Pricing of myopic multi-sided platforms: theory and application to carpooling

Guillaume Monchambert[1]

March 18, 2024

Abstract

This paper investigates pricing decisions when a monopolistic multi-sided platform is myopic, that is unable to distinguish between two agents who participate on the same side of the platform but produce different externalities. We find that the structure of prices is the same for profit- and welfare-maximizing platforms. The unique price supplied to the two undistinguishable agents is a weighted average of the perfect information prices, where the weights depend on demand elasticities and externalities produced by the other undistinguishable agent. The prices supplied to the distinguishable agents are also affected by platform's myopia through an extra term than can be positive or negative. Introducing Hotelling competition does not affect results. We apply the model to a monopolistic short-distance carpooling platform with and without HOV lane, and show that the profit-maximizing platform does not subsidize efficiently the "good" side of the market, leading to very little traffic reduction. These results call for a discussion of the regulation of myopic platforms in general, and those of carpooling in particular.

JEL Codes: D82; D85; L12; L13; L51; R49

Keywords: network effect; information asymmetry; externality

---

[1] Affiliation: Univ Lyon, Université Lyon 2, LAET, F-69007, LYON, France - g.monchambert@univ-lyon2.fr.
Acknowledgments: We thank participants at the Annual Conference of the International Economics Association (ITEA) in Roma, June 2021.

1. Introduction

Multi-sided platforms arise when it is possible to generate externalities by connecting two (or more) groups of agents. These externalities influence the prices charged by the platforms. The group that generates the highest positive externality is usually subsidized by the other groups. However, there are platforms on which agents who generate distinct externalities in (or outside) the platform nevertheless participate in the same side of the platform. The externalities generated by two agents on the same side of a platform can even be of opposite sign. For example, a carpool passenger who comes from driving alone reduces congestion and other external costs related to cars, while one who comes from public transportation does not. On a homestay platform, a host who withdraws his property from the long-term rental market generates negative externalities, unlike the host who does not. If the platform has perfect information and is able to discriminate between these two agents, it will consider them as two distinct sides and will offer them different prices that internalize the externalities generated. Otherwise, the platform is myopic, unable to distinguish the two agents. It will then offer them a single price.

This paper investigates the implications of this specific information asymmetry between the platform and the agents. Our primary interest is to compare prices set by profit- and welfare-maximizing platforms to analyze how inefficient the decentralized equilibrium monopoly is and discuss the possible regulation of such platforms. Our second interest is to understand if the effects are mitigated by competition between platforms. If so, promoting competition could be fruitful. Our third interest is more practical: it is to improve our understanding of the practices of carpooling platforms and to question their possible regulation.

We address these questions by extending Armstrong's (2006) model. As one of our interests is to investigate carpooling platforms, we must take into account their specificities. We identify the following four characteristics specific to carpooling platforms. (i) Cross-side effect that affects the matching quality through decreasing waiting time and scheduling costs. Basically, the agent utility increases with the number of agents on the other side of the platform. (ii) Within-side effect that also affect the matching quality but in an opposite way. The agent utility decreases with the number of agents on the same side of the platform, due to rivalry mechanism (Belleflamme and Toulemonde, 2009). (iii) Information asymmetry because the platform does not know what transport mode carpoolers would have used in the absence of carpooling opportunity. Carpool platforms allow to decrease congestion if ex ante drivers become carpool passengers. (iv) Outside the platform externalities as the vehicle-kilometers created or cancelled by the platform affect congestion and other external costs related to cars, which do not only concern the potential users of the platform but also agents outside the platform. We therefore extend Armstrong's (2006) model by considering three groups of agents, cross- and within-group externalities, outside the platform externalities, and a myopic platform that cannot distinguish between two agents from two different groups.

We first study prices set by the monopolistic platform to three different groups when it maximizes profit then welfare with perfect information. The results are in line with the literature. The price is the sum of the marginal cost of the platform, the marginal effect of an additional agent on all the other agents present on the platform, and a last term which is the mark-up when the platform maximizes profit and the internalization of externalities outside the platform when it maximizes welfare. We then introduce information asymmetry. The platform is unable to distinguish between two groups of agents and offers them the same price. In this situation, prices set by the profit- and the welfare-maximizing platform have the same structure. The unique price supplied to the two non-distinguishable groups is a weighted average of the two prices that would be supplied with perfect information. The weight of a group increases with its demand elasticity, and also depends on the externalities produced by the agents in the other undistinguishable group. Interestingly, the prices supplied to the distinguishable group is also affected by an extra term than can be positive or negative. It is positive if among the two non-distinguishable groups, the group that is favored by information asymmetry (the one whose platform's myopia reduces the price) is also the one that benefits more from the presence of agents from the distinguishable group, and negative if not. Second, we introduce single-homing competition between two platforms à la Hotelling. Competition does not change much the structure of prices. The main difference is that the externality occurring on another platform are accounted into a platform price.

Finally, we apply the model to a carpooling platform. We separate agents into three groups: agents in one group chooses between solo driver and carpool driver, agents in another groups between solo driver and carpool passenger, and agents in the last group between public transport and carpool passenger. Agent utility functions are calibrated from a stated preferences survey (see le Goff et al., 2022). Our results indicate that information asymmetry increases the gap in welfare between profit- and welfare-maximizing platforms and increases road traffic, appealing for more regulation. We also ask whether the implementation of a HOV lane could reduce this gap. We find that an HOV lane improve the welfare but does not reduce the gap. Moreover, the allocation of surplus changes according to the type of platform. The profit-maximizing platform increases its profit more, while the welfare-maximizing platform increases the agents' surplus more.

This paper contributes to the literature on two aspects. First, it adds to the theoretical literature on multi-sided platforms a new form of information asymmetry. Here, the platform is myopic and unable to distinguish between two agents that participate in the same side of the platform but produce different externalities. Second, it contributes to the literature on carpooling platforms by making explicit the pricing mechanisms of a platform that does not differentiate between passenger carpoolers who come from solo driving and those who come from public transport.

Section 2 presents the related literature, Section 3 the motivating evidences. In Section 4 we model a monopoly platform and introduce competition in Section 5. Section 6 displays the empirical application to carpool platforms with and without HOV. Section 7 concludes.

2. Related literature

There is a substantial literature on two-sided or multi-sided markets and platforms that emerged in the late 1990s and early 2000s, following the seminal work of Caillaud and Jullien (2003), Evans (2003), Rochet and Tirole (2003) and Armstrong (2006), among others. These researches have paved the way for a wealth of research addressing different questions on pricing, coordination, and regulation of multi-sided markets. Reviews of the literature are available in Roson (2005), Rysman (2009) and more recently in Sanchez-Cartas and Léon (2021) and Jullien et al. (2021).

Our model follows the theoretical framework developed by Armstrong (2006). He models a platform that performs matches between two types of agents. The presence of agents on one side of the platform creates a positive externality for agents on the other side of the platform. Armstrong studies the pricing implemented by a profit-maximization monopoly platform, a welfare-maximization monopoly platform and two competing platforms in an Hotelling manner. We extend this model by introducing within-group externalities, externalities outside the platform and information asymmetry between the platform and the agents.

A few papers explicitly address the issue of within- (also called intra-) group externality. Belleflamme and Toulemonde (2009) consider within-group negative externality (what they refer to as rivalry) in addition to a positive cross-group externality, and analyze how this externality can influence the entry of a new platform in the market. They show that if this negative externality is neither too strong nor too weak, market entry is impossible. Bardey et al. (2014) consider the case where agents on both sides of the platform benefit (or lose) from an increase in one group size. They refer to these as common network externalities. The signs of the externalities are the same for both groups, but the intensities may vary. This feature results in the switching of subsidies from one side of the platform to the other.

We did not find a paper that explicitly included externalities produced by the platform or agents participating in the platform that affect agents outside the platform. These externalities are however crucial when it comes to regulation.

