one tariff product, which one may call the pay-as-you-go ticket for a single trip. In reality, public transport operators offer a range of alternative tariff products as substitutes for the single ticket. Typical examples include season tickets which enable unlimited public transport use within a given time horizon and geographical area, and block tickets, i.e. quantity discounts on advanced purchases. Such complex tariff systems are called *non-linear or non-uniform pricing* techniques in the literature because in such cases the unit price of travelling depends on the user's individual travel volume. The purpose of this section is to review existing knowledge on the economic impact of non-linear pricing in public transport.

Lessons from microeconomics

The general literature of economics and management recognises non-linear pricing as a realisation of second-degree price discrimination, which is an effective solution for revenue generation (Littlechild, 1975; Brown and Sibley, 1986). That is, non-linear pricing techniques are predominantly used by profit-oriented firms who thus can exploit differences in the price sensitivity of frequent and infrequent consumers. In the context of public transport, this can be understood by considering that the combination of single tickets and subscriptions offers a cheap solution for price-sensitive frequent travellers while the price of single trips can be maintained high for less sensitive occasional users. This way higher revenues can be achieved compared to uniform pricing (with only single tickets). The caveat is that public transport providers are normally not profit-oriented service providers, for at least two good reasons. First, transport is prone to externalities that would not be taken into account by private firms, and second, transport is a network industry where scale economies would lead to a monopolistic market structure, even if the market was open to competition.

Public service providers might still have an obligation to raise revenues efficiently if the cost of public funds (i.e. the tax revenue premium) is relatively high. Carbajo (1988) shows that subscriptions to public transport are efficient if the service is provided by a private monopolist anyway, compared to the alternative scenario when it is restricted to offer single tickets only. This implies that financially restricted public operators should be allowed to offer subscriptions. However, Carbajo's model does not contain any further externalities from this paper's list above. Hörcher, Graham and Anderson (2018) extended Carbajo's model with crowding in public transport and showed that the presence of this externality neutralises the benefits of non-linear pricing in revenue generation. Their intuitive explanation is that subscription holders do not face any further payments prior to travelling as long as their subscription is valid, and therefore pricing has no usage-dependent incentive effect.

More practically: an individual who owns a pass travels more than she would travel in a pay-as-you-go system, because individual demand is sensitive to the trip price, and some of these extra trips might generate less personal benefit than net social cost. More technically: due to the presence of externalities, resource allocation is inefficient without financial incentives, as explained in the introduction of the previous section.

Public perception of subscriptions

In light of the microeconomic analyses reviewed in this paper, one may wonder why subscriptions to public transport are still so popular in industrial practice. The satisfaction of certain groups of travellers with subscriptions is certainly among the reasons: as subscriptions offer cheap travelling for a large group of frequent users, they might associate subscriptions with low price. However, lower fares can be delivered by cheaper usage fees as well. What would be the outcome of ceasing subscription sales in a city where they had a large market share, in combination with a reduction in PAYG fares? Some former subscription holders might be better off if the new PAYG fare is much lower than their average trip price with the subscription. On the other hand, users who travelled more frequently than a critical level would be worse off, as their average trip price is much lower with subscriptions, compared to the new PAYG level. Theoretically, phasing out subscriptions cannot be Pareto improving, that is there will always be some extremely frequent users who profit from season tickets, no matter how low the usage dependent fee is.

Besides their mere financial properties, additional cognitive reactions might also be attributed to subscriptions. First, subscriptions offer unlimited travel within the period of validity, providing a sense of freedom for the user. In other words, subscription holders do not need to consider any economies prior to their trips, they save a cognitive effort, as the monetary trip price is necessarily zero for them. Indeed, users perceive this as a benefit, but from an economics point of view, this is exactly the main issue with subscriptions. Second, subscription purchasing requires advance payment. Even though advance payments may improve the financial stability of public transport operations, they are disadvantageous for users, given the time value of money, and also because future trip volumes in the period of validity are not known in advance with certainty – therefore, the choice of tariff product must be made under uncertainty. This is a cost both from the user's and from an economic efficiency perspective. In low-income groups the burden of advance payments may even become prohibitive, condemning people on low and uncertain wages to one-off purchases.

Why are public transport subscriptions so popular among transport professionals, including proponents of mobility packages in the MaaS framework as well? One hypothesis is a misperception of the magnitude of externalities that public transport and other modes generate. The externality nature of crowding and the cost of public funding is not widely recognised among professionals, while substitution between car use and public transport is often overestimated intuitively. This leads to the biased perception that public transport and other alternative modes are practically costless for society, but they have unlimited capabilities in mitigating car externalities, including congestion. From this point of view, the inefficiency of subscriptions is much less apparent.

Equity considerations

In many countries, subscriptions to public transport are provided for redistributional reasons. Jara-Díaz, Cruz and Casanova (2016) explain, using Chilean data for illustration, that individual demand for public transport is negatively correlated with income, primarily because higher income groups in society are more likely to have access to private cars. Similar patterns might be recognised in other countries where the low-income segments of society are wealthy enough to afford basic mobility, but car ownership is still out of their reach. Jara-Díaz, Cruz and Casanova (2016) extend Carbajo's model with an income effect, considering that the price of a public transport subscription might reduce the individual trip demand. They find, neglecting crowding externalities, that travel pass provision is a progressive policy as it favours lower-income groups.

