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Abstract

We study hours worked by drivers in the peer-to-peer transportation sector with cross-side network effects. Medallion lease (regulated market), commission-based (Uber-like pay) and profit-sharing ("pure" taxi coop) compensation schemes are compared. Our static model shows that network externalities matter, depending on the number of active drivers. When the number of drivers is limited, in the presence of positive network effects, a regulated system always induces more hours worked, while the commission fee influences the comparative incentives towards effort of Uber-like pay *versus* profit-sharing. When the number of drivers is infinite (or close to it), the influence of network externalities on optimal effort vanishes.

Keywords: Uber, network effects, ride-sharing, pay schemes, effort, taxi industry.
JEL classification: L91; J22; J33

1 Introduction

A long standing literature, as reviewed by Bloom and Van Reenen (2011), has documented that incentive pay mechanisms positively influence worker effort. In particular, Kato and Kauhanen (2018) found that group incentive performance related pay is more potent in boosting productivity than individual incentive pay. This literature, so far, has failed to account for cross-side network externalities, which may cause strict concavity in the product demand with respect to the supply of effort (when effort reflects into product quantity), thereby making the relationship between pay and performance more difficult to assess.

The ride-sharing industry, also referred to as the peer-to-peer (P2P) transportation sector (possibly mediated by digital platforms), where drivers provide on-demand transport to riders using their personal vehicles, offers an interesting case for studying this issue, as it presents both alternative compensation schemes adopted by alternative platforms (typically, taxi companies *versus* ride-hailing) and non-negligible cross-side network effects (Spulber, 2019).

Loosely speaking, when the number of drivers is below a critical level, the network externality dominates, causing marginal value to grow with quantity (e.g., due to reduced wait-times); when the supply exceeds the critical level, the network externality is exhausted and demand has a standard shape (i.e. negative slope). Against this background, P2P rides may be supplied under alternative driver contracts. On the one side, traditional taxi drivers in most US cities and in Europe must own or lease one of a limited number of medallions granting them the right to drive. So, they keep every dollar earned, but need to pay for the medallion (in principle, also "pure" taxi coops may be possible, with total earnings divided evenly among drivers-members, with or without leasing). On the other side, ride-hailing platforms (like Uber) base drivers' pay on a proportional compensation scheme, according to which, in return for a commission fee, drivers can set their work schedule without having to worry about covering a lease.

Empirical evidence on comparative drivers performance in the P2P transportation sector, as measured by hours worked, is available. By using administrative data on drivers using the Uber platform from 2012 to 2014, Hall and Krueger (2018) documented that drivers who reported having no other job in 2014 worked more than 35 hours per week on the Uber app. Hall *et al.* (2018) measured how supply of hours worked by drivers reacts to ride fares and reported that for a 10% increase in the fare, drivers eventually work 6% more hours. Uber drivers have been found to have higher capacity utilization (the fraction of time a driver has a fare-paying passenger in the car while he or she is working) compared to taxi drivers (Cramer and Krueger, 2016); however, taxi drivers are shown to work slightly more hours (Berger *et al.*, 2018). With data from an experiment on random samples of Boston Uber drivers, Angrist *et al.* (2017) found that drivers who work more hours are better off being taxi drivers, while drivers with low hours prefer work on a ride-hailing platform with a proportional compensation scheme.

While these empirical figures tell that drivers' effort varies with the fare and the pay scheme, they do not allow to understand to which extent it is so under the same market entry conditions (i.e. under a given size of the market and with utilization rates being equal between platforms) and which are the implications of network effects.

With this paper, we shed some light on this from a theoretical point of view, which allows us to circumvent important empirical issues, including data availability constraints (e.g., the lack of empirical measures of cross-side externalities). We analyze comparatively the effort supplied under three driver pay schemes or contracts: medallion lease (regulated market), commission-based (Uber-like) and profit-sharing ("pure" taxi coop). We do so with a simple short-run model, where both the number of drivers and capacity utilization are exogenous. As a static exercise, moreover, we abstract away from surge dynamics.

