Research in Transportation Economics 90 (2021) 100993

Contents lists available at ScienceDirect

Research in Transportation Economics

journal homepage: http://www.elsevier.com/locate/retrec

The provision of mobility as a service with autonomous vehicles. The necessity of regulatory schemes for a natural monopoly

Francisco J. Bahamonde-Birke [a,*], Mirko Goletz [b], Dick Ettema [a]

[a] Sociale Geografie en Planologie, Universiteit Utrecht, Utrecht, the Netherlands
[b] Institut für Verkehrsforschung, Deutsches Zentrum für Luft- und Raumfahrt, Berlin, Germany

ARTICLE INFO

Keywords:
Autonomous vehicles
MaaS
Regulation
Ride sourcing
JEL
R41

ABSTRACT

This paper addresses the provision of Mobility-as-a-Service (MaaS) once autonomous vehicles become available, putting special emphasis on the cost structures of MaaS-providers. The results show the existence of significant economies of scale and, therefore, the market is likely to become a natural monopoly. The difference with the current situation is explained by the absence of a driver and it provides an explanation for the aggressive and deficitary expansion strategies of current TNC providers. Furthermore, given that natural monopolies require regulation in order to avoid losses of social welfare, the paper considers five different regulation scenarios. For this purpose, we also take into account the existence of negative and positive externalities as well as other issues specific to the provision of MaaS, such as spatio-temporal considerations and complementarity/competition with other transport modes.

1. Introduction

Ride-sourcing, the use of private cars to provide on-demand mobility services, has become a global phenomenon since it first appeared in the Bay Area/California in 2009 (Flores and Rayle, 2017), with the biggest Transportation Network Company (TNC) Uber being already active in over 80 countries. However, this rapid expansion has not necessarily met with financial success. While concerns have been raised regarding possible negative effects of ride-sourcing on the labor market (Cramer and Krueger, 2016; Zoepf et al., 2018) and on the transportation systems (Pangbourne et al., 2019; Tirachini and Gomez-Lobo, 2019), it is also not clear, whether, even from a purely private financial viewpoint, there is a clear path towards financial profitability. In April 2019 released IPO documents preceding the public offerings of Uber and Lyft revealed that both companies made high financial losses in 2018, losing 1,8 Billion US $ and 0,9 Billion US$, respectively (IPO, 2019). In fact, the media has extensively covered the rapid expansion course of TNCs in the light of their high financial losses (CNBC, 2017), and rumors about market consolidations/mergers (WSJ, 2016). Even Uber itself stated in its IPO documents the threat that it “may not achieve profitability” in the future. Furthermore, the existence of scenarios leading to profitability of TNCs has cast doubt among researchers, with automation being mentioned as the only pathway to economic viability (Goletz and Bahamonde-Birke, 2019).

Under this scenario, the aggressive expansion of TNCs has been explained as an indispensable strategy to generate consumers’ loyalty and gain market-shares in the hopes of higher future returns (Horan, 2017). With the advent of vehicle automation, TNCs are set to collide with other forms of Mobility as a Service (MaaS), in which case having a market dominate position may prove crucial. In fact, Goletz and Bahamonde-Birke (2019), considering operational costs only, showed that providing MaaS with autonomous vehicles (understood as the provision of on-demand mobility services with small vessels) is likely to be associated with economies of scale, leading to a natural monopoly to be characterized by decreasing marginal costs per driven kilometer for all levels of service. Thus, in deregulated markets, dominant companies are likely to advance to a monopolistic position, which may be the goal of TNCs and provide a clear explanation of their aggressive and deficitary expansion strategies.

In the present paper, we extend the work by Goletz and Bahamonde-Birke (2019), considering not only operational costs, but also entrance barriers and fixed costs and the fact that the costs per driven kilometer do not represent the actual production function, as not all driven kilometers are actually requested/paid by the users. This analysis shows that the dominant position of the market leader is to become even more dominant than predicted by Goletz and

* Corresponding author. Sociale Geografie en Planologie, Universiteit Utrecht, Princetonlaan 8a, 3584 CB, Utrecht, the Netherlands.
E-mail addresses: bahamondebirke@gmail.com (F.J. Bahamonde-Birke), mirko.goletz@dlr.de (M. Goletz), d.f.ettema@uu.nl (D. Ettema).