Subscriptions are often used to implement further income redistributional goals in the form of concession discounts for vulnerable groups of society. Once again, there is no economic justification behind applying discounts on subscriptions instead of PAYG fares, as the social (that is, operational and external) cost of public transport trips does not depend on the social status of the traveller. In other words, the overconsumption threat is present in concession-based subscription discounts as well, while vulnerable target groups could realise the same level of financial savings from discounted PAYG fares as well.

What is more worrying is that the full welfare effect of discounted subscription provision is rarely computed and revealed in the political decision-making process. It is rarely known how much extra operational and crowding cost is generated due to discounted subscription policies, even after the implementation. This gives ground for opportunistic decision-making strategies in the political arena: offering concession discounts is a popular policy, with transparent benefits for the beneficiaries, but the true welfare costs are not visible, and therefore the implementation of such policies is easier than achieving redistributional goals with lump-sum monetary transfers.

Optimal pricing in MaaS: Subscriptions or pay-as-you-go?

This section presents a simple microeconomic model to study the impact of subscription-based pricing on mode choice and car ownership. Assume two isolated zones in the geographic space and a multimodal transport corridor between them. Three modes of transport are available: private car use, car sharing and public transport. The two zones may be called the “suburb” and the “central business district” (CBD). In this setup, one would anticipate strong directional demand imbalance during peak periods, as the majority of commuters move from the suburb to the CBD. Therefore the model has N_a=8 000 *potential* users towards the CBD and N_b=2 000 in the opposite direction. The two markets are modelled with the *representative consumer* approach. In other words, travellers are assumed to have the same preferences in terms of major trip attributes, but they will receive a random taste shock, thus introducing heterogeneity in their travel behaviour.

Model description

The representative consumers (in both directions) face a three-level choice situation depicted in Figure 2. They make a long-run (say, yearly updated) binary decision on whether they own a car. On the second level, they take a monthly decision on whether they purchase a subscription for a period of one month. This choice is also binary: if they decide not to own a subscription, then they have to pay for public transport and car sharing on a PAYG basis. Finally, in the short run, they make a mode choice decision for commuting on a daily basis. Besides the three modes introduced above (private car, car sharing, public transport), the individual may also decide to opt out, so that *aggregate* travel demand is less than the *potential* number of users in both multimodal markets.

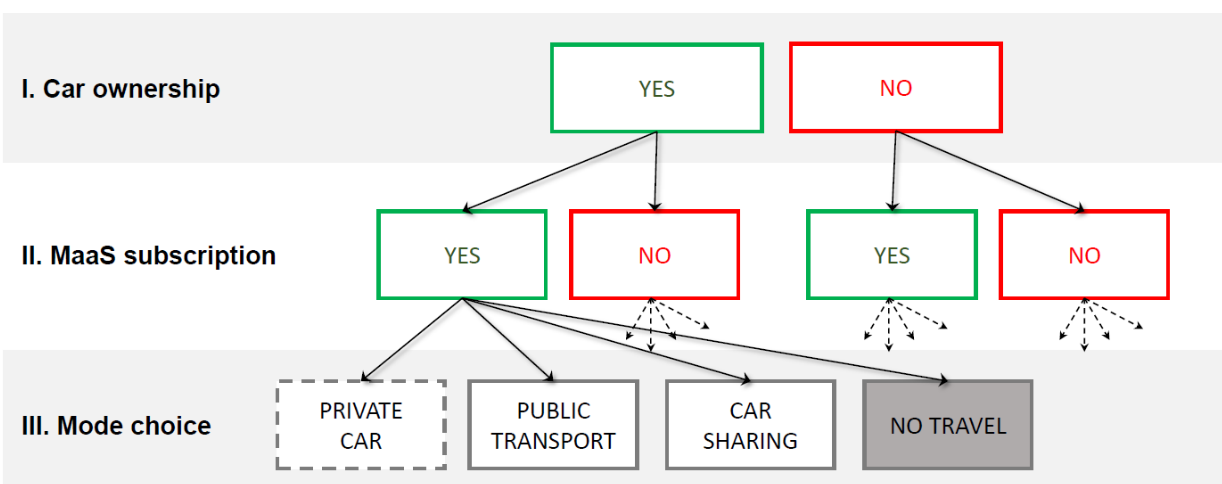
The three-level choice tree depicted in Figure 2 is formulated as a recursively evaluated nested logit demand system. On each decision level, there is a systematic component of utility. On the mode choice level, the utility of *private car use* includes

- a mode-specific constant representing the general superiority of certain modes, potentially,
- the cost of travel time loss, taking the congestible nature of road use into account,
- the monetary car operational cost, and
- a parking cost, which is also an exponential function of the number of private car users in the two zones, representing the scarcity of urban land.

The systematic utility of *car sharing* differs from the specification above in several ways; it includes the following components:

- mode-specific constant,
- travel time cost, identical to private car use,
- a monetary fare, τ^s, and
- the access cost of car sharing, which captures that shared vehicles are not necessarily available in the close proximity of the passenger's origin. This cost increases with the number of car sharing users in a given zone and decreases with (i) the available car fleet as well as (ii) the number of car sharing users travelling in the opposite direction.

