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Business models for interoperable mobility services

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Abstract

Travelers often combine transport services from different firms to form trip chains: e.g. first train and then a bus. Integration of different forms of public and private transport into a single service is gaining attention with the concept of Mobility as a Service (MaaS). Usually, the focus is on such things as ease of use, and shifting demand away from the car. We solely focus on the effects on behaviour and welfare via the market structure of transport. In particular, we analyse three archetype ways in which MaaS could be operationalized: Integrator, Platform, and Intermediary. We find that these models differ strongly in how consumers and firms are affected. The Integrator seems best for consumers and social welfare. It always leads to lower prices than Free Competition without MaaS and therefore benefits consumers; transport firm profits can be lower or higher. The Platform tends to lead to an outcome that is relatively close to Free Competition without MaaS: prices can be higher or lower, while transport firm profits are lower. Finally, the Intermediary tends to lead to much higher prices. Regulation of the price that the MaaS firm has to pay may further lower prices, but compared to the Integrator the difference is often small. So, even without price regulation, MaaS supply can already benefit consumers by increasing competition and removing serial marginalization, even before we consider other benefits of MaaS such as information provision, ease of use and a demand shift towards public transport.

JEL codes: D21, D43, R40

Key words: MaaS, market structure, platform, intermediary, integrator, regulation

1. Introduction

Travelers often combine complementary transport services to form trip chains: e.g. taxi as egress mode after a train trip. Specific parts of the trip chain are either offered by as services supplied by individual firms, or can be supplied by vertically integrated firms. Vertical integration refers to the combination of individual services by a single supplier, jointly forming a trip chain from the origin to the destination. Travelers are interested in combining complementary (compatible) services, and as such an integrated bundle is easier for them. From a welfare perspective, the provision by a single firm may reduce the vertical negative externality that arises when firms with market power each apply their mark-ups in prices, and so customers face multiple mark-ups. However, there is also a downside of integration of transport services within a single firm: for alternative trip options such as parallel routes it may limit competition and thus yield higher prices. Horizontal competition among substitutable transport services does have benefits. The issue of competition vs integration/coordination has been important in the economics of transport services, as well as in other network industries. Competition is important in decreasing costs and prices and improving quality. Coordination is vital to ease travellers' life, but may also increase or decrease fares. In the past decades, integration of transport services within a single firm or by alliances of firms received considerable attention demonstrating considerable difficulties (Brueckner, 2001; Verhoef, 2008; Van der Velde et al, 2005; Meurs et al, 2019; Vij et al, 2020).

In recent years integration of various forms of public and private transport services offered by different firms into a single mobility service offering, accessible by an App or Website, has gained attention with the emergence of the concept of Mobility as a Service (MaaS). MaaS is defined as a user-centric, intelligent mobility distribution model in which all mobility services are aggregated by an operator and supplied to users through a single digital platform (Kamargianni et al., 2016; Jittrapirom et al., 2017). Its current popularity is based on the expectation that it will bring significant social, economic and environmental benefits to urban societies, including accessibility, social inclusion and environmental challenges (Jittrapirom et al., 2017). For the users, MaaS offers added value through the use of a single application to provide access to mobility, with a single payment channel instead of multiple ticketing and payment operations. and increased services for planning of trips. With MaaS, disjoint networks offered by different suppliers are interconnected through a virtual platform. The platform could be realized by public or private agencies. In some cases, the platform is owned by a major transport firm: for instance, Transdev and Toyota who have shares in the Finnish MaaS-provider MaaS Global (Pöllänen, 2020).

The introduction of MaaS, often acting as an *intermediary* between the providers of transport services, raises many issues with respect to economic consequences for the current transport service providers, as well as for the travellers. What are the effects of the introduction of a MaaS service provider on the demand for transport services and the fares users pay? Which effects will the

introduction of MaaS have on pricing behaviour and profits of the transport providers? What prices can the MaaS provider charge to transport firms or to final customers? Will society be better off with the provision of MaaS integrating independent transport providers, or with a single integrated firm offering all transport, or with independent transport providers without any integration via MaaS?

Although policymakers, researchers and consultants are spending much effort in addressing these issues, an economic framework for addressing them is lacking. In this paper we aim at developing such a framework and applying it to the issues mentioned above. For this purpose, we adopt the approach developed by Economides and Salop (1992) to analyse the effect of competition and integration among complementary services on the equilibrium prices by examining a variety of alternative market structures. This approach was applied in analysing public transport networks, airlines, logistics, roads, etc. (e.g. Clark et al., 2014; D'Alfonso et al, 2016; Lin, 2004; Park et al, 2003; Silva et al, 2013; Zhang et al, 2012; Mantin, 2012; Verhoef, 2008; van den Berg, 2013). Application of this framework for MaaS is new to the best of our knowledge.¹

In this paper, we study the effects of the introduction of MaaS-platforms in the market for transport services on prices, profits and welfare. We analyse different supply chain structures with two competing transport providers and one MaaS service provider. The MaaS-provider sells multimodal services from each of the two transport providers. We formulate a number of noncooperative games with different pricing strategies by the players, as well as different power structures. By comparing these equilibria, we can assess the implications of different business structures for prices, demands, profits, consumer surplus and social welfare.

The paper is structured as follows. In the second section, we formulate the supply chain structures and the associated models. In section three the results will be shown for the key models. Section 4 presents a numerical example and some sensitivity analysis. In section 5 we reflect on possible price regulation. In section 6 we present the conclusions.

2. Modelling supply chain structures for mobility services

2.1 The supply chain structures

The setting is illustrated in Fig. 1. Let there be two types of transport services, Mode 1 and 2, such as public transport and bike sharing services. Each service supports two links (components) required to travel from origin to destination. A denotes the upstream segment, and B downstream. Travelers can use four combinations A_i and B_j ($i, j=1, 2$). Hence, the service components A_1 versus A_2 , and B_1 versus B_2 are substitutes, while the four pairs A_1 and B_1 , A_1 and B_2 , A_2 and B_1 , and A_2 and B_2

¹ Pandey et al. (2019) look at cooperation and competition between MaaS/ridesharing operators but in terms of supplying rides without considering pricing. Related papers looking at pricing of innovative transport technologies include Ma and Zhang (2017) and Kaspi et al. (2014) on ride sharing, Tan et al. (2019) on parking space sharing, Van den Berg and Verhoef (2016) and Simoni et al. (2019) on autonomous vehicles, and Verhoef et al. (1996) on information provision.

are complements. We assume that all travellers are making trips from the single origin to the single destination and have to use a complete bundle using one segment A and one segment B; so no individual segments can be used (no partial trips).

We consider two cases presented in Figure 1: one with and one without a platform provider. The left panel represents the case of two independent firms that compete for individual trips. In the right-hand panel a MaaS-provider is added, which provides the two multimodal services shown as diagonals in the diagram. We assume that the key proposition of MaaS is to sell multimodal trips. The situation with the two independent firms without MaaS will serve as a reference situation for the analysis.

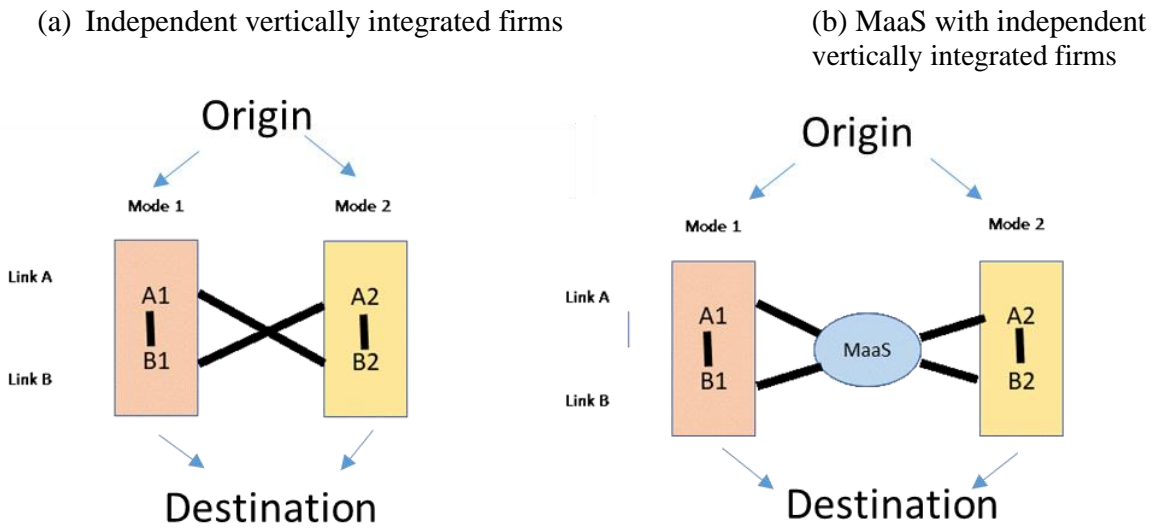


Fig. 1: combining mobility services with and without MaaS) with two transport providers offering door-to-door services.

The price of using firm i for the first link A is p_i , and for using i for the second link B it is q_i . When solely using one firm for the complete trip, the firm may sell the combined trip at a different bundle price s_{ii} . Further, the MaaS supplier may sell a complete cross-network trip at price s_{ij} .² The combined price, P_{ii} , for using only firm one is thus p_i+q_i or s_{ii} if the transport firm offers bundling; a cross network trip has a combined price P_{ij} of p_i+q_i or s_{ij} if there is a MaaS supplier that offers bundling.

We have two reference cases without a platform:

- **Free competition** in which within- and cross-firm services can be used by the traveller. Each firm can set up to three prices: the prices of the service on both links, p_i and q_i , and a complete trip price with “door-to-door services” (assuming no access before A , or regress after B) from a specific firm with a discount $s_{ii} \leq p_i + q_i$.
- **Independent services** when there is no cross-firm travel. This latter case gives the minimum profit that firms must make for them to be willing to be part of a platform as a single firm can

² Non-arbitrage conditions hold: i) the price of the bundle cannot be larger than the price of the individual components ($s_{ii} \geq p_i; s_{ii} \geq q_i; s_{ij} \geq p_i; s_{ij} \geq q_j$), and ii) the price of the bundle cannot be larger than the sum of prices of individual components ($s_{ii} \leq p_i + q_i; s_{ij} \leq p_i + q_j$).

always choose not to allow cross travel by not stopping at the point of intersection between A and B where the alternative mode stops.

With a MaaS platform, we consider three different cases (for simplicity, in all three cases we assume that cross-network trips are impossible without using the MaaS Platform):

- **System integrator model.** The firms set the own price (s_{ii}) and the platform sets the cross-travel prices s_{ij} , the platform keeps an exogenously fixed share ϕ of revenue. This reflects for instance the business structure of the *Apple computers for hardware components*: individual firms sell hardware components to Apple which integrates these components into their Macs. The integrator sells the combined (cross-network) services to end-users at the price they set. So if this case there are only bundle prices, and no link prices.
- **Platform model.** In this model, the transport firms set all prices, the platform keeps share ϕ of revenue. This reflects the business models of platform firms such as Airbnb, Booking.com, eBay, Amazon or AliExpress.³ The price for an on-network trip of firm i is $P_{ii}=s_{ii}$, a cross network trip first using firm i and then firm j has a price of $p_i + q_j$.
- **Intermediary model, transport firms as the leader.** Transport firm i sells the segments of the cross trips to the platform at wholesale prices p_i and q_i and the platform sets cross trips at retail price s_{ij} to the travellers. This model reflects the retail market where intermediaries sell products and services that are bought from manufacturers or wholesalers. An example is Amazon, who buys products from many wholesalers and the sell them on-line to customers. Although, as noted above Amazon, also operates as a Platform.⁴

2.2 The model

Consider a representative traveller deriving utility from making trips, described by a quadratic and strictly concave utility function (Singh and Vives,1984) that allows for imperfect substitutability between the four options:

$$\begin{aligned}
 &U(Q11, Q12, Q21, Q22) \\
 &= \alpha(Q11 + Q12 + Q21 + Q22) - \frac{\beta(qQ11^2 + Q12^2 + Q21^2 + Q22^2)}{2} \\
 &- \gamma(Q11 Q12 + Q11 Q21 + Q11 Q22 + Q12 Q21 + Q12 Q22 + qQ21 Q22) \quad (1)
 \end{aligned}$$

³ Most of these platforms offer information and payment services allowing easy access of users to the suppliers of the services as hotel rooms, car seats and so on. In the analysis in this paper we will omit these extra services and leave it for future work.

