Two-Sided Dynamics in Duopolistic Markets with Ride-hailing and Ride-pooling

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Short summary

Network effects in driver-traveller matching suggest that ridesourcing markets with multiple platforms may be less efficient than monopolistic ones. The practice of pairing travellers in ride-pooling introduces additional network effects, suggesting that market segmentation costs may be further elevated in ride-pooling compared to ride-hailing. We examine the evolution of a duopolistic ridesourcing market, with service providers offering solo or pooled rides, using an agent-based model that considers day-to-day processes and within-day operations. Results reveal winner-takes-all scenarios in markets with two solo providers, but not with two pooling providers offering ex-ante discounts. Coexistence is also possible when one platform offers solo ride-hailing and the other pooling, with both services targeting different users. Our study provides insights into market segmentation costs when platforms co-exist, as well as how ridesourcing vehicle mileage efficiency and modal shifts depend on the service type (solo or pooled) offered by each provider.
Keywords: Agent-based model, Competition, Evolution, Ride-hailing, Ride-pooling

1 Introduction

Ridesourcing platforms have revolutionised the taxi industry by leveraging the ubiquity of smartphones and mobile data to connect travellers directly with private drivers, allowing for more efficient pick-ups and better alignment between supply and demand. As the efficiency of the matching of drivers and riders in ride-sourcing services is intricately linked to the scale of a platform (de Ruijter, Cats, & van Lint, 2022), the overall system efficiency is likely smaller in ridesourcing markets where multiple service providers compete compared to monopolistic markets (Séjournè et al., 2018). This affects travellers through longer waiting, drivers through less productive working, platforms through lower market shares and the general public through higher vehicle mileage. At the same time, Kondor et al. (2022) demonstrate why network effects in ridesourcing provision facilitate winner-takes-all markets, in which service providers may end up raising fares and commission to the detriment of travellers and drivers.

It is plausible that market segmentation costs are larger — and winner-takes-all markets more likely — in the provision of ride-pooling, compared to ride-hailing without shared rides. The reason is that ride-pooling system efficiency is highly scale-dependent (Tachet et al., 2017) given that pooling relies on compatibility in trip requests in addition to driver-request pairings. Similarly to private ride-hailing, trip density and market shares are crucial for generating sufficient demand to obtain acceptable waiting times, i.e. the likelihood of finding a driver in proximity. However, in the case of ride-pooling there is the additional need to obtain acceptable detour times, i.e. the likelihood of finding in addition to a driver also several travel requests within spatial and temporal proximity. Passenger utility can either increase (better matches, occurring particularly when demand for ride-pooling is already high) or decrease (longer detours, particularly when demand is moderate) with demand for ride-pooling (Fielbaum et al., 2023).

At the same time, markets with service differentiation between platforms, for instance when one service provider offers hailing and the other one pooling, may be less prone to winner-takes-all equilibria (Vignon et al., 2021). These service types target (at least partially) different market segments: pooling serves cost-sensitive users, while hailing accommodates the preferences of time-sensitive individuals.

There exists a present deficiency in understanding regarding market segmentation costs in duopolistic ridesourcing markets depending on whether solo or hailing is offered, including comprehending the likelihood of winner-takes-all market outcomes. Our study makes the following specific (inter-related) contributions to the existing literature:

1. **Evaluating Two-Sided Day-to-Day Dynamics**: We develop an agent-based day-to-day model for ridesourcing supply and demand, representing diffusion of platform awareness, tactical registration decisions and daily market participation decisions in consideration of imperfect information, i.e. following from learning from own and others' experience. The need for accounting for such (disaggregate) dynamic processes has been reiterated by (Guo & Huang, 2022). The day-to-day model enables exploring under which conditions initial differences in market shares between platforms — resulting from platform entry timing or random advantages — translate to winner-takes-all (or asymmetric) market outcomes.
2. **Capturing Detailed Ridesourcing Dynamics with Competition**: We model the within-day interactions between service providers, users and drivers, accounting for their spatio-temporal attributes. Specifically, we represent platform matching, ride offer acceptance decisions and repositioning decisions, all affecting experiences with the platform and, consequently, market participation levels.
3. **Considering Ride-Hailing and Ride-Pooling**: In addition to modelling within-day ride-hailing operations exclusively for platforms offering private rides, we extend our analysis to incorporate ride-pooling services. This allows us to examine the likelihood of winner-takes-all markets in ride-pooling compared to solo ride-hailing, considering network effects in traveller pairings. We also explore market competition when one platform offers ride-hailing and the other offers ride-pooling, potentially targeting distinct user groups based on trip-related attributes, mode preferences, and socio-economic characteristics, the importance of which has been underlined by the results of (Zhang & Nie, 2021).
4. **Capturing Mode Choice**: Unlike previous studies, we account explicitly for alternative modes, thereby capturing how ridesourcing propensity depends on travellers' departure time and trip origin and destination. This allows us to investigate modal split shifts associated with the introduction of ridesourcing services depending on several factors, including which service types are offered by each provider, considering also the attractiveness of the ridesourcing market for job seekers.

2 Methodology

Assume a ridesourcing market with platforms $P = \{p_1, \ldots, p_n\}$, each offering private rides (from hereon referred to as 'solo' rides) or pooled rides in area A. Platforms in P generate revenue by charging a commission on each transaction between travellers and drivers in the market. We assume constant pricing and commissions, both within-day (operational) and day-to-day (tactical). Demand for each platform follows from the mode choice decisions of traveller agents $T = \{t_1, \ldots, t_b\}$ which make a daily trip within the boundaries of A. The fleet size of ridesourcing platforms depends on the daily work decisions of job seeker agents $J = \{j_1, \ldots, j_l\}$, who compare the utility derived from driving in the ridesourcing market to the utility of alternative opportunities.

Day-to-day and within-day processes

We study the implications of ridesourcing market segmentation using a simulation model designed to capture multiple day-to-day processes associated with ridesourcing supply and demand, as well as the within-day operations of such markets, as visualised in the conceptual framework in Fig. 1. Specifically, each day in our day-to-day simulation model of the ridesourcing market the following five subsequent processes take place:

I. *Diffusion of market awareness* - a precondition for platform registration - is captured through a peer-to-peer communication process for the aggregated ridesourcing market, i.e. agents learn about the existence of all platforms in P when (first) exposed to information about the ridesourcing market. The awareness diffusion speed depends on the number of unaware individuals as well as the number of market participants.

II. Agents that are aware of the existence of the market make an occasional *platform registration decision*, in which they trade off expected benefits from participating in a platform with long-term costs associated with platform registration. All agents are assumed to single-home, i.e.

at any day they can be registered with at most one platform. In registration decisions, we also model how agents learn about system performance by communicating with agents about recent experiences in the market.

III. Registered agents then make a daily *platform participation decision*, in which they compare the (expected) utility derived from platform participation to the utility of alternatives, i.e. alternative modes for travellers and alternative activities for job seekers. The expected utility derived from using the platform for travellers depends on the expected waiting time, in-vehicle time and ride fare. For job seekers, it depends on the expected financial return.

IV. In representing the *within-day ride-hailing operations* following from previously mentioned participation decisions, we capture platforms' matching of drivers to customers, customers' ride offer acceptance decisions, as well as drivers' repositioning behaviour.

V. Customers and drivers update their expected participation utility for the next day based on their individual experience participating in the ridesourcing market. *Day-to-day learning* is modelled using a Markov process formulation.

