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A duopoly of transportation network companies and traditional radio-taxi dispatch service agencies

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Transportation network companies commonly enter the market for taxi ride intermediation and alter the market outcome. Compared to cooperatively organized radio-taxi dispatch service agencies, transportation network companies run larger fleets and serve more customers with lower fares, when the fixed costs of the dispatch office are relatively small. The same holds for private dispatch firms, when the fixed costs of a taxicab are not too small. These results are shown in a two-stage duopoly of fare and fleet size competition with fare- and waiting-time-dependent demand.

Keywords: *digitization, regulatory capture, taxi dispatch market, transportation network companies.*

1. Introduction

Especially in large cities, taxi rides are an important part of public transportation. People demand taxi services because they are convenient and fast, they may not have a driving license, they can disembark without searching for parking, or do not have access to a private car. The market for taxi rides can be divided into three submarkets (Schaller, 2007). The first is the cabstand market, found, for example, at railway stations or city centers, where taxicabs are waiting for customers in a line. In Germany, this accounts for about 30-40 percent of taxi ride starts. The second market is the street hail market, where customers in cities flag down taxicabs driving in the streets. In German cities, only around ten percent of taxi rides are initiated in this way. In some American and Asian cities, this share is notably higher. The most important market in German cities (50-60 percent), but also for example in Paris or Stockholm (Darbéra, 2010), is the dispatch market. Customers order taxicabs by contacting a taxi firm or radio-taxi dispatch service agency (RDS) by phone or app. These agencies or central offices then select a cab for the customers (Cooper et al., 2010). Because the paper analyses the behavior of such taxi intermediaries, it focuses on the dispatch market. There are mostly only a few RDSs in each city, so that monopolistic, duopolistic or oligopolistic market structures predominate. An analysis of the largest German cities presented in Figure 1 shows that, for example, in Munich and Cologne, nearly all taxi drivers and companies use the services of two large radio-taxi dispatch service agencies. In Stuttgart and Nuremberg, only one RDS is present. Similar forms of the dispatch market prevail, for example, in other countries of the EU like France and Italy and in the USA (Cooper et al., 2010; Frazzani et al., 2016).

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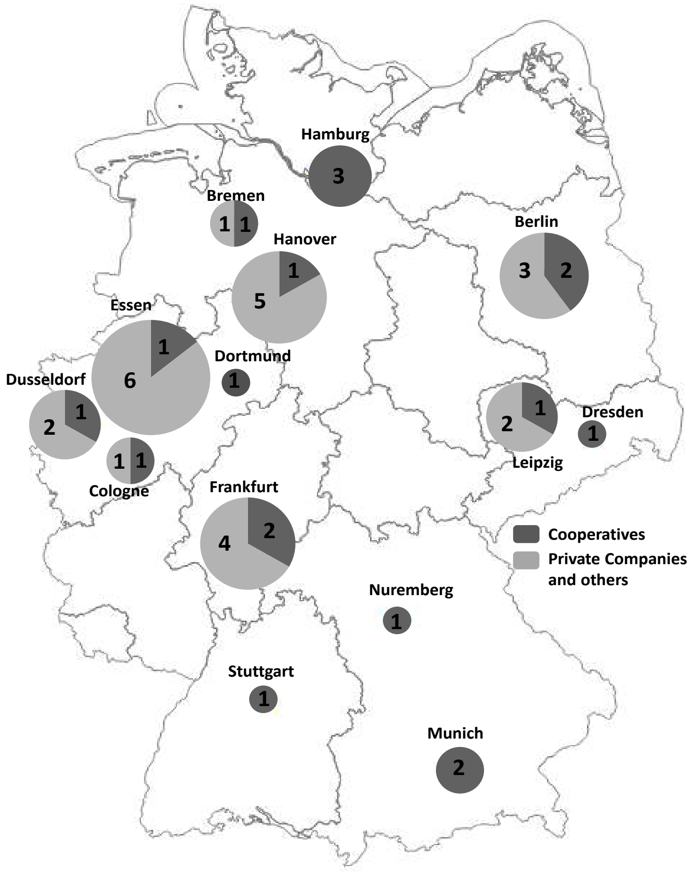

Figure 1. Number of RDSs in German Cities

RDSs can be organized privately or cooperatively and the two types pursue different objectives. Cooperatively organized agencies distribute their revenue among all members (i.e. all drivers) and therefore aim to maximize the profit accruing to each driver, i.e. the average profit. Private firms take into account only the firm owner's profit, which is the aggregate profit of all drivers.

The market for taxi rides is characterized by some specifics that should be noted for analytical purposes. The demand for taxi services is not only determined by the fare of a ride, the waiting time also plays an important role. Customers prefer a straightaway service, so that a ride creates a negative externality. When a customer occupies a taxicab, all other potential customers have to wait longer than before (Orr, 1969; Cairns and Liston-Heyes, 1996; Fernandez et al., 2006). Contrariwise, there are economics of density; doubling trips and taxicabs reduces waiting time (Arnott, 1996). Depending on the market type, these externalities are regularly not internalized in the fare, speaking in favor of regulation. In most countries, the fares taxi drivers should charge, the number of taxicab licenses and minimum standards for vehicles are regulated. But regulation can be inefficient as well. Many economists share the view that rent-seeking plays a large role in taxi market regulation (Barrett, 2003; Darbéra, 2010; Cetin and Eryigit, 2013), because taxi firms are able to capture the regulatory process and ensure regulation that corresponds to their own objectives (regulatory capture). We can integrate the implications of regulatory capture with regard to the market entry of taxicab drivers into our model.

Information asymmetries leading to quality problems, another argument in favor of regulation, are not important in the dispatch market, because customers can choose a particular company from which to order a taxi ride. The firms therefore aim at a stable customer relationship and repeat purchases, so they do not exploit uninformed customers, but have an incentive to satisfy them. Furthermore, bad reviews could deter other customers.

Over the last few years, digitization has enabled new business models, creating an ability to earn money in the market for taxi rides, especially in the dispatch market. Customers can order a taxi service with the help of a smartphone app like Uber or Lyft, and the app operator allocates a nearby driver to the requester. The ride route and the fare are usually set by the operator of this transportation network company[3] (TNC), which earns a fixed share of the driver's revenue. These companies differ in their business model from the traditional RDSs. When fares are not regulated, Uber adjusts the fare using a so-called "surge pricing" algorithm to balance supply and demand (Hall et al., 2015). Cramer and Krueger (2016) show that joining Uber may increase capacity utilization and thus the productivity of taxi drivers, by reducing empty drives and idle time. Apps claim that they serve as an interface where taxi drivers and taxi customers meet, but in fact, by fixing the product (route) and the price (fare), they act as an ordinary taxi firm. TNCs can compete with the present radio-taxi dispatch service agencies in each town.

