Modelling competition in ride hailing platforms

The limits of network effects replicated using a biological model

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June 23 2020

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COMPUTATIONAL PRIVACY GROUP

The growth of ride-hailing platforms

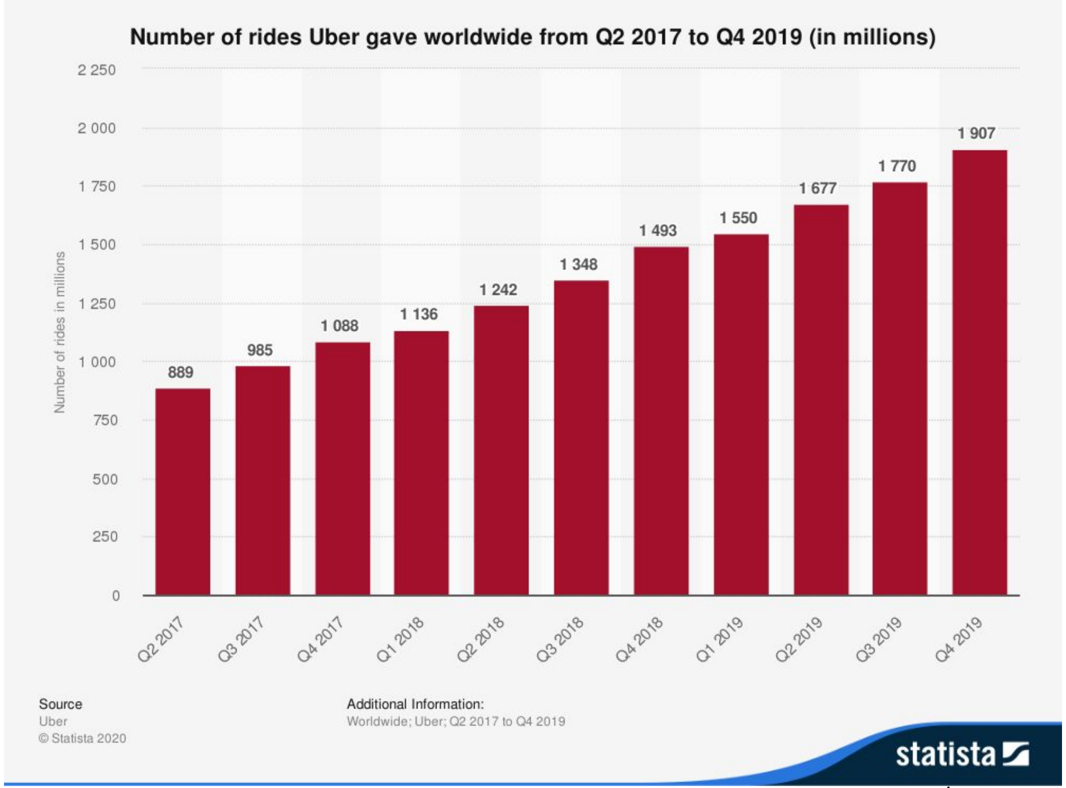
Ride Hailing Platforms are everywhere

- After 11 years, Uber serves 785 metropolitan areas (63 countries)
- 14 million rides a day
  - 18k per city
- 26% of 18-24 yo in London use Uber

iqbal, mansoor (2019). *Uber Revenue and Usage Statistics (2019)*. [online] Business of Apps. Available at: https://www.businessofapps.com/data/uber-statistics/.

Their growth is impressive

- Number of rides given by Uber nearly doubles in 2 years
- Averages a quarterly growth of 8%

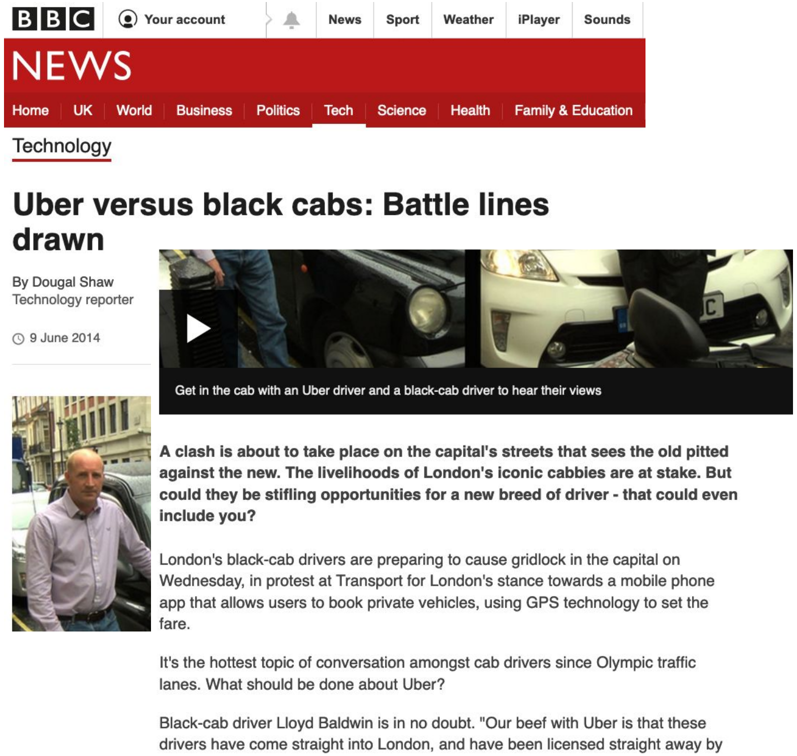


Statista. (n.d.). *Uber: quarterly number of rides worldwide 2020*. [online] Available at: https://www.statista.com/statistics/946298/uber-ridership-worldwide/ [Accessed 19 Jun. 2020].