⁴ The difference with the Integrator is that now there are two layers of price setting—wholesale and final cross-network prices—and thus extra serial marginalization, whereas with the Integrator this is integrator and only the integrator affects cross-network prices.

Q_{11} is the number of trips using mode or firm 1 for both legs of the trip, Q_{21} is the number of trips using first firm 2 and then firm 1, and so on. Here, $\alpha > 0$, $\beta > 0$ and $\gamma > 0$ are parameters. Goods are imperfect substitutes when $\beta > \gamma$.

When setting the marginal utility of income fixed and normalized to 1, U also represents Marshallian benefits and consumer surplus can be written as (with P_{11} being the total price of using firm 1 for both legs of the trip, P_{12} of using first firm 1 and then 2, and so on):

$$CS = U(Q_{11}, Q_{12}, Q_{21}, Q_{22}) - (P_{11} Q_{11} + P_{12} Q_{12} + P_{21} Q_{21} + P_{22} Q_{22}) \quad (2)$$

From which the inverse demand (or marginal willingness-to-pay) functions for all trip types can be derived; e.g. for P_{11} :

$$P_{11} = \alpha - \beta Q_{11} + \gamma(Q_{12} + Q_{21} + Q_{22}) \quad (3)$$

Inverting this system yields the direct demand functions, with D denoting quantity demanded; e.g. for D_{11} :

$$D_{11} = a - bP_{11} + c(P_{12} + P_{21} + P_{22}) \quad (4)$$

$$\text{with } a = \frac{\alpha(\beta - \gamma)}{\delta}, b = \frac{(2\gamma + \beta)}{\delta}, c = \frac{\gamma}{\delta}, \text{ and } \delta = (\beta - \gamma)(\beta + 3\gamma) \quad (5)$$

The newly introduced composite parameters can be interpreted as follows: a is the amount of consumption when all prices are zero, and is the same for all product types because of the assumed symmetry; b is the own-price sensitivity; and c the cross-price sensitivity. Finally, $\beta > \gamma$ must hold for the demand system to be consistent, which implies $b > 3c$.⁵ The condition indicates that, with imperfect substitutes, the sensitivity to all other prices needs to be smaller than that to the own price. This results Table 1, which gives the demand and profit functions for each of the supply chain structures for demand D_{ij} for transport service bundle (A_i, B_j) . Indeed, we use quadratic utility and the resulting simple linear functions as these allow for clear analytical results.

For conceptual transparency we ignore possible economies of scale or fixed costs, as this would mean that changes in market structure would also alter cost, while we want to focus on the isolated impacts via changes in competitive conditions. We may then next normalize the marginal cost to zero for all links for further notational ease. So, in the social optimum, the prices would equal the marginal cost of zero.

⁵ Since $b = \frac{2\gamma + \beta}{\delta} > \frac{2\gamma + \gamma}{\delta} = 3c$.

Table 1: Demand for routes with links i and j ($i,j=1,2$) and profits for the supply chain models

	Demand	Profit
Free competition	$D_{11}: a - b*s_{11} + c*(p_1 + q_2) + c*(p_2 + q_1) + c*s_{22}$ $D_{12}: a + c*s_{11} - b*(p_1 + q_2) + c*(p_2 + q_1) + c*s_{22}$ $D_{21}: a + c*s_{11} + c*(p_1 + q_2) - b*(p_2 + q_1) + c*s_{22}$ $D_{22}: a + c*s_{11} + c*(p_1 + q_2) + c*(p_2 + q_1) - b*s_{22}$	Firm 1: $D_{12}*p_1 + D_{21}*q_1 + s_{11}*D_{11}$ Firm 2: $D_{21}*p_2 + D_{12}*q_2 + s_{22}*D_{22}$
No-cross network trips	$D_{11}: a - b*s_{11} + c*s_{12} + c*s_{21} + c*s_{22}$ $D_{22}: a + c*s_{11} + c*s_{12} + c*s_{21} - b*s_{22}$	Firm 1: $s_{11}*D_{11}$ Firm 2: $s_{22}*D_{22}$
System integrator model	$D_{11}: a - b*s_{11} + c*s_{12} + c*s_{21} + c*s_{22}$ $D_{12}: a + c*s_{11} - b*s_{12} + c*s_{21} + c*s_{22}$ $D_{21}: a + c*s_{11} + c*s_{12} - b*s_{21} + c*s_{22}$ $D_{22}: a + c*s_{11} + c*s_{12} + c*s_{21} - b*s_{22}$	Firm 1: $D_{12}*s_{12}*(1-\phi)/2 + D_{21}*s_{21}*(1-\phi)/2 + s_{11}*D_{11}$ Firm 2: $D_{12}*s_{12}*(1-\phi)/2 + D_{21}*s_{21}*(1-\phi)/2 + s_{22}*D_{22}$ Platform: $D_{12}*s_{12}*\phi + D_{21}*s_{21}*\phi$
Platform model, transport providers setting prices	$D_{11}: a - b*s_{11} + c*(p_1 + q_2) + c*(p_2 + q_1) + c*s_{22}$ $D_{12}: a + c*s_{11} - b*(p_1 + q_2) + c*(p_2 + q_1) + c*s_{22}$ $D_{21}: a + c*s_{11} + c*(p_1 + q_2) - b*(p_2 + q_1) + c*s_{22}$ $D_{22}: a + c*s_{11} + c*(p_1 + q_2) + c*(p_2 + q_1) - b*s_{22}$	Firm 1: $D_{12}*p_1*(1-\phi) + D_{21}*q_1*(1-\phi) + s_{11}*D_{11}$ Firm 2: $D_{12}*p_2*(1-\phi) + D_{21}*q_2*(1-\phi) + s_{22}*D_{22}$ Platform: $D_{12}*(p_1 + q_2)*\phi + D_{21}*(p_2 + q_1)*\phi$
Intermediary model, transport firms setting prices	$D_{11}: a - b*s_{11} + c*s_{12} + c*s_{21} + c*s_{22}$ $D_{12}: a + c*s_{11} - b*s_{12} + c*s_{21} + c*s_{22}$ $D_{21}: a + c*s_{11} + c*s_{12} - b*s_{21} + c*s_{22}$ $D_{22}: a + c*s_{11} + c*s_{12} + c*s_{21} - b*s_{22}$	Firm 1: $D_{12}*p_1 + D_{21}*q_1 + s_{11}*D_{11}$ Firm 2: $D_{12}*p_2 + D_{21}*q_2 + s_{21}*D_{22}$ Platform: $D_{12}*(s_{11} - (p_1 + q_2)) + D_{21}*(s_{22} - (p_2 + q_1))$

As costs are zero by assumption, social surplus equals consumer surplus plus the profits of the transport firms (PR_1 and PR_2) plus any profit of the platform (PR_p):

$$W = CS + PR_1 + PR_2 + PR_p$$

With marginal cost and fixed cost both at zero, all prices can directly be interpreted as mark-ups.

Based on these assumptions, the profit functions presented in the second column of Table 1 are defined for the transport firms and MaaS providers. We use game theory to analyse the different business structures. For most structures we use the Bertrand formulation in which firms choose optimal prices taking the prices of the other firm. The Bertrand-Nash equilibrium then determines equilibrium demands and profits. For the intermediary model, we only consider a Stackelberg-price game. The transport firms are the leaders, and in setting wholesale prices for cross-trips to the platform take into account how the platform will react to changes in whole-sale price. Such Stackelberg behaviour seems more natural in this case than Nash behaviour where the wholesalers would take the prices to consumers as given. Moreover, under the Nash assumption, the intermediary model will always lead

to zero cross trips (and in effect no platform, which defeats the purpose of analyzing the intermediary model).⁶

From these functions, we derive the Bertrand-Nash equilibria for prices and profits for the reference situations as well as for situations with MaaS-platforms. Each transport firm and MaaS-operator chooses a price that maximizes its own profits, taking the prices of the other firms as given. The profit-maximization of each firm is characterized by the first-order conditions by differentiating the profit functions with respect to the price variables. From these we can then solve for the equilibrium prices, and thus demands and profits. By comparing these equilibria for different business models, we can assess their relative benefits for travellers and firms; and for social surplus.

3. Analytical analysis

3.1 *The effects of providing cross-network transport options*

We consider two cases as references: the situation with and the one without cross-network supply services. This analysis serves two purposes: (a) we examine the effects of cross supply on prices and profits and (b) it provides benchmarks for the business structures with the MaaS-provider.

Comparing the equilibrium-prices for the two bundles s_{ii}^* (asterisks will represent equilibrium outcomes) in Table 2 we find that the prices for the cases with cross-network supply are lower than without cross-network supply, except for the obvious case when the cross-price sensitivity c equals 0. (We remind the reader that $b > 3c$.) This implies that the introduction of cross-network competition quite intuitively lowers the prices, from which travellers benefit. The price of the within network bundle, s_{ii} , is lower than the price of the cross-network bundle $p_i + q_j$. Finally, profits of the firm providing both services are higher than firms that only provide the direct services. Hence, in this case there is also an incentive for firms to provide cross-network services, so that everyone benefits.

In this setting we do see ‘serial marginalization’ as in (Economides and Salop, 1992) and the full price P for a cross-network trip is higher than on of an on-network trip. Each firm independently, maximizes profits and ignores the externality that raising the price on the one link (p or q) lowers the profit of the other firm by depressing demand. So, given s_{12} and s_{22} , these prices p_1 , p_2 , q_1 and q_2 are higher than what a monopolist would ask, and lowering them would raise both aggregate profits and consumer surplus. But of course, such collusive behaviour is not possible in a Nash setting. We will see later that a MaaS supplier may remove such serial marginalization, and may then benefit consumers and firms. However, it may also add an extra layer of serial marginalization, which would work the other way. The ultimate outcome depends on which of the three MaaS models will prevail.

⁶ Under Nash behavior, a transport firm would take the final price of the platform as a given and thus also the quantity is seen as fixed; consequently, it believes that raising the wholesale price always increases its profit. Accordingly, we would always end up with very high (infinite) wholesale prices, and the Intermediary being unwilling to sell any cross trips.

Table 2: Price, profit and demand equilibria for the supply chain structures “Free Competition” and the “Independent Services” structure

	Free Competition	Independent Services (without cross-network trips)
Prices	$s_{ii}^* = \frac{a}{2b-5c}, i=1,2$	$s_{ii}^* = \frac{a(b+c)}{2b^2-3bc-3c^2}, i=1,2$
	$p_i^* = q_i^* = \frac{2a}{6b-15c}, i=1,2$	
Profit	$\pi_i^* = \frac{a^2(17b-32c)}{36b^2-180bc+225c^2}, i=1,2$	$\pi_i^* = \frac{a^2(b^3+2b^2c+bc^2)}{4b^4-12b^3-3b^2c^2+18bc^3+9c^4}$
Demand	$D_{11}^* = D_{22}^* = \frac{4ac-3ab}{15c-6b}$ $D_{21}^* = D_{12}^* = \frac{a}{3}$	$D_{11}^* = D_{22}^* = \frac{ab(b+c)}{2b^2-3bc-3c^2}$ $D_{21}^* = D_{12}^* = 0$

3.2 System integrator model of MaaS

Now we turn to the first form of MaaS supply. The transport firms set the own price (s_{ii}) and the platform sets the cross-travel prices s_{12} and s_{21} , the platform keeps a share ϕ of revenue. The integrator setting leads to two changes to the market structure.