From a theoretical point of view, the question arises as to what a taxi dispatch market, including transportation network companies like Uber or Lyft, looks like. RDSs and TNCs have different business concepts that, as we will show, result in different fleet sizes, different fares, and different numbers of rides. There has been some research on modeling the market for taxi rides. While, for example, Douglas (1972), Cairns and Liston-Heyes (1996), Fernandez et al. (2006) and Qian and Ukkusuri (2017) generated aggregated models for the street hail market, Häckner and Nyberg (1995) and von Massow and Canbolat (2010) developed models for the dispatch market. Von Massow and Canbolat (2010) provide a spatial dispatch model, where taxis are located in specific zones and receive orders in a certain chronology. Häckner and Nyberg (1995) designed an aggregated model for an oligopolistic dispatch market and showed that cooperatively organized RDSs are relatively less efficient than privately owned RDSs.

Another large group of studies integrated the spatial structure of taxi services into taxi market models, especially for the street hail market. Yang and Wong (1998) developed a network model to analyze taxi movements in cities. The model has been extended to consider demand elasticity and road congestion (Wong et al., 2001), market competition and regulation (Yang et al., 2002), multi-period dynamic taxi services with endogenous service intensity (Yang et al., 2005), multiple user classes and vehicle modes (Wong et al., 2008) and nonlinear pricing (Yang et al., 2010a). Wong et al. (2005) and Yang et al. (2010b) introduced mathematical models to consider the bilateral-searching behavior of vacant taxis and customers in the street hail market through meeting functions. These models were further enhanced to analyze the equilibrium properties (Yang and Yang, 2011) and deal with congestion effects (Yang et al., 2014). He and Shen (2015) included the presence of an e-hailing platform in a network model, and Wang et al. (2016) generated the pricing strategies of a taxi-hailing platform using the meeting function. In their model, taxi drivers are free to use the e-hailing platform or to do roadside hailing. The model most closely related to ours is that of Zha et al. (2016). They investigate the market impacts of a monopoly ride-sourcing service like Uber, and of a duopoly of ride-sourcing services in an aggregated model. They state that regulated competition may not necessarily lead to lower prices and higher social welfare than a regulated monopoly.

We include transportation network companies in the taxi dispatch market model of Häckner and Nyberg (1995). In contrast to Zha et al. (2016), we compare the market outcomes of a duopoly of TNCs with those of a duopoly of traditional radio-taxi dispatch service agencies. Additionally, an asymmetric duopoly of one cooperatively organized RDS and one TNC and the regime of regulatory capture are considered.

In our two-stage game, companies first choose the number of taxicabs in their fleet and then compete on price. We compare the market outcomes and focus on the fleet sizes or on the market entry of taxi drivers in four different regimes: The first is a symmetric duopoly of cooperatively organized RDSs that attempt to maximize the average profit of each driver, because they

[3] This terminology was introduced by the California Public Utilities Commitee in 2013 to classify Uber-like companies.

distribute their revenue among all members (Regime 1). By contrast, privately organized RDSs attempt to maximize the overall profit of each company/RDS (Regime 2). The third regime is a duopoly of transportation network companies, where each TNC pays taxicab drivers a fraction of the revenue and therefore tries to maximize revenue (Regime 3). Finally, the regime of regulatory capture is added. We analyze full regulatory capture by assuming in this regime, that two cooperatively organized RDSs collude and are able to capture the regulatory process, so that the price and the number of taxicabs are set to maximize their aggregate profits (Regime 4).

Market entry, and even the principle of revenue sharing, foster competition and serve customers well in the radio-taxi dispatch market. It can be shown that fleet sizes are larger and fares smaller, in a duopoly of transportation network companies (Regime 3), than in a duopoly of privately organized RDSs (Regime 2), if the fixed costs of a taxicab are not too small. The level of fixed costs of an intermediary determines the relationship between Regime 2 (cooperatively organized RDSs) and Regime 3 (TNCs). The fleet sizes in a duopoly of TNCs exceed those in a duopoly of cooperatively organized RDSs, if the fixed costs of an intermediary are small. If the fares and number of licenses are regulated, and the regulation is captured by the taxi firms (Regime 4), this leads to the smallest fleet sizes of all regimes. In an asymmetric duopoly of one cooperatively organized RDS and one TNC, both increase their fleet sizes compared to those in their symmetric duopolies.

2. The Model

Similarly to Häckner and Nyberg (1995), we consider a duopoly of firms that serve as an intermediary for taxi rides. Each RDS or TNC has f_i affiliated taxicabs as a fleet, and offers dispatched taxicab services to customers with fares that are linear in the quantity q of (homogenous) taxi rides consumed.
Consumers derive utility from taxi rides and the consumption of composite good y. Utility increases at a decreasing rate with the number of trips q and decreases in waiting time. To simplify the analysis, a specific utility function of a representative consumer that single-homes with taxi intermediary i is assumed:

$$U = y_i + (w - \alpha\, q_i)q_i - \frac{\beta}{\delta}\frac{Q_i}{f_i}q_i. \tag{1}$$

The marginal utility of the first taxi trip is assumed to be w. This utility exceeds the variable costs of a ride ($w>c$), because otherwise, there would be no equilibrium in the market. The diminishing marginal utility of additional trips is parameterized by α. Waiting time depends on the quotient of aggregate demand Q_i of firm i and the fleet size f_i of this company. The technical ability to match customers and taxicabs to reduce idle and waiting time is denoted by δ. The marginal disutility of the first second of waiting time is zero, but the marginal disutility increases when more trips are demanded and waiting time rises, which is parameterized by β.