We find that network effects may matter crucially, depending on the number of active drivers. Precisely, the analysis presented here argues for a simple but useful result. That is, when the number of drivers is not infinite (or close to it), in the presence of positive network effects, a regulated system always induces more hours worked, while a Uber-like fee influences the comparative incentives towards effort of commission-based pay *versus* profit-sharing, with the fee having to be sufficiently low for Uber to provide more hours worked than a "pure" taxi coop. When the number of drivers is very high, the influence of network externalities on optimal effort tends to disappear, and a pay scheme based on medallion lease continues to induce more hours worked than both a Uber-like platform and "pure" taxi coops. Some intuitions for explaining these results are provided.

The model offers insights to regulators seeking to improve coverage by P2P transportation services, thereby reducing wait-times.

2 Hours worked under alternative pay schemes

We model the P2P transportation sector as a two-sided market with cross-side network effects. In the short-run, there is a given finite number of active drivers $L > 1$. Denote with $\sum_{i=1}^{L} h_i = H$ the total amount of hours worked, with h_i being the hours worked for driver i. Too keep notation simple, denote the average hours worked with h, i.e. $H/L = h$, and assume that in the short-run the utilization rate is fixed. To simplify, we assume full capacity utilization.[1] Due to the cross-side externality, the average time $h \in [0, h^{max}]$, with $h_i^{max} = h^{max} \quad \forall i$, spent by drivers while driving (i.e. the amount of service supplied) increases the utility of riders and thereby their willingness to pay for a ride until a critical threshold in supply is reached; above the threshold, the marginal value for riders is decreasing and so is their willingness to pay. The inverse demand function for hours of service therefore is

$$p(h) = \alpha h^{1/2} - \beta h \tag{1}$$

The turning point is $\overline{h} \equiv (\alpha/2\beta)^{-1/2} < h^{max}$.[2] Notice that (1) is strictly concave.[3] If $h < \overline{h}$, network effects are positive; if $h > \overline{h}$, more hours worked generate negative externalities. With L being fixed, for any level of hours worked, supply is always met by available demand, with $p(h)$ being the corresponding willingness to pay. Suppose L is fixed by a regulator such that, when all the drivers work h^{max} hours, demand is just exhausted. The typical demand function for ride-sharing is represented in Figure (1).

[insert Figure (1) about here]

The driver's problem is

$$\max_{h_i} \quad U_i = f(p(h), h_i) - c_i(h_i) \tag{2}$$

where $f(\cdot)$ is a function increasing in both price and effort and where $c_i(h_i)$ is a continuous and twice differentiable function for the cost of effort (with $c_i(h_i)' > 0$ and $c_i(h_i)'' > 0$). We omit fixed costs (e.g. the fixed cost of the car) from (2) for simplicity, as they are irrelevent for the propositions here.

Next, we consider three alternative platforms or driver pay schemes.

Medallion lease (regulated market). With a medallion system, drivers must own or lease a medallion granting them the right to drive. Assume that the number of available medallions is

[1] This is not a critical assumption here.

[2] The upper limit h^{max} can be thought of as due to drivers' physical constraints or to a regulatory cap.

[3] The functional form we assume for the inverse demand function is not crucial for our argument; it is sufficient that $p((1-a)h_1 + ah_2) > (1-a)p(h) + ap(h)$ for any $a \in (0,1)$ and $h_1, h_2 \in [0, h^{max}]$, with $h_1 \neq h_2$.

$M = L$, with m_i being the price of one medallion for driver i (with $m_i = m_j \quad \forall i \neq j$). Then, the driver's utility is

$$U_i^m = p(h_i, h_{L-1})h_i - c_i(h_i) - m_i \tag{3}$$

where the notation $p(h_i, h_{L-1})$ (with $h_{L-1} = \sum_{j=1}^{L-1} h_j/L-1$, $j \neq i$) is functional to make h_i explicit as an argument of $p(\cdot)$. By substituting U_i^m in problem (2), we obtain the following FOC:

$$p(h_i, h_{L-1}) + p'(h_i, h_{L-1})h_i = c_i'(h_i) \tag{4}$$

whose corresponding optimal level of effort is h_i^m.