- i) While Free Competition without MaaS leaves uninternalized ‘serial-marginalization’ externalities between the prices of cross-network services, the integrator internalizes these and thus removes the serial marginalization. This lowers cross-network prices, and this in turn leads to lower on-network prices by increasing competition.
- ii) There are now in effect three transport suppliers: Firm 1, Firm 2, and the MaaS operator. This intensifies competition and lowers prices.

Both these effects benefit consumers by lowering prices. Conversely, the removal of serial marginalization raises transport firm profits, while the extra competitor lowers their profits. Table 3 gives an overview of the results.

Table 3: Price, profit and demand for the system integrator model of the supply chain structure

	Nash equilibria for the system integrator model
Prices	$s_{11}^* = s_{22}^* = \frac{2ab - (\phi - 1)ac}{4b^2 - 6bc + (2\phi - 4)c^2}$ $s_{12}^* = s_{21}^* = \frac{2ab + ac}{4b^2 - 6bc + (2\phi - 4)c^2}$
Profit transport	$\pi_t^* = -1 \cdot \frac{(\phi^2 - 3\phi + 2)a^2c^3 + ((\phi^2 - 7\phi + 6)a^2bc^2 + (4\phi - 8)a^2b^3)}{(4\phi^2 - 16\phi + 16)c^4 + (48 - 24\phi)bc^3 + (16\phi + 4)b^2c^2 - 48b^3c + 16b^4}$
Profit platform	$\pi_p^* = -1 \cdot \frac{\phi^2a^2c^3 + 3\phi a^2bc^2 - 4\phi a^2b^3}{2\phi^2 - 8\phi + 8)c^4 + (24 - 12\phi)bc^3 + (8\phi + 2)b^2c^2 - 24b^3c + 8b^4}$

Demand direct	$D_{11}^* = D_{22}^* = \frac{2ab^2 + (\varphi - 1)abc + (\varphi - 1)ac^2}{4b^2 - 6bc + (2\varphi - 4)c^2}$
Cross demand	$D_{21}^* = D_{12}^* = \frac{2ab^2 - abc - ac^2}{4b^2 - 6bc + (2\varphi - 4)c^2}$

Proposition 1: *The system integrator setting lowers all prices compared with the free competition case, and thus raises demands, consumer surplus and social surplus (as prices get closer to the marginal costs of zero). The price decreases are larger when demand is less sensitive to the own price (i.e. smaller b), more sensitive to the price of the other travel options (i.e. larger c), and when the integrator keeps a larger share, ϕ , of revenue.*

Proposition 2: *Transport firm profits can be lower or higher with the integrator than with Free competition: the integrator removes the serial marginalization that hurts profit, but effectively acts as a third supplier and this raises competition. Transport firms' profits with the integrator are larger than with Free competition when the revenue share for the platform is not too large and the travel options are not too strong a substitutes; the parameter conditions are:*

- $\phi < \frac{1}{2c^2(18b^2 - 81bc + 97c^2)}(-72b^4 + 396b^3c - 658b^2c^2 + 213bc^3 + 163c^4 + 3(2b - 5c)\sqrt{144b^6 - 864b^5c + 1784b^4c^2 - 1200b^3c^3 - 423b^2c^4 + 658bc^5 + 225c^6})$
- $c < \frac{2}{(9 + \sqrt{19})}b$

Proofs for propositions 1-2 can be found in Appendix A.

The price decreases can be rather large. If the travel options would be perfect substitutes and thus $b=3c$ —with the own-price sensitivity being as small as it can be and the cross-price sensitivity being as large as it can be—the price decrease would be 50-62.5% for on-network trips, and 62.5-67.2% for cross-firm trips, where the exact percentages depends on the share ϕ the integrator gets of revenue. Hence, in this setting, MaaS-supply has the advantage of lowering prices. If demand would be perfectly elastic with respect to the own price ($b=\infty$), all prices are always zero; and, so in this extremum, the price decreases from the Intermediary reaches zero. When $c=0$, the demands would be independent of the price of the other options, and hence the price of within-firm trips is unaffected by the presence of the platform. Under $c=0$, the cross-trip trip prices would be 25% lower with the integrator than under free-competition, as the integrator still removes serial marginalization.

We see that profits of transport providers decrease with b and decrease with ϕ . Profits of the MaaS-integrator decrease with b but quite intuitively increase with ϕ . Transport firm profits tend to be larger with the Integrator than with the no-cross-network trips of the Independent services unless is really unsensitive to the own price (i.e. low b) and/or really sensitive to other prices (i.e. high c). So typically firms will not have an incentive to stop supplying cross-network trip, but this may be a problem in some parameter ranges. For all MaaS cases we assume away the option of cross-network trips that do not use the MaaS supplier, and this market seems an interesting option for further research.

We may conclude that MaaS with an independent integrator setting the cross-network prices leads to lower prices than Free competition. Travelers benefit and demand for transport services will increase. The profits of transport providers may rise or fall depending on the parameters.

3.3 Analysis of the Platform model

This section discusses the Platform model in which the transport firms set the prices for the direct services s_i , and for their parts of the cross-network services p_i and q_i . The MaaS operator only offers a platform on which the cross-network services are sold, and unlike with the Integrator there is no bundling of cross-network trips. So the price for the cross-network trip is the sum of prices charged by the operators for using their links, while a fraction ϕ of the revenues remains with the MaaS operator. The Nash equilibria are presented in Table 4.

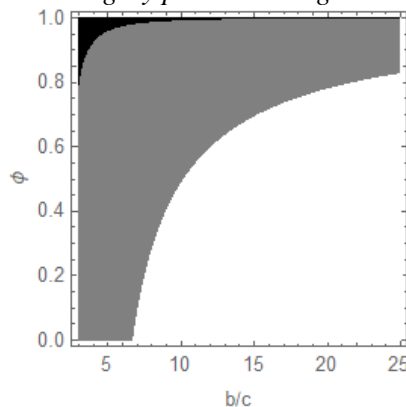
We can compare prices, profits and demand with the reference model of Free competition. The equilibrium prices of the direct services of the platform model are lower than with Free competition, and so demand is higher. This price decrease gets smaller as b increases: demand then becomes more price sensitive, and all mark-ups are lower. For cross-network services we see that prices are higher for the platform model compared to the reference model. The transport firms setting these prices demonstrate the tendency to advance the direct services compared to the network services with this model. This effect decreases with increasing b , and increases with increasing ϕ .

Proposition 3: *The Platform model of the MaaS supplier leads to higher prices than the Integrator, and thus it leads to lower consumer and social surpluses. Compared with the Free-competition case, the Platform model leads to lower prices for on-network trips but higher prices for cross-network trips; and thus consumer surplus and welfare can be higher or lower.*

Proposition 4: *The platform setting always leads to lower profits for the transport firms than the Free-competition setting. Compared to the Integrator setting, the Platform can lead to higher or lower transport-firm profits depends on the revenue share for the MaaS supplier and the ratio of demand sensitivities, b/c . Fig. 2 illustrates these parameter ranges.*

Proof for Propositions 3-4 can be found in Appendix B.

Fig 2. The platform gives higher profits in the grey parameter region and the Intermediary in the white region.



Note: In the black region, there is a corner solution of no supply of MaaS trips with a Platform

Table 4: Price, profit and demand equilibria for the platform model of the market structure⁷

<i>Nash equilibria for prices, profits and demand for the platform supply chain model</i>	
<i>Price</i>	$s_{ij}^* = \frac{a(1-\phi)(3b+c(3-2\phi))}{6b^2(1-\phi)-9bc(1-\phi)-c^2(15(1-\phi)+4\phi^2)}$
	$p_i^* = q_i^* = \frac{a(c(2-\phi) + 2b(1-\phi))}{6b^2(1-\phi) - 9bc(1-\phi) - c^2(15 - 15\phi + 4\phi^2)}$
<i>Profit Transport firm</i>	$(-1) \frac{\pi_t^* = (4\phi^4 - 28\phi^3 + 72\phi^2 - 80\phi + 32)a^2c^3 + (4\phi^4 - 36\phi^3 + 103\phi^2 - 118\phi + 47)a^2bc^2 + (-2\phi^2 + 4\phi - 2)a^2b^2c + (8\phi^3 - 33\phi^2 + 42\phi - 17)a^2}{(16\phi^4 - 120\phi^3 + 345\phi^2 - 450\phi + 225)c^4 + (-72\phi^3 + 342\phi^2 - 540\phi + 270)bc^3 + (48\phi^3 - 147\phi^2 + 198\phi - 99)b^2c^2 + (108\phi^2 + 216\phi - 108)b^3c + 36\phi^2 - 72\phi + 36b^4}$
<i>Profit platform</i>	$(-1) \frac{\pi_p^* = (12\phi^3 - 44\phi^2 + 40\phi)a^2c^3 + (28\phi^3 - 84\phi^2 + 64\phi)a^2bc^2 + (8\phi - 8\phi^2)a^2b^2c + (-16\phi^3 + 32\phi^2 - 16\phi)a^2b^3}{(16\phi^4 - 120\phi^3 + 345\phi^2 - 450\phi + 225)c^4 + (-72\phi^3 + 342\phi^2 - 540\phi + 270)bc^3 + (48\phi^3 - 147\phi^2 + 198\phi - 99)b^2c^2 + (-108\phi^2 + 108)b^3c + (36\phi^2 - 72\phi + 36)b^4}$
<i>Demand direct services</i>	$D_{11}^* = D_{22}^* = \frac{(2\phi^2 - 6\phi + 4)ac^2 + (\phi - 3)abc + 3\phi - 3ab^2}{(4\phi^2 - 15\phi + 15)c^2 + (9 - 9\phi)bc + (6\phi - 6)b^2}$
<i>Demand, cross-network services</i>	$D_{21}^* = D_{12}^* = (-1) \frac{(3\phi - 5)ac^2 + (\phi - 3)abc(2 - 2\phi)ab^2}{(4\phi^2 - 15\phi + 15)c^2 + (9 - 9\phi)bc + 16\phi - 6b^2}$

⁷ With respect to prices s_{ij} we see that equilibrium prices decrease in b and increase in ϕ . The equilibrium prices of the cross-network links p_i and q_j decrease with increase in b and increase with increase in ϕ , especially when ϕ is high.

With respect to the profits of the transport providers, we see that the profits decrease with higher price sensitivity b . In addition, the profits of the transport firms decrease a little with small ϕ but increase fast for large values for ϕ . The former may be related to having to share the profits with the MaaS platform. The larger effects of large values of ϕ may be due to lower demand for cross-network services; these may not be attractive anymore due to high prices. For the MaaS platform, the profits decrease with increasing b and become negative when the share ϕ gets large.

Demand for the direct services decreases with b and increases with ϕ . Demand for the cross-services increases with b and decreases with increasing ϕ .

To conclude, the platform model—with transport providers setting all prices and no bundling—yields lower equilibrium prices for the direct services and higher cross-network prices, promoting usage of direct services. The effects of the introduction of a platform on the transport firm profits are negative compared to the free competition setting, and the effects on demand are positive.

3.4 Analysis of the Intermediary model

Consider the Intermediary model in which transport firms set the prices for the direct services and the wholesale prices for services provided by the platform. The platform sets the prices for the travellers using the cross-network services. For this model we adopt a Stackelberg game. First, the transport providers set their prices for the direct services and the wholesale cross-network prices. Thereafter, the **intermediary** sets the cross-network prices as seen by the customers. The two transport providers compete Bertrand-Nash amongst themselves, but each is a leader towards the **intermediary**: setting wholesale prices while taking into account how the platform will respond to their wholesale price. Based upon this we derive the profits and demands. The results are presented in table 5.