Facing a budget constraint of $I = y_i + p_i\, q_i$, where the composite good y_i is the numeraire, the utility-maximizing consumption of taxi rides is

$$q_i = \frac{w - p_i - \beta/\delta\; Q_i/f_i}{2\alpha}. \tag{2}$$

If the number of consumers is normalized to one, the aggregate demand for firm i is $Q_i = q_i\, m_i$, where $m_1 = m$ is the market share of firm 1 and $m_2 = 1\text{-}m$ is the market share of firm 2. Consumers search for the best combination of price and waiting time, but if both firms are operating in the market, customers must be indifferent between the two, i.e., the indirect utilities have to be identical: $V(p_1,Q_1,I) = V(p_2,Q_2,I)$, which means that

$$p_1 + \frac{\beta}{\delta}\frac{Q_1}{f_1} = p_2 + \frac{\beta}{\delta}\frac{Q_2}{f_2}. \tag{3}$$

Solving this equation for the market share *m* leads to

$$m = \frac{f_1(2\alpha\delta f_2(p_1 - p_2) + \beta(p_1 - w))}{\beta(f_1 p_1 + f_2 p_2 - (f_1 + f_2)w)}. \tag{4}$$

This value for the market share determines the aggregate demand Q_i of company *i*:

$$Q_i = \frac{\delta f_i(2\alpha\delta f_j(p_j - p_i) + \beta(w - p_i))}{\beta(\beta + 2\alpha\delta(f_i + f_j))}. \tag{5}$$

In the two-stage game of this model, firms first choose the number of taxicabs in their fleet and then compete on price. We do not include congestion resulting from different fleet sizes in the regimes. On the one hand, larger fleet sizes should c.p. lead to more congestion. On the other hand, Li et al. (2016) have shown that the market entry of a TNC like Uber decreases congestion in the urban areas of the United States, because the traffic of private cars shrinks. Thus, the effect of fleet size on congestion is ambiguous, thus preventing a tractable inclusion in the model.

To solve the dynamic game of determining fleet sizes and prices we use the method of backward induction and consider and compare different types of firms. RDSs can be organized cooperatively or privately. Moreover, a duopoly of transportation network companies can be considered, or a regime of regulatory capture, so that firms collude and maximize their aggregate profits.

2.1 Stage 2: price competition

At Stage 2, the total contribution margins *(TCM)* of the companies are considered, because fixed costs for the fleet sizes and the intermediaries have already been paid. In Regimes 1-3, the two symmetric companies compete on price, so that equilibrium prices can be calculated. In the regime of regulatory capture, there is no competition, because the companies collude and are able to set a common price to maximize the *TCMs*.

RDSs

We begin with the analysis of a duopoly of RDSs (either cooperatively or privately organized; Regime 1 and 2). Aggregate demand Q_i leads to a *TCM* at Stage 2 of the game of each RDS *i* that bears variable costs of *c* per taxi trip of

$$TCM_i = (p_i - c) \cdot Q_i. \tag{6}$$

The firms maximize their *TCMs* with respect to prices, so that the reaction functions $p_i(p_j)$ can be derived and the equilibrium prices $p_i^e(f_i, f_j)$ are

$$p_i^e(f_i, f_j) = \frac{c(\beta + 2\alpha\delta f_i)(\beta + 3\alpha\delta f_j) + \beta(\beta + \alpha\delta(2f_i + f_j))w}{2\beta^2 + 6\alpha^2\delta^2 f_i f_j + 4\alpha\beta\delta(f_i + f_j)} \tag{7}$$

and the equilibrium quantities are

$$Q_i^e(f_i, f_j) = \frac{\delta f_i(\beta + \alpha\delta(2f_i + f_j))(\beta + 2\alpha\delta f_j)(w - c)}{2(\beta + 2\alpha\delta(f_i + f_j))(\beta^2 + 3\alpha^2\delta^2 f_i f_j + 2\alpha\beta\delta(f_i + f_j))}. \tag{8}$$

The corresponding *TCM* of each RDS at Stage 2 is

$$TCM_i^e(f_i, f_j) = \frac{\beta\delta f_i(\beta + \alpha\delta(2f_i + f_j))^2(\beta + 2\alpha\delta f_j)(c - w)^2}{4(\beta + 2\alpha\delta(f_i + f_j))(\beta^2 + 3\alpha^2\delta^2 f_i f_j + 2\alpha\beta\delta(f_i + f_j))^2}. \tag{9}$$

TNCs
A taxi firm that is organized as a TNC (Regime 3) behaves differently.[4] First of all, by matching only customers and taxicabs, the firm does not bear the variable costs of an additional trip. Because of that, the total contribution margin equals the revenue accruing to each company ($\widehat{TCM}_i = \hat{R}_i$). On the other hand, the TNC only receives a share γ_i of the fares charged. Therefore, at Stage 2, the TNC maximizes

$$\widehat{TCM}_i = \gamma_i \cdot p_i \cdot Q_i. \tag{10}$$

The two TNCs maximize their total contribution margins with respect to prices and the equilibrium prices $\hat{p}_i^e(f_i, f_j)$ are

$$\hat{p}_i^e(f_i, f_j) = \frac{\beta(\beta + \alpha\delta(2f_i + f_j))w}{2\beta^2 + 6\alpha^2\delta^2 f_i f_j + 4\alpha\beta\delta(f_i + f_j)} \tag{11}$$

with $\partial\hat{p}_i^e / \partial f_i < 0$ and the equilibrium quantities are

$$\hat{Q}_i^e(f_i, f_j) = \frac{\delta f_i(\beta + \alpha\delta(2f_i + f_j))(\beta + 2\alpha\delta f_j)w}{2(\beta + 2\alpha\delta(f_i + f_j))(\beta^2 + 3\alpha^2\delta^2 f_i f_j + 2\alpha\beta\delta(f_i + f_j))}. \tag{12}$$

The corresponding total contribution margin (revenue) of each TNC at the Stage 2 is

$$\widehat{TCM}_i^e(f_i, f_j) = \gamma_i \frac{w^2}{(c-w)^2} TCM_i^e(f_i, f_j). \tag{13}$$

Comparing equations 7 and 11 shows:

Proposition 1 If the fleet sizes in a duopoly of RDSs are as large as those in a duopoly of transportation network companies, taxi fares are lower in a duopoly of TNCs.