https://doi.org/10.1016/j.retrec.2020.100993
Received 17 October 2019; Accepted 19 October 2020
Available online 1 November 2020

Bahamonde-Birke (2019). Therefore, our results imply that once autonomous vehicles (AVs) become available, the regulation of TNCs and the provision of MaaS will be a necessity because of market power considerations. Along these lines, it is important to consider that the provision of MaaS with autonomous vehicles is likely to be associated with large negative externalities (Bahamonde Birke, Kickhöfer, Heinrichs, & D Kuhnimhof, 2018; Smith, 2012; Zmund et al., 2016). Therefore, in order to regulate the market, cities will be in the necessity of developing multi-objective regulatory schemes. Thus, this paper also considers five different regulation strategies, taking the aforementioned issues into account.

The remaining of the paper is organized as follows: Section 2 presents an analysis of the cost structure of MaaS providers, showing why the provision of MaaS with AVs is likely to become a natural monopoly. Section 3 introduces different regulatory schemes that can eventually be put in place by regulatory authorities, in light of their advantages, benefits and possible outcomes. Finally, Section 4 presents the conclusions of the study.

2. The cost structure of MAAS with AVs

For the purpose of this analysis, at a first stage, we will consider a provider of Mobility as a Service with autonomous vehicles (small vessels; mass transport will be considered ahead).[1] Also, at a first stage, we will consider that the regulatory authority does not put any regulations in place and that providers are free to enter and exit the market, as well as to vary their offer, which can be characterized in terms of the fare per kilometer (*F*) and the number of vehicles (fleet size) *N*. Under this condition, the providers would aim at maximizing their own profit, which is given by:

$$Max \quad \mathscr{L} = F \cdot D(F,N) - C(F,N) \qquad [1]$$

where *D(F,N)* represents the yearly demand for kilometers faced by the company and *C(F,N)* stands for the yearly costs. *F* and *N* are to be freely chosen by the provider in order to maximize its profit. Here, the yearly cost can be expressed as:

$$C(F,N) = c \cdot K(F,N) + RR \cdot P_{veh} + M(A) \cdot K(F,N) + FC \qquad [2]$$

where *c* stands for the cost of operating a vehicle per kilometer, and *K(F, N)* the total amount of kilometers being traveled by the company's vehicles (note that it differs from *D(F,N)* as it includes kilometers without passengers) P_{veh} stands for the price of purchasing a new vehicle minus the residual price (so that $P_{veh}=P_{new}-P_{res}$), while *RR* represents the replacement rate (expressed in vehicles per years). Finally, *FC* represents the fixed costs and entrance barriers while *M(A)* represents the average maintenance costs per kilometer, which monotonically increases with the average age of the fleet *A*[2]. In eq. [2] both *RR* and *A* are endogenous to the optimization process and can be expressed in terms of both *F* and *N*. First, the replacement rate can be expressed as a function of the total amount of kilometers *K(F,N)* and the maximal amount of kilometers that can be driven by a vehicle before being taken out of circulation q_{max}. Hence, the replacement rate can be modeled as:

$$RR = \frac{K(F,N)}{q_{\max}} \qquad [3]$$

The average age of the fleet, in turn, is a function of the fleet size and the replacement rate, so that assuming a stationary state:

$$A = \frac{1}{2}\frac{N}{RR} = \frac{1}{2}\frac{N \cdot q_{\max}}{K(F,N)} \qquad [4]$$

If we then insert eq. [3] into the cost function [2]:

$$C(F,N) = c \cdot K(F,N) + \frac{K(F,N)}{q_{\max}} \cdot P_{veh} + M(A) \cdot K(F,N) + FC \qquad [5]$$

Then, if we calculate the average costs per driven kilometer (AC_K) as well as the marginal costs per driven kilometer (MC_K) akin to the analysis conducted by Goletz and Bahamonde-Birke (2019), we will observe that:

$$AC_K(F,N) = \frac{C(F,N)}{K(F,N)} = c + \frac{P_{veh}}{q_{\max}} + M(A) + \frac{FC}{K(F,N)} \qquad [6]$$

and

$$MC_K(F,N) = \frac{\partial C(F,N)}{\partial K(F,N)}$$
$$MC_K(F,N) = c + \frac{P_{veh}}{q_{\max}} + M(A) \cdot \frac{\partial K(F,N)}{\partial K(F,N)} + \frac{\partial M(A)}{\partial A} \cdot \frac{\partial A}{\partial K(F,N)} \cdot K(F,N) \qquad [7]$$
$$MC_K(F,N) = c + \frac{P_{veh}}{q_{\max}} + M(A) - \frac{1}{2}\frac{N \cdot q_{\max}}{K(F,N)} \cdot \frac{\partial M(A)}{\partial A}$$