The wholesale prices of the transport providers decrease with b . The prices for the direct services paid by the travellers decrease with b , so again when demand becomes more strongly price-sensitive. The cross-network prices also decrease with b . Comparing the margins of the platform, we see a positive margin for the platform provider, which is decreasing in b . The profits for the transport provider decrease with b . The platform makes some profit for larger values of b . Comparing this supply chain structure with the reference model of Free competition, we find that the prices resulting from this intermediary model are higher than the prices of the reference model. With increasing price sensitivity (higher b), this difference decreases.

Proposition 5: *The Intermediary model leads to higher prices than the Integrator model and even the Free-competition setting.*

Proposition 6: *The Intermediary model can lead to higher or lower transport-firm profits than the Integrator and Free-competition settings depending on the ratio of demand sensitivities b/c and ϕ .⁸*

Proof for Propositions 5-6 can be found in Appendix C.

It can be concluded that the model in which the platform acts as an intermediary is not very attractive for travellers because of the high prices. An important mechanism behind this result is the combination of Stackelberg behaviour of the service operators in combination with extra double marginalization that is introduced,⁹ with both the transport operators and the MaaS operator trying to skim off the same consumer surplus.

⁸ Note that ϕ only affects the profits with the Integrator and is irrelevant for the Intermediary and Free-competition cases.

⁹ Although, as argued in Section 2, full Nash-Bertrand would even worse than our Stackelberg setting as it would always lead to cross-network trip prices that are so high that there are no cross trips.

Table 5: Price, profit and demand equilibria for the intermediary model of the supply chain structure

	Equilibria for the Stackelberg game for transport services with the intermediary supply chain model with the transport firm as leader
Equilibrium prices	$p_i = q_i = (-1) \frac{ac^4 + 7abc^3 + 4ab^2c^2 - 16ab^3c + 8ab^4}{c^5 + 32bc^4 + b^2c^3 - 122b^3c^2 + 108b^4c - 24b^5}$
	$s_{ii}^* = (-1) \frac{4ac^4 + 13abc^3 - 11ab^2c^2 - 20ab^3c + 12ab^4}{c^5 + 32bc^4 + b^2c^3 - 122b^3c^2 + 108b^4c - 24b^5}$
	$s_{ij} = \frac{5ac^4 - 13abc^3 - 30ab^2c^2 + 92ab^3c - 40ab^4}{2c^5 + 64bc^4 + 2b^2c^3 - 244b^3c^2 + 216b^4c - 48b^5}$
Profit Transport firm	$\pi_t^* = \frac{a^2(c^9 + 3bc^8 - 39b^2c^7 + 18b^3c^6 + 368b^4c^5 - 435b^5c^4 - 800b^6c^3 + 1784b^7c^2 - 1088b^8c + 208b^9)}{(c^5 + 32bc^4 + b^2c^3 - 122b^3c^2 + 108b^4c - 24b^5)^2}$
Profit platform	$\pi_p^* = (-1) \frac{81a^2c^9 + 189a^2bc^8 - 297a^2b^2c^7 + 111a^2b^3c^6 + 808a^2b^4c^5 - 1916a^2b^5c^4 + 2032a^2b^6c^3 + 1456a^2b^7c^2 + 512a^2b^8c - 64a^2b^9}{2c^{10} + 128bc^9 + 2052b^2c^8 - 360b^3c^7 - 15182b^4c^6 + 13240b^5c^5 + 27128b^6c^4 - 52800b^7c^3 + 35040b^8c^2 - 10368b^9c + 1152b^{10}}$
Demand direct services	$D_{11}^* = D_{22}^* = \frac{2ac^5 + 10abc^4 - 5ab^2c^3 - 21ab^3c^2 + 36ab^4c - 12ab^5}{c^5 + 32bc^4 + b^2c^3 - 122b^3c^2 + 108b^4c - 24b^5}$
Demand, cross-network services	$(-1) \frac{9ac^5 + 6abc^4 - 29ab^2c^3 + 42ab^3c^2 - 36ab^4c + 8ab^5}{2c^5 + 64bc^4 + 2b^2c^3 - 244b^3c^2 + 216b^4c - 48b^5}$

4. Numerical analysis

In this section, we compare the outcomes of the different business models using a numerical example. In addition, some sensitivity analysis will be presented.

4.1 Numerical example.

Consider a market with at maximum 100 000 trips for each of the four services when all fees are zero, hence $a=100\ 000$. We assume an own-price elasticities of -0.4 for the transport services in the free competition case. This results in $b=20\ 000$ and $c=4\ 000$. Assume that the share of revenue for the platform (when relevant) is $\phi =0.02$. Informal statements by people involved in the negotiations reveal such shares are on the table to be discussed. This share appears in the discussions between transport operators and MaaS service providers¹⁰, although ride sourcing services as Uber require a much larger share (up to 35%). Based on these assumptions, we can compare equilibrium prices and profits for each of the business models. The results are presented in Table 6. The sensitivity analysis will focus on the effects of changing b , c and ϕ .

Table 6: Results of the different market structures under the base calibration

	Free competition	Independent services	Marginal cost pricing	System Integrator	Platform	Intermediary
$P_{11}=P_{22}$	5.000	4.688	$0=MC$	4.157	4.989	5.312
$P_{12}=P_{21}$	6.666	NA	$0=MC$	4.164	6.678	7.927
$Q_{11}=Q_{22}$	73 333.3	93 750	100 000	66 808.0	73 601.3	78 434.7
$Q_{12}=Q_{21}$	33 333.3	0	100 000	66 626.3	33 061.8	15 653.3
Consumer surplus	2 233 330	2 197 270	7 500 000	3 338 890	2 291 760	1 947 140
Transport firm's profit	588 890	439 453	0	549 585	583 571	525 387
Platform's profit	NA	NA	NA	11 100	8 828	30 626
Social surplus	3 411 110	3 076 170	7 500 000	4 448 650	3 411 880	2 987 600
Relative efficiency	0	-0.0819	1	0.2537	0.0002	-0.1036

Note: Marginal costs are normalized to zero, and with assume that there are neutral scale economies and no fixed cost. Social surplus = Consumer surplus + Transport firms profits + MaaS Supplier profit ; relative efficiency: is the gain in social surplus of a policy from the base case of Free Competition and no MaaS relative to the gain of going to the first-best outcome of marginal cost pricing.

Table 6 shows a number of results:

- The prices in free competition are higher than the prices with independent services, and so are the profits of the transport firms. In case of absence of costs to make services of different firms compatible for travellers, e.g. costs of information exchange or integration of payment systems, , firms do have an interest in realizing cross-network services, and charge higher prices to

¹⁰ The Belgium transport providers offers third-parties selling their mobile tickets fixed fee of 6 eurocents per ticket or about 2% of the ticket-price.

travellers for this. This result matches insights from the literature on standardization literature for models under comparable assumptions.

- For the Integrator model prices are lower than in the Free-competition case as the Integrator platform basically is a third competitor and removes serial marginalization. Total profits are slightly lower, but firms would not choose to stop supplying to the platform;
- For the Platform case, profits for the firms are higher than for the Integrator case, and the profit for the platform is lower. Consumers face higher prices, but are better off than in the Free competition case. Hence, under the base parameters, this seems a good option but less so than the Integrator model.
- The Intermediary adds extra serial marginalization, as now there are three price setters for the cross-network trips. Prices are relatively high, and profits low. Accordingly, this does not seem to be an attractive setting. This does assume that the platform does not increase travel demand by making it easier to make cross-firm trips, but the same holds for all three MaaS settings.

These results suggest that both the Integrator model as well as the Platform model seem to contribute to realizing cross-network services with lower prices than would result from Free competition. The difference between these two models is the actor that sets the cross-network prices; in case of the Integrator model this is the platform, in case of the Platform model this is done by the transport providers. This is also reflected in the allocation of profits; in the former case the platform profits are higher, in the latter case the transport providers get higher profits.

4.2 Sensitivity analyses

Now we turn to sensitivity analysis of our numerical model to see how robust our results are, when which policy is better for profits or welfare and what the effects are of parameters. We will focus on prices, profits and social surplus. We will study the three MaaS models—Integrator, Platform, and Intermediary—and compare their outcomes to the reference cases of Free competition. As the demand functions are unaffected by which outcome holds, a lower price for a service always means a higher demand for that service, a higher total demand and a higher consumer surplus.

4.2.1. Sensitivity analysis: system integrator vs Free Competition without MaaS

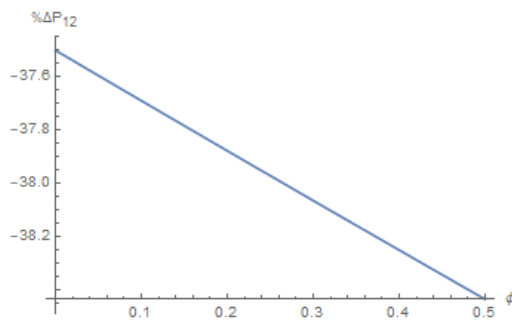
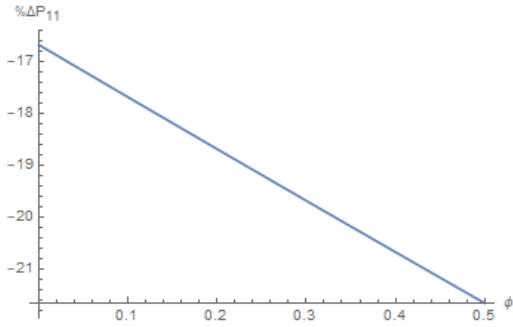
Let us first consider the Integrator. Figures 3 and 4 show the changes from the Free-competition setting. Fig. 3 does this over ranges ϕ (share of revenue going to the platform) and Fig. 4 over ranges of b (own-price sensitivity) for three levels of c (cross-price sensitivity, i.e. the sensitivity to the prices of the other options). As the analytics predicted, the MaaS supply via Integrator lowers the prices by removing the serial marginalization. Hence, the price drop is especially large for cross-network trips. The lowered prices also raise consumer surplus. Because prices become closer to the zero marginal costs, social surplus also increases. Transport firm profits fall unless the own-price sensitivity is very large (i.e. very large b). The introduction of the Integrator removes serial marginalization—which

raises profits—and leads to more competition—which lowers profits. With a high b , competition is always intense and profit low, so the competition effect of the Integrator is weak and thus even the firms benefit. Note again that for simplicity we ignore any demand increasing effect (i.e. a shift of the demand function rather than along the demand function) that MaaS may have. So, in reality the Integrator is likely to be even more beneficial for transport firms.

The analytics showed that the profit for the transport firms falls with ϕ , and the platform profits increases with ϕ . The price decreases more due to the integrator when ϕ increases.

For the demand sensitivities, we see that that prices change less in percentage terms when demand is more own-price sensitive, and prices change more when demand is more sensitive to the prices of the other options (i.e. larger c). The effect on consumer surplus and welfare changes is non-monotonic and depends on the interplay of c and b . Finally, we clearly see the boundary $b > 3c$ for a working demand system, as the functions become asymptotically vertical at this point.