Regulatory capture
In many countries, the fares and the number of taxicabs are determined by a regulatory authority. Accordingly, a regime with regulation is considered. It is possible that the regulatory authority does not serve the interests of society as a whole, but is captured by special interest groups (Stigler, 1971; Barrett, 2003; Cetin and Eryigit, 2013; Gorecki, 2017). In Germany, for example, fare increases in cities are often initiated by the local RDSs. Political bodies then mostly authorize the applications for fare increases by these firms. We analyze full regulatory capture (Regime 4), by assuming that two cooperatively organized RDSs collude and are able to capture the regulatory process so that the price and the number of taxicabs are set to maximize their aggregate profits. This regime is not equivalent to the monopoly case, because the waiting time for customers depends on the fleet size of each company. In the captured regime, there are still two companies and two different fleets. In a monopoly there is only one fleet. Therefore, demand is different even if the monopoly runs as many taxis as the two duopolists combined. In the regime of regulatory capture, the demand is calculated as follows. Because the firms are symmetric and there is no competition between the two companies ($p_i = p_j = p$, $q_i = q_j = q$, $f_i = f_j = f$), the market shares of the two companies are $1/2$, so that in this case, $Q_i = 1/2\ q$. The utility maximizing number of taxi rides (equation 2) then equals

$$q = \frac{2(w-p)\delta f}{4\alpha\delta f + \beta}. \tag{14}$$

[4] The variables of the different regimes are denoted with the following accent marks: Regime 1: $\bar{p}$; Regime 2: $\tilde{p}$; Regime 3: $\hat{p}$; Regime 4: $\hat{\hat{p}}$.

The resulting joint total contribution margin at Stage 2 is

$$\widehat{TCM} = (p-c)\cdot q. \tag{15}$$

The maximization of TCM with respect to the price $(\partial\widehat{TCM}/\partial p = 0)$ leads to an equilibrium price of

$$\hat{p}^* = \frac{c+w}{2}. \tag{16}$$

The price in this regime is influenced only by the parameters *w* and *c*. The equilibrium *TCM* of each company at Stage 2 is

$$\widehat{TCM}_i^e = \frac{\delta f(c-w)^2}{4(\beta+4\alpha\delta f)}. \tag{17}$$

2.2 *Stage 1: fleet size competition*

We now analyze the maximization at Stage 1 by using the results of the price equilibria at Stage 2. Taxi intermediaries can determine the number of taxicabs in their fleet f_i. It is assumed for all regimes that operating a taxi intermediary costs K_r, independently of the number of taxicabs and customers using the service. A taxicab bears fixed costs of K_c plus variable costs of *c* per trip. Similar to Stage 2, there is competition in Regimes 1-3. In the regime of regulatory capture, there is no competition, because the companies collude and are able to set the fleet sizes to maximize the aggregate profit. In the following analysis, the results for the four regimes are presented.

Cooperatively organized RDSs

A cooperatively organized RDS (Regime 1) maximizes profits per taxicab

$$\bar{\pi}_i = \frac{TCM_i^e}{f_i} - K_c - \frac{K_r}{f_i} \tag{18}$$

with a first-order condition

$$\frac{\partial\bar{\pi}_i}{\partial f_i} = \frac{\partial TCM_i^e/\partial f_i\, f_i - TCM_i^e}{f_i^2} + \frac{K_r}{f_i^2} = 0, \tag{19}$$

which holds if

$$\frac{\partial TCM_i^e}{\partial f_i} = \frac{TCM_i^e - K_r}{f_i}. \tag{20}$$

Furthermore, because RDSs are only profitable if TCM_i^e-$K_c f_i \geq K_r$, $\partial TCM_i^e/\partial f_i \geq K_c$ must hold. For the comparative statics of the equilibrium of cooperatively organized RDSs, see Häckner and Nyberg (1995) or Appendix B.

Privately organized RDSs

Now consider a duopoly of RDSs comprising privately owned firms (Regime 2) that maximize their profits by determining the fleet size. At Stage 2 of the game, they follow the same strategy as cooperatively organized RDSs. However, at Stage 1, they do not maximize the average profit of a taxicab, but the aggregate profit

$$\tilde{\pi}_i = f_i\bar{\pi}_i = TCM_i^e - f_iK_c - K_r. \tag{21}$$

The first-order condition is

$$\frac{\partial \tilde{\pi}_i}{\partial f_i} = \frac{\partial TCM_i^e}{\partial f_i} - K_c = 0. \tag{22}$$

For the comparative statics of the equilibrium of privately organized RDSs, see Häckner and Nyberg (1995) or Appendix B.

TNCs

At Stage 1, each TNC (Regime 3) fixes the share γ_i that it claims from the taxicab drivers. The drivers then decide to enter the market and to join a TNC. At the equilibrium, taxicab drivers who have to pay the fixed cost of entry K_c as well as the variable costs of cQ_i / f_i and receive a share of $1-\gamma_i$ of revenue of company i, continue to enter the market until their profit is zero (see Appendix A for derivation):

$$\Psi(\gamma_i, f_i) = \frac{(1-\gamma_i)}{\gamma_i} \frac{\widehat{TCM}_i^e}{f_i} - \frac{c\hat{Q}_i^e}{f_i} - K_c = 0. \tag{23}$$

The transportation network company can anticipate the reaction of the taxicab drivers who wish to join the TNC if it changes the revenue share. This share, as a function of the fleet sizes $\gamma_i(f_i)$, can be determined from the equation above (see Appendix A). It is shown in the Appendix that the impact of the fleet size on the revenue share is negative $(\partial\gamma_i / \partial f_i < 0)$ and vice versa. If the TNC claims a higher share of revenue, fewer taxicab drivers join the TNC. Because this relationship is bijective, the TNC determines one of the strategy variables γ_i or f_i, and the other is then determined as well. Whereas in reality, the TNC determines γ_i, we can analyze the behavior by assuming that the TNC determines f_i. The transportation network company maximizes

$$\hat{\pi}_i = \widehat{TCM}_i^e - K_r, \tag{24}$$

which is maximized if

$$\frac{\partial \hat{\pi}_i}{\partial f_i} = \frac{\partial \gamma_i}{\partial f_i} \frac{w^2}{(c-w)^2} TCM_i^e + \gamma_i \frac{w^2}{(c-w)^2} \frac{\partial TCM_i^e}{\partial f_i} = 0. \tag{25}$$

In Appendix B, it is shown that the fixed costs K_r of the TNC and K_c of a taxicab have no effect on the fleet sizes of the TNCs. K_r are sunk costs for the TNC. Furthermore, the drivers bear the fixed costs K_c of a taxicab, so that they do not influence the fleet size determination of the revenue-maximizing TNC. A rise in variable costs c leads to higher prices and lower quantities in this regime, while the demand parameter w has a positive effect on the quantity.