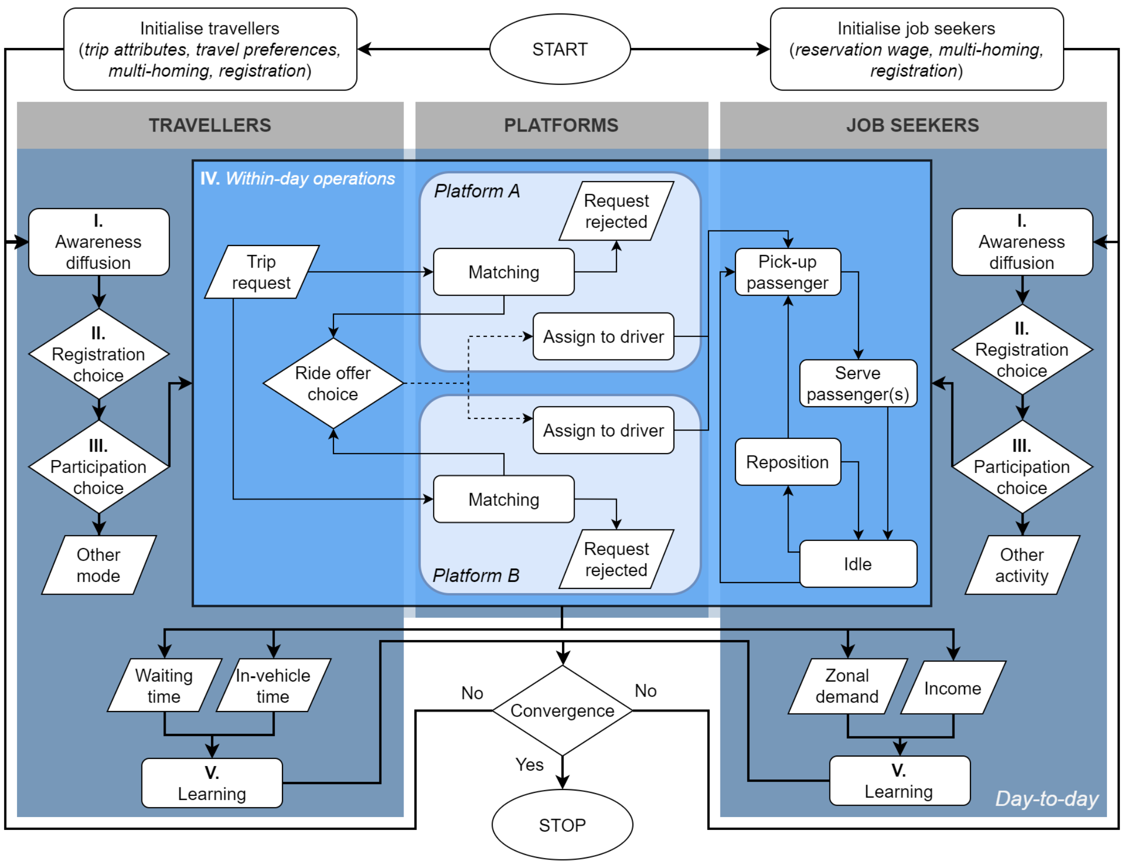

Figure 1: Conceptual representation of the day-to-day simulation model.

Convergence

We define several criteria related to double-sided market participation levels that need to be met for the market to have reached an equilibrium state. Our convergence criteria should neglect random - i.e. non-systematic - day-to-day variations in market participation levels following from random components in peer-to-peer communication and decision-making processes.

Replications

In light of previously described stochastic processes pertaining to ridesourcing supply and demand, we need to run multiple replications to test and prove the statistical significance of our simulation results. In doing so, we utilise the same indicators that are used to determine convergence. We opt for a method previously applied in simulating monopolist ridesourcing markets (de Ruijter, Cats, Kucharski, & van Lint, 2022; de Ruijter, Cats, & van Lint, 2022).

Computational complexity

We limit the computational complexity of the simulation model by applying a filter to the traveller population based on their propensity of selecting ridesourcing based on their individual mode choice preferences.