Several types of information asymmetry have been studied in the context of multi-sided platforms. One of them is the disclosure of prices by the platform. Hagiu and Halaburda (2014) analyze the effect on the price structure of price disclosure on one side for monopoly and duopoly platforms. Belleflamme and Peitz (2019) allow partial disclosure on both sides of the platform. Another asymmetry relates to the externalities produced by the platform. Peitz et al (2017) study the price charged by the platform when there is uncertainty about the level of externalities produced. Our work is in line with the literature on a third type of asymmetry, that of a myopic platform that fails to distinguish certain groups on one of its sides, which also refers to the possibility of discriminating by price or not. Liu and Serfes (2013) analyze the price discrimination of horizontally differentiated two-sided platforms, but do not allow the externalities generated to differ for agents on the same side of the platform. Jeon et al (2022) study the second-degree price discrimination for a monopoly platform. They relax the assumption of the same externality on one side of the platform and focus on the effect of discrimination on one side on discrimination on the other side. Lin (2020) analyzes the price discrimination of media platforms by incorporating content versioning depending on the valuation level of the agents.

3. Motivating examples: “good” and “bad” agents

We model a two-sided platform with within- and cross-group externalities, which is quite usual. The specificity of our model is that there are agents on one side of the platform that will generate different externalities in or outside the platform. When these externalities are of different signs, we can talk about "good" and "bad" agents. The platform is sometimes unable to distinguish between these two types of agents, which can have crucial consequences for pricing and regulation. This section provides examples of such platforms.

Our first example is carpooling platforms that match drivers with free seats with passengers who want to make a trip. An example of such a platform is BlaBlaCar, which claims to have 100 million users in 22 countries in 2021.[2] Some of the externalities on the platform are clear: positive cross-group externalities and negative within-group externalities (Viotto da Cruz, 2015). Agents on one side benefit from an increase in the number of agents on the other side: a passenger benefits from more drivers because it increases the supply and variety of possible trips; a driver benefits from more passengers because it increases the likelihood that a passenger will choose the carpool he or she has offered. Agents are also in competition with other agents on the same side of the platform as they rival to find the best match. However, there are other externalities on the passenger side: other things being equal, an additional passenger reduces road traffic, congestion, and other cars external costs if he comes from

[2] See https://blog.blablacar.com/newsroom/news-list/blablacar-reaches-100-million-members-for-its-15th-anniversary.

solo driving. This is a “good” carpool passenger. This positive externality affects agents on and off the platform.

Similarly, if this additional passenger comes from public transport, he can produce a negative external effect: a decrease in demand for public transport leads the operator to decrease the frequency of service, which increases the waiting time and the cost for the remaining users. This is the Morhing effect (Mohring, 1972). This is a “bad” carpool passenger. There is the same type of externality on the drivers' side: it is possible that the carpooling driver would not have made the trip without the financial compensation allowed by the carpooling platform. By incentivizing this agent to make a trip, the platform increases road traffic, congestion, and other external costs related to cars. Thus, the emergence of carpooling platforms may have created road traffic. These elements explain why the appraisal of carpooling platforms is not clearcut (Wang, 2011; Wagner, 2016).

Another example comes from the Airbnb platform. Airbnb is an international accommodation rental platform which connects hosts who offer accommodation for rent with guests who rent accommodation. As of March 2022, Airbnb claims more 4 million hosts worldwide.[3] As for carpooling platforms, there are clear positive cross-group externalities and negative within-group externalities on the platform. There are also other externalities on the host side. These externalities are related to the reallocation of housing from the long-term rental market to the short-term rental market. This reallocation leads to an increase in prices and rents in the area which affects agents on and off the platform. For example, Barron et al. (2020) find that a 1% increase in Airbnb listings leads to a 0.018% increase in rents and a 0.026% increase in house prices in the US. Hosts who are owner-occupiers or vacation homeowners do not generate this externality (at least via the platform), because their homes would not have been available for long-term rental, regardless of the existence of Airbnb. In this context, they are the "good" hosts, whereas hosts who reallocate their accommodation from long- to short-term rental market are the “bad” hosts.

---

[3] See https://news.airbnb.com/about-us/.

4. A general monopoly platform model

4.1. Perfect information

Suppose there are three groups of agents, denoted 1, 2 and 3, who can be interested in joining a monopoly platform. An agent of one group cares on the number of agents from other groups who use the platform but also on agents from her own group using the platform. Consequently, the utility of a group-i agent when the platform attracts n_1, n_2, and n_3 agents from group 1, group 2 and group 3, respectively, is

$$u_i = \beta_i + g_i(n_1, n_2, n_3) - p_i, \qquad i = 1,2,3 \tag{1}$$

where β_i is the utility of joining the platform for a group-i agent and $g_i(.)$ measures the externalities produced by other agents using the platform on a group-i agent. $g_i(.)$ can be an increasing or a decreasing function of its arguments, depending on whether the externalities created by n_1, n_2 and n_3 are positive or negative. This means that both cross- and within-group utility may exist. p_i is the monetary price paid by agents from group i. This price is set by the platform.

The number of group-i agents using the platform is a function of group-i utility such that

$$n_i = \phi_i(u_i), \qquad i = 1,2,3 \tag{2}$$

where $\phi_i'(.) > 0$. Demand increases with utility.

Equations (1) and (2) show that group-i demand, n_i, depends on p_i, but also on n_j. The derivatives of n_i and n_j with respect to p_i are the solutions of the following system

$$\begin{cases} \frac{\partial n_i}{\partial p_i} = \phi_i'(u_i)\left[\sum_{k=1}^{3}\left(\frac{\partial n_k}{\partial p_i}\frac{\partial g_i}{\partial n_k}\right) - 1\right] \\ \frac{\partial n_j}{\partial p_i} = \phi_j'(u_j)\sum_{k=1}^{3}\left(\frac{\partial n_k}{\partial p_i}\frac{\partial g_j}{\partial n_k}\right) \end{cases}, i \neq j \text{ and } i,j = 1,2,3. \tag{3}$$

4.1.1. Profit-maximizing platform

While Armstrong (2006) defines the platform's profit as a function of the utilities, we define it as a function of the prices. The platform bears a per agent-i cost f_i for serving group-i agent. The platform profit is then

$$\pi(p_1, p_2, p_3) = \sum_{i=1}^{3} n_i(p_1, p_2, p_3) \times [p_i - f_i] \tag{4}$$

The first-order profit-maximizing condition is

$$n_i + \sum_{k=1}^{3} \frac{\partial n_k}{\partial p_i} [p_k - f_k] = 0, \qquad i = 1,2,3. \tag{5}$$

The platform increases p_i until the benefit of charging n_i agents one monetary unit more equals the loss due to the decrease in demand on each of the three sides of the platform.

From Equations (3) and (5), we find that the profit-maximizing price, denoted by a superscript e, satisfies

$$p_i^e = \underbrace{f_i}_{\substack{\text{marginal}\\ \text{cost}}} - \underbrace{n_i \frac{\partial g_i}{\partial n_i}}_{\substack{\text{marginal within-group}\\ \text{externality}}} - \underbrace{\sum_{k \neq i} n_k \frac{\partial g_k}{\partial n_i}}_{\substack{\text{marginal cross-group}\\ \text{externalities}}} + \underbrace{\frac{\phi_i(u_i)}{\phi_i'(u_i)}}_{\text{mark-up}}, \qquad i = 1,2,3. \tag{6}$$

The group-i profit-maximizing price equals the marginal cost of providing service to a group-i agent. This marginal cost is adjusted by the sum of the marginal benefits or losses due to a variation in n_i on group-i agents (within-group externality) and on other groups agents (cross-group externality). The price also includes a positive factor related to the group-i demand elasticity[4] such that

$$\frac{\phi_i(u_i)}{\phi_i'(u_i)} = \frac{u_i}{\eta_{n_i/u_i}}, \qquad i = 1,2,3.$$

where $\eta_{a/b}$ denotes the elasticity of a wrt b. This monopoly mark-up increases with group-i utility and decreases with the elasticity of group-i participation wrt utility.

[4] As in Armstrong (2006), this result can be rewritten in the form of Lerner indice: $\frac{p_i - \left(f_i - \sum_{k=1}^{3} n_k \frac{\partial g_k}{\partial n_i}\right)}{p_i} = \frac{1}{\eta_{n_i/p_i}}$, where $\eta_{n_i/p_i} = p_i \frac{\phi_i'(u_i)}{\phi_i(u_i)}$.