Regulatory capture

In this regime, the profit per driver with the inserted equilibrium price is

$$\bar{\pi}_i = \frac{\widehat{TCM}_i^e}{f} - K_c - \frac{K_r}{f}. \tag{26}$$

The maximization with respect to the fleet size $(\partial\bar{\pi}_i / \partial f = 0)$ results in an equilibrium fleet size of

$$\bar{f}^* = \frac{\beta K_r}{\delta(w-c)\sqrt{\alpha K_r} - 4\alpha\delta K_r}. \tag{27}$$

Under the assumptions of the model, this fleet size is positive if $0 < K_r < (w-c)^2/(16\alpha)$ holds. An increase in the parameter w and the matching ability parameter δ reduces the fleet size. If the willingness to pay of the customers, or the technical ability to match customers and taxicabs rise, the RDSs will, c.p., reduce their fleet size to maximize the average profit. In contrast, the equilibrium fleet sizes rise in terms of the cost parameters c and K_r, and in the parameter β. The RDSs choose larger fleet sizes to spread the costs over a larger number of drivers. If the disutility accruing to customers from waiting time is high, the RDSs choose a greater fleet size as well, to reduce the average waiting time (see Appendix B).

2.3 Comparison of regimes

To compare the fleet sizes of the cooperatively organized RDSs (C-RDSs) and the fleet sizes of the TNCs, we look at the marginal profit of the C-RDS

$$\frac{\partial \bar{\pi}_i}{\partial f_i} = \frac{\partial TCM_i^e / \partial f_i \, f_i - TCM_i^e}{f_i^2} + \frac{K_r}{f_i^2} \tag{28}$$

at the profit maximizing TNC fleet size $f_1 = f_2 = \hat{f}^*$. The first-order condition (25) can be transformed into

$$\frac{\partial TCM_i^e}{\partial f_i} = TCM_i^e \frac{-1}{\gamma_i} \frac{\partial \gamma_i}{\partial f_i} = TCM_i^e \frac{1}{\varepsilon_{f,\gamma}} \frac{1}{f_i}, \tag{29}$$

where $\varepsilon_{f,\gamma}$ can be called the "revenue share elasticity of fleet size". Therefore, at the profit maximum of the TNC, equation 28 is denoted by

$$\frac{\partial \bar{\pi}_i}{\partial f_i}_{|f_i=\hat{f}^*} = \frac{TCM_i^e(\hat{f}^*)}{(\hat{f}^*)^2} \frac{1}{\varepsilon_{f,\gamma \, |f_i=\hat{f}^*}} - \frac{TCM_i^e(\hat{f}^*)}{(\hat{f}^*)^2} + \frac{K_r}{(\hat{f}^*)^2}, \tag{30}$$

which is negative, if

$$K_r < TCM_i^e(\hat{f}^*) \cdot \left(1 - \frac{1}{\varepsilon_{f,\gamma \, |f_i=\hat{f}^*}}\right) = \hat{K}_r. \tag{31}$$

In this case, the fleet sizes of the TNCs are larger than those of the C-RDSs. The opposite is true if K_r is larger than $\hat{K}_r$. For the TNCs, K_r are fixed costs that do not influence the determination of fleet sizes. The C-RDS maximizes the average profit of a taxi driver. Each driver has to bear a portion of K_r, which depends on the number of taxicabs in the C-RDS. If an additional driver joins the C-RDS, each driver bears less of K_r. In the case of high fixed costs, the C-RDS has an incentive to increase the fleet size, so as to split costs between more taxicabs. Transportation network companies optimize without considering variable taxi costs and therefore operate with lower prices, which usually implies larger taxicab fleets. If K_r is large ($K_r > \hat{K}_r$), the incentive for C-RDSs to split costs overcompensates for the price competition effect, and C-RDS fleet sizes become larger than TNC fleet sizes.

Proposition 2 In a duopoly of TNCs, the fleet sizes are larger than in a duopoly of cooperatively organized RDSs, if and only if $K_r < \hat{K}_r$.

In this case, the fares are smaller in a duopoly of transportation network companies than in a duopoly of cooperatively organized RDSs.[5]

Next, we can compare the fleet sizes of a duopoly of TNCs with those of two privately organized RDSs. The marginal profit of a privately organized RDS

$$\frac{\partial \tilde{\pi}_i}{\partial f_i} = \frac{\partial TCM_i^e}{\partial f_i} - K_c \tag{32}$$

[5] This holds because $\partial \hat{p}_i^e / \partial f_i < 0$, and the TNC fares are already smaller if fleet sizes are similar (see Proposition 1).

at the optimal fleet sizes of the TNCs $f_1 = f_2 = \hat{f}^*$, using equation 29 is

$$\frac{\partial \tilde{\pi}_i}{\partial f_i}_{|f_i=\hat{f}^*} = TCM_i^e(\hat{f}^*)\frac{1}{\varepsilon_{f,\gamma\,|f_i=\hat{f}^*}}\frac{1}{f^*} - K_c, \tag{33}$$

which is negative, if

$$K_c > TCM_i^e(\hat{f}^*)\frac{1}{\varepsilon_{f,\gamma\,|f_i=\hat{f}^*}}\frac{1}{f^*}. \tag{34}$$

In this case, the fleet sizes of the TNCs are larger than those of privately organized RDSs. The opposite is true if K_c is small. As shown in Appendix B, the fixed costs of a taxicab do not influence the determination of the fleet sizes of the TNCs. If K_c changes, the revenue-maximizing company adjusts γ_i so that the number of taxicabs in the fleet remains constant. Privately organized RDSs reduce the number of taxicabs in their fleet if K_c rises.

Proposition 3 In a duopoly of TNCs, the fleet sizes are larger than in a duopoly of privately organized RDCs if and only if K_c is sufficiently large.

A larger fleet implies that the fares are smaller in a duopoly of transportation network companies than in a duopoly of privately organized RDSs as proved in Proposition 1. Häckner and Nyberg (1995) stated that a duopoly of privately organized RDSs always leads to larger fleet sizes than a duopoly of cooperatively organized RDSs ($\tilde{f}^* > \bar{f}^*$). This means that if the fleet sizes of the TNCs exceed those of privately organized RDSs, the fleet sizes are also larger than those of cooperatively organized RDSs.
To compare the results of the regime of regulatory capture with a duopoly of cooperatively organized RDSs, we consider the partial derivative $\partial \bar{\pi}_i / \partial f_i$ at the profit-maximizing fleet size of the captured regime. This is positive and leads to the following result:

Proposition 4 In a duopoly of cooperatively organized RDSs, the fleet sizes are larger than in the captured regime.