Fig.3: Effect of ϕ (share of revenue going to the platform) on the changes from going from Free-competition with no MaaS to the Integrator setting
 (a) Price for direct services (b) Price for cross network trip using the integrator



(c) Transport firm profits

(d) Consumer surplus

(e) Welfare

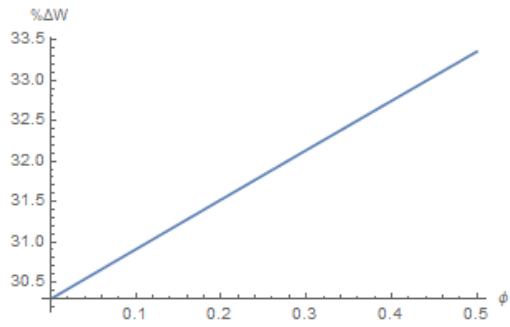
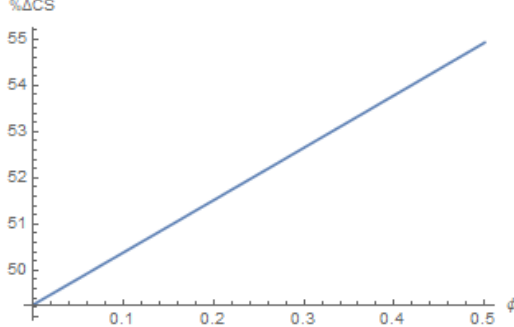
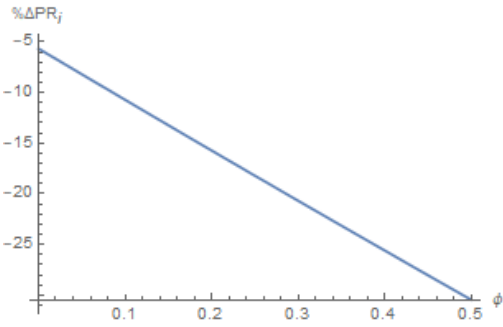
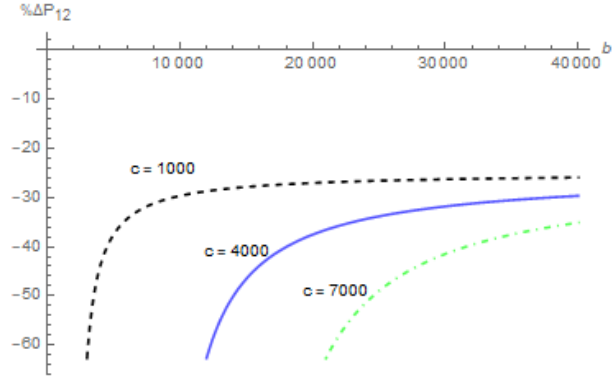
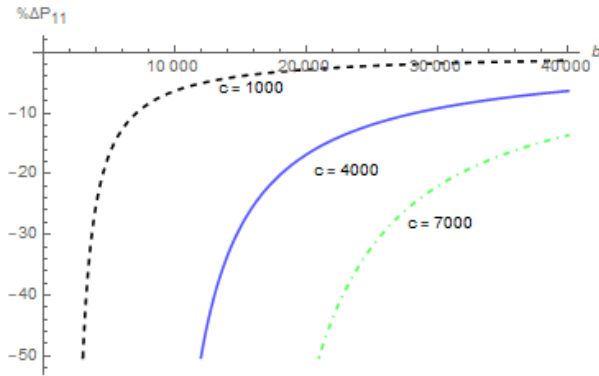


Fig.3: Effect of b (own price sensitivity) and c (cross price sensitivity) on the changes from going from Free-competition with no MaaS to the Integrator setting

(a) Price for direct services

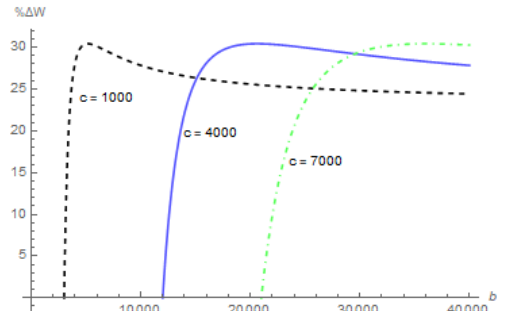
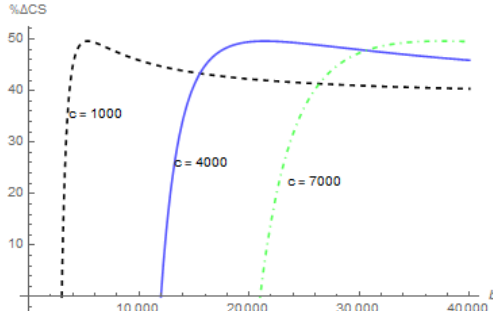
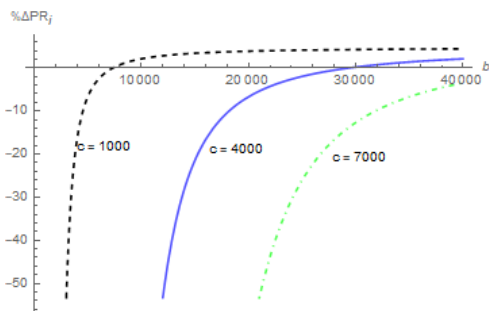
(b) Price for cross network trip using the integrator



(c) Transport firm profits

(d) Consumer surplus

(e) Social surplus



4.2.2. Sensitivity analysis: Platform model vs Free competition with no Maas

Now we turn to the changes that the Platform model of MaaS causes from the Free competition setting without MaaS. Just as previous, we will do so for ϕ in Fig. 5 and for b in Fig. 6. The introduction of MaaS via a Platform has two effects on price setting. 1) The MaaS basically becomes a third supplier of transport and so creates more competition for on-network trips and thus lowers prices P_{11} and P_{22} for these. 2) The MaaS uses the trips made by the transport firms, consequently it causes even more serial marginalization for the cross trips and raises these prices P_{12} and P_{21} . It therefore depends on the parameters whether consumer surplus and social surplus are higher or lower with the Platform than without MaaS, although for social surplus this is hard to see. The lower the share going to the Platform or the less price sensitive demand, the better the Platform setting performs compared to the Free competition setting with no MaaS.

Fig.5: Effect of ϕ (share of revenue going to the platform) on the changes from going from Free-competition with no MaaS to the Platform setting
 (a) Price for direct services (b) Price for cross network trip using the Platform

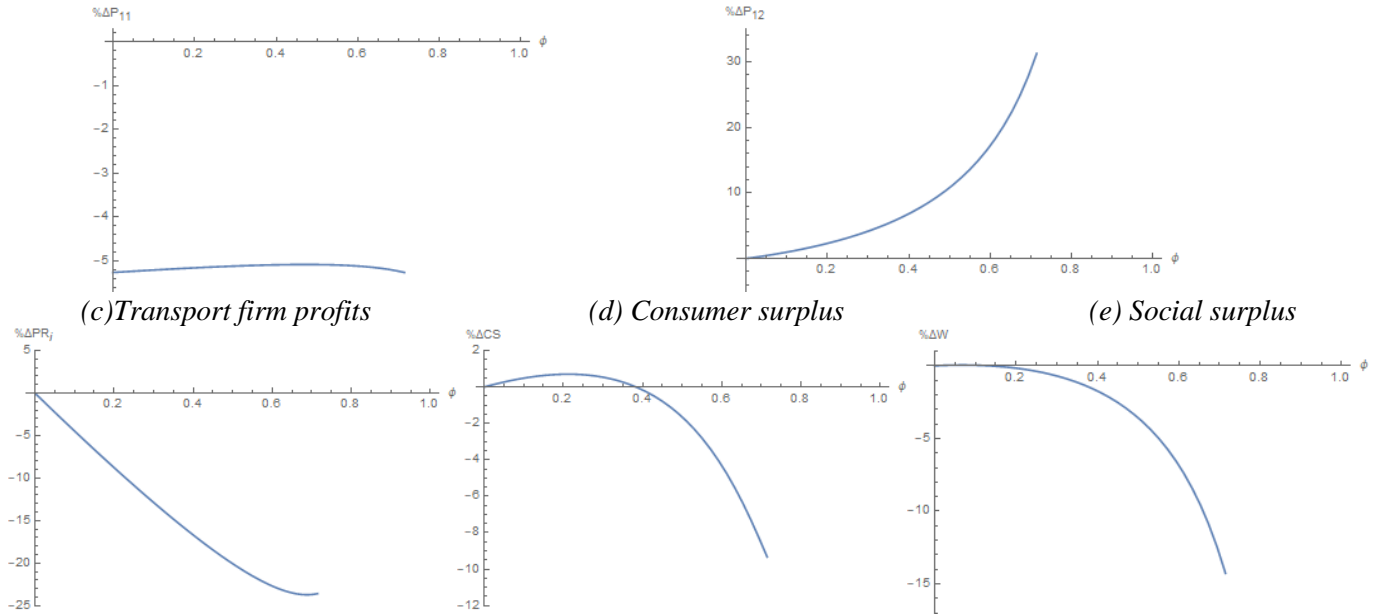
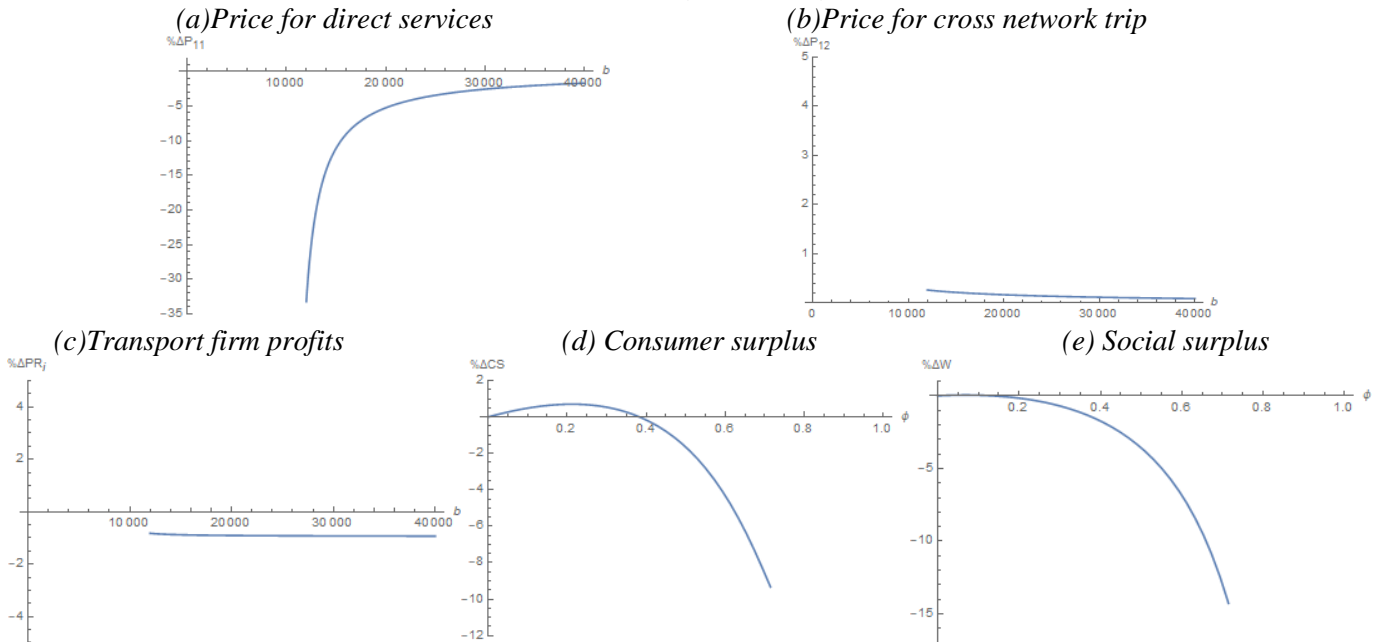


Fig.6: Effect of b (own price sensitivity) on the changes from going from Free-competition with no MaaS to the Platform setting



4.2.3. Sensitivity analysis: Platform model vs Integrator Model

Now we turn to comparing the Platform model of MaaS to the Integrator model of MaaS, and look at the effect of ϕ in Fig. 7 and b and c in Fig 8. As predicted by the analytics, the Platform always has higher prices and thus lower consumer and social surpluses. It depends on the parameters which setting transport firm profits are higher. The Platform setting does relatively better for the firms when the

share going to the MaaS supplier is lower, demand is less sensitive to the own price, and demand is more sensitive to the price of other transport option.