4.1.2. Welfare-maximizing platform

Let the aggregate consumer surplus of group i be $v_i(u_i)$, satisfying the envelope condition $v_i'(u_i) = \phi_i(u_i)$. We also assume that an agent joining the platform may produce positive or negative externalities outside of the platform.

The welfare, w, is the sum of the platform profit, the consumers surplus and externalities produced by the agents joining the platform

$$w(p_1,p_2,p_3) = \pi(p_1,p_2,p_3) + \sum_{k=1}^{3} v_i[u_i(p_1,p_2,p_3)] + E[n_1(p_1,p_2,p_3), n_2(p_1,p_2,p_3), n_3(p_1,p_2,p_3)] \qquad (7)$$

where $E(n_1,n_2,n_3)$ is the social benefit or cost due to n_i group-i agents joining the platform which is not supported by agents in the platform.

The welfare-maximizing condition is

$$n_i + \sum_{k=1}^{3}\left(\frac{\partial n_k}{\partial p_i}[p_k - f_k] + \frac{\partial u_k}{\partial p_i} v_k'(u_k) + \frac{\partial n_k}{\partial p_i}\frac{\partial E}{\partial n_k}\right) = 0, \qquad i = 1,2,3. \qquad (8)$$

The welfare-maximizing platform set prices that equalize marginal profit with marginal utility and marginal outside the platform externality. By combining Equations (3) and (8), we find the welfare-maximizing price, denoted by superscript o

$$p_i^o = \underbrace{f_i}_{\text{marginal cost}} - \underbrace{n_i \frac{\partial g_i}{\partial n_i}}_{\text{marginal within-group externality}} - \underbrace{\sum_{k \neq i} n_k \frac{\partial g_k}{\partial n_i}}_{\text{marginal cross-group externalities}} - \underbrace{\frac{\partial E}{\partial n_i}}_{\text{outside the platform externality}}, \qquad i = 1,2,3. \qquad (9)$$

This price is similar to the profit-maximizing price described in Equation (6). Only the last term differs: the monopoly mark-up is replaced by a factor which internalized the marginal outside the platform externality produced by group-i agents. In some favourable situations, the mark-up might be equal to the (negative) outside the platform externality, and the profit-maximizing platform would then set an optimal price. In these very specific cases, there would be no need for regulation.

4.2. Myopic platform

This model involves monopoly platform but assumes now that for some reasons, the platform is myopic. We define myopia as the inability of the platform to distinguish between two agents that are on the same side of the platform but produce different externalities. However, the platform knows that these two agents exist and knows their characteristics. So the platform is now not able to distinguish group-2 agents from group-3 agents.[5] It implies that agents from group-2 and group-3 pay the same price if they join the platform. This price is denoted $p_{2;3}$:

$$p_{2;3} = p_2 = p_3. \tag{10}$$

From Equation (3) and (10), the derivatives of the n_i with respect to prices now become

$$\begin{cases} \frac{\partial n_1}{\partial p_1} = \phi_1'(u_1)\left[\sum_{k=1}^{3}\left(\frac{\partial n_k}{\partial p_1}\frac{\partial g_k}{\partial n_k}\right) - 1\right] \\ \frac{\partial n_j}{\partial p_1} = \phi_j'(u_j)\sum_{k=1}^{3}\left(\frac{\partial n_k}{\partial p_1}\frac{\partial g_k}{\partial n_k}\right) & j = 2,3 \\ \frac{\partial n_1}{\partial p_{2;3}} = \phi_1'(u_1)\sum_{k=1}^{3}\left(\frac{\partial n_k}{\partial p_{2;3}}\frac{\partial g_k}{\partial n_k}\right) \\ \frac{\partial n_j}{\partial p_{2;3}} = \phi_j'(u_j)\left[\sum_{k=1}^{3}\left(\frac{\partial n_k}{\partial p_{2;3}}\frac{\partial g_k}{\partial n_k}\right) - 1\right] & j = 2,3 \end{cases} \tag{11}$$

We find that the profit- and welfare maximizing prices set by the platform with information asymmetry have the same structure and are

$$\begin{cases} \tilde{p}_1^k = p_1^k + \underbrace{\frac{\phi_2'(u_2)\phi_3'(u_3)}{W_2 + W_3}}_{\text{weighting coeff}} \underbrace{\left(\frac{\partial g_2}{\partial n_1} - \frac{\partial g_3}{\partial n_1}\right)}_{\text{group-2 and -3 relative externality from group 1}} \underbrace{\left[p_2^k - p_3^k\right]}_{\text{group-2 and -3 relative price}} \\ \tilde{p}_{2;3}^k = \frac{W_2}{W_2 + W_3} p_2^k + \frac{W_3}{W_2 + W_3} p_3^k \end{cases} \quad k = e, o \tag{12}$$

where $W_2 \equiv \phi_2'(u_2)\left[1 - \phi_3'(u_3)\left(\frac{\partial g_3}{\partial n_3} - \frac{\partial g_2}{\partial n_3}\right)\right]$, and $W_3 \equiv \phi_3'(u_3)\left[1 - \phi_2'(u_2)\left(\frac{\partial g_2}{\partial n_2} - \frac{\partial g_3}{\partial n_2}\right)\right]$.

Interestingly, the group-1 price includes one extra element that was not present with perfect information (see Equation (6)). This element can be positive or negative. It is positive if the group that marginally

[5] This is the case, for example, for platforms operating in the transport sector. They do not know which transport mode would have been used by agents if the platforms did not exist.

benefits most from n_1, for example group-2 if $\frac{\partial g_2}{\partial n_1} > \frac{\partial g_3}{\partial n_1}$, is also the one whose price is lower due to information asymmetry, for example group-2 if $p_2^k > p_3^k$.

The price offered to the two groups that the platform cannot distinguish is the weighted average of the prices in perfect information of groups 2 and 3. The weights are given by W_2 and W_3, respectively. W_2 and W_3 are symmetric, we then discuss W_2.

W_2 is proportional to $\phi_2'(u_2)$. It will be higher or lower than $\phi_2'(u_2)$ depending on the relative marginal effect of group-3 agents on group-2 agents (cross-group effect) and on group-3 agents (within-group effect). If the cross-group marginal effect is higher than the within-group marginal effect ($\partial g_3/\partial n_3 < \partial g_2/\partial n_3$), then W_2 will be higher than $\phi_2'(u_2)$, otherwise ($\partial g_3/\partial n_3 > \partial g_2/\partial n_3$), W_2 will be lower than $\phi_2'(u_2)$. This difference is itself weighted by $\phi_3'(u_3)$.

To sum-up, the weight given to group-2 agents increases with the sensitivity of the group-2 demand (i.e $\phi_2'(u_2)$). This sensitivity is affected by a coefficient that varies according to the externalities produced by the individuals in the other group. If agents in group 2 marginally benefit more from the presence of group-3 agents on the platform than individuals in group 3, then the weight given to group 2 increases.

The structure of the price offered to indistinguishable agents is such that that agents in the group that was most subsidized must pay more, while those in the least subsidize group will pay less. Winners and losers are thus clearly identified. Myopia diminishes the platform's ability to identify the agents that create the externalities that are most beneficial to it.

The gap between the prices offered by profit- and welfare-maximizing platforms is tricky to interpret, as many parameters affect it. This gap depends in particular on the price differences under perfect information. Other things being equal, the myopia of the profit-maximizing platform favors indistinguishable agents with a lower price elasticity of demand (i.e. those that the profit-maximizing platform charges the most), while the myopia of the welfare-maximizing platform favors indistinguishable agents who produce the more negative (or less positive) externality outside the platform.

5. Single-homing Hotelling competition

We consider now two platforms A and B which compete to attract group-1, -2 and -3 agents. We use a single homing framework, which means that each agent in any group joins one and only one platform.[6] Consequently, each agent chooses between platform A and platform B.