From here, it is straightforward to see that the marginal costs per driven kilometer are necessarily lower than the average costs, as the first three summands of eqs. [6] and [7] are the same, the fixed costs are necessarily positive and the maintenance costs monotonically increase with the average age of the fleet *A* (which implies that the first derivative of *M(A)* after *A* is always positive and the fourth summand of eq. [7] is negative).

However, the former results refer to the kilometers actually being driven and not to the kilometers being requested/sold by/to the customers. Hence, they cannot be directly understood as the marginal cost of production. For this purpose, it is necessary to express the costs in terms of the amount of kilometers that are actually requested by the users. Therefore, it is convenient to express the total amount of driven kilometers *K(F,N)* as a function of the demand for kilometers *D(F,N)* faced by the provider in the following fashion:

$$K(F,N) = D(F,N) \cdot \alpha(D(F,N),N) \qquad [8]$$

where *α(D(F,N),N)* stands for the relation between the total amount of driven kilometers and the kilometers that are effectively being paid/requested by the customers (i.e. discounting kilometers driven in order to pick up customers and to reposition vehicles). Here, it is straightforward to see that *α(D(F,N),N)* is necessarily larger than one. Furthermore, *ceteris paribus* (i.e. keeping the number of vehicles and the spatial characteristics of the demand constant) there is a monotonically decreasing relation between *α(D(F,N),N)* and *D(F,N)*, as a larger demand necessarily implies a more balanced and regular spatial distribution (because of the law of large numbers) and a higher density of trip requests, which, consequentially, implies that a more efficient allocation of the vehicles is possible (reducing the amount of dead kilometers).

If we now consider the average (AC_D) as well as the marginal costs per requested kilometer (MC_D), we will observe the following situation:

$$AC_D(F,N) = \frac{C(F,N)}{D(F,N)} = \frac{C(F,N)}{K(F,N)} \cdot \frac{K(F,N)}{D(F,N)} \qquad [9]$$
$$AC_D(F,N) = AC_K(F,N) \cdot \alpha(D(F,N),N)$$

and

[1] Note that the reach of the framework goes beyond car-sharing with AVs, covering mobility on-demand with small AVs entirely, be it understood as individual mobility, share-mobility or as feeder-system.

[2] Note that the maintenance costs increase with both the average age and the average mileage of the fleet. However, as we are considering a stationary state, the average mileage can be assumed to be constant and equal to the half the maximal amount of kilometers that can be driven by a vehicle before being taken out of circulation q_{max}

$$MC_D(F,N) = \frac{\partial C(F,N)}{\partial D(F,N)} = \frac{\partial C(F,N)}{\partial K(F,N)} \cdot \frac{\partial K(F,N)}{\partial D(F,N)}$$

$$MC_D(F,N) = MC_K(F,N) \cdot \left[\alpha(D(F,N),N) + D(F,N) \cdot \frac{\partial \alpha(D(F,N),N)}{\partial D(F,N)}\right] \quad [10]$$

Here, again the marginal costs are necessarily lower than the average costs for all levels of demand, as the first summand of (MC_D) is lower than the average costs (given that $MC_K < AC_K$; see eqs. [6] and [7]) and the second is necessarily negative (given that $\alpha(D(F,N),N)$ monotonically decreases with *D(F,N)*). As a consequence, we are in presence of a natural monopoly, in which the larger provider will always face lower costs (both average and marginal) than the competition. Hence, in absence of regulation the larger provider may attain monopolistic power, distorting the market and reducing the social welfare (Berg and Tschirhart, 1988; Joskow, 2007).