Commission-based (Uber-like pay). Under a commission-based pay, drivers are paid the fare less a percentage retained by Uber. The driver's utility is

$$U_i^e = (1-\varphi)p(h_i, h_{L-1})h_i - c_i(h_i) \tag{5}$$

where $\varphi \in (0, 1]$ is the proportional commission fee to be paid to Uber. After substituing U_i^e in problem (2), we obtain the following FOC:

$$(1-\varphi)p(h_i, h_{L-1}) + (1-\varphi)p'(h_i, h_{L-1})h_i = c_i'(h_i) \tag{6}$$

whose corresponding optimal level of effort is h_i^e.

Profit-sharing ("pure" taxi coop). With profit-sharing, total earnings are divided evenly between drivers (in this case, we ignore possible medallion leasing). Here, the driver's utility is

$$U_i^w = \frac{p(h_i, h_{L-1})h_i + p(h_i, h_{L-1})h_{L-1}(L-1)}{L} - c_i(h_i) \tag{7}$$

Again, after substituing U_i^w in problem (2), we obtain the FOC

$$\frac{p(h_i, h_{L-1}) + p'(h_i, h_{L-1})h_i + p'(h_i, h_{L-1})h_{L-1}(L-1)}{L} = c_i'(h_i) \tag{8}$$

whose corresponding optimal level of effort is h_i^w.

Proposition 1. *In the presence of positive network externalities (namely, $h \leq \overline{h}$), average hours worked are always higher under a medallion system compared to Uber-like pay; when $h > \overline{h}$, $h_i^m > h_i^e$ iff $|p(h_i, h_{L-1})| > |p'(h_i, h_{L-1})h_i|$. The fee used in the commission-based pay does not matter. Moreover, the medallion system always induces more hours worked than profit-sharing, regardless of network effects.*

Proof. See Appendix A.1. ■

The intuition behind Proposition 1 is simple. By comparing (4) and (6) and manipulating, it is easy to see that $h_i^m > h_i^e$ when $p(h_i, h_{L-1}) + p'(h_i, h_{L-1})h_i > 0$, i.e. when $MR > 0$ (with MR denoting the marginal revenue). Since, under a medallion system, drivers enjoy full revenue extraction, whilst they are required to pay some proportional commission fee on revenues under a Uber-like pay, the latter will be superior only when $MR < 0$. Related to Proposition 1, in particular, MR is always positive in the upward sloping section of the demand curve (i.e., with positive network externalities). When the demand curve is downward sloping, then MR can be either positive or negative; in this case, therefore, the additional condition

$|p(h_i, h_{L-1})| > |p'(h_i, h_{L-1})h_i|$ (which implies $MR > 0$) needs to be imposed for $h_i^m > h_i^e$ to hold.

Also, by comparing Equation (6) and Equation (8), we obtain that $h_i^e < h_i^w$ iff

$$\varphi > 1 - \frac{1}{L}\left[1 + (L-1)\frac{p'(h_i, h_{L-1})h_i}{p(h_i, h_{L-1}) + p'(h_i, h_{L-1})h_i}\right] \equiv \overline{\varphi} \tag{9}$$

Two additional propositions follow.

Proposition 2. *In the presence of positive network externalities (namely, $h \leq \overline{h}$), $\overline{\varphi}$ is always lower than 1, i.e. it always exists a value of φ in the interval $(0, 1)$ above which profit-sharing induces more hours worked compared to Uber-like pay.*

Proof. See Appendix A.2. ■

Proposition 3. *When positive network externalities are absent (namely, $h > \overline{h}$), it exists a value $h^* \in (\overline{h}, h^{max})$ such that $\overline{\varphi} = 1$ for any $h \geq h^*$; i.e., when the average of hours worked is sufficiently high, Uber-like pay always induces more hours worked compared to profit-sharing.*

Proof. See Appendix A.3. ■

The joint message of the three propositions can be summarized as follows. In the presence of positive network effects, the medallion system always induces more hours worked, while the commission fee influences the comparative incentives towards effort of Uber-like pay *versus* profit-sharing, with the fee having to be sufficiently low for Uber-like pay to provide more hours worked than profit-sharing. This holds critically under the assumption of having the same number of drivers under the three pay schemes, with $L = M$ (in the short-run, we do not allow for free entry of drivers).