We model competition by introducing a Hotelling specification. The two platforms are located at each endpoint of a one-unit length road, along which agents of each group are uniformly distributed. The utility of a group-i agent joining platform l is

$$u_i^l = \beta_i^l + g_i^l\left(n_1^l, n_2^l, n_3^l\right) - p_i^l, \qquad i = 1,2,3 \;\; l = A, B \tag{13}$$

The agents also incur a transport cost αt_i to join the platform, where α relates to the agent location and is a uniformly distributed 0-1 parameter, and t_i is the transport cost per space unit (or the product differentiation parameter) The indifferent group-i agent verifies

$$\begin{gathered}\beta_i^l + g_i^l\left(n_1^l, n_2^l, n_3^l\right) - p_i^l - \alpha t_i = \beta_i^{-l} + g_i^{-l}\left(n_1^{-l}, n_2^{-l}, n_3^{-l}\right) - p_i^{-l} - (1-\alpha) t_i, \\ i = 1,2,3 \;\; l = A, B\end{gathered} \tag{14}$$

Therefore, the demand from group-i for each platform is

$$\begin{cases} n_i^l &= \dfrac{1}{2} + \dfrac{u_i^l - u_i^{-l}}{2t_i} \quad i = 1,2,3 \;\; l = A, B \\ n_i^{-l} &= 1 - n_i^l \end{cases} \tag{15}$$

5.1. Perfect information

With perfect information, the derivatives of n_i^l and n_j^l with respect to p_i^l are given by

$$\begin{cases} \dfrac{\partial n_i^l}{\partial p_i} = \dfrac{1}{2\mathrm{t_i}}\left[\sum_{k=1}^{3}\left(\dfrac{\partial n_k^l}{\partial p_i^l}\dfrac{\partial g_i^l}{\partial n_k^l}\right) - \sum_{k=1}^{3}\left(\dfrac{\partial n_k^{-l}}{\partial p_i^l}\dfrac{\partial g_i^{-l}}{\partial n_k^{-l}}\right) - 1\right] \\ \dfrac{\partial n_j^l}{\partial p_i} = \dfrac{1}{2\mathrm{t_j}}\left[\sum_{k=1}^{3}\left(\dfrac{\partial n_k^l}{\partial p_i^l}\dfrac{\partial g_j^l}{\partial n_k^l}\right) - \sum_{k=1}^{3}\left(\dfrac{\partial n_k^{-l}}{\partial p_i^l}\dfrac{\partial g_j^{-l}}{\partial n_k^{-l}}\right)\right] \end{cases}, i \neq j, \quad i, j = 1,2,3 \text{ and } l = A, B. \tag{16}$$

[6] This assumption seems to be in line with the transport platforms. An agent uses a single platform when making a trip.

Due to the Hotelling specification, an additional agent who joins platform l necessarily leaves platform $-l$. Therefore

$$\frac{\partial n_i^l}{\partial p_i} = -\frac{\partial n_i^{-l}}{\partial p_i}, \qquad i,j = 1,2,3 \;\; l = A,B \tag{17}$$

Combining Equations (16) and (17) lead to

$$\begin{cases} \frac{\partial n_i^l}{\partial p_i} = \frac{1}{2\mathrm{t_i}}\left[\sum_{k=1}^{3} \frac{\partial n_k^l}{\partial p_i^l}\left(\frac{\partial g_i^l}{\partial n_k^l} + \frac{\partial g_i^{-l}}{\partial n_k^{-l}}\right) - 1\right] \\ \frac{\partial n_j^l}{\partial p_i} = \frac{1}{2\mathrm{t_j}}\left[\sum_{k=1}^{3} \frac{\partial n_k^l}{\partial p_i^l}\left(\frac{\partial g_j^l}{\partial n_k^l} + \frac{\partial g_j^{-l}}{\partial n_k^{-l}}\right)\right] \end{cases}, i \neq j, \quad i,j = 1,2,3 \text{ and } l = A,B. \tag{18}$$

When comparing Equations (3) and (18), we observe that competition reinforces the effect of price on demand by adding a term that reflects the fact that any agent leaving a platform joins the competing platform and makes it more competitive. The effect of the externalities on prices is then amplified by externalities on the other platform.

Solving Equation (5) with Equations (18) gives the symmetric information equilibrium price

$$\begin{aligned} p_i^l = \underbrace{f_i^l}_{\substack{\text{marginal}\\ \text{cost}}} - \underbrace{n_i^l \frac{\partial g_i^l}{\partial n_i^l}}_{\substack{\text{same platform}\\ \text{marginal within-group}\\ \text{externality}}} - \underbrace{\sum_{k \neq i} n_k^l \frac{\partial g_k^l}{\partial n_i^l}}_{\substack{\text{same platform}\\ \text{marginal cross-group}\\ \text{externalities}}} - \underbrace{n_i^l \frac{\partial g_i^{-l}}{\partial n_i^{-l}}}_{\substack{\text{competing platform}\\ \text{marginal within-group}\\ \text{externality}}} \\ - \underbrace{\sum_{k \neq i} n_k^l \frac{\partial g_k^{-l}}{\partial n_i^l}}_{\substack{\text{competing platform}\\ \text{marginal cross-group}\\ \text{externalities}}} + \underbrace{2n_i^l t_i}_{\text{market power}}, \qquad i = 1,2,3. \end{aligned} \tag{19}$$

The price set by a competing platform takes into account the externalities existing on the other platform. The platform retains its patronage by adjusting its price with respect to negative or positive externalities on the competing platform.

If the two platforms are symmetric (i.e. similar), the externalities functions $g(\cdot)$ and their derivatives are equal. Therefore, the two platforms offer the same price to each group

$$p_i^l = \underbrace{f_i^l}_{\text{marginal cost}} - \underbrace{2n_i^l \frac{\partial g_i^l}{\partial n_i^l}}_{\text{marginal within-group externality}} - \underbrace{2\sum_{k\neq i} n_k^l \frac{\partial g_k^l}{\partial n_i^l}}_{\text{marginal cross-group externalities}} + \underbrace{2n_i^l t_i}_{\text{market power}}, \qquad i = 1,2,3 \tag{20}$$

Comparing Equations (19) or (20) with Equation (6) show that competition reinforces the role played by externalities in the price. Thus, if all other things being equal, one platform manages to generate more positive externalities, the other platform will react by lowering its prices.

5.2. Myopic platform

We introduce asymmetric information by considering than p_2 and p_3 are equal, as defined in Equation (10). We find the following prices

$$\begin{cases} \tilde{p}_1^l = p_1^l + \underbrace{\frac{1}{Z_2 + Z_3}}_{\text{weighting coeff}} \underbrace{\left(\frac{\partial g_2^l}{\partial n_1^l} + \frac{\partial g_2^{-l}}{\partial n_1^{-l}} - \frac{\partial g_3^l}{\partial n_1^l} - \frac{\partial g_3^{-l}}{\partial n_1^{-l}}\right)}_{\text{group-2 and -3 relative externality from group 1}} \underbrace{[p_2^l - p_3^l]}_{\text{group-2 and -3 relative price}} \\ \tilde{p}_{2;3}^l = \frac{Z_2}{Z_2 + Z_3} p_2^l + \frac{Z_3}{Z_2 + Z_3} p_3^l \end{cases} \qquad l = A, B \tag{21}$$

where $Z_2 \equiv 2t_3 + \frac{\partial g_2^l}{\partial n_3^l} + \frac{\partial g_2^{-l}}{\partial n_3^{-l}} - \frac{\partial g_3^l}{\partial n_3^l} - \frac{\partial g_3^{-l}}{\partial n_3^{-l}}$, and $Z_3 \equiv 2t_2 + \frac{\partial g_3^l}{\partial n_2^l} + \frac{\partial g_3^{-l}}{\partial n_2^{-l}} - \frac{\partial g_2^l}{\partial n_2^l} - \frac{\partial g_2^{-l}}{\partial n_2^{-l}}$.

The structure of prices is similar to those in Equation (12). Again, we find that competition strengthens the effect of within- and cross-group externalities. Indeed, an individual who is not on a platform is on the competing platform and, if the externality produced is positive, reinforce its attractiveness. This increases the value of the presence of an agent for a platform.

Equation (21) also shows that competition does not mitigate the effect of the platform's myopia.

6. Empirical application to carpool

We propose an empirical application of our model to short-distance carpooling to illustrate the effects of the information asymmetry on a study case. This type of platform has already proved its worth for long-distance carpooling. Every month in France, more than one million people use the leading carpooling platform (Blablacar.com) to make a long-distance trip by carpooling (ADEME, 2015). However, it is not clear that the success of long-distance carpooling has led to a reduction in the number of vehicle-kilometers. Indeed, Wagner (2016) shows that most long-distance carpool passengers would have travel by train in the absence of carpool opportunity, and a non-negligible share of carpool drivers (close to 10%) would have not make the trip without financial reward due to carpool.