The main difference with the current situation, if we consider providers of MaaS-services such as ride sourcing, car-sharing or taxis, is that when providing MaaS with autonomous vehicles the requirement of human drivers to operate the vehicle or to reposition them (in the case of car-sharing) disappears. As a consequence, the costs of operating a vehicle do no longer depend on the labor market and the availability of drivers and can be considered to be constant (note that the drivers' availability constraint implies that the output - the amount of kilometers being offered - depends on the local labor market, and consequentially higher wages are requested to increase it, i.e. to recruit more drivers and being able to increase the output). Thus, the marginal costs of operating a fleet are no longer increasing and the decreasing marginal costs, associated with fixed costs, maintenance and the age of the fleet, as well as the more efficient allocation of vehicles to requested trips, dominate the supply function.

3. Regulatory schemes

As discussed in the previous section the provision of MaaS with AVs is likely to require regulatory schemes in order to maximize social welfare. In this section different regulatory schemes will be considered in light of their expected results and their social desirability from a welfare perspective. This section, however, does not aim at offering a complete review of possible regulatory schemes (for this purpose, the author is referred to Berg and Tschirhart, 1988 or Joskow, 2007, among many others), but rather to consider the specifics of the MaaS market.

3.1. Unregulated market – single price

If the regulatory authorities do not act on the MaaS-market, different MaaS providers may eventually enter the market. In this situation, however, the larger company would be confronted with the smallest marginal costs and, therefore, it is likely to prevail and drive the competition out of the market. After the consolidation of the monopoly, the entrance of new companies will be unlikely as they will experience higher costs per kilometer.

If the market is not regulated, the monopolistic provider would aim at maximizing its own profit. Thus, the MaaS provider would aim at maximizing the profit function (eq. [1]) by selecting an optimal fare F and an optimal fleet size N. Note that opposite to the standard optimization problem faced by monopolies, in which the profit function is expressed in terms of the quantity, eq. [1] is expressed in terms of the fare (the price), as the monopolistic provider controls the fare (and the number of vehicles N) and not the output (the amount of kilometers being requested). The results, however, are analogous. Hence, by considering the first order conditions, we obtain that the optimal fare would be given by the markup price, so that:

$$F = \frac{\varepsilon}{\varepsilon + 1} \cdot MC_D(F,N) \quad [11]$$

where ε represents the price elasticity of demand. Consequently, the company would select F and N such that the requested kilometers fall within the elastic segment of the demand function ($\varepsilon < -1$) and the fare will be above the marginal costs. Hence, the output will be below optimal societal levels and the monopolistic provider would be earning a monopoly rent at expenses of a reduction of the economic welfare.

However, in a market such as MaaS, in which the provider has a big amount of information at its disposal (including both the spatio-temporal characteristics of demand – i.e. origin, destination and time of the trips - as well as the usage profiles of the customers), the aforementioned scheme is not likely to occur and the provider may introduce price differentiation schemes in order to increase the monopoly rent.

3.2. Unregulated market – price discrimination

While most studies addressing the future demand for MaaS-services with AVs draw from the premise that the access will be equal for all customers, similarly to current TNCs or taxi companies (e.g. Fraedrich et al., 2015; Heinrichs and Cyganski, 2015), as previously discussed, this assumption is not likely to hold in a scenario where a provider has monopolistic power. By using its information about the demand, the MaaS provider is in position to put second-degree and third-degree price discrimination schemes in place.

Second-degree price discrimination schemes are straightforward to implement. In fact, we observe that current MaaS providers, such as car-sharing companies, put schemes such as two-part tariffs and quantity-dependent pricing in place. These schemes allow increasing both the outcome and the economic welfare (compared with monopolistic markup pricing), but this increase in welfare is being entirely captured by the provider (when contrasted with the social optimum).

Furthermore, given the specific spatio-temporal characteristics of the mobility demand, a MaaS provider can also introduce third-degree price discrimination schemes, offering differentiated prices depending on the origin and destinations of the trips as well as on the time of day (or week, or month, or year). For instance, a quick check of eq. [11] reveals that if the demand for trips originating in two different parts of the city (or at different times of day) is not equally elastic, the fare is also likely to be different. Hence, higher fares could be expected for commuting trips than for more elastic leisure trips or for trips based (having their origin or destination) on business districts or on transport hubs (train stations, airports, etc.) than for trips between residential areas (more elastic).