Simulation framework

The day-to-day processes associated with ridesourcing supply and demand are implemented in MaaSSim (Kucharski & Cats, 2022), and the within-day operational model in FleetPy (Engelhardt, Dandl, et al., 2022), both of which are open-source agent-based simulators of mobility-on-demand services programmed in Python.

3 Experimental design

Set-up

In this section, we outline the set-up of our experiments, which has been designed to mimic the city of Amsterdam, the Netherlands. This pertains to relevant aspects such as the potential ridesourcing market, the underlying road network, ridesourcing operations, and characteristics of alternative modes.

For the travel demand in Amsterdam, we employ a data set generated with activity-based model Albatross (Arentze & Timmermans, 2000), selecting only trips of 2 kilometres and longer. In terms of the number of trip requests, we sample one-tenth of the total estimated demand in Amsterdam during an eight-hour window. Similarly, we aim to represent one-tenth of all job seekers residing in Amsterdam. In absolute terms, this sampling yields a total of $b = 100,000$ travellers and $l = 2,500$ job seekers. In our analysis, travellers with a likelihood of below 5% to select ridesourcing when there are immediate pick-ups and no (pooling) detours are assumed to completely disregard ridesourcing.

Ridesourcing vehicles utilise a road network with spatially heterogeneous yet static travel speeds. Drivers incur per-kilometre operational costs of €0.25. Pricing of solo ridesourcing rides is set following Uber's approach in Amsterdam, omitting surge pricing. This entails charging a base fee of 1.5€ and a per-kilometre fee of 1.5€. We assume that pooling platforms offer travellers a guaranteed one-third discount on solo trip fares even when no sharing eventually occurs. Platforms withhold 25% of the fares paid by travellers, the remaining 75% is transferred to the respective drivers. Platforms adopt a maximum allowed pooling delay of 40% relative to the direct route travel time when matching customers to other customers.

Beyond ridesourcing, the set of potential travel modes M encompasses cycling, private vehicle usage and public transportation. Travellers' in-vehicle time perceptions, cost perceptions and mode-specific constants are based on a mixed logit model estimated using a data set of stated preference choices (Geržinič et al., 2023) for urban travel behaviour in the Netherlands.

Scenarios

We evaluate three duopolistic market types (two providers at the start of the simulation) as well as two benchmark scenarios (monopolistic markets):

- **Solo-solo:** two platforms each offering a solo (ride-hailing) service
- **Solo-pool:** one platform offering a solo service, the other a ride-pooling service
- **Pool-pool:** two platforms each offering a ride-pooling service
- **Solo:** monopolistic platform offering solo (ride-hailing) service (benchmark)
- **Pool:** monopolistic platform offering ride-pooling service (benchmark)

4 Results and discussion

Fig. 2 shows that when two platforms offer a solo service (*solo-solo* scenario), the market develops towards a winner-takes-all market equilibrium. Initial random differences in the participation decisions of travellers and job seekers result in differences in drivers' income and travellers' waiting time (considering network effects in matching), which induces a reinforcing feedback loop in which the bigger platform attracts even more supply and demand. Fig. 2 also demonstrates that such a market equilibrium is similar to the market equilibrium if only one platform had initially entered the market (*solo*).