Carpooling for short-distance daily trips is also often seen as an effective way to reduce road traffic and the external costs generated by the car. Many passenger and/or driver subsidy schemes for public authorities exist across the world (Wang, 2011, Shaheen et al., 2018, Aguiléra, and Pigalle, 2021). For example, the French government plans to give 100€ to drivers who register on a daily carpooling platform and make at least 10 trips.[7] However, if these platforms do not allow reduce traffic then the question of their regulation and subvention arises. We address this question by comparing a welfare-maximizing and a profit-maximizing carpool platform in terms of pricing, modal shifts and congestion.

6.1. Calibration assumptions

6.1.1. Demand

We consider a simple 20km road segment with three groups of agents who makes a trip along the road. We assume that each group chooses between two modes: Group 1 ($N^1 = 150$) choose between solo driver ($N^1 - n^1$) and carpool driver (n^1), Group 2 ($N^2 = 50$) choose between solo driver ($N^2 - n^2$) and carpool passenger (n^2), and Group 3 ($N^3 = 50$) choose between public transport passenger ($N^3 - n^3$) and carpool passenger (n^3).

The utility of a trip for an agent from group j using mode i is $V_i^j = U_i^j + \frac{\varepsilon_i^j}{\phi_i}$, where U_i^j is the deterministic part of the utility, ε_i^j the stochastic part, and ϕ_i defines the scale of systematic utility of type i users. The larger ϕ_i the more deterministic the choices are. ϕ_i is set at 0.2. By assuming that these stochastic terms are identically and independently extreme value distributed, the mode choice for each group is modelled with a binomial logit such that $n_i^j = N^j \times \frac{1}{1+e^{\phi_i\left(U_{-i}^j - U_i^j\right)}}$.

We use results from a Discrete Choice Experiment carried out in Lyon (Le Goff et al., 2022) to calibrate the following utility functions. The estimation of utility function is made through a multinomial logit

[7] See https://www.brusselstimes.com/336589/france-introduces-e100-carpooling-bonus-in-2023.

model estimated on 21 714 choices made by 4 119 individuals ($n = 4119$). The complete estimation results are available in Appendix A.

The utility of agent from group $i \in \{1, 2, 3\}$) using mode $j \in$ {SD (solo driver), CD (carpool driver), CP (carpool passenger), PT (public transport)} measured in monetary units is

$$\begin{aligned} U_{SD}^1 &= 0 - 0{,}29 \times TT_{road} \\ U_{CD}^1 &= 7.76 - 0.48 \times (TT_{road} - TG_{HOV}) - 0.46 \times WT_{CD} - p_{CD} \\ U_{SD}^2 &= 0 - 0{,}29 \times TT_{road} \\ U_{CP}^2 &= 4.87 - 0.45 \times (TT_{road} - TG_{HOV}) - 1.50 \times WT_{CP} - p_{CP}^2 \\ U_{PT}^3 &= 0 - 0.38 \times TT_{PT} - 0.61 \times WT_{PT} \\ U_{CP}^3 &= 4.87 - 0.45 \times (TT_{road} - TG_{HOV}) - 1.50 \times WT_{CP} - p_{CP}^3 \end{aligned} \quad (22)$$

Where TT_{road} is the travel time by road, TG_{HOV} is the time gain due to HOV lane, WT_{CD} is the average carpool driver waiting time when meeting the passenger. These three variables are measured in minutes. p_{CD} is the price paid by carpool driver, WT_{CP} is the average carpool passenger waiting time when meeting the driver, p_{CP}^i is the price paid by carpool passenger from group i, TT_{PT} is the travel time by public transport, set at 45 minutes, and WT_{PT} the average public transport waiting time, set at 5 minutes.

6.1.2. Externalities

We consider several sources of externality.

The on-platform externalities are related to waiting times. The waiting time of passenger (resp. driver) depend on the number of passengers (resp. drivers) AND on the number of drivers (resp. drivers) on the platform. We model these waiting times based on Ray (2004), such that $WT_{CP} = e^{(n_{CP}/(1+n_{CD}))^2-1}$ and $WT_{CD} = e^{(n_{CD}/(1+n_{CP}))^2-1}$, where $n_{CP} = n^2 + n^3$ and $n_{CD} = n^1$. These functions are drawn in Appendix B.

The road is congestible. All agents from Group 1 use their car independently of their modal choice so that the extra travel time only depends on solo driver from group 2 ($N^2 - n^2$), $TT_{road} = 30 \times \left(1 + e^{-3(N^2-n^2)/N^2}\right)$, expressed in minutes. This formula mimics in a simplified way the BPR[8] function

[8] Bureau of Public Roads.

(Spiess, 1990). This externality is both on and outside the platform as it affects both agents in- and out-the-platform. We draw the transport time function in Appendix C.

Traffic produces outside the platform negative externalities at a cost of 0.1€ per veh.km. This figure reflects the order of magnitude described in the Handbook on the external costs of transport (European Commission, 2019, which stipulates an average car external cost of €-cent 7.8 per passenger-km without congestion (see p. 157), the average car occupancy rate being 1.6 passengers per vehicle. These costs include accidents, air pollution, climate, noise, well-to-tank, and habit damage costs.

6.1.3. Aggregates

On the platform side, we assume that the marginal cost of serving an additional agent is 0. Therefore the profit-maximizing platform maximizes $\Pi = p_{CD}n^1 + p_{CP}^2 n^2 + p_{CP}^3 n^3$ in perfect information case, and $\Pi = p_{CD}n^1 + p_{CP}(n^2 + n^3)$ in information asymmetry case. The welfare-maximizing platform maximizing the sum of the agent's surplus, of the profit and of the out-the-platform externalities. The agent surplus is computed with the log-sum formula (Train, 2009). The Welfare is then

$$W = \sum_{j=1}^{3} N^J \times \frac{\log\left(e^{\phi_i U_{-i}^j} + e^{\phi_i U_i^j}\right)}{\phi_i} + \Pi + 0.1 \times 20 \times (N^1 + N^2 - n^2) \qquad (23)$$

6.2. Results without HOV lane

Table 1 displays the results of the empirical calibration. The "No carpool" regime is the reference scenario where carpooling is not available. We then display profit- and welfare-maximizing prices and aggregates in perfect and asymmetric information.

Table 1: Empirical application results without HOV lane

Variables	Baseline	Perfect information Profit-max	Perfect information Welfare-max	Asymmetric information Profit-max	Asymmetric information Welfare-max
Carpool platform users (ind.)					
n_1	0.00	42.54	90.81	46.92	94.70
n_2	0.00	25.76	45.15	16.43	44.00
n_3	0.00	17.57	41.22	35.62	49.21
Carpool prices (euros)					
p_{CD}		4.84	-1.14	3.26	-1.69
Marginal within-group externality		*-0.78*	*-1.08*	*-0.58*	*-0.94*
Marginal cross-group externality		*2.92*	*2.22*	*4.59*	*2.63*
Mark-up		*6.98*		*7.28*	
Outside the platform externality			*0.00*		*0.00*
p_{CP}^2		-2.97	-12.95	-0.20	-11.86
Marginal within-group externality		*2.75*	*1.23*	*3.68*	*1.30*
Marginal cross-group externality		*10.53*	*7.51*	*23.76*	*8.29*
Mark-up		*10.31*		*7.45*	
Outside the platform externality			*4.21*		*4.27*
Congestion			*2.21*		*2.27*
Other car-related external costs			*2.00*		*2.00*
p_{CP}^3		9.89	1.24	-0.20	-11.86
Marginal within-group externality		*-1.19*	*-1.13*	*-2.89*	*-1.42*
Marginal cross-group externality		*-0.99*	*-0.11*	*-0.82*	*-0.33*
Mark-up		*7.71*		*17.39*	
Outside the platform externality			*0.00*		*0.00*
Asymmetric prices coefficients					
W_2				2.21	1.06
W_3				2.05	0.15
Aggregates					
Profit (euros)	0.00	303.20	-637.43	142.36	-1265.21
Welfare (euros)	-4860.30	-2604.88	-2076.45	-2907.86	-2114.40
Other car-rel. extern. costs (euros)	400.00	348.49	309.69	367.14	312.01
road travel time (min.)	60.00	36.40	32.00	41.19	32.14
Pass. carpool waiting time (min.)		0.99	0.89	1.20	0.95
Driv. carpool waiting time (min.)		0.92	1.08	0.80	1.01
Individual expected surplus Gr. 1	-17.30	-8.83	-4.58	-10.00	-4.28
Individual expected surplus Gr. 2	-17.30	-6.88	2.44	-9.89	1.33
Individual expected surplus Gr. 3	-19.99	-17.83	-11.29	-13.76	0.77

The welfare aggregate shows that all scenarios are preferable to the reference scenario in which carpooling is not available. This is an expected result. Indeed, the structure of the logit means that the surplus of agents increases mechanically when alternatives are added to their choice set.