Fig.7: Effect of ϕ (share of revenue going to the platform) on the changes from going from Integrator setting to the Platform setting

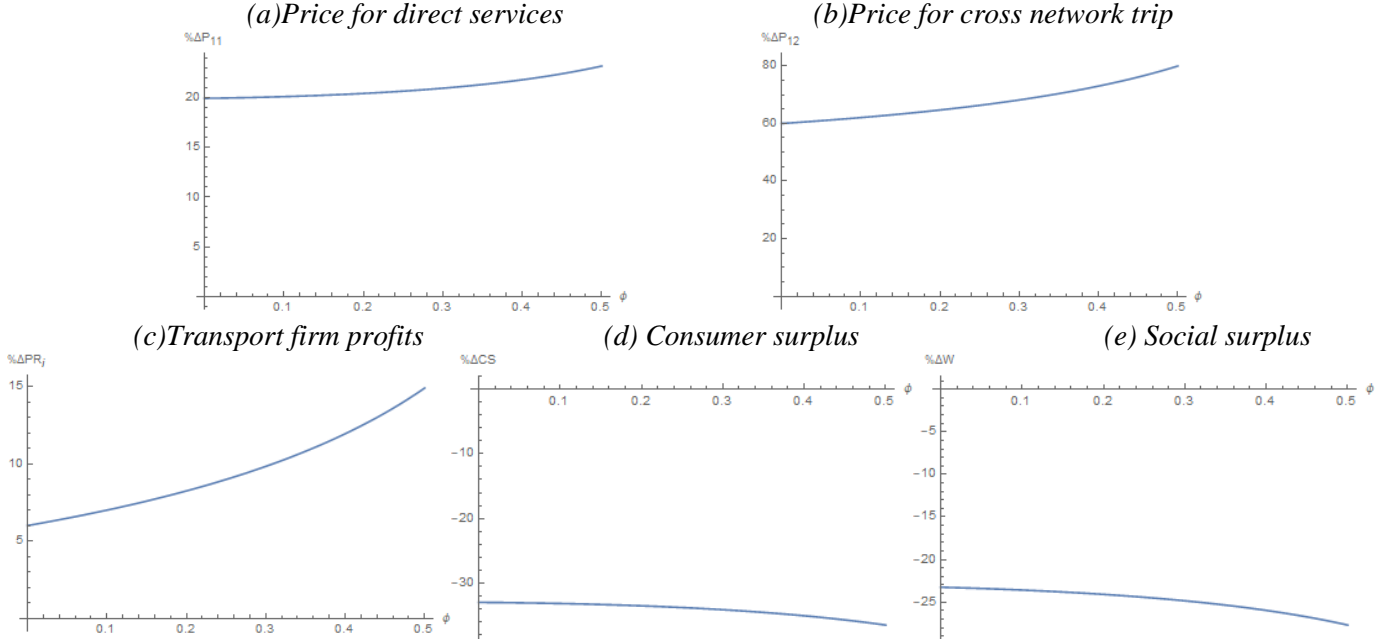
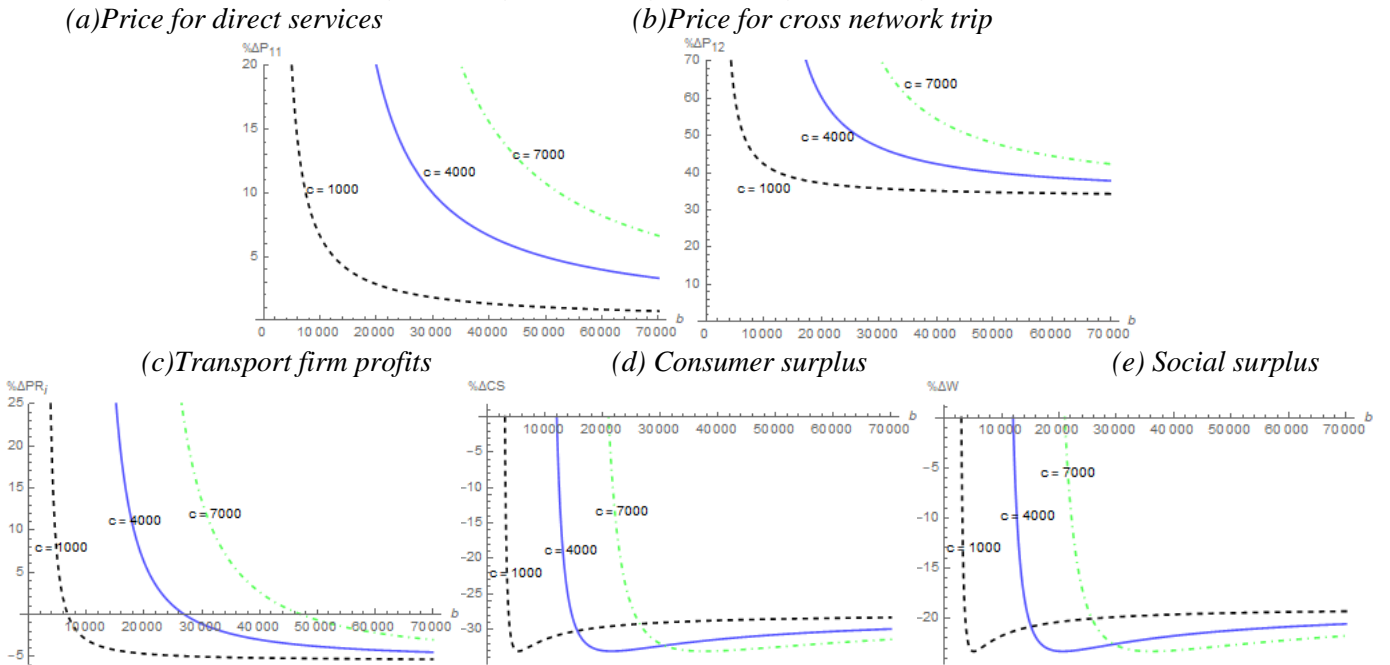


Fig.8: Effect of b (own price sensitivity) and c (cross price sensitivity) on the changes from going from Integrator setting to the Platform setting



4.2.4. Sensitivity analyses for the Intermediary model

Finally, we turn to the sensitivity analyses for our third form of MaaS supply: the Intermediary. We will focus on the effects of the own-price sensitivity as it is most interesting. Fig. 9 shows that the

intermediary leads to much higher prices than even the Platform, and thus to lower social surplus, where the Platform leads to higher prices than the Integrator. It depends on the parameters whether profits are higher or lower. Finally, Fig 10 show that prices are also much higher with the Integrator than without any MaaS. The Intermediary tends to perform better for customers when demand is more sensitive to the own price, as this intensifies competition lowers mark-ups in all settings. Thus, the Intermediary does not seem to be an attractive option for MaaS Supply. The platform and especially integrator seem much better.

Fig.9: Effect of b (own price sensitivity) on the changes from going from the Platform setting to the Intermediary setting

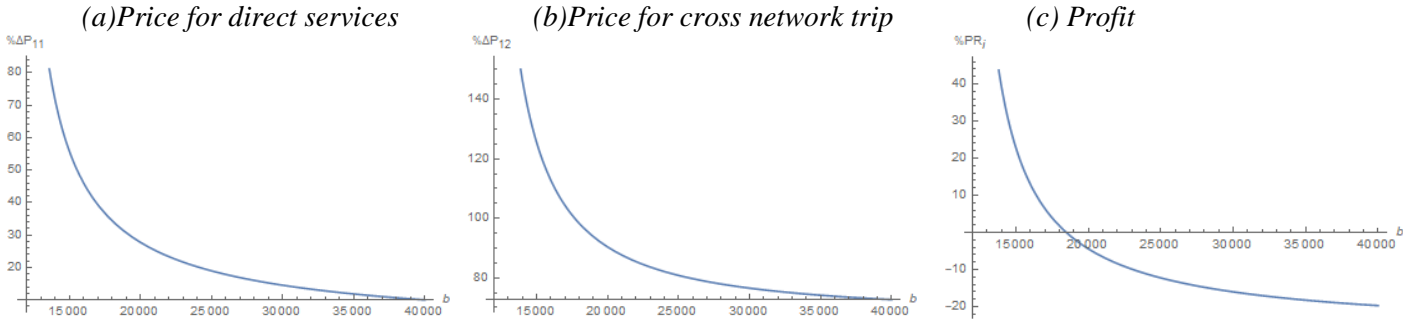
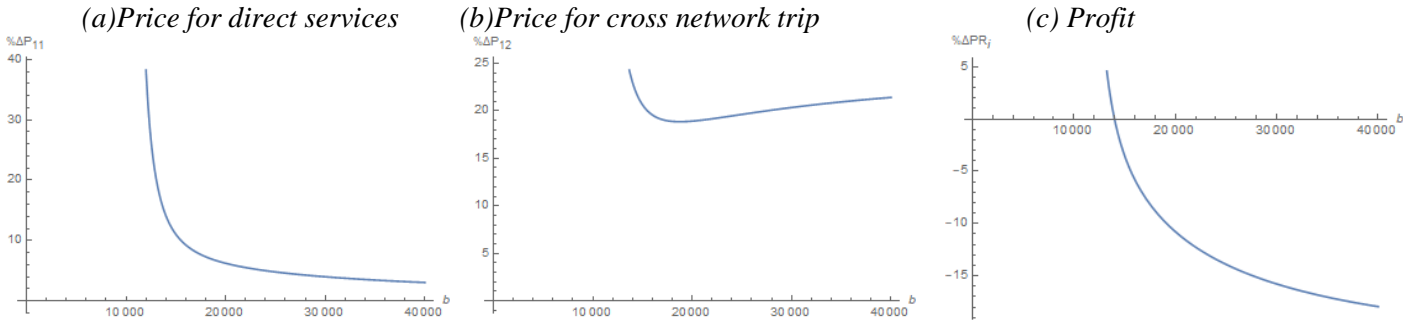


Fig. 10: Effect of b (own price sensitivity) on the changes from going from the Free Competition setting without MaaS to the Intermediary setting



5. Regulation of wholesale prices

5.1 Introduction

It has been argued (Ecorys, 2015) that transport providers should offer their services at marginal costs to the platforms, or at collectively agreed whole-sale prices. To be able to offer mobility services, platforms need access to public transport services and possibly other additional transport services, to the payment systems with which customers can pay for their journeys and to data (including travel information) with which travellers can make travel plans. Without access to the relevant services, platforms cannot enter the market for mobility services. In addition, the mobility service providers currently have limited access to the public transport services offered by these firms. For example,

(certain) transport firms do not offer access to discount products, and (some) carriers can unilaterally adjust the agreements. This often implies that mobility service providers can only offer public transport services to private individuals at full-rate retail prices. As a result, mobility service providers cannot match the offers of transport firms who do sell various products with discounts to travellers.

One option to realize a level playing field is to require that transport firms offer these services at marginal costs (or a fixed and commonly agreed wholesale price) to the platforms. This is the case suggested by Economides and Salop (1992) with the name “one-sided joint price setting” or “one-sided regulation” this section, we will evaluate the general analysis of these authors case for MaaS-applications.

5.2 Analytical model

In this case transport firms have to sell cross network trips at marginal costs. Problem with this setting are that the government needs enormous amounts of information and firms would make losses if there are economies of scale (which we assume away by using constant marginal costs). Perhaps more realistic but even more information intensive would be allowing some profit. The current setting can be seen as an extreme ideal case that is best for consumers and social surplus. The platform maximizes its profit by setting the cross prices (s_{12} and s_{21}) taking these input costs as a starting point.