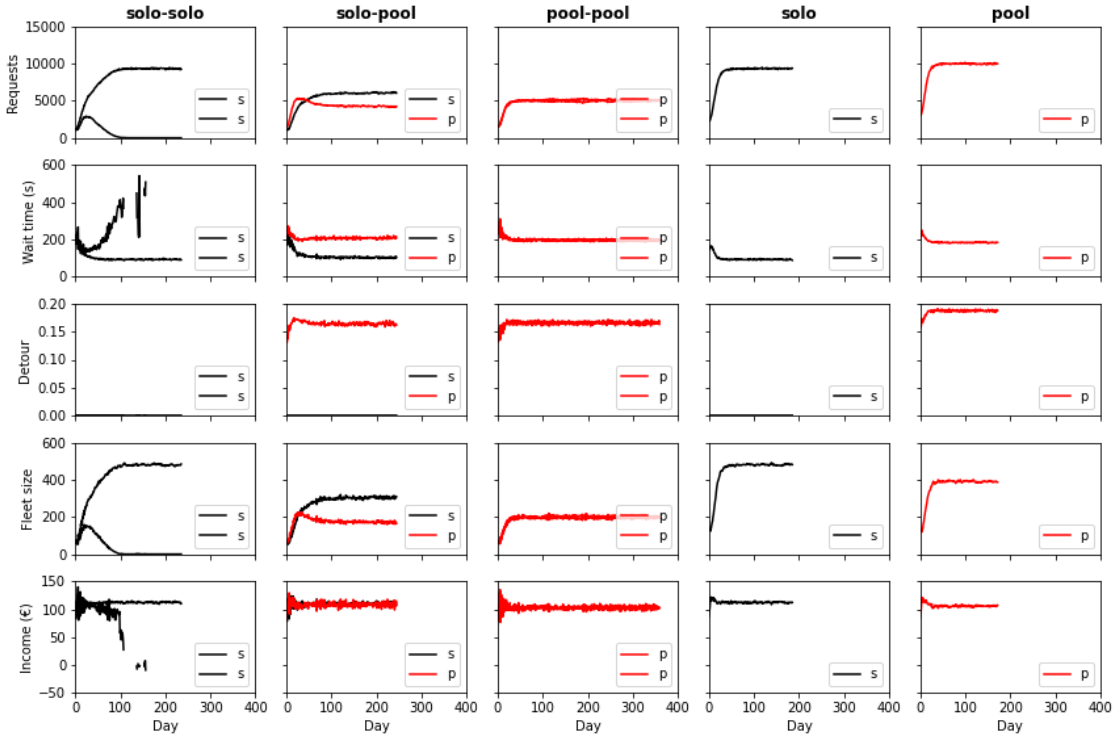

Figure 2: Evolution of five key ridesourcing market indicators (demand for ridesourcing, the average time from requesting a trip to being picked up by a driver, the average ride-pooling detour time relative to travellers' average shortest-path travel time, ridesourcing fleet size, and the average income of a ridesourcing driver) for a single replication of the experiment for each of the market types.

In a market in which one platform offers a solo service and the other a pooling service (*solo-pool*), both platforms can co-exist. We observe that the solo platform attracts more demand (and particularly) more supply than the ride-pooling platform. Consequently, travellers opting for the solo provider experience a lower waiting time than ride-pooling users. In addition, ride-pooling users experience an approximately 17% higher in-vehicle time due to detouring to pick up other travellers. Yet, approximately 4,000 travellers prefer ride-pooling over ride-hailing due to the lower pooling fares. Notably, drivers experience the same earnings on both platforms. When selecting the platform that offers solo rides, it leads to a higher revenue per served traveller; however, it also results in elevated operational costs per served traveller. Additionally, there is an increased idle time, a consequence of heightened supply-side competition within the solo platform.
The market with two ride-pooling providers (*pool-pool*) evolves towards an equilibrium with two approximately equally large platforms. The reason that a winner-takes-all scenario does not occur in such a market (as opposed to a *solo-solo* market) is likely that pooling discounts are offered ex-ante, i.e. discounts are independent of actual sharing. Hereby, travellers inherently prefer the smaller platform as it provides them with smaller detours for the same fares.
When considering the market share of ridesourcing markets depending on the services offered (Fig. 3), we find that the largest market share (over 10%) is attained when one platform offers a solo service and the other a ride-pooling service, catering for more and less time-sensitive users. If only ride-pooling is offered, either by a single provider or two providers, the market share is still

close to 10%, as time-sensitive users may opt for ride-pooling (instead of the solo service) when no private rides are offered. We find that in all scenarios in which ride-pooling is provided by at least one platform a relatively large share of ridesourcing users would have otherwise opted for public transport (2.3-2.4% of all travellers). The market share of ridesourcing is most limited when only the solo service is provided, as some cost-sensitive users prefer using public transport considering its lower fares. Yet, still over 9% of travellers will choose ridesourcing in such a scenario.