Figure 2. Schematic overview of the decision tree of a model with endogenous car ownership, subscription purchases and daily mode choice



Source: Hörcher and Graham (2020).

Note that car sharing users do not pay for parking and car operations. In public transport, utility in mode choice consists of:

- a mode-specific constant,
- the cost of waiting time, which decreases with service frequency f,
- travel time cost, assumed to be constant, representing a rail service with its own right of way,

- the cost of crowding, captured by an occupancy rate-dependent multiplier on the value of in-vehicle travel time, and
- the monetary fare τ^p imposed by the public transport operator.

The representative user's utility includes a Gumber distributed random component, so that choice probabilities (and thus market-level mode shares) can be derived from the well-known logit specification.

The logit formulation also enables us to derive consumer surplus on the mode choice level, utilising the *logsum* formula of expected utility (Small and Rosen, 1981). From the definitions above it is clear that expected utility on the mode choice level depends on τ^s and τ^p, the monetary fares of car sharing and public transport. These prices drop to zero when someone holds a subscription. Thus, on the second level of the decision tree, systematic utilities include:

- consumer surplus in mode choice, with zero or non-zero τ^s and τ^p, depending on subscription ownership, and
- the price of subscription j, denoted by T_j.

On the second decision level, subscription choice probabilities are also derived using the logic expression, but expected utility is simply the weighted average of expected utilities on the mode choice level, where the weights are the market shares of the available subscription/PAYG options. In other words, the model does consider some level of randomness in the tariff choice situation, which may represent the uncertainty of advance payments in case of subscriptions, but *love of variety* is excluded on this level. In other words, consumer welfare cannot be increased by introducing a large number of very cheap tariff products, which would otherwise be the case if the random component of utility were considered as a tangible benefit for users (see a detailed discussion on this assumption in Hörcher and Graham, 2020).

Finally, on the top level of the demand system, the representative user decides on car ownership. The main consequence of this decision is the availability of the private car on level III. In other words, commuters who do not own a car can only select public transport, car sharing and "no travel" in their daily mode choice decision. The car ownership rate is derived from a utility function, which includes:

- consumer surplus in the subscription choice situation (thus, implicitly, in the mode choice situation) with and without a car, and
- the fixed annualised ownership cost of a car.

As in the previous cases, the car ownership rate is expressed with the logit assumptions, and expected utility, which captures consumer surplus in the entire model, is computed with the logsum formula. Detailed mathematical formulations of the model are available in Hörcher and Graham (2020).

Model parameters, including unit operational costs per public transport frequency and car sharing fleet, and the unknown parameters of the demand system (i.e. alternative specific constants and scale parameters) are calibrated to comply with typical demand elasticities in the literature and the modal split of a representative European city.

Model evaluation

The model introduced above is implemented in a numerical simulation environment. The results presented below were computed in R, but they could be replicated in any other equivalent programming environments such as Python or Matlab.

The main feature of the model is that by varying the monetary prices τ^s, τ^p, T_j and public transport frequency f, a series of system characteristics can be derived endogenously. Important outputs are:

- mode shares, and thus the level of road congestion and public transport crowding,
- the car ownership rate, i.e. the number of commuters owning a car,
- financial result of public transport and car sharing operations, including frequency and fleet size dependent operational costs and fare revenues, and
- social welfare, defined as the sum of consumer surplus and the financial result of public transport and car sharing operations.

Thus, the model is also suitable to optimise τ^s, τ^p, T_j and f according to a predefined objective such as social welfare or profit maximisation, and evaluate the optimal supply policies according to the performance metrics above.

In the following simulation scenarios, three types of tariff products were investigated in combination with standard PAYG pricing. These are:

1. Rail pass: For a predetermined subscription price T_1>0, the usage dependent rail fare drops to zero on the mode choice level, τ^p=0.
2. Car sharing pass: For a predetermined T_2>0, the usage dependent car sharing fee disappears, τ^s=0.
3. Multimodal pass: A monthly payment T_3 enables its owner to travel for τ^p=0 as well as τ^s=0.

Scenario 1: The impact of subscriptions at a fixed price

Before investigating a wider range of subscription prices and their impact on car ownership and congestion, this section considers the introduction of a subscription at a given price. The purpose of this analysis is illustrative. Assume the initial public transport and car sharing fares are τ^p=USD 2.00 and $\tau^s =$ USD 7.70 per trip, rail frequency is eight trains per hour, and the car sharing fleet size is 500 cars.

Under these conditions, a rail pass is introduced at T_1=USD 50. Given that the model includes 30 days per month, the cost of daily rail trips with PAYG would be 30 USD 2.00=USD 60.00. Thus, the rail pass at $T_1 =$ USD 50 might be a more attractive option for frequent rail commuters. Table 1 confirms this prior expectation and provides several other model outputs.