The results of the model can be also explained on the basis of Figure 2 that displays numerical (with Wolfram Mathematica) calculated reaction functions of the fleet sizes for the parameter values $\alpha = 1.4$, $\beta = 0.02$, $\delta = 1$, $c = 0.265$, $K_c = 0.05$, $w = 2$ and $K_r = 0.05$. It can be shown that for cooperatively organized RDSs, $\partial f_i / \partial f_j > 0$ holds. In this case, the fleet sizes are strategic complements. The opposite is true for TNCs and privately organized RDSs. The reaction functions have a negative partial derivative with respect to the fleet size of the other company j ($\partial f_i / \partial f_j < 0$). In this case, the fleet sizes are strategic substitutes (see Figure 2). Point A represents the small fleet sizes of the companies in the regime of regulatory capture (Regime 4). The equilibrium in a market with two cooperatively organized RDSs is denoted by the intersection of the reaction functions at point B (Regime 1). The fleet sizes are larger than in the captured regime (see Proposition 4). With these parameter values, a duopoly of TNCs (point C) leads to larger fleet sizes than a duopoly of cooperatively organized RDSs (B) (see Proposition 2). The largest fleet sizes can be seen in a market with two privately organized RDSs (point D; see Proposition 3).
In the last few years, transportation network companies have entered (or tried to enter) the market still served by traditional RDSs, which is an asymmetric oligopoly of cooperatively organized RDSs competing with TNCs. If we analyze the asymmetric oligopoly of one C-RDS and one TNC (see equilibria E and F in Figure 2), both companies increase their fleets to a size larger than those in their symmetric equilibriums. All drivers would prefer to be member of the cooperatively organized RDS, but only a limited number is accepted.

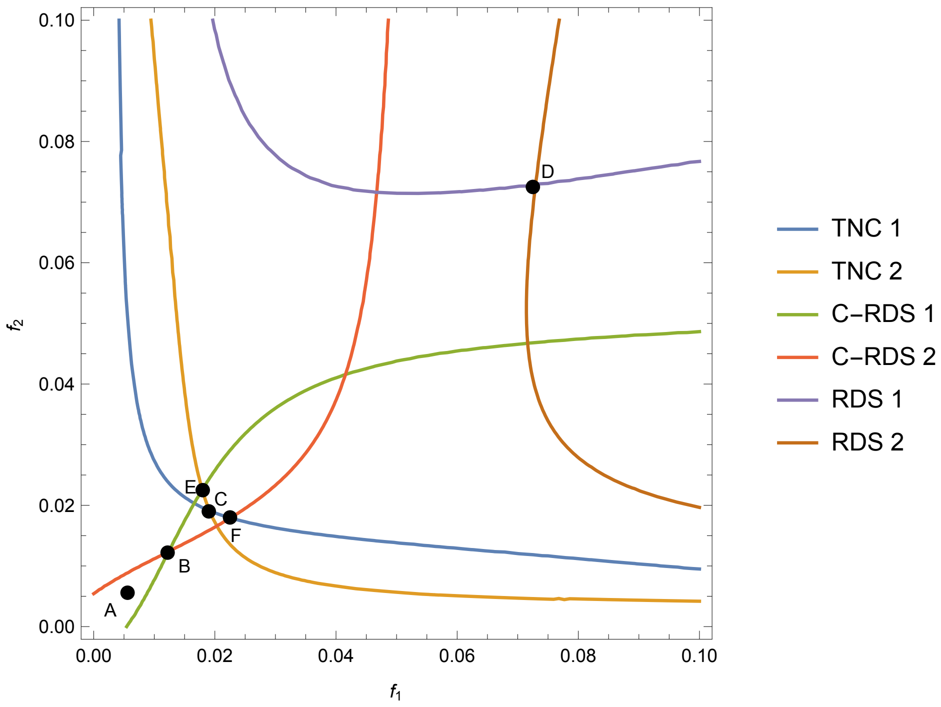

Figure 2. Best response functions and equilibria

Parameter values are: $\alpha = 1.4$, $\beta = 0.02$, $\delta = 1$, $c = 0.265$, $K_c = 0.05$, $w = 2$ and $K_r = 0.05$.

Furthermore, whether or not RDSs can survive the competition with TNCs depends not only on operating costs, which may be similar, but also on the technique of matching drivers and customers and changing prices according to demand. Available empirical evidence (Cramer and Krueger, 2016; Peck, 2017) supports the notion of more efficient TNCs, which may result in an exit of RDSs and the emergence of a duopoly or monopoly of transportation network companies. In the model, regime-dependent deltas (δ) could represent this. However, we did not implement this in the model because it is not clear whether TNCs can maintain a technological advantage in the matching software over in the long term as well. In the current transition phase, the TNCs' matching technology is better, but in the long run, it is likely that traditional taxi companies will be able to develop or buy similar software. From a theoretical point of view, it can be shown that the results of the model do not change significantly if regime-dependent deltas are included. Propositions 1 and 4 still hold. Furthermore, regime-dependent deltas shift the limits in Propositions 2 and 3, but the basic results remain the same.

3. Conclusion

Taxi intermediaries are the most important agents in the market for dispatched taxi rides. Traditionally, intermediaries have been organized as private firms or as cooperatives; nowadays new firms applying different business models successfully enter the market. Because the number of taxi rides that are ordered via transportation network companies increases day by day, we included TNCs in a duopolistic dispatch market model and compared the market outcomes of different regimes.

We find that the largest fleet sizes emerge in the regime of two transportation network companies (Regime 3), if the fixed costs of a taxicab are relatively high. In this case, the fleet sizes are larger than those of privately organized RDSs (Regime 2). In a duopoly of TNCs, more taxi drivers enter the market and fares are smaller than in a duopoly of cooperatively organized RDSs (Regime 1), if the fixed costs of an intermediary are small. If the fares and the number of licenses are regulated, and the regulation is captured by the taxi firms (Regime 4), this leads to smaller fleet sizes than in a duopoly of cooperatively organized RDSs. The agencies try to maximize the profit per taxicab and therefore reduce their fleet sizes and raise fares.

Our study offers a theoretical explanation for the positive employment effect of TNCs' market entry that is evident from several studies. Berger et al. (2017) found that while the number of Uber drivers in the US increased since 2010, there are no negative effects on the number of workers in conventional taxi services. For France and especially Paris, it is evident that the number of taxi licenses in fact increased after the market entry of Uber (Facta, 2016).