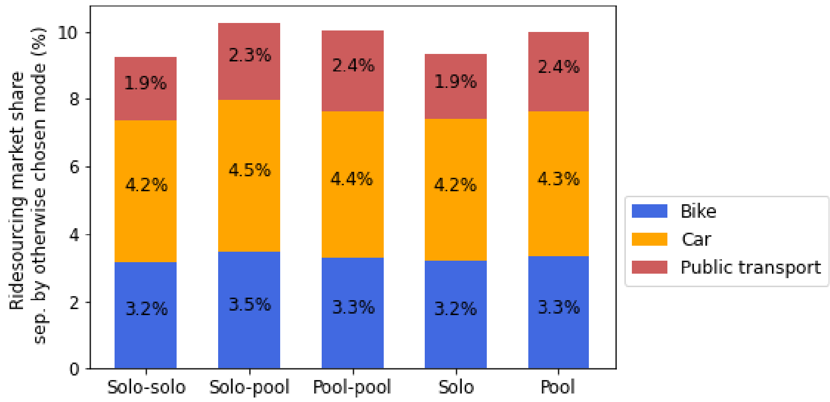

Figure 3: Market share of ridesourcing in the market equilibrium depending on the number of (initial) service providers and their service types, including what modes would have been chosen if ridesourcing had not been offered.

Ride-pooling is anticipated to provide a more efficient service in terms of the vehicle mileage needed to serve a single user compared to solo ride-hailing. Fig. 4 shows for different market types the number of ridesourcing vehicle kilometres divided by the sum of the shortest path distances between users' origins and destinations in the market equilibrium. A value of less than 1 essentially implies that the ridesourcing system is more efficient than a system in which everybody uses a private car to travel between their origins and destinations. We observe, however, that in all scenarios, independent of the number of (initial) service providers and service types that are offered, the number of vehicle kilometres per effective passenger kilometre is at least 1. The ridesourcing market is most efficient when ride-pooling is offered by a single service provider (*pool*). In such a scenario, there is more than 1 passenger on-board a vehicle for a substantial portion of all vehicle kilometres. Yet, high-occupancy sharing is rare given the fairly limited market share of the ride-pooling provider. In fact, due to empty vehicle kilometres for repositioning and driving to users' pick-up locations, the system is not more efficient in terms of vehicle mileage than private cars. When the ride-pooling market is subdivided over two platforms (*pool-pool*), less efficient matches are produced, and hence, the total vehicle mileage (to serve similar demand) is higher.

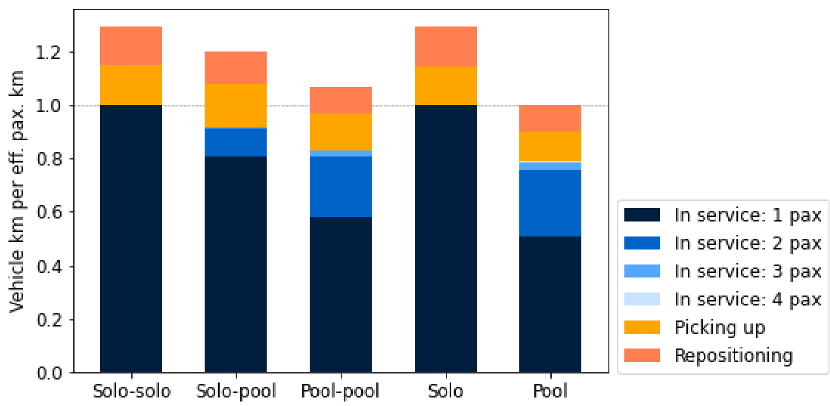

Figure 4: Total mileage of ridesourcing vehicles divided by the sum of the shortest path distances between ridesourcing users' origins and destinations.