The first four lines of Table 1 details how the introduction of a pass, T_1, affects travel utility for rail, private car and car sharing users, differentiating the off-peak and peak markets. The disutility of rail commuting was -7.44 in the off-peak and -9.7 in the peak. For pass holders, these disutilities decrease in magnitude to -6.48 in the off-peak and -8.85 in the peak. This is the well-anticipated consequence of rail subscriptions: it makes the rail service more attractive for pass holders. However, note that those who eventually do not purchase the rail pass at T_1=USD 50, the disutility increases mildly to -7.48 in the off-peak and -9.85 in the peak. That is, non-pass holders experience worsening travel conditions, primarily due to the crowding caused by pass holders.

Rows 5-8 of Table 1 describe the demand effects of the availability of the rail subscription. Note that due to the savings enabled by the rail pass, almost 55% of off-peak rail users are pass holders. This ratio reaches 64% in the peak direction. The total number of rail users increases in the two markets from 902 and 3 578 to 950 and 3 657 passengers, respectively. In sum, demand intensifies in the rail mode, due to the savings enabled by the rail subscription.

Table 1. The impact of a rail pass at USD 50 on travel utilities and commuting demand

Market	Off-Peak		Peak	
Subscription available	No	Yes*	No	Yes*
Rail utility				
- non-pass holders	-7.44	-7.48	-9.70	-9.85
- pass holders		-6.48		-8.85
Private car utility	-4.01	-4.01	-6.18	-6.23
Car sharing utility	-8.34	-8.13	-11.34	-11.06
Rail demand				
- non-pass holders	902	429	3578	1306
- pass holders		521		2351
Private car utility	846	831	3806	3837
Car sharing utility	250	217	342	331

*Subscription price set to T_1=USD 50.

However, Table 1 reveals a less anticipated consequence of the introduction of subscriptions: the number of private car users also increases in the peak direction, from 3 806 daily trips to 3 837. The reason for this effect is overcrowding in public transport, due to the intensifying demand of pass holders. Those who do not purchase a rail pass face worsening travel conditions, and therefore are more likely to shift to private car use. This may have a degrading effect on urban congestion as well.

This simple analysis reveals that the introduction of a subscription to only one mode strengthens demand not only in that mode but also in private car use. The first outcome might have been anticipated from regular empirical demand model as well, but predicting the impact on car use also requires the modelling of how (i) crowding and road congestion evolves as a result of the policy, and (ii) how non-pass holders react to changing travel conditions. This chain of consequences may remain hidden without a simulation-based forecasting exercise.

Scenario 2: Variable subscription prices

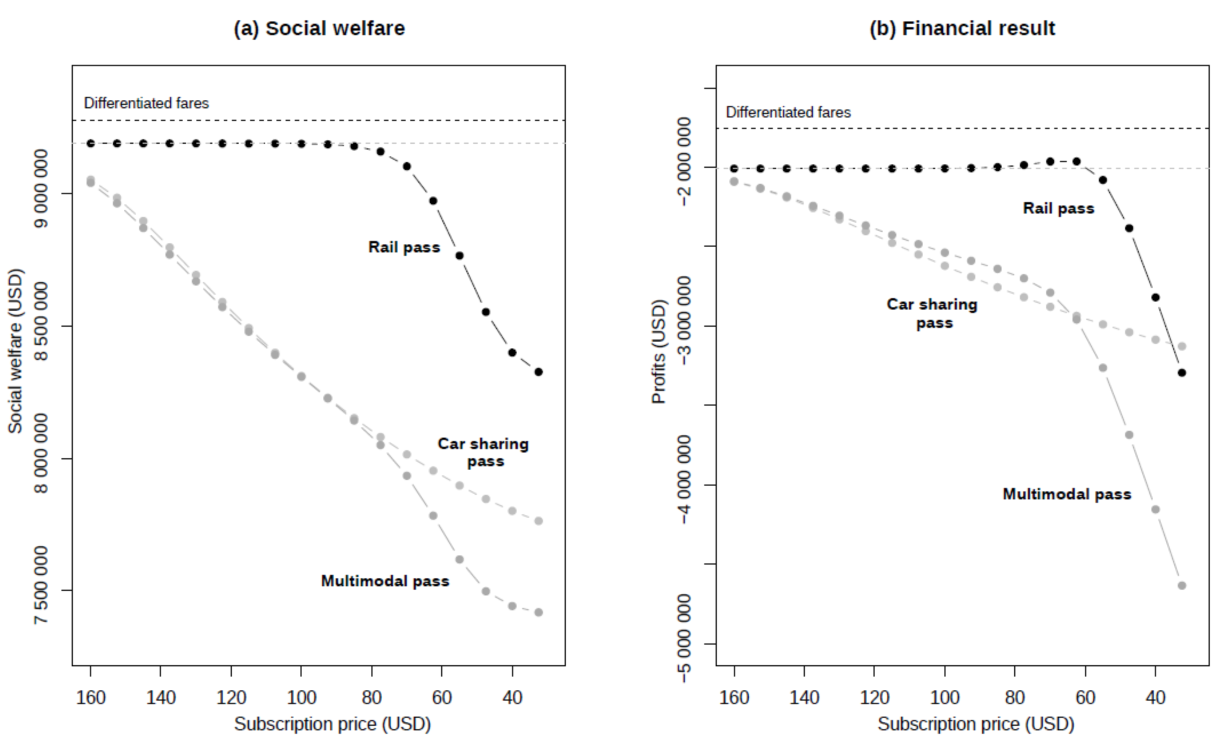
The previous section's simulation has assumed that subscription price T_1 is exogenously given. In reality, public transport operators or MaaS providers can control the price of this tariff product over a wide range, thus affecting market share and also several other characteristics of the multimodal system. In this scenario the rail, car sharing and multimodal passes (T_1, T_2 and T_3) are jointly investigated in the price range between USD 30 and USD 160.