It is important to consider that a monopolistic provider can also implement second- and third-degree price discrimination schemes simultaneously, further increasing its profit. Summarizing, given that in an unregulated MaaS market the provider is also able to monitor the demand of every user, it will be in position to tailor its service (and price schemes) to every level of demand capturing a large proportion of the consumer surplus. While price discrimination will allow increasing the total economic welfare (compared with a monopolistic provider using single prices) the users are most likely to end up worse-off.

3.3. Regulated market – private costs

As previously mentioned, it is not the purpose of this paper to review different alternatives to regulate natural monopolies and when addressing the provision of MaaS from the perspective of private costs only, the regulatory provisions to be implemented are quite standard. Basically, an optimal outcome (if all costs are being internalized by the users) would be achieved by imposing fares equal to the marginal costs (given an optimal fleet size N, which is also subject of regulation), but it would require a substantial subsidy, as the fare would not cover the costs (Joskow, 2007). Similarly, and instead of providing a subsidy, the regulatory authority may allow for price discrimination schemes so that the additional revenue would allow the provider to break even; however, unless price discrimination is perfect (first-degree price discrimination), it would also result in losses in social welfare, as the fare would be above the optimal (and consequentially the consumption would be below the social optimum). Other second-best regulatory schemes include making the fares equal to the average costs or Ramsey-Boiteux pricing, among many others (Joskow, 2007).

However, the aforementioned regulation is unlikely to yield socially optimal results in this specific case, as MaaS is part of a broader transportation system, and, as such, the provision of MaaS is associated with several negative and positive externalities, such as congestion, air pollutant emissions, safety, noise, accessibility, inclusion/exclusion, etc. Furthermore, while the provision of MaaS with AVs itself will be a natural monopoly, when considering the services in a broader sense, the provider would still face some level of competition from private, public and non-motorized transport. The latter further complicates implementing adequate regulation.

3.4. Regulated market – social costs

Opposite to private transport, and akin to public transport, a monopolistic provider of MaaS would internalize a proportion of the congestion associated with the service (the proportion to which the congestion affects its own vehicles). However, the MaaS provider would not internalize the congestion cost induced on public, private and non-motorized transport. Hence, the extent to which congestion costs are internalized depends on the market share (modal share) of the MaaS provider (which is likely to increase when AVs become available, given the new lower cost structures, Fagnant and Kockelman, 2015; Bahamonde Birke, Kickhöfer, Heinrichs, & D Kuhnimhof, 2018; Fraedrich et al., 2018). Nevertheless, while congestion costs are partially internalized, other externalities, such as air pollutant emissions, safety, noise or inclusion remain as such.

When considering the total social costs *SC(F,N)* of providing MaaS-services, we have the following situation:

$$SC(F,N) = C(F,N) + E(F,N) \quad [12]$$

where *E(F,N)* is a reduced expression representing all costs not being internalized by the provider. Consequentially, the social marginal costs per requested kilometer are given by:

$$MSC_D(F,N) = MC_D(F,N) + \frac{\partial E(F,N)}{\partial D(F,N)} \quad [13]$$

A priori, nothing can be said regarding the marginal external costs, as they may be even negative if positive externalities (such as safety inclusion) dominate, although it is unlikely, or at least, unlikely for the entire system (however, positive externalities may be dominant for services provided to e.g. socially marginalized groups or the elderly or in areas with low accessibility). Nevertheless, it is important to acknowledge that even if the marginal external costs would increase with the demand, and eventually the marginal social costs would be above the average social costs, it does not change the fact that the provision of MaaS with AVs is likely to be a natural monopoly. The reason is that marginal costs are equal for all providers (as they depend on the total traffic and its effect on of their level-of-service), and therefore, the larger provider would still have lower costs than eventual competition.