When one platform offers a solo service and one a ride-pooling service (*solo-pool*), substantially less sharing takes place. Users opting for the ride-pooling platform for instance never share their vehicle with more than 1 co-rider at a time. At the same time, more repositioning takes place as more drivers are attracted to the ridesourcing market (relative to ridesourcing demand), inducing higher driver idle time. In such a market, approximately 1.2 vehicle kilometres are generated for each effective kilometre on the shortest path between users' origins and destinations. A ridesourcing market without ride-pooling (*solo* or *solo-solo*) is least beneficial from a vehicle mileage standpoint as each effective passenger kilometre induces 1.3 vehicle kilometres. Not only do drivers never serve multiple passengers simultaneously, they also spend significant time repositioning in anticipation of new requests. The reason is that relatively many drivers are attracted by the higher fares of the solo service compared to the pooling service, resulting in substantial driver idle time.

5 Conclusions

In this work, we study the evolution of ridesourcing platforms in duopolistic markets, exploring the likelihood of winner-takes-all market equilibria depending on whether ride-hailing or ride-pooling is offered by each platform, as well as market segmentation costs in the case that multiple platforms co-exist.

Our experiments demonstrate that network effects in the provision of (solo) ride-hailing facilitate winner-takes-all markets. Specifically, random initial differences in platforms' (two-sided) market shares translate into structural differences in platforms' attractiveness for users and drivers. We observe that a winner-takes-all scenario does not occur when two service providers offer ride-pooling, given that ex-ante pricing discounts lead travellers to using the smaller platform, inducing negative rather than positive network effects. A market in which one provider offers solo ride-hailing and the other ride-pooling is also less likely to converge towards a winner-takes-all market as the different services cater for different users based on their sensitivity to time and cost. We observe that in such a market the solo provider likely attracts more users and particularly more drivers.

We find that markets in which ride-pooling is offered by at least one platform are not only more efficient in terms of the total vehicle mileage per served passenger following vehicle sharing but also from more limited (empty-vehicle) repositioning. The reason is that ride-pooling markets attract less supply as drivers receive a smaller financial reward per satisfied request, resulting in more limited driver idle time. Our results also provide insights into the extent to which monopolistic ride-pooling markets yield more efficient matches than duopolistic ride-pooling markets.

Furthermore, our study sheds light on potential modal shift patterns following from the introduction of ridesourcing, indicating that markets in which ride-pooling is offered attract relatively many public transport users relative to markets without ride-pooling. This may at least partially negate the benefits of ride-pooling when it comes to serving passengers with minimal vehicle mileage. At the same time, our results demonstrate that solo ride-hailing and ride-pooling generally may target similar users, i.e. the market share of ridesourcing is only marginally larger when both solo ride-hailing and ride-pooling are offered compared to markets in which one of the two is offered.

Many research directions associated with oligopolistic ridesourcing market equilibria remain unexplored. This includes evaluating (possibly dynamic) platform pricing strategies — i.e. platforms strategically setting fares of ride-hailing and ride-pooling as well as platform commission — to gain better insights into the implications of platform competition, rather than platform co-existence as studied in this work. Furthermore, future research may explore in more detail cooperation strategies to minimise market segmentation costs among platforms, such as the introduction of a broker platform (Engelhardt, Malcolm, et al., 2022). Possibly, multi-homing behaviour by travellers and job seekers, i.e. simultaneous usage of multiple platforms, minimises market segmentation costs and prevents the emergence of winner-takes-all markets, reducing the need for platform cooperation strategies. Future studies should investigate segmentation costs for two and more service providers, including examining how oligopolistic ridesourcing markets adjust to changing market conditions.

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