Figure 3 presents a snapshot of the simulation results. Panel (a) of the figure plots social welfare as a function of the price of subscriptions. Note that social welfare includes (i) consumer surplus, (ii) revenues from pricing, and (iii) the operational costs of public transport and car sharing provision. Panel (a) shows that social welfare strictly decreases with the attractiveness of subscriptions, no matter which type one considers. The welfare loss is most pronounced with the multimodal pass, in which case both rail and car sharing use are free at the point of use for pass holders. The multimodal pass induces *overconsumption* (that is, trips with a negative net welfare effect) in both alternative modes, and the mode shift of non-pass holders towards private car use is also more intense.

Panel (b) of Figure 3 shows similar tendencies in terms of the financial result of public transport and car sharing provision. The horizontal grey dashed line represents financial result (more precisely, the deficit) in the baseline setting of the model, in the absence of subscriptions. The graph indicates that there is only one short section of the "rail pass" curve where minor financial gains can be achieved. This is the positive consequence of second-degree price discrimination with non-linear pricing, from a financial point of view. On a wider range of subscription prices, a robust negative tendency is observed. However, in this exercise the PAYG fares are kept constant, which limits the possibilities of price discrimination; Scenario 3 will relax this assumption in the next subsection.

The present modelling framework is suitable for testing *differentiated pricing* as well. Recall that the model has two travel directions: a more congested market in the peak direction and a calmer market in the opposite direction. Usage dependent fees τ^s and τ^p were restricted to be the same in both directions so far, assuming a *flat fare* regime. Now, differentiated pricing can be tested by allowing τ^s and τ^p to differ between the two directions. Thus, it is anticipated that the welfare maximising differentiated pricing system will have higher fares in the peak market to address congestion externalities and lower fares in the calm market.

Figure 3. The impact of the attractiveness of MaaS subscriptions on system-level efficiency (social welfare) and the financial result of public transport and car sharing provision



Source: Hörcher and Graham (2020)

Figure 3 shows the impact of differentiated pricing on (a) social welfare and (b) financial performance. The dashed black line represents the social welfare and financial deficit with differentiated fares. As opposed to subscriptions, this form of pricing actually increases social welfare and reduces the deficit. The explanation stems from the difference in congestion and crowding levels between the two markets. Higher congestion and crowding imply that the marginal social cost of travelling is also higher. With differentiated pricing, users perceive a differentiated incentive amid capacity shortages, and therefore resource allocation becomes more efficient.

Scenario 3: Profit oriented subscriptions

The final simulation scenario considers a profit-oriented objective in pricing. That is, consumer surplus is neglected in the objective of supply optimisation, and τ^s, τ^p, T_j and f are set to minimise the gap between fare revenues and operational costs only. Table 2 benchmarks six potential supply regimes:

1. Baselines scenario: no subscriptions, flat rail and car sharing fees are set to maximise social welfare.
2. Profit maximisation with flat fares: no subscriptions, but the flat rail and car sharing fees are varied to maximise the financial result.
3. Profit maximising rail subscription with flat fares: τ^s and τ^p are optimised but undifferentiated between directions, and T_1 is optimised together with them to maximise profits.
4. Profit maximising car sharing subscription with flat fares.
5. Profit maximising multimodal subscription with flat fares.
6. Profit maximising differentiated pricing: no subscriptions, but τ^s and τ^p vary between the two directions.

The optimal supply variables are derived using numerical optimisation (for technical details, see Hörcher and Graham, 2020). The first seven columns of Table 2 show the optimal fare and subscription levels in all six scenarios. The final two columns are profit and welfare indices. The profit index is normalised to zero in the baseline scenario and 1 with profit-maximising flat fares, while the welfare index is scaled the other way round.

The column of the profit index indicates that surpassing the financial result of profit maximising flat fares is indeed possible with the rail as well as multimodal subscriptions. With the rail pass T_1 set optimally, 12% higher profits can be achieved, while the multimodal pass can be even more profitable, boosting net revenues by an additional 35% compared to flat fares. This indicates the power of second-degree price discrimination when both usage fees and the subscription prices can be amended. However, profit maximisation has a cost in the form of welfare losses: with profit maximising rail subscriptions, the welfare index drops to – 61%. That is, if the monopolist is allowed to apply nonlinear pricing, then the deadweight loss is 61% higher than if it is restricted to sell flat fares. This loss is even greater with the multimodal pass, reaching – 84% in terms of the welfare index.