This study is in line with the well-known policy advice that liberalization and the market entry of new firms fosters competition, raises the number of taxi drivers and increases consumer surplus. TNCs often claim that they are only a platform where customers and taxi drivers meet. According to our analysis of taxi intermediaries, TNCs that determine the fare, the quality of cars and drivers and the route (which all constitute the product) and the number of taxicabs, are similar to a traditional taxi firm. However, by claiming not to be a firm, some TNCs try to avoid compliance with social legislation, tax legislation, minimum wages and other legal worker rights (Harding et al., 2016). Thus, to support a level playing field, TNCs and RDSs should be subject to the same obligations and quality standards.

Our model sheds some light on the positive aspects of TNCs, but there is one drawback we should mention. There are economies of scale in dispatching taxi ride services that may result in a natural monopoly. In combination with the freedom to set prices in a liberalized market, and extensive information about customers, this is a tempting basis for abusing market power (Darbéra, 2015; Harding et al., 2016). So far, at the agency level, the market in many countries is often only minimally regulated, although there is a high market concentration at this level. As long as the number of licenses and the fares are regulated, there is little leeway to abuse market power. But before liberalization, regulators have to include a category of "intermediary" that includes traditional RDSs as well as TNCs of all kinds. In Ireland, for example, intermediaries must obtain a license and in Hungary, they must satisfy certain requirements, including financial capacity (Frazzani et al., 2016). Only the future will reveal whether competition in the market for dispatching taxi services or competition from such other modes of transport as shuttle services, lift services, car sharing or public transport can prevent the abuse of monopolistic market power by TNCs, or whether governmental action is required.

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Appendix A. Derivation of equation 23

To derive the revenue of a taxi driver (first term of equation 23), we can use the information that, in the regime of two TNCs, the total contribution margin equals the revenue of a TNC ($\widehat{R}_i=\widehat{TCM}_i^e$), because the company does not bear the variable costs. The total revenue ($\widehat{TR}$), which includes the revenue of all taxi drivers of one TNC, as well as the revenue of the TNC, can be calculated with the help of equation 13. The TNC earns a fraction γ_i of the total revenue

$$\hat{R}_i = \widehat{TCM}_i^e = \gamma_i \cdot \widehat{TR} \tag{35}$$

so that the total revenue can be expressed as

$$\widehat{TR} = \frac{\widehat{TCM}_i^e}{\gamma_i}. \tag{36}$$

The taxi drivers earn a share $1-\gamma_i$ of the total revenue and this is divided among f_i taxi drivers in the fleet of TNC_i. The revenue accruing to each taxi driver ($\widehat{R}_{TD}$) can be determined as

$$\hat{R}_{TD} = (1-\gamma_i)\frac{\widehat{TR}}{f_i} = \frac{(1-\gamma_i)}{\gamma_i}\frac{\widehat{TCM}_i^e}{f_i}, \tag{37}$$

which is used in equation 23. Solving equation 23 for γ_i leads to

$$\gamma_i(f_i) = 1 - \frac{2\rho(2(\beta+2\alpha\delta(f_i+f_j))K_c\rho + c\delta w(2\alpha\delta f_j+\beta)(\alpha\delta(2f_i+f_j)+\beta))}{\beta\delta w^2(2\alpha\delta f_j+\beta)(\alpha\delta(2f_i+f_j)+\beta)^2} \tag{38}$$

with $\rho = \beta^2 + 3\alpha^2\delta^2 f_i f_j + 2\alpha\beta\delta(f_i+f_j)$ and therefore

$$\frac{d\gamma_i}{df_i} = -\frac{2\alpha\left(24\alpha\beta^4\delta(f_i+f_j)K_c+\alpha\beta^3\delta^2(12\alpha(4f_i^2+10f_if_j+5f_j^2)K_c+cf_jw)\right)}{\beta w^2(2\alpha\delta f_j+\beta)(\alpha\delta(2f_i+f_j)+\beta)^3}$$
$$-\frac{2\alpha\left(4\beta^5K_c+6\alpha^4\delta^5f_j^2(6\alpha f_i(2f_i^2+3f_if_j+2f_j^2)K_c+cf_j(2f_i+f_j)w)\right)}{\beta w^2(2\alpha\delta f_j+\beta)(\alpha\delta(2f_i+f_j)+\beta)^3}$$
$$-\frac{2\alpha\left(2\alpha^2\beta^2\delta^3(2\alpha(8f_i^3+48f_i^2f_j+57f_if_j^2+20f_j^3)K_c+cf_j(f_i+3f_j)w)\right)}{\beta w^2(2\alpha\delta f_j+\beta)(\alpha\delta(2f_i+f_j)+\beta)^3}$$
$$-\frac{2\alpha\left(\alpha^3\beta\delta^4f_j(12\alpha(f_i+f_j)(8f_i^2+13f_if_j+4f_j^2)K_c+cf_j(10f_i+11f_j)w)\right)}{\beta w^2(2\alpha\delta f_j+\beta)(\alpha\delta(2f_i+f_j)+\beta)^3}<0 \quad (39)$$

Appendix B. Comparative statics

Duopoly of cooperatively organized RDSs

It can be shown that for cooperatively organized RDSs, the marginal utility of the first taxi trip has a negative impact on the fleet sizes. The variable costs c and the fixed costs of an intermediary K_r have a positive effect on the fleet sizes, and the fixed costs of a taxicab K_c have no effect on the fleet sizes:

$$\frac{\partial^2\bar{\pi}_i}{\partial f_i\partial w}<0, \frac{\partial^2\bar{\pi}_i}{\partial f_i\partial c}>0, \frac{\partial^2\bar{\pi}_i}{\partial f_i\partial K_r}>0, \frac{\partial^2\bar{\pi}_i}{\partial f_i\partial K_c}=0. \quad (40)$$

The price of a taxi ride rises, if the parameter w increases $d\bar{p}^*/dw > 0$. This is true because

$$\frac{d\bar{p}^*}{dw}=\frac{\partial p_i^e(\bar{f}^*,\bar{f}^*)}{\partial f_i}\frac{\partial f_i}{\partial w}+\frac{\partial p_i^e(\bar{f}^*,\bar{f}^*)}{\partial f_j}\frac{\partial f_j}{\partial w}+\frac{\partial p_i^e(\bar{f}^*,\bar{f}^*)}{\partial w} \quad (41)$$

is positive. We assume that a larger fleet size has a negative effect on the price. The effect of w on the fleet size is negative, and the direct effect of w on the price is positive, so that the total effect is positive as well. The effects of the other parameters in this regime are indeterminate.