Table 7: Analytical outcomes with the wholesale regulation

	demand	profits
Demand and profit functions	$D_{11}=a- b* s_{12} + c* s_{12} + c*s_{21} + c*s_{22};$ $D_{12}=a + c* s_{11}- b* s_{12} + c*s_{21} + c*s_{22};$ $D_{21}=a + c *s_{11} + c* s_{12} - b*s_{21} + c*s_{22};$ $D_{22}=-a + c* s_{11} + c* s_{12} + c*s_{21}-b s_{22};$	Transport firm 1: $s_{11}*D_{11};$ Transport firm 2: $s_{22}*D_{22};$ Platform: $D_{12}*s_{12} + D_{21}*s_{21};$
Equilibrium prices	$s_{11} = s_{22} = \frac{ab}{2b^2-3bc-c^2}$ $s_{12} = s_{21} = \frac{a(2b+c)}{4b^2-6bc-2c^2}$	
Equilibrium demand and profits	$D_{11} = D_{22}$ $= \frac{ab^2}{2b^2 - 3bc - c^2}$ $D_{21} = D_{12}$ $= \frac{ac^2 + abc - 2ab^2}{2c^2 + 6bc - 4b^2}$	Transport providers: $\frac{a^2b^3}{c^4 + 6bc^3 + 5b^2c^2 - 12b^3c + 4b^4}$ Platform: $\frac{-1 * (a^2c^3 + 3a^2bc^2 - 4a^2b^3)}{2c^4 + 12bc^3 + 10b^2c^2 - 24b^3c + 8b^4}$

5.3 Numerical model

With respect to the numerical analysis we calculate that $s_{11}=s_{22}=3.68$ and $s_{12} = s_{21} = 4.04$. The profits of the transport firms will be 270.329 and of the platform 523.356. In this situation travellers will benefit, since they will experience much lower prices. The transport firms will experience much

lower profits, even in comparison with the case without cross-network services. Hence, they are unlikely to be willing to participate (unless they get a higher fee for cross trips than just the mc). This case is unlikely to be accepted by the firms due to the much lower profit than the free competition or independent services cases, they also have lower profits than with the integrator model. Compared to the integrator model, direct trips have much lower prices, while for cross trip the benefit is much smaller.

Table 7: Numerical outcomes with the wholesale regulation under the base calibration

	<i>Free competition</i>	<i>Independent services</i>	<i>System Integrator</i>	<i>Platform</i>	<i>Regulated</i>
$P_{11}=P_{22}$	5.000	4.688	4.157	4.989	3.676
$P_{12}=P_{21}$	6.666	NA	4.164	6.678	4.044
$Q_{11}=Q_{22}$	73 333.3	93 750	66 808.0	73 601.3	73 529.4
$Q_{12}=Q_{21}$	33 333.3	0	66 626.3	33 061.8	64 705.9
<i>Consumer surplus</i>	2 233 330	2 197 270	3 338 890	2 291 760	1 947 140
<i>Transport firm's profit</i>	588 890	439 453	549 585	583 571	270 329
<i>Platform's profit</i>	NA	NA	11 100	8 828	523 352
<i>Welfare</i>	3 411 110	3 076 170	4 448 650	3 411 880	4 651 820
<i>Relative efficiency</i>	0	-0.0819	0.2537	0.0002	0.3034

To conclude, a MaaS with regulated supply may help consumers even more than an Integrator MaaS. However, transport firms will dislike it and will often prefer not to supply any cross trips to the MaaS firm, making it difficult to implement. Further, regulation may be difficult and costly to implement and there is the danger of misregulation if the marginal cost is not known or due to corruption. If we need to allow firms some profits instead of forcing them to sell at marginal costs, such regulation would be even more complex and less beneficial for consumers.

6. Conclusions

In this paper, we analysed the effects of the introduction of MaaS-platforms in the market for transport services on prices, demands and profits. We considered different supply chain structures with two competing transport providers and one MaaS service provider. The MaaS-provider sells multimodal services from each of the two transport providers. We compared these models with a reference model in which two firms provide own-network and cross-network services without a MaaS-platform. We focus on the effects of MaaS via the market structure, and to do so ignore all other possible effects—such as ease of use and increased demand—to make the results on the impacts via changes in competitive conditions as transparent as possible; when incorporating all possible effects of MaaS, it becomes difficult if not impossible to see the separate impacts of each.

The first MaaS model considered was the system **Integrator model** where the transport firms set the own prices for direct services and the MaaS provider sets the cross-network travel prices. The MaaS providers keeps a share ϕ of revenue. Prices are lower than without MaaS, since the MaaS-provider can be considered as an additional competitor and there will be elimination of serial marginalization. Total profits for the transport firms may be a bit higher or lower. In more extreme parameter ranges, transport firm profits with the Integrator may be lower than with the no-cross-network trips, so that then firms may not want to participate in the MaaS setting.

The second model is the **Platform model** where the transport firms sets all prices and the MaaS-services provider keeps share of the revenue. In this case, profits for the transport firms may be higher or lower than in the integrator model, but lower than without MaaS. Compared to the setting without MaaS, consumers see lower prices for trips that use a single firm but higher prices for across-firm trips. In the base calibration of our numerical model, the platform and no-MaaS settings lead to similar prices, and this remains true unless demand is very price insensitive or the platform gets a very large share of revenue. Compared to the Integrator setting, prices are higher with the platform. So, the Platform seems a decent option as prices and profits are similar as without MaaS, but the integrator model seems even better as it leads to lower prices.

The third model is the **Intermediary model** with the transport firms as the leaders and setting their prices first. This model reflects the retail market where intermediaries sell products and services that are bought from manufacturers or wholesalers. This option adds extra serial marginalization—from the transport firms to the platform—but also adds more competition between the suppliers of final trips (now there are 3). Prices are high, and profits are low. This does not seem to be a good way to introduce MaaS, and this shows the importance of the way MaaS is supplied.

We finally considered the **regulated case** where the transport firms are required to offer the MaaS-platform transport services at marginal costs. This case is great for the customers, who see much lower prices for the direct and especially cross-network transport services. The transport firms see much lower profits than with free competition and often also lower than when they stop supplying cross network services. So, firms are unlikely to be willing to voluntarily participate (unless they get a higher fee for cross trips than just the marginal costs). The government also needs accurate information on the marginal cost, which may be difficult to find leading to dangers of mis-regulation

Overall, we find that intermediaries, especially when they are system integrators, will contribute to lower prices due to increased competition and less serial marginalization. So MaaS seems beneficial even without considering the usual benefit of information provision, ease of use for consumers and increased demand for public transport. But for other market structures, in particular the Intermediary setting, prices are much higher and profits low.

Our models have a number of limitations which could be dealt with in future work.

- Most importantly, most platforms offer value added services that we omitted for the sake of transparency. So, for instance, if MaaS makes public transport more attractive and thus shift out its demand function, this would make all our MaaS settings more attractive for firms and customers.
- For all MaaS cases, we assume away the option of cross-network trips that do not use the MaaS supplier.
- We use constant marginal cost, whereas in transport we often see strong economies of scale. Adding this would make results much less clear, as any change in total demand also leads to changes in average costs.
- We used linear demand functions, with strong assumptions about the parameters. We also assumed that demands and cost functions are symmetric.
- We assumed that firms are free to set their prices, but public transport fares are often heavily regulated.
- Quality differences between the services have not been dealt with: e.g., a higher frequency of public transport vehicles makes travel by public transport more flexible and more attractive for users. If quality is important, this also raises the danger of serial marginalization in the quality setting (e.g., Czerny et al., 2016).
- We assumed linear price contracts between the transport firms and the intermediaries. Marketing research developed a number of other contract strategies that may circumvent some of the limitations of the linear contract.

The methodology applied in this paper is rich enough to be used in assessing the contribution of MaaS-service providers and the appropriate business models. This allows ex ante analysis of the different business configurations, obviously to be followed by real-world implementation and evaluation. The results show that how the MaaS supply is organized—integrator, platform or Intermediary—strongly affects the outcomes. So, care is needed in setting it up. Regulation can further improve things for the consumer, but it depends on the parameter values whether the benefits are small or more noticeable. Also without price regulation, MaaS supply can benefit consumer by increasing competition and removing serial marginalization, even before we consider other possible benefits of MaaS such as information provision, ease of use and a demand shift towards public transport. Moreover, transport firms and the MaaS firms make profits, so the setting is viable from their perspective.

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Appendix A: Detail results for the Integrator model

With respect to the *equilibrium prices* s_{11} , s_{22} and s_{12} and s_{21} we have for this specific model:

- Equilibrium prices are decreasing in b . So as expected the more price sensitive demand is, the smaller equilibrium prices/mark-ups are, both for the direct services as well as for the cross-network services.
- Equilibrium prices are decreasing with the substitution parameter γ of the utility function. This implies that higher substitution between services leads to lower equilibrium prices for the direct services; competition among the different suppliers of direct and indirect services is increasing.
- Equilibrium prices for direct services are decreasing in ϕ ; a higher share of the revenue for for the platform will lead to lower equilibrium prices for the direct services as well as for the cross-network services.
- The cross-network prices are higher than the prices of the direct services. This difference is decreasing in b and increasing in the share ϕ that the platform takes.

Proof of proposition 1:

Using the price equations in Tables 1-3, we see that prices are strictly positive as $b > 3 \cdot c > 0$ must hold with substitutes, $a > 0$ and $0 < \phi < 1$. We get the following differences in prices between the Integrator and the Free-competition cases:

$$\Delta P_{11} = \Delta P_{22} = -\frac{ac}{2(2b-5c)} \frac{2b+c+2b\phi-3c\phi}{2b^2-3bc+c^2(2-\phi)} < 0$$

$$\Delta P_{12} = \Delta P_{21} = -\frac{a}{6(2b-5c)} \frac{b^2-c^2+8c^2\phi}{2b^2-3bc+c^2(2-\phi)} < 0,$$

which are clearly negative. Consequently, the Integrator has lower prices than the Free-competition. Logically, consumers are better off with lower prices and so consumer surplus is higher. Social surplus is maximizes with prices equal to the marginal cost of zero, so the closer the prices are to zero the higher welfare. Hence, the Integrator case also has the higher welfare.

Now turning to the effects of parameter ranges, we will focus on the price difference for ΔP_{11} , for the others the proofs work in the same way. We see that the first term, $\frac{ac}{2(2b-5c)}$ clearly increases with c . For the second term, the derivative is $\frac{2b+c+2b\phi-3c\phi}{2b^2-3bc+c^2(2-\phi)}$, which again is positive when $b > 3c$. Remembering, the minus sign at the equation, ΔP_{11} becomes more negative (i.e. smaller) the larger c is. Now for b , the derivative for the first term of ΔP_{11} is negative and the second is negative as well being $-\frac{4b^2+4bc+c^2+\phi b(4b-12c)+c^2\phi(11-2\phi)}{(2b^2-3bc-2c^2+c^2\phi)^2}$. So ΔP_{11} becomes

less negative the larger b is. Finally to the derivative of to ΔP_{11} is negative: the first term is independent of b , while the second term has a positive derivative of $\frac{(2b-5c)(b-c)(2b+c)}{(2b^2-3bc-2c^2+c^2\phi)^2}$. ■

Proof of proposition 2:

Using the profit equations in Tables 1-3, we see that the difference in transport-firm profit follows the messy equation of:

$$\Delta PR = \frac{-a^2(2b+c)}{36(2b-5c)^2(2b^2-3bc+c^2(-2+\phi))^2} [12b^3c(5-33\phi) + 8b^4(9\phi-1) + 2b^2c^2(329\phi+9\phi^2-10) - 3bc^3(50+71\phi+27\phi^2) + c^4(97\phi^2-62-163\phi)].$$

Here, the fraction is clearly negative, but the term between brackets thereafter can be positive or negative. So profits can be lower or higher with the Integrator than with Free competition. ■

Appendix B: Detail results for the Platform model

Proof of Proposition 3:

To start we derive two conditions for an interior solution for the Platform model that will help. For non-negative prices $p_i=q_i$ in Table 3, we need the denominator not to be negative: $6b^2(1-\phi) - 9bc(1-\phi) - c^2(15-15\phi+4\phi^2) \geq 0$. If this were not to hold, the best the firms could do would not to supply any cross-network trips. Using $0 \leq \phi \leq 1$ and the necessary conditions for a working demand system with imperfect substitutes $b>3c>0$ and $a>0$, we can rewrite this to:

$$\phi < \frac{3}{8} \left(5 - \frac{2b^2}{c^2} + \frac{3b}{c} \right) + \frac{1}{8} \sqrt{3} \sqrt{-5 + \frac{12b^4}{c^4} - \frac{36b^3}{c^3} - \frac{b^2}{c^2} + \frac{42b}{c}}, \quad (\text{B.1})$$

which puts things in term of ϕ vs ratio of demand sensitivities $\frac{b}{c}$. Note that condition (B.1) is not very strict. When $b=3c$, the ϕ would need to be below 0.7913; and, as b becomes larger or c smaller, the restrictions becomes even more lacks. Further, for an existing MaaS we need a positive demand for cross-network trips, $D_{ij}>0$. Using (B.1), this implies:

$$\frac{2b-5c}{2b-3c} > \phi. \quad (\text{B.2})$$

Again, this condition is not very strict. At the base calibration of Section 4, it would be $\phi < 0.71$; when $b=\infty$, the condition would become $\phi < 1$, and for the lowest possible $b=3c$, it would become $\phi < 1/3$. So only for a very low b , may this condition be a realistic problem.