The final regime in Table 2 simulates the case when a private operator does not offer subscriptions, but PAYG fares are allowed to differ between the busy and calm markets in the modelled network. Indeed, the monopolist would increase the peak fares: for example, the rail fare τ^p becomes USD 7.17 in the peak market and USD 3.48 in the off-peak, which is more than a two-fold difference. The key result is that profits in this pricing regime are 16% higher than with flat fares only, so price differentiation is indeed profitable.

However, the welfare index remains positive: this means that social welfare is actually higher than in the flat fare regime. In other words, differentiated pricing is not only profitable but also less harmful than flat PAYG fares in terms of economic efficiency.

Table 2. Profit maximisation with flat PAYG fares, non-uniform tariffs and differentiated pricing.

	τ_a^p	τ_b^p	τ_a^s	τ_b^s	T_1	T_2	T_3	Profit Index	Welfare Index
Baseline scenario	2.00	2.00	7.70	7.70				0	1
Flat fares	6.62	6.62	8.96	8.96				1	0
Rail subscription	8.58	8.58	8.87	8.87	191			1.12	-0.61
Car share subscription*	6.62	6.62	8.96	8.96		*High**			
Multimodal subscription	17.65	17.65	18.33	18.33			202	1.35	-0.84
Differentiated pricing	7.17	3.48	11.34	7.80				1.16	0.12

* Profits cannot be increased with car sharing subscriptions having non-zero market share.

These numerical results can be interpreted in the following way. If the MaaS provider is profit-oriented, and it has the possibility to select a pricing regime, then its first preference is the introduction of a multimodal pass in combination with PAYG fares. However, this regime causes significantly higher inefficiency for society than simple profit maximising flat fares. On the other hand, if subscriptions are prohibited by regulation while directionally differentiated pricing is enabled, then profits, as well as social welfare, are both increasing compared to the flat fare regime.

The role of economic objectives in MaaS pricing

One of the apparent lessons learnt from the previous modelling exercises is that the objective function behind price setting has a crucial impact on fare/subscription levels as well as system performance. It is surprising to observe that very little attention is being paid to the economic objective of the MaaS provider in the currently available literature. Several new entrants in the emerging global MaaS market are actually private firms, whose economic objective is expected to be closer to profit maximisation than a publicly owned service provider’s target. Research is in its early stages in terms of understanding the implications of governance in the MaaS framework.

Pure social welfare or profit maximising objectives, as frequently used in microeconomic analyses, are indeed simplified representations of reality. In the public sector, the concept of social welfare is still not widely understood and applied in practical decision-making. Many decisions are instead governed by political considerations (for example, vote maximisation) or personal ambitions of decision makers in key management positions. Also, publicly owned companies might not reach the same level of *internal* *efficiency* in terms of operations and management, as their pressure to innovate and keep internal processes efficient might not be as high as in a private enterprise. All these factors imply that the pricing policies set by a publicly owned MaaS provider might diverge to some extent from what we derive in a theoretical model assuming pure welfare maximisation.

The profit-oriented objective of private operators is a desirable property in many industries where competition between a large number of firms can be maintained and market failures do not gain ground. Economic theory suggests that under such conditions, the outcome of competition might be close to the social welfare maximising optimum. However, transport is a network industry with strong scale economies, and this endangers the long-run prevalence of competition. In particular, scale economies provide substantial efficiency advantages to the largest competitor in the market, and this might lead to monopolies in the long run, as smaller competitors cannot survive. The literature calls this the threat of *natural monopolies*. Due to the tendency of public transport networks to become a natural monopoly, this industry has remained publicly controlled in major cities around the world. Another dominant market failure in transport is the presence of externalities, as introduced earlier in this paper. If travelling generates externalities, then even a highly competitive (privatised) market would not lead to the socially optimal outcome. Thus, it is likely that (i) a private MaaS market would not become/remain competitive in the long run, and (ii) a private monopoly in the role of the MaaS integrator would not deliver the same level of economic efficiency as a publicly owned one.

Indeed, the behaviour of profit-oriented firms might also diverge from what the microeconomic analyses predict based on a pure profit maximising objective. The threats of bad public reputation and regulatory intervention can incentivise them and limit the extent to which they exploit the potential monopoly power they have, and also trigger them to take externalities into consideration. This way the performance of a private monopolist as MaaS provider might not be as devastating as stylised simulations predict. However, the gap between social welfare and profit maximising outcomes is so wide in most cases that minor convergence between them definitely cannot make public and private MaaS ownership equivalent.

Forcing publicly owned and managed service providers to compete with private contenders in a liberalised market is a particularly confusing market structure. Public and private firms might both compete for passengers, but the underlying economic objective is completely different. In many cases, this market structure is not just confusing but also unfair. Public companies may enjoy the benefit that they can rely on public subsidies, so they can sustain a negative result in their balance sheet. By contrast, private firms enjoy greater flexibility in a series of corporate decisions, for example by facing fewer restrictions in negotiating with trade unions. Due to these limitations, fostering competition between public and private MaaS providers on the same market (i.e. in the same city) is not desirable without substantive justification.