6.2.1. Perfect information results

We first compare the scenarios in a situation of perfect information. The ranking of the prices proposed to the three groups is the same in the profit- (4.84; -2.97; 9.89) and welfare-maximizing (-1.14; -12.95; 1.24) platform scenarios. However, the price levels are quite different, mainly because the profit-maximizing platform applies a mark-up premium linked to the elasticity of demand while the welfare-maximizing platform values the externalities affecting agents outside the platform, as described in Equations (6) and (9). On the other hand, marginal externalities affecting agents on the platform are considered in similar orders of magnitude in the two scenarios. Note that a positive (resp. negative) externality implies a reduction (resp. increase) in price.

Thus, the profit-maximizing platform offers a negative price (i.e. subsidy) to the agents of group 2 because each additional solo driver who becomes a carpool passenger reduces the congestion affecting the transport times of all the agents carpooling. This subsidy is even more important in the welfare-maximizing scenario because the platform then takes into account the congestion reduction marginal effect on all agents outside the platform (-2.21€), and also the other car-related external costs reduction effect (-2€).

Agents in group 3 pay the highest prices, as they produce more negative externalities (increased waiting time for their group and group 2) than positive externalities (decreased waiting time for group 1). This is the only group that is not subsidized by the welfare-maximizing platform, as a public transport user who becomes a carpool passenger does not reduce congestion and other external costs related to cars.[9]

Group-1 agents produce more positive externalities (decrease in waiting time for carpooling passengers) than negative externalities (increase in waiting time for carpooling drivers). They therefore benefit from a subsidy (-2.14€ in profit-max, -1.14€ in welfare-max), which is more than compensated by the mark-up in the profit-maximization scenario.

---

[9] This effect is reinforced by the economies of scale that characterize public transport supply: one less user leads the operator to reduce frequencies, which increases the waiting time of the remaining users. This is the well-known Mohring effect (see 1972).

Price levels affect demands and aggregates. The subsidies offered by the welfare-maximizing platform attract twice as many carpoolers as the prices offered by the profit-maximizing platform. This leads to less external costs related to cars, less congestion, lower waiting times, higher individual surpluses but a largely negative profit for the platform. The penalizing pricing applied to group 3 does not discourage its agents from joining the platform and being almost as numerous as those in group 2.

6.2.1. Myopic platform results

Let now analyze the scenarios with asymmetric information. As a reminder, in this situation the platform is myopic and cannot distinguish between group 2 and group 3 agents. It therefore offers them a unique price.

The second element on the right side of the group 1 price (see Equation (12)) is equal to 0, because the value of the marginal externality produced by agents in group 1 on agents in groups 2 and 3 is the same. The waiting time decreases in the same way. This explains why the differences are slight for the price of group 1 between perfect and asymmetric information.

The single price offered to groups 2 and 3 is a weighted average of the price structures that would have been offered to them with perfect information. The weights are W_2 and W_3. These coefficients are close to each other in the profit-maximizing scenario, which results in a median price (-0.20€) between the price that would have been offered to group 2 $(-3.68 - 23.76 + 7.45 = -19.99)$ and to group 3 $(2.89 + 0.82 + 17.39 = \ 21.1)$ under these conditions. On the other hand, the weights are very different in the welfare-maximization scenario. The weight of group 2 is much higher than the weight of group 3, resulting in a single price (-11.86€) much closer to that which would have been charged for group 2 $(-1.3 - 8.29 - 4.27 = -13.86)$ than that of group 3 $(1.42 + 0.33 = 1.75)$.

The myopia of the platform degrades both welfare and profit for the profit- and the welfare-maximizing platform. The welfare maximizing platform manages to maintain a low level of congestion, but at the expense of a near doubling of losses. The effects of the myopia on individual surpluses are very heterogeneous: the surplus of group 2 agents decreases while that of group 3 agents increases. The effect is more neutral for group 1.

6.3. Results with HOV lane

We simulate the implementation of an HOV lane with a myopic platform. A HOV lane is a restricted traffic lane reserved for the exclusive use of multi-occupancy vehicles with a driver and one or more passengers (including carpools, vanpools, and transit buses). The mechanism is that HOV lane allows for shorter and more reliable trip times. It is expected to encourage people to carpool.

The HOV lane allows carpoolers to save from 1 to 10 minutes on their travel time. However, it has no influence on congestion. This corresponds to a situation where a bottleneck is located upstream of the HOV lane. Figure 1a present the effects on prices, Figure 1b the effects on participation in the platform and Figure 1c the effects on welfare and profit.

Figure 1a: effects of HOV lane on prices with asymmetric information

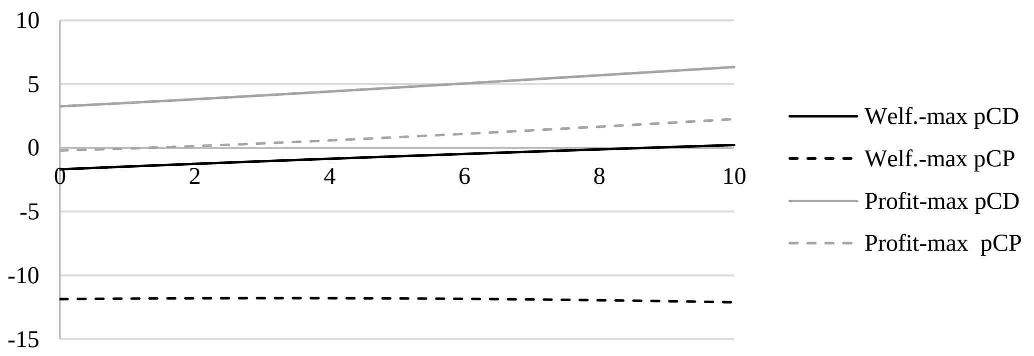


Figure 1b: effects of HOV lane on participation with asymmetric information

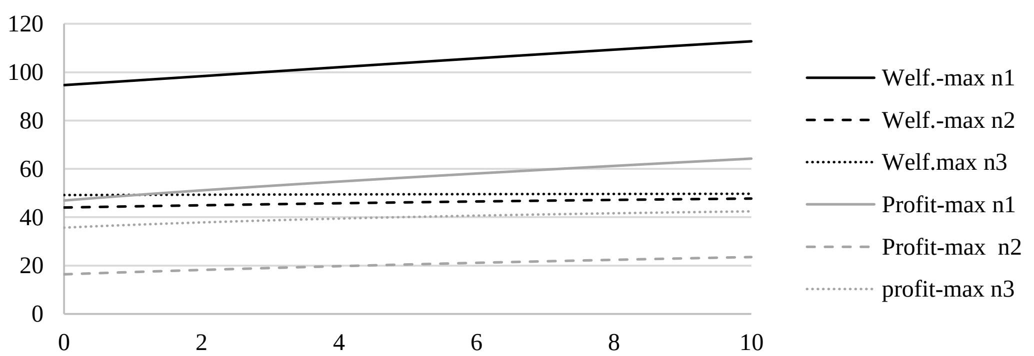
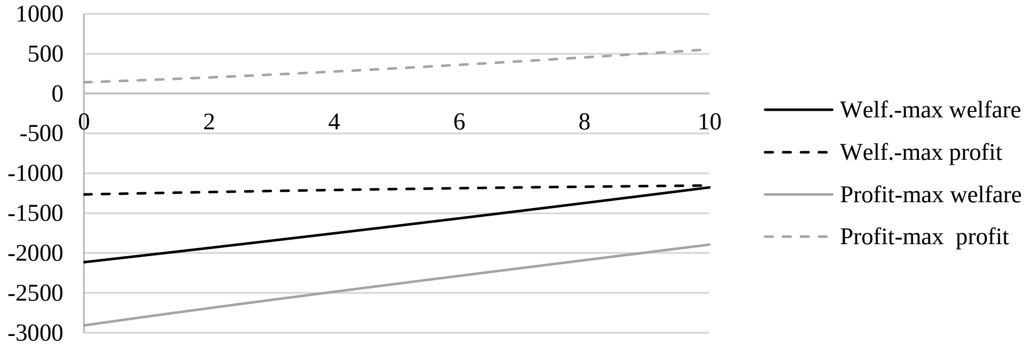