Under these circumstances, the social optimum would be given by a price equal to $MSC_D(F,N)$ and it would require from the regulatory authority to impose a tax (or a subsidy if the value is negative) equal to:

$$Tax(F,N) = MC_D(F,N) + \frac{\partial E(F,N)}{\partial D(F,N)} - AC_D(F,N) \quad [14]$$

While imposing such a tax/subsidy on the provision of MaaS with AVs, would indeed lead to a social optimum for the MaaS market, its implementation may be subject to a series of problems:

- If only the provision of MaaS is subject to this regulation, it will not lead to an optimal set-up for the transportation network, as MaaS-services interact with private, public and non-motorized transport. If only the MaaS provider is forced to internalize the external costs, we will observe levels of demand/supply above the optimum for all alternatives having negative net externalities. Vice versa, alternatives where positive net externalities are not fully captured – this may be the case for public transport – may even face a demand below the social optimum.
- Establishing accurately the level of externalities would be highly complicated. The reason behind this, is that the provision of MaaS would be characterized not only by the usual negative externalities of transport (such as congestion and air pollutant emissions) but also by a complicated interaction with public transport, and, therefore, the net effect on desirable external effects, such as accessibility and social inclusion will be hard to measure.
- If the service would indeed require a subsidy, it may be hard to plead for it from a political perspective, as MaaS-services would interact and partially compete with public transport, which, in turn, is also a subsidized natural monopoly (Evans, 1991). In fact, even from a purely welfare-economic viewpoint, it is debatable whether two natural monopolies with some degree of interaction/competition should both be subsidized: as increasing the subsidy of one alternative would result in higher modal share, this would lead to lesser demand and increased marginal costs for the other natural monopoly.

3.5. Integration into public transport

In the previous sections, we have considered the provision of MaaS (understood as the provision of on-demand mobility services with small vessels) as an alternative to public transport (understood as the on-schedule provision of mass transport). However, it is not uncommon to consider the integrated provision of both kinds of services under the umbrella term MaaS. Given these considerations and aforementioned problems to regulate the provision of MaaS with AVs, the integration of MaaS-services into public transport (PT) could be taken into consideration. This way, a single monopolistic provider would offer both public transport and MaaS. This scheme would exhibit the following advantages:

- A larger degree of internalization of congestion costs by the provider.
- No partial competition between two services with decreasing marginal costs.
- Short-term synergies between MaaS and PT: complementarity between mass transport modes in congested links and individualized services in sparsely populated areas.
- Long-term synergies between MaaS and PT: better level-of-service and flexibility avoids the switch to private transport (characterized by a higher level of negative externalities).
- Simplification of the regulation (from the perspective of the regulatory authority).
- Currently existing public support for subsidies to public transport.

Despite the former advantages, integrating MaaS and public transport also carries some risks, as from an operational viewpoint both services are substantially different and an integrated provider of MaaS/PT may lack the required know-how in either MaaS or PT, which may lead to inefficient operation. Furthermore, and also because of operational reasons, an integrated provider of MaaS/PT may subdivide the operation, which, in turn, may affect the internalization of congestion costs and taking advantage of the synergies. Finally, it might still be necessary to establish a service-specific subsidy, as a gross subsidy may be used by the provider in a socially inefficient way, leading to an undersupply of some services and oversupply of others.

4. Conclusions

The present paper discusses the cost structure of the provision of Mobility as a Service, once autonomous vehicles become available. It extends the analysis by Goletz and Bahamonde-Birke (2019) by taking fixed costs into account as well as the fact that the actual production costs do not directly relate to the total amount of kilometers driven by the provider of MaaS, but to the amount of kilometers being actually paid/requested by the users. The paper concludes that for all levels of demand, the provision of MaaS with AVs will be associated with lower marginal than average costs, configuring a natural monopoly. The reason behind this phenomenon is that AVs allows disposing of drivers, which are a limited resource, and consequentially subject to increasing marginal costs. Without the drivers' cost, all remaining components of the cost function are subject to economies of scale (for all levels of demand).

The fact that the provision of MaaS is likely to become a natural monopoly once AVs becomes available, implies that regulation may be necessary, as otherwise social losses can be expected. Furthermore, as the provision of MaaS is part of a broader transportation system, externalities can also be expected. We considered five different regulatory schemes in light of their advantages and shortcomings. The analysis shows that an unregulated market with single prices would lead to suboptimal levels of supply, or more specifically to suboptimal high prices (as the provider controls the fare and not the production). Allowing for prize discrimination will increase the output as well as the total economic welfare, but the consumer surplus would be largely captured by the monopolistic provider, as it would be in position to implement very aggressive and effective second- and third-degree price discrimination schemes (given the spatiotemporal characteristics of demand as well as the possibility to implement usage profiles). A regulated market considering only private costs only would lead to suboptimal results given the existence of significant externalities, while implementing effective regulatory schemes may prove overly complicated given the complexity of the transportation systems as well as the interaction of MaaS with public transport (another natural monopoly). Finally, we consider integrating the provision of MaaS and public transport, which would exhibit several advantages including a substantial reduction in the complexity of the regulation. However, other problems (such as lack of know-how or inefficient use of the subsidies) may arise. Further research is required on how the provision of MaaS with small vessels interacts with mass transit, and how regulation among partially competing monopolies should be enacted, especially in the presents of large negative (congestion, emissions, etc.) and positive externalities (accessibility, inclusion, safety, etc.). Along these lines it is necessary to study how regulation can be enforced.