Duopoly of privately organized RDSs

We can state with respect to the fleet size, that higher fixed costs K_c lead to a smaller fleet size of privately organized RDSs ($\partial^2\tilde{\pi}_i/\partial f_i\partial K_c<0$) and in this case, K_r does not influence the fleet sizes. In this regime, the price is positively influenced by the variable costs c:

$$\frac{d\tilde{p}^*}{dc}=\frac{\partial p_i^e(\tilde{f}^*,\tilde{f}^*)}{\partial f_i}\frac{\partial f_i}{\partial c}+\frac{\partial p_i^e(\tilde{f}^*,\tilde{f}^*)}{\partial f_j}\frac{\partial f_j}{\partial c}+\frac{\partial p_i^e(\tilde{f}^*,\tilde{f}^*)}{\partial c} \quad (42)$$

We assume that a larger fleet size has a negative effect on the price, as shown above. The effect of c on the fleet size is negative, and the direct effect of c on the price is positive, so that the total effect is positive as well.

For the quantity, the effect of c is negative and that of w is positive.

$$\frac{d\tilde{Q}^*}{dc}=\frac{\partial Q_i^e(\tilde{f}^*,\tilde{f}^*)}{\partial f_i}\frac{\partial f_i}{\partial c}+\frac{\partial Q_i^e(\tilde{f}^*,\tilde{f}^*)}{\partial f_j}\frac{\partial f_j}{\partial c}+\frac{\partial Q_i^e(\tilde{f}^*,\tilde{f}^*)}{\partial c} \quad (43)$$

We assume that a larger fleet size has a positive effect on the quantity. The effect of c on the fleet size is negative, and the direct effect of c on the quantity is negative as well, so that the total effect is negative.

$$\frac{d\tilde{Q}^*}{dw}=\frac{\partial Q_i^e(\tilde{f}^*,\tilde{f}^*)}{\partial f_i}\frac{\partial f_i}{\partial w}+\frac{\partial Q_i^e(\tilde{f}^*,\tilde{f}^*)}{\partial f_j}\frac{\partial f_j}{\partial w}+\frac{\partial Q_i^e(\tilde{f}^*,\tilde{f}^*)}{\partial w} \tag{44}$$

We assume that a larger fleet size has a positive effect on the quantity. The effect of w on the fleet size is positive, and the direct effect of w on the quantity is positive as well, so that the total effect is positive. The effects of the other parameters in this regime are indeterminate.

Duopoly of TNCs

It can be shown that for TNCs, the marginal costs c have a negative impact on the fleet sizes, and that the fixed costs of an intermediary K_r and the fixed costs of a taxicab K_c have no effect on the fleet sizes:

$$\frac{\partial^2\hat{\pi}_i}{\partial f_i\partial c}<0,\frac{\partial^2\hat{\pi}_i}{\partial f_i\partial K_r}=0,\frac{\partial^2\hat{\pi}_i}{\partial f_i\partial K_c}=0. \tag{45}$$

In the regime of TNCs, the price is positively influenced by the variable costs c.

$$\frac{d\hat{p}^*}{dc}=\frac{\partial\hat{p}_i^e(\hat{f}^*,\hat{f}^*)}{\partial f_i}\frac{\partial f_i}{\partial c}+\frac{\partial\hat{p}_i^e(\hat{f}^*,\hat{f}^*)}{\partial f_j}\frac{\partial f_j}{\partial c}+\frac{\partial\hat{p}_i^e(\hat{f}^*,\hat{f}^*)}{\partial c} \tag{46}$$

We assume that a larger fleet size has a negative effect on the price, as shown above. The effect of c on the fleet size is negative, and the direct effect of c on the price is zero, because the TNCs do not have to bear these costs. In this case, the total effect is positive.

For the quantity, the effect of w is positive and the effect of c is negative.

$$\frac{d\hat{Q}^*}{dw}=\frac{\partial\hat{Q}_i^e(\hat{f}^*,\hat{f}^*)}{\partial f_i}\frac{\partial f_i}{\partial w}+\frac{\partial\hat{Q}_i^e(\hat{f}^*,\hat{f}^*)}{\partial f_j}\frac{\partial f_j}{\partial w}+\frac{\partial\hat{Q}_i^e(\hat{f}^*,\hat{f}^*)}{\partial w} \tag{47}$$

We assume that a larger fleet size has a positive effect on the quantity, as shown above. The effect of w on the fleet size is positive, and the direct effect of w on the quantity is positive as well, so that the total effect is positive.

$$\frac{d\hat{Q}^*}{dc}=\frac{\partial\hat{Q}_i^e(\hat{f}^*,\hat{f}^*)}{\partial f_i}\frac{\partial f_i}{\partial c}+\frac{\partial\hat{Q}_i^e(\hat{f}^*,\hat{f}^*)}{\partial f_j}\frac{\partial f_j}{\partial c}+\frac{\partial\hat{Q}_i^e(\hat{f}^*,\hat{f}^*)}{\partial c} \tag{48}$$

We assume that a larger fleet size has a positive effect on the quantity, as shown above. The effect of c on the fleet size is negative, and the direct effect of c on the quantity is zero, so that the total effect is negative. The effects of the other parameters in this regime are indeterminate.

Regulatory capture

In the regime of regulatory capture, the different parameters have the following effects on the fleet size:

$$\frac{\partial\widehat{f}^*}{\partial w}<0,\frac{\partial\widehat{f}^*}{\partial c}>0,\frac{\partial\widehat{f}^*}{\partial K_r}>0,\frac{\partial\widehat{f}^*}{\partial\beta}>0,\frac{\partial\widehat{f}^*}{\partial\delta}<0. \tag{49}$$

K_c has no effect on the fleet size, and the effect of α depends on the size of the fixed costs K_r. If K_r is large, it holds that $\partial\widehat{f}^*/\partial\alpha>0$.

The parameters affect the price of a taxi ride as follows:

$$\frac{\partial\widehat{p}^*}{\partial w}>0,\frac{\partial\widehat{p}^*}{\partial c}>0. \tag{50}$$

K_r, K_c, α, β, δ have no influence on the price in the regime of regulatory capture.

The demand for the services of each RDS depends on the following two parameters:

$$\frac{\partial \hat{Q}^*}{\partial K_r} > 0, \frac{\partial \hat{Q}^*}{\partial \alpha} < 0. \tag{51}$$

c, w, K_c, β, δ have no influence on the demand in this regime .