Figure 1c: effects of HOV lane on aggregates with asymmetric information



The effect of the HOV lane on prices is heterogeneous. Other things being equal, the introduction of an HOV lane reduces the travel time of carpoolers, and thus favors the platform over alternative modes, via an increase in utility. The demand for the platform thus grows for all three groups. These increasing levels of demand lead to a reduction in the marginal effect of an additional participant on waiting times and a decrease in the derivatives of demand with respect to utility levels.

As a result, the profit-maximizing platform raises its prices when the time savings allowed by the HOV lane increases, from 3.53€ (driver) and -0.05€ (passenger) for a 1-minute time gain to 6.33€ and 2.25€ for a 10-minute time gain. Indeed, other things being equal, the subsidies related to the positive externalities on waiting times decline while the numerator of the mark-up rises and the denominator falls. Despite these price increases, the participation in the platform still rises. The platform thus improves its profit from 171 (1-minute time gain) to 555€ (10-minute time gain).

The analysis is more mixed for the welfare-maximizing platform prices. The price offered to drivers increases with the time savings of the HOV lane because the decline in the within-group externality is more than offset by the rise in the number of drivers on the platform, which is not the case for the positive cross-group externality, whose overall effect declines. The sum of the two effects thus leads to a price increase. The variation in the single price offered to passengers is minimal. Demand levels do not change much, and neither do the externalities produced. The HOV lane allows the welfare-maximizing platform to increase welfare from -2026€ for 1-minute time gain to -1177€ for a 10-minute time gain. However, it does not solve its deficit (from -1265 to -1154€).

Comparing the results for both platforms, we observe equivalent welfare gains. However, the allocation of these gains is different according to the objectives of the platforms. The increase in platform profit caused by the introduction of a 10-minute time gain HOV lane accounts for 40% of the welfare gains for the profit-maximizing platform, compared to 11% for the welfare-maximizing platform, while the agents' surplus gain accounts for 58% and 87%, respectively, the rest being due to a decrease in other external costs related to cars. The choice of platform regulation has important effects on the distribution of welfare gains.

7. Conclusion

We present a model that extends Armstrong's model (2006) by including more than two groups, within-group externalities, outside the platform externalities and myopia for the platform which is not able to distinguish between the participants of two groups and therefore offers them the same price.

The results with perfect information are as expected: the price charged by the platforms is the sum of their marginal cost incurred the platform, the marginal externalities produced by an additional agent on the other groups but also on its group, and a third element which is the mark-up for the profit-maximizing platform, and the externalities produced outside the platform for the welfare-maximizing platform.

The introduction of myopia affects prices. The price offered to the two groups that the platform cannot distinguish is a weighted average of the perfect information prices. The weights are related to the demand elasticities of the two groups: the higher the relative elasticity of one group with respect to the other, the higher its weight will be. The price of the group that is not affected by the information asymmetry is also changed. It is adjusted upwards or downwards by an element that depends on the elasticities of the other groups, the relative externalities on the other groups and the relative prices of the other groups. Depending on the relative value of demand elasticities and externalities that affect agents outside the platform, the platform's myopia may increase or decrease the gap between the profit- and welfare-maximizing platform.

The introduction of competition à la Hotelling between two platforms does not change the structure of the prices charged. However, this reinforces the weight of externalities, because the price of one platform considers the externalities on the other platform. If the externality produced by an agent is positive, then it is doubly interesting for the platform that this agent joins it. On the one hand it increases the utility on the platform, on the other hand it decreases the externalities on the other platform, which reduces its attractiveness.

We then apply the model to short-distance carpool platform. For carpooling to significantly improve welfare, it is preferable that solo drivers become carpool passengers in order to reduce congestion and other car-related external costs. We therefore separate the agents into three groups: one group chooses between solo driver and carpool driver, another between solo driver and carpool passenger, and the last between public transport and carpool passenger.

In the perfect information situation, profit- and welfare-maximizing platforms offer the same prices ranking. The values of these prices are however very different, because the first adds a mark-up while the second internalizes the externalities outside the platform. However, information asymmetry makes carpooling less effective in reducing road traffic. Indeed, it is more difficult for platforms to subsidize "good" passengers, those who would be solo drivers in the absence of carpooling, as passengers coming from public transport also benefit from these subsidies.

We also simulate the effect of an HOV lane. The introduction of an HOV lane is overall positive in the sense that it increases welfare. The distribution of welfare is different depending on the objective of the platform. A very large part of the surplus gain created by the HOV lane is captured by the agents when the platform maximizes welfare, while the profit-maximizing platform manages to increase its profit substantially.

These results call for a broader reflection on the regulation of myopic platforms, especially in situations where externalities affecting agents outside the platforms are produced. In these cases, myopia can increase the gap between profit-maximizing and welfare-maximizing platforms. Ridesharing platforms are a good example of this risk. They do not necessarily reduce traffic if they attract new passengers from public transport rather than from driving alone. This motivates a discussion on the financing and regulation of these platforms.

References

ADEME (2015) Etude nationale sur le covoiturage de courte distance, 233 p.

Aguiléra, A., & Pigalle, E. (2021). The Future and Sustainability of Carpooling Practices. An Identification of Research Challenges. *Sustainability*, *13*(21), 11824.

Armstrong, M. (2006). Competition in two-sided markets. *The RAND Journal of Economics*, *37*(3), 668-691.

Bardey, D., Cremer, H., & Lozachmeur, J. M. (2014). Competition in two-sided markets with common network externalities. *Review of Industrial Organization*, *44*, 327-345.

Barron, K., Kung, E., & Proserpio, D. (2021). The effect of home-sharing on house prices and rents: Evidence from Airbnb. *Marketing Science*, *40*(1), 23-47.

Belleflamme, P., & Peitz, M. (2019). Price disclosure by two-sided platforms. *International Journal of Industrial Organization*, *67*, 102529.

Belleflamme, P., & Toulemonde, E. (2009). Negative intra-group externalities in two-sided markets. *International Economic Review*, *50*(1), 245-272.

Caillaud, B., & Jullien, B. (2003). Chicken & egg: Competition among intermediation service providers. *RAND Journal of Economics*, 309-328.

European Commission, Directorate-General for Mobility and Transport, Essen, H., Fiorello, D., El Beyrouty, K., et al. (2020) *Handbook on the external costs of transport : version 2019 – 1.1*. Publications Office. https://data.europa.eu/doi/10.2832/51388

Evans, D. S. (2003). Some empirical aspects of multi-sided platform industries. *Review of Network Economics*, *2*(3).

Hagiu, A., & Hałaburda, H. (2014). Information and two-sided platform profits. *International Journal of Industrial Organization*, *34*, 25-35.

Jeon, D. S., Kim, B. C., & Menicucci, D. (2022). Second-degree price discrimination by a two-sided monopoly platform. *American Economic Journal: Microeconomics*, *14*(2), 322-69.

Jullien, B., Pavan, A., & Rysman, M. (2021). Two-sided markets, pricing, and network effects. In *Handbook of Industrial Organization* (Vol. 4, No. 1, pp. 485-592). Elsevier.

Le Goff, A., Monchambert, G., & Raux, C. (2022). Are solo driving commuters ready to switch to carpool? Heterogeneity of preferences in Lyon's urban area. *Transport Policy*, *115*, 27-39.