References

Bahamonde Birke, F. J., Kickhöfer, B., Heinrichs, & D Kuhnimhof, T. (2018). A systemic view on autonomous vehicles: Policy aspects for a sustainable transportation planning. *disP – The Planning Review, 54*(3), 12–25.

Berg, S. V., & Tschirhart, J. (1988). *Natural monopoly regulation: Principles and practice*. New York: Cambridge University Press.

CNBC. (2017). *Uber's loss jumped 61 percent to $4.5 billion in 2017*. https://www.cnbc.com/2018/02/13/ubers-loss-jumped-61-percent-to-4-point-5-billion-in-2017.html.

Cramer, J., & Krueger, A. B. (2016). Disruptive change in the taxi business: The case of Uber. *American Economic Review, 106*(5), 177–182.

Evans, A. W. (1991). Are urban bus services natural monopolies? *Transportation, 18*(2), 131–150.

Fagnant, D. J., & Kockelman, K. (2015). Preparing a nation for autonomous vehicles: Opportunities, barriers and policy recommendations. *Transportation Research Part A: Policy and Practice, 77*, 167–181.

Flores, O., & Rayle, L. (2017). How cities use regulation for innovation: The case of uber, Lyft and sidecar in san francisco. *Transportation Research Procedia, 25*, 3756–3768.

Fraedrich, E., Beiker, S., & Lenz, B. (2015). Transition pathways to fully automated driving and its implications for the sociotechnical system of automobility. *European Journal of Forest Research, 3*, 3–11.

Fraedrich, E., Heinrichs, D., Bahamonde-Birke, F. J., & Cyganski, R. (2018). Autonomous driving, the built environment and policy implications. *Transportation Research Part A: Policy and Practice, 122*, 162–172.

Goletz, M., & Bahamonde-Birke, F. J. (2019). The ride-sourcing industry: Status-quo and Outlook. In *15th world Conference on transport research, Mumbai, India* (pp. 26–31).

Heinrichs, D., & Cyganski, R. (2015). Automated driving: How it could enter our cities and how this might af fect our mobility decisions. *disP-The Planning Review, 51*(2), 74–79.

Horan, H. (2017). Will the growth of Uber increase economic welfare. *Transportation Law Journal, 44*, 33–105.

Joskow, P. L. (2007). Regulation of natural monopoly. In A. M. Polinsky, & S. Shavell (Eds.), *Handbook of law and economics, 2* pp. 1227–1348).

Pangbourne, K., Stead, D., Mladenović, M., & Milakis, D. (2019). Questioning mobility as a service: Unanticipated implications for society and governance. *Transportation research Part A: Policy and practice*.

Smith, B. W. (2012). Managing autonomous transportation demand. *Santa Clara Law Review, 52*(4), 1401–1422.

Tirachini, A., & Gomez-Lobo, A. (2019). Does ride-hailing increase or decrease vehicle kilometers traveled (VKT)? A simulation approach for santiago de Chile. *International Journal of Sustainable Transportation*. https://doi.org/10.1080/15568318.2018.1539146

WSJ. (2016). Uber China-didi fight drives merger talk. *The wall street journal*. https://www.wsj.com/articles/uberchina-didi-fight-drives-merger-talk-1466004980.

Zmund, J., Sener, I. N., & Wagner, J. (2016). *Consumer acceptance and travel behavior impacts of automated vehicles, 15–49*. F Texas A&M Transportation Institute.

Zoepf, S. M., Chen, S., Adu, P., & Pozo, G. (2018). *The Economics of ride-hailing: Driver revenue, expenses, and taxes*.