Some of the currently available MaaS concepts feature several additional decision takers beside the MaaS provider, the service integrator. Most of these concepts agree that the actual transport service providers will remain a group of publicly and privately owned operators, including current public transport companies and emerging private bike and car sharing start-ups, for example. The numerical model in the previous section has considered the case when the MaaS provider takes control over pricing and capacity supply entirely. However, if some of these decisions remain with the actual transport operators, or the MaaS provider has to negotiate the financial and operational parameters of transport services, then managing MaaS will become a complex system of bargaining processes in which outcome prediction is increasingly uncertain. To perform an objective assessment of future MaaS policies, a rich toolbox of industrial organisation and game theory will have to be mobilised.

The threat of unpredictable outcomes and potential market failures can be eliminated by limiting the scope of MaaS into a unified platform for information provision and digital transactions, utilising the growing range of technological solutions developed to support integration. The benefits of information provision have been recognised by a series of influential contributions in transport economics, including Ettema and Timmermans (2006) and Engelson and Fosgerau (2020). Information increases the diversity of travel options as perceived by travellers, and neutralises the user cost of uncertainty regarding the gap between expected and observed trip attributes, such as travel times. In this area Mobility as a Service has enormous future potential.

Societal impacts during and after Covid-19

Since early 2020, the ongoing Covid-19 pandemic has had a transformative impact on urban lifestyle, including everyday urban mobility. Due to lockdown measures and social distancing rules, the diversity of people's activity locations has reduced to their home and surrounding areas within walking distance. Working from home and shopping in nearby stores have become the new norm. This has resulted in an unprecedented reduction in urban travel demand, especially in the morning and afternoon peak periods when commuting to work was a major pressure on transport supply. Public transport and shared mobility, the modes that form the backbone of MaaS, are especially hard hit by physical distancing requirements and people's general fear from the infection risk. Early reviews of the demand effects of Covid-19 are provided by Beck and Hensher (2020) as well as Tirachini and Cats (2020). Even though there is no tangible evidence on the risks of public transport use when passengers comply with face mask policies, the global public transport industry is currently under enormous stress, primarily due to disappearing fare revenues and restrictions in funding from local and higher-level governments.

Can we define an ideal pricing strategy for the case of an infectious disease crisis? Very few (if any) reliable quantitative measurements are available about how travel conditions in public transport can be associated with infection rates among passengers and staff. We can infer some indicative guidance, however, from general economic theory.

An important point to make is that infection risk is in fact an *externality* of public transport use, just like the inconvenience that passengers impose on each other under regular conditions. The risk of contagion can be modelled as a substantial increase in the crowding multiplier on the user cost of travelling. This implies that the marginal external cost of public transport use is much higher than normal, which implies that the optimal fare as financial incentive should raise people's awareness to the risk they impose on fellow travellers. With non-financial tools, Governments are already trying to discourage users from unnecessary trips (Tirachini and Cats, 2020), but the political process of crisis management has rarely led to the economically justifiable decision to raise public transport fares. In general, the efficient use of the available resources is especially important amid the health crisis when demand is expected to surpass the capacity limited by social distancing.

Due to the increased external cost of travelling, subscription-based travel products are especially harmful, for at least two reasons. First, because of the overconsumption problem discussed earlier in this article: subscription holders do not face a financial incentive prior to the marginal trip, and therefore the threat of unnecessary trips is more pronounced. Second, advance payments are especially risky from the consumer's point of view when lockdown rules may change on a weekly basis. An extreme example is that those who have purchased a yearly public transport pass by early 2020 could not extract the same value from this tariff product that they might have expected.

It is even more difficult to make recommendations about optimal transport policies post Covid-19. The very fundamentals of the functioning of cities are uncertain at the moment. Some commentators predict that remote working will become prevalent after the crisis, curbing urban travel demand substantially. This would imply enormous changes in urban spatial form as the main engine of urbanisation and the densification of cities was the value of physical proximity between workers and consumers, and the resulting agglomeration economies. The death of distance and the glory of technology over traditional cities was part of many prophecies during the 20th century, but none of them turned out to be justified so far.

Given the uncertainties regarding the future way of urban life, what can public transport operators do to prepare for the post-Covid era? Improving demand management capabilities seems to be essential. Operators currently do not have the ability to effectively control the intensity of public transport use, and therefore they are vulnerable to social distancing regulations, and cannot ensure the efficient use of limited capacities. Dynamic pricing is one of the ways in which demand can be effectively controlled both spatially and temporally. This possibility is neutralised with subscription-based travel products. On the other hand, the novel technological features of the MaaS concept, for example, smartphone app-based information provision and ticketing could be helpful for capacity allocation. In particular, online reservation and slot auctioning systems are easy to implement in a smartphone environment. Real-time information on present and future capacity availability could also limit the inconvenience of slot rationing when public transport and shared mobility cannot be utilised to their physical capacity.

Conclusions

This paper identifies a research gap in the academic literature of Mobility as a Service: numerous studies have investigated the impact of MaaS-specific pricing strategies such as mobility packages and subscription bundles on *travel demand*, but the existing policy proposals are yet to be supported by thorough economic analyses. The article draws attention to the presence of substantial external costs in urban transport, including crowding in public transport and the external costs of occupying shared vehicles in peak periods. The presence of externalities suggests, based on economic theory, that the price of travelling should reflect its net welfare effect, to ensure that external social costs are considered in individual travel decisions. The paper urges that this principle is likely violated by advance payment subscriptions that reduce the price of incremental trips to zero. Thus, the full potential of the technological initiatives of the MaaS framework can only be exploited with usage dependent pricing policies.