Lin, S. (2020). Two-sided price discrimination by media platforms. *Marketing Science*, *39*(2), 317-338.

Liu, Q., & Serfes, K. (2013). Price discrimination in two-sided markets. *Journal of Economics & Management Strategy*, *22*(4), 768-786.

Mohring, H. (1972). Optimization and scale economies in urban bus transportation. *American Economic Review*, *62*(4), 591-604.

Ray, J. B. (2014). Planning a real-time ridesharing network: critical mass and role of transfers. In *Transport Research Arena (TRA) 5th Conference.*

Rochet, J. C., & Tirole, J. (2003). Platform competition in two-sided markets. *Journal of the European Economic Association*, *1*(4), 990-1029.

Rochet, J. C., & Tirole, J. (2006). Two-sided markets: a progress report. *The RAND Journal of Economics*, *37*(3), 645-667.

Roson, R. (2005). Two-sided markets: A tentative survey. *Review of Network Economics*, *4*(2).

Rysman, M. (2009). The economics of two-sided markets. *Journal of Economic Perspectives*, *23*(3), 125-143.

Sanchez-Cartas, J. M., & León, G. (2021). Multisided platforms and markets: A survey of the theoretical literature. *Journal of Economic Surveys*, *35*(2), 452-487.

Shaheen, S., Cohen, A., & Bayen, A. (2018). The benefits of carpooling.

Spiess, H. (1990). Conical volume-delay functions. *Transportation Science*, *24*(2), 153-158.

Train, K. E. (2009). *Discrete choice methods with simulation*. Cambridge university press.

Viotto da Cruz, J. (2015). Competition and regulation of crowdfunding platforms: A two-sided market approach. *Communications & Strategies*, *99*, 33-50.

Wagner, N., (2016). Covoiturage longue distance : état des lieux et potentiel de croissance. Collection « Études et documents » du Service de l'Économie, de l'Évaluation et de l'Intégration du Développement Durable (SEEIDD) du Commissariat Général au Développement Durable (CGDD).

Wang, R. (2011). Shaping carpool policies under rapid motorization: the case of Chinese cities. *Transport Policy*, *18*(4), 631-635.

Weyl, E. G. (2010). A price theory of multi-sided platforms. *American Economic Review*, *100*(4), 1642-72.

Appendix A

To calibrate the utility functions, we need to assign a monetary value to travel time and waiting time for each of the modes available in the empirical application. For this purpose, we use the results of a stated preference survey conducted in spring 2019 in the region of Lyon, France. A detailed description of the survey construction, experimental design and collection is available in Le Goff et al. (2022). n this publication, the authors restrict the sample to commuters who use their car for commuting, and study different elements of travel time (scheduling, travel time, reliability...). Here, our needs are different. We therefore include in the sample the 6 choices made by 4119 individuals interviewed. The model is also largely simplified as we focus on the price/travel time/waiting time trade-off.

The utility functions to be calibrated are the following:

$$\begin{aligned} U_{SD} &= \alpha_{SD} + \beta_{SD} \times TT_{SD} + \varepsilon_{\mathrm{SD}} \\ U_{CD} &= \alpha_{CD} + \beta_{CD} \times TT_{CD} + \gamma_{CD} \times WT_{CD} + \delta \times p_{CD} + \varepsilon_{\mathrm{CD}} \\ U_{CP} &= \alpha_{CD} + \beta_{CP} \times TT_{CP} + \gamma_{CP} \times WT_{CP} + \delta \times p_{CP} + \varepsilon_{\mathrm{CP}} \\ U_{PT} &= \alpha_{PT} + \beta_{PT} \times TT_{PT} + \gamma_{PT} \times WT_{PT} + \delta \times p_{PT} + \varepsilon_{\mathrm{PT}} \end{aligned} \tag{24}$$

We assume that the errors terms ε are identically and independently extreme value distributed over individual, alternatives, and choice situations, and we estimate a multinomial logit with the Apollo package built by Hess & Palma (2019) for the R software. Results are displayed in Table A1.

Table A1: Estimations results of multinomial logit model

Attribute	Alternative	(1)
Alternative-Specific Constants α	Solo Driver	0
	Carpool Driver	0.5336***
	Carpool Passenger	0.3349***
	Public Transport	-0.0393
Travel time β	Solo Driver	-0.0198***
	Carpool Driver	-0.0333***
	Carpool Passenger	-0.0313***
	Public Transport	-0.0259***
Waiting Time γ	Carpool Driver	-0.418***
	Carpool Passenger	-0.0317***
	Public Transport	-0.1029***
Cost δ	All	-0.0688***
Nb of individuals		4119
Nb of observations		24714
Nb of parameters		11
LL (final)		-311117.34
Adj.Rho-squared (0)		0.0914
AIC		62256.69
BIC		62345.95

Notes: p-values: 1 ( ) 0.1 (*) 0.05 (**) 0.01 (***) 0.

The monetary value of attributes is obtained by dividing the related coefficient by the cost coefficient, δ.

Appendix B

Figure B1: Passengers waiting time as a function of the number of drivers

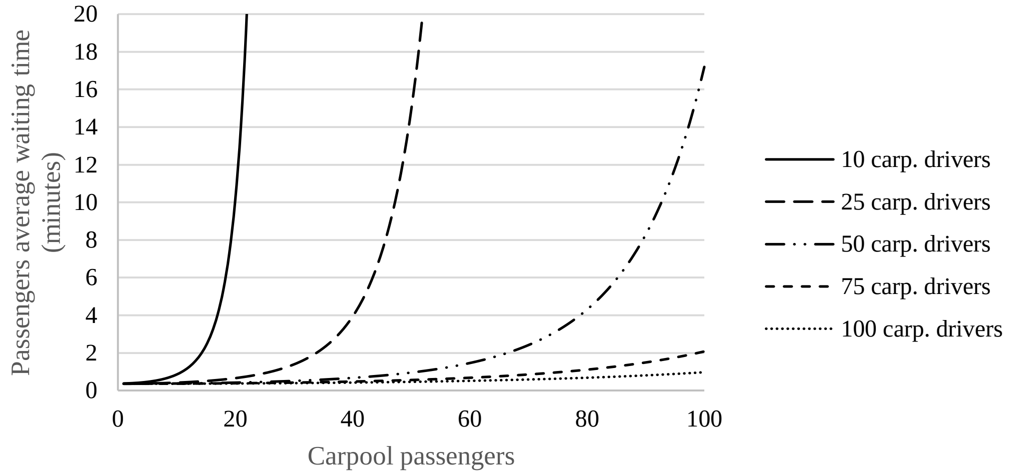
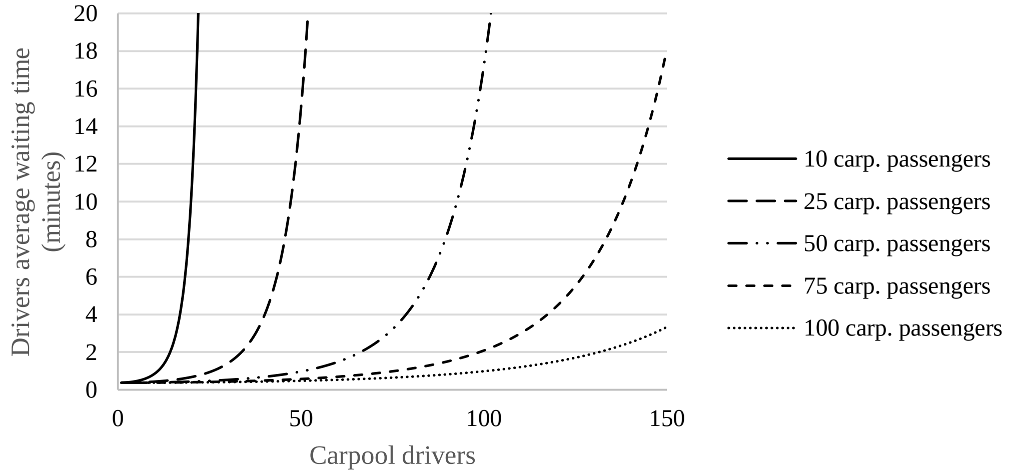


Figure B2: Drivers waiting time as a function of the number of passengers



Appendix C

Figure C1: Road travel time as a function of the number of drivers