Using the prices from Tables 1-3, $0 \leq \phi \leq 1$, $b>3c>0$ and $a>0$, we see that the difference in prices between the Platform and Integrator are:

$$\Delta P_{11} = \Delta P_{22} = -\frac{a(2b+c-c\phi)}{4b^2-6bc+2c^2(-2+\phi)} - \frac{a(-1+\phi)(-3b+c(-3+2\phi))}{6b^2(-1+\phi)-9bc(-1+\phi)+c^2(15-15\phi+4\phi^2)} > 0.$$

$$\Delta P_{12} = \Delta P_{21} = -\frac{a(2b+c)}{4b^2-6bc+2c^2(-2+\phi)} + \frac{2a(c(-2+\phi)+2b(-1+\phi))}{6b^2(-1+\phi)-9bc(-1+\phi)+c^2(15-15\phi+4\phi^2)} > 0. \quad (\text{B.3})$$

Both of which are positive when (B.1) holds and so the Platform has higher prices than the Intermediary. This is not obvious in (B.3) or the price equations, but whenever the equations would suggest somethings else the outcome would be a corner solution as the Platform and possibly the Intermediary would have negative prices following them and this cannot be.

The differences in prices when going from Free competition to the Platform are:

$$\Delta P_{11} = \Delta P_{22} = \frac{2ac\phi(2b(1-\phi)-c(5-3\phi))}{(2b-5c)(6b^2(-1+\phi)-9bc(-1+\phi)+c^2(15-15\phi+4\phi^2))} < 0.$$

$$\Delta P_{12} = \Delta P_{21} = -\frac{(2/3)ac\phi(6b-c(15-8\phi))}{(2b-5c)(-6b^2(1-\phi)+9bc(1-\phi)+c^2(15(1-\phi)+4\phi^2))} > 0.$$

The denominators of these two are the same and are negative when condition (B.2) holds. The nominators are similar and both are positive when (B.2) holds. So remembering the minus sign for $\Delta P_{12} = \Delta P_{21}$, this implies $\Delta P_{11} = \Delta P_{22} < 0$ and $\Delta P_{12} = \Delta P_{21} > 0$. Hence, compared with Free competition, the platform has the lower prices for on-network trips and higher prices for cross-network trips. ■

Proof of Proposition 4:

We will first look at what happens at a transport firm's profit when we go from free competition to the Platform. The change in profit is:

$$\Delta PR = \frac{-4a^2\phi}{9(2b-5c)^2 (6b^2(-1+\phi)-9bc(-1+\phi)+c^2(15-15\phi+4\phi^2))^2} \{(72b^5(-1+\phi)^2 - 360b^4c(-1+\phi)^2 + 6b^3c^2(39 - 100\phi + 55\phi^2 + 6\phi^3) - 6b^2c^3(-156 + 245\phi - 113\phi^2 + 24\phi^3) + c^5(-900 + 1290\phi - 615\phi^2 + 97\phi^3) + bc^4(-630 + 1284\phi - 699\phi^2 + 113\phi^3))\}$$

Here, the fraction is clearly negative due the minus sign. The term between curly brackets is less obvious but is positive when (B.1) holds. Accordingly, introducing MaaS via a Platform leads to lower profits for transport firms.

Compared to the integrator the platform can lead to higher or lower transport firm profits. The difference in profits is:

$$\Delta PR = \frac{a^2}{4(2b^2-3bc-2c^2+c^2\phi)^2 (-6b^2+9bc+15c^2+6b^2\phi-9bc\phi-15c^2\phi+4c^2\phi^2)^2} \{(16b^7(-1+\phi)^3 - 16b^6c(-1+\phi)^2(-5+3\phi) + c^7(-1+\phi)^2(-62+93\phi-47\phi^2+8\phi^3) + bc^6(-398+1083\phi-1081\phi^2+473\phi^3-77\phi^4) - 8b^4c^3(21-51\phi+64\phi^2-39\phi^3+5\phi^4) + 4b^5c^2(57-120\phi +$$

$$110\phi^2 - 56\phi^3 + 9\phi^4) + b^2c^5(-930 + 2067\phi - 1565\phi^2 + 481\phi^3 - 61\phi^4 + 8\phi^5) + b^3c^4(-894 + 1833\phi - 1507\phi^2 + 675\phi^3 - 187\phi^4 + 16\phi^5))\}$$

The first fraction is clearly positive. It is proportional to a^2 , the demand intercept only affect overall scale of profits and profits are proportional to a^2 . The denominator of the fraction is positive as all terms are squared. The term between curly brackets is very messy and can be positive or negative, but this is not obvious. Let us replace b with $r \cdot c$, where $r=b/c > 3$ is the relative size of b . Then the term between curly brackets becomes:

$$(-1 - 3r - 2r^2 + \phi - r\phi + 2r^2\phi)(62 + 212r + 170r^2 - 40r^3 - 52r^4 + 8r^5 - 155\phi - 468r\phi - 271r^2\phi + 130r^3\phi + 72r^4\phi - 16r^5\phi + 140\phi^2 + 348r\phi^2 + 128r^2\phi^2 - 108r^3\phi^2 - 20r^4\phi^2 + 8r^5\phi^2 - 55\phi^3 - 100r\phi^3 - 11r^2\phi^3 + 18r^3\phi^3 + 8\phi^4 + 8r\phi^4),$$

which is still messy but more manageable. The first term between parenthesis is always positive under our needed assumptions. The second can be positive or negative. So, compared with the Intermediary, with the Platform, transport-firm profits can be higher or lower. Fig. 2 in text depicts this, and is based on the second part of the above expression. The black area is where (B.1) is violated.

Now we turn to the comparison with Free competition. The profit difference is:

$$\Delta PR = \frac{-4a^2\phi}{\left(9(2b - 5c)^2(6b^2(-1 + \phi) - 9bc(-1 + \phi) + c^2(15 - 15\phi + 4\phi^2))^2\right)} (72b^5 - 360b^4c + 234b^3c^2 + 936b^2c^3 - 630bc^4 - 900c^5 - 144b^5\phi + 720b^4c\phi - 600b^3c^2\phi - 1470b^2c^3\phi + 1284bc^4\phi + 1290c^5\phi + 72b^5\phi^2 - 360b^4c\phi^2 + 330b^3c^2\phi^2 + 678b^2c^3\phi^2 - 699bc^4\phi^2 - 615c^5\phi^2 + 36b^3c^2\phi^3 - 144b^2c^3\phi^3 + 113bc^4\phi^3 + 97c^5\phi^3)$$

The fraction is again clearly negative, while the term between curly brackets is positive if (B.2) holds. So, this implies that Free competition always leads to higher firm profits than the Platform, and this completes the proof of Proposition 4. ■

Appendix C: Detail results for the Intermediary model

Proof proposition 5:

Let us first compare the prices with the Intermediary with those under the integrator. The difference in prices are:

$$\Delta P_{11} = \Delta P_{22} = \frac{a(b-c)c(c^4(15-7\phi) - bc^3(-57+\phi) + 8b^4(5+3\phi) + 2b^2c^2(5+11\phi) - 4b^3c(17+15\phi))}{2(-24b^5 + 108b^4c - 122b^3c^2 + b^2c^3 + 32bc^4 + c^5)(2b^2 - 3bc + c^2(-2+\phi))} > 0,$$

$$\Delta P_{12} = \Delta P_{21} = \frac{a(32b^6 - 112b^5c + 120b^4c^2 - 44b^2c^4 + 23bc^5 + 11c^6 + 40b^4c^2\phi - 92b^3c^3\phi + 30b^2c^4\phi + 13bc^5\phi - 5c^6\phi)}{2(24b^5 - 108b^4c + 122b^3c^2 - b^2c^3 - 32bc^4 - c^5)(2b^2 - 3bc - 2c^2 + c^2\phi)} > 0.$$

Of both of these the nominator and denominator are positive when $b > 3c > 0$, $a > 0$ and $0 \leq \phi \leq 1$ hold.

So the Intermediary has higher prices than the Integrator.

Similarly when compared to Free competition we get:

$$\Delta P_{11} = \Delta P_{22} = \frac{ac(8b^4 - 44b^3c + 82b^2c^2 - 25bc^3 - 19c^4)}{(2b-5c)(24b^5 - 108b^4c + 122b^3c^2 - b^2c^3 - 32bc^4 - c^5)} > 0,$$

$$\Delta P_{12} = \Delta P_{21} = \frac{a(48b^5 - 288b^4c + 584b^3c^2 - 364b^2c^3 + 31bc^4 + 83c^5)}{6(2b-5c)(24b^5 - 108b^4c + 122b^3c^2 - b^2c^3 - 32bc^4 - c^5)} > 0,$$

Which again are positive and so the Intermediary has higher prices than Free competition. ■

Proof proposition 6:

We will first compare the transport firm's profit with the intermediary to that with the integrator. The difference in profit is:

$$\Delta PR = \frac{a^2}{4c} \left\{ \frac{4(1 + 3r - 39r^2 + 18r^3 + 368r^4 - 435r^5 - 800r^6 + 1784r^7 - 1088r^8 + 208r^9)}{(1 + 32r + r^2 - 122r^3 + 108r^4 - 24r^5)^2} + \frac{2 + 4r^3(-2 + \phi) - 3\phi + \phi^2 + r(6 - 7\phi + \phi^2)}{(-2 - 3r + 2r^2 + \phi)^2} \right\},$$

with $r=b/c$ being the ratio of demand sensitivities just as for Proposition 4 and ϕ the revenue share for the platform in the Integrator setting. The profit difference can be negative or positive depending on r and ϕ .

Let us now compare the profit with the intermediary to that with free competition. The difference is profit is:

$$\Delta PR = \frac{-a^2}{9(2b-5c)^2(24b^5 - 108b^4c + 122b^3c^2 - b^2c^3 - 32bc^4 - c^5)^2} \{2304b^{11} - 29952b^{10}c + 156864b^9c^2 - 414720b^8c^3 + 545648b^7c^4 - 233056b^6c^5 - 177420b^5c^6 + 161696b^4c^7 + 12024b^3c^8 - 22465b^2c^9 - 2526bc^{10} - 257c^{11}\}.$$

The first term of which is clearly negative when we consider the squares in the denominator. The second term between curly brackets can be negative or positive. This depends on the demand-parameters ratio $r=b/c$ just as for Proposition 4. The second term is positive when:

$$-257 - 2526r - 22465r^2 + 12024r^3 + 161696r^4 - 177420r^5 - 233056r^6 + 545648r^7 - 414720r^8 + 156864r^9 - 29952r^{10} + 2304r^{11} > 0.$$

This proves that the profit with the intermediary can be higher or lower than with Free competition depending on $r=b/c$. ■