Traditionally, one of the main benefits of subscriptions (e.g. monthly passes) was the simplicity of use. However, with the advent of new payment technologies, usage-dependent (pay-as-you-go, PAYG) and even dynamic (e.g. time of day dependent) pricing becomes much easier to communicate and administer even on a busy public transport service. The experience of successful ride hailing applications shows that the dynamic price schedule determined by a sophisticated algorithm can be implemented in a user-friendly way with smartphone technology. This article points out that the single, digital customer interface of MaaS offers a unique opportunity to implement marginal cost pricing in public transport as well, thus improving the efficiency of this mode in line with economic theory.

Investigating the future market structure of MaaS, the paper discusses the distinction between publicly and privately owned transport providers and how their economic and financial objectives affect their pricing practices. In the case of private operators and MaaS providers, it is unlikely that they pursue a purely social welfare maximising objective. If profit maximisation is part of their objective, then one may expect that they depart from marginal cost pricing by applying a monopoly mark-up. This mark-up and the efficiency loss it generates depend on the monopoly power that a supplier enjoys. From this perspective, a private firm acting in the role of the MaaS provider sounds particularly delicate, as in most of the published MaaS concepts the integrator is in exclusive monopoly by definition. The regulator can moderate the deadweight loss of monopolistic MaaS provision by encouraging competition between individual service providers, or by imposing price regulations on the market. The paper draws the reader's attention to a range of open questions regarding the industrial organisation of Mobility as a Service that are currently unanswered by the existing demand-oriented MaaS literature, and where earlier findings of transport economics provide useful guidance.

Finally, this study argues that the ongoing Covid-19 crisis and capacity restrictions due to social distancing regulation raises the importance of resource allocation in urban transport. Infection risk is recognised as a consumption externality, because the probability of getting infected increases with the occupancy rate of vehicles. Thus, demand dependent pricing coupled with a MaaS-based capacity reservation system might offer an effective way for public transport operators to maximise resource utilisation under the constraint of social distancing.

References

Anupriya, Graham, D. J., Carbo, J. M., Anderson, R. J., & Bansal, P. (2020). Understanding the costs of urban rail transport operations. *Transportation Research Part B: Methodological, 138*, 292-316.

Beck, M. J., & Hensher, D. A. (2020). Insights into the impact of COVID-19 on household travel and activities in Australia–The early days under restrictions. *Transport Policy.*

Brown, S. J., 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*, 153-173.

Engelson, L., & Fosgerau, M. (2020). Scheduling preferences and the value of travel time information. *Transportation Research Part B: Methodological, 134*, 256-265.

Ettema, D., & Timmermans, H. (2006). Costs of travel time uncertainty and benefits of travel time information: conceptual model and numerical examples. *Transportation Research Part C: Emerging Technologies, 14(5),* 335-350.

Graham, D. J., & Gibbons, S. (2019). Quantifying Wider Economic Impacts of agglomeration for transport appraisal: Existing evidence and future directions. *Economics of Transportation, 19*, 100121.

Hörcher, D., Graham, D. J., & Anderson, R. J. (2017). Crowding cost estimation with large scale smart card and vehicle location data. *Transportation Research Part B: Methodological, 95*, 105-125.

Hörcher, D., Graham, D. J., & 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.

Hörcher, D. et al. (2020a). Public transport provision under agglomeration economies. *Regional Science and Urban Economics, 81*, 103503.

Hörcher, D., & Graham, D. J. (2020). MaaS economics: Should we fight car ownership with subscriptions to alternative modes?. *Economics of Transportation, 22*, 100167.

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

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

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

Tirachini, A., & Cats, O. (2020). COVID-19 and public transportation: Current assessment, prospects, and research needs. *Journal of Public Transportation, 22(1)*, 1.

Tirachini, A., Hensher, D. A., & Rose, J. M. (2013). Crowding in public transport systems: effects on users, operation and implications for the estimation of demand. *Transportation Research Part A: Policy and Practice, 53*, 36-52.

Pricing and Efficient Public Transport Supply in a Mobility as a Service Context

Mobility as a Service (MaaS) is widely expected to make sustainable transport choices more attractive. New approaches to ticketing will be a core part of MaaS, both to attract users and fund services. The associated pricing decisions will be a matter of public policy as much as business objectives, because they can have large social welfare effects. This paper describes options for different pricing structures and their relative efficiency. It considers the potential impact that differing objectives of public and privately-owned transport providers might have on pricing decisions. It concludes with an assessment of the possible effects of Covid-19 on the MaaS market.

All resources from the Roundtable on Integrating Public Transport into Mobility as a Service Roundtable are available at: www.itf-oecd.org/integrating-public-transport-mobility-service-maas-roundtable.

International Transport Forum
2 rue André Pascal
F-75775 Paris Cedex 16
+33 (0)1 73 31 25 00
contact@itf-oecd.org
www.itf-oecd.org

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