The intuition for explaining why the commission fee matters for $h_i^e < h_i^w$ to hold is that, under both Uber-like pay and profit-sharing, drivers do not fully enjoy individually raised revenues, with "pure" taxi coop drivers partly compensating the loss by capturing a share of the revenues raised by the other members of the team. When the average number of hours worked is sufficiently high (i.e., MR is relatively low) the compensation mechanism provided by profit-sharing has a lower power, thus Uber-like pay can be shown to be superior even with a higher commission fee. Phrased differently, profit-sharing works better than Uber-like pay in terms of effort when marginal revenues are higher. Figure (2) shows the pattern of $\overline{\varphi}$ along the range of hours worked.

[insert Figure (2) about here]

3 Optimal effort when the market is very large

Suppose that the number of active drivers L is very high or infinite. Assume that the number of riders is proportionally high, so that they continue to be concerned with h (i.e. average hours worked) and the demand curve again can be described by (1). Alternatively, the number of riders is very high and L is increased proportionally by a regulator. In this case, variation in the hours worked by driver i has no effect on prices, i.e. the first derivative of $p(\cdot)$ with respect to h_i is 0. Now, manipulating from (4), (6) and (8), optimal effort under alternative platforms needs to satisfy respectively:

$$\textit{Medallion lease:} \qquad p(h) = c_i'(h_i) \Rightarrow h_i^M \tag{10}$$

$$\textit{Commission-based:} \qquad (1-\varphi)p(h) = c_i'(h_i) \Rightarrow h_i^E \tag{11}$$

$$\textit{Profit-sharing:} \qquad p(h)/L = c_i'(h_i) \Rightarrow h_i^W \tag{12}$$

Proposition 4. *When the number of active drivers is very high or infinite, network effects do not influence optimal effort, under any pay contract. Moreover, a pay scheme based on medallion lease always provides higher hours worked than Uber-like pay and profit-sharing; Uber-like pay induces higher effort than profit-sharing iff* $\varphi < (L-1)/L \sim 1$.

Proof. See Appendix A.4. ■

As one might intuit, the h_i^M equilibrium has some attractive welfare properties, as it corresponds to maximization of total surplus. In all the other instances, the number of hours worked will deviate from the socially optimal level. The reason is simple. When the number of drivers is very high, the market of rides is perfectly competitive and drivers are price-takers. So, both the Uber-like fee and the profit-sharing can be thought of as a tax on output influencing optimal supply decisions.

Clearly, the model is compatible with a market where more platforms are active at the same moment. In this case, the level of h will be a weighted average of the hours worked by drivers under the different work arrangements.

Finally, from (10), (11) and (12), it is easy to see that hours worked are higher in a small market with respect to very large markets when network effects are positive (i.e. $h < \overline{h}$), under any pay scheme. When $h > \overline{h}$ and therefore $p'(h_i, h_{L-1}) < 0$, the opposite holds: $h_i^M > h_i^m$, $h_i^E > h_i^e$ and $h_i^W > h_i^w$.

4 Conclusions

Our analysis suggests that the driver pay scheme has implications for riders' welfare through two main mechanisms. The first mechanism is "pecuniary externalities": more hours worked influence the price for a ride, with this effect being positive or negative depending on whether the change in hours worked occurs below or above the turning point of the demand curve (i.e. positive network effects are present or not). The second mechanism is "quality externalities": since the hours worked positively correlate with lower wait-times for riders, a pay scheme induces longer or shorter wait-times depending on network effects and, for a Uber-like pay, the commission fee. The shorter wait-times for Uber riders compared to riders of traditional taxi companies documented for many US cities can be reconciled with our model also by noticing that the number of Uber drivers tends to be much larger than taxi drivers in local markets (Cramer and Krueger, 2016; Angrist *et al.*, 2017).

With non-crucial changes of the model, the comparative results presented here can be generalized to other types of quality improving effort and to other markets where network externalities are non-negligible. Extensions of this model in a dynamic context may possibly include risk bearing and platform competition.

Appendix

A.1. Proof of Proposition 1

As for the first part of Proposition 1, by comparing (4) and (6) and manipulating, it is straightforward to observe that, for any $\varphi > 0$, $h_i^m > h_i^e$ when $p(h_i, h_{L-1}) + p'(h_i, h_{L-1})h_i > 0$. This is verified for any $p'(h_i, h_{L-1}) > 0$ and when $|p(h_i, h_{L-1})| > |p'(h_i, h_{L-1})h_i|$. As for the second part of Proposition 1, we need to compare (4) and (8). We obtain that $h_i^m > h_i^w$ when $p(h_i, h_{L-1}) + p'(h_i, h_{L-1})h_i > p(h_i, h_{L-1})/L + p'(h_i, h_{L-1})h_i$, with $h_i = h$. This always holds if $L > 1$.

A.2. Proof of Proposition 2

Manipulating (9), $\overline{\varphi}$ can be expressed as $1-(1/L)-\delta+(\delta/L)$, with $\delta = [p'(h)h_i]/[p(h)+p'(h)h_i]$. When $h < \overline{h}$, $p'(h) > 0$. Thus, we have that $0 < \delta < 1$. This implies that $1-(1/L)-\delta+(\delta/L) < 1$.

A.3. Proof of Proposition 3

Denote again $[p'(h)h_i]/[p(h) + p'(h)h_i]$ with δ. Then, from $\overline{\varphi} = 1 - (1/L) - \delta + (\delta/L)$ it results that $\overline{\varphi} = 1$ when δ is lower than 0 and precisely equal to $1/(1 - L)$. $\delta < 0$ when $p'(h) < 0$, that is when $h > \overline{h}$.

A.4. Proof of Proposition 4

As for the first part of Proposition 4, it is sufficient to notice that (10), (11) and (12) do not include $p'(h)$. As for the second part of Proposition 4, we need to compare (10), (11) and (12). With $\varphi > 0$, $h_i^M > h_i^E$. Moreover, $h_i^E > h_i^W$ when $(1 - \varphi)p(h) > p(h)/L$, i.e. when $\varphi < (L - 1)/L$, with $\lim_{L\to\infty}(L - 1)/L = 1$.

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Figure 1: Demand function for hours of service in the P2P transportation sector.

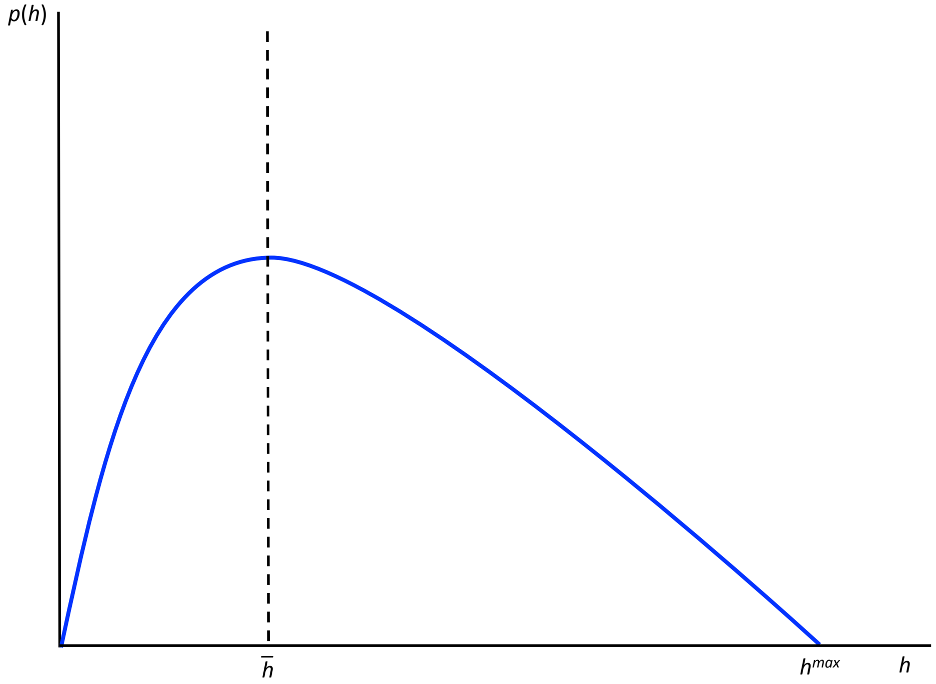

Figure 2: Fee threshold for Uber-like pay inducing more hours worked than profit-sharing.