They are raising questions about competition

- Will Uber bring healthy competition, or crush the market into a monopoly?

- These platforms are thought to benefit from a “rich get richer” effect[1]. Is this growth uncontrolled?



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Technology

Uber versus black cabs: Battle lines drawn

By Dougal Shaw
Technology reporter

9 June 2014

Get in the cab with an Uber driver and a black-cab driver to hear their views

A clash is about to take place on the capital's streets that sees the old pitted against the new. The livelihoods of London's iconic cabbies are at stake. But could they be stifling opportunities for a new breed of driver - that could even include you?

London's black-cab drivers are preparing to cause gridlock in the capital on Wednesday, in protest at Transport for London's stance towards a mobile phone app that allows users to book private vehicles, using GPS technology to set the fare.

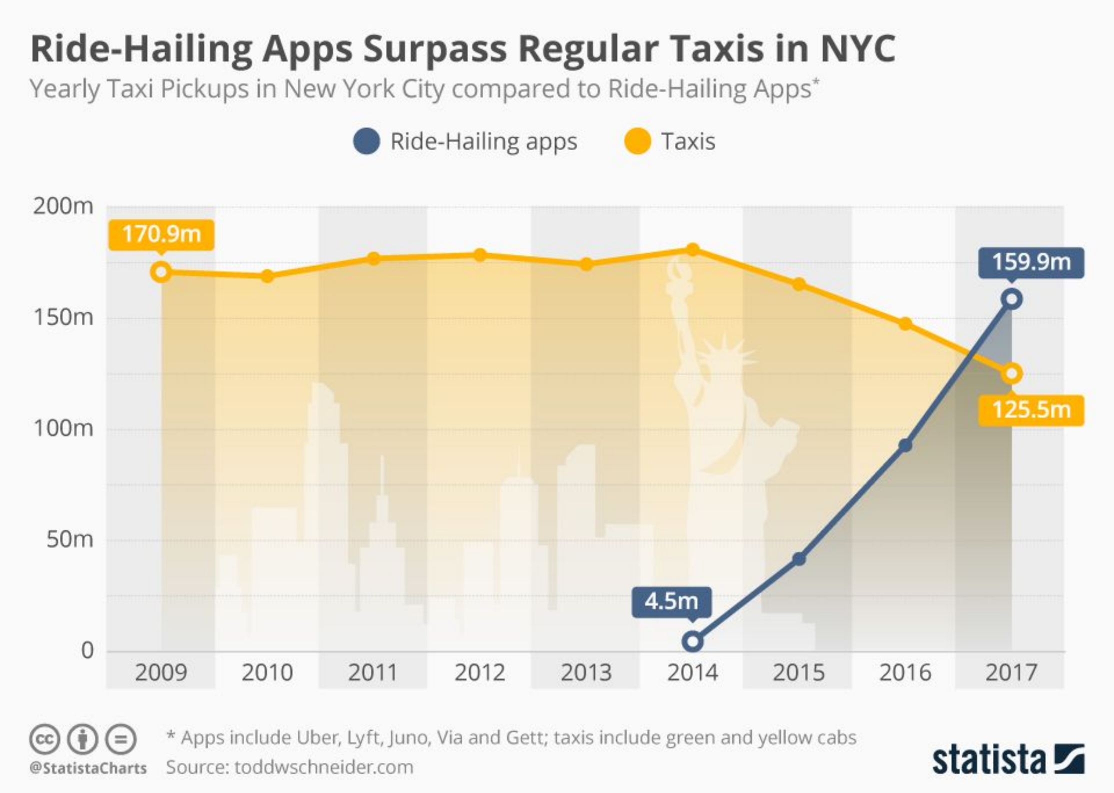
It's the hottest topic of conversation amongst cab drivers since Olympic traffic lanes. What should be done about Uber?

Black-cab driver Lloyd Baldwin is in no doubt. "Our beef with Uber is that these drivers have come straight into London, and have been licensed straight away by

[1] O'Connor, D., 2016. Understanding online platform competition: Common misunderstandings. *Internet Competition and Regulation of Online Platforms (May 2016), Competition Policy International*.

image: Shaw, D. (2014). Clash of cabs: Uber v London taxis. *BBC News*. [online] 9 Jun. Available at: https://www.bbc.co.uk/news/technology-27733971.

Their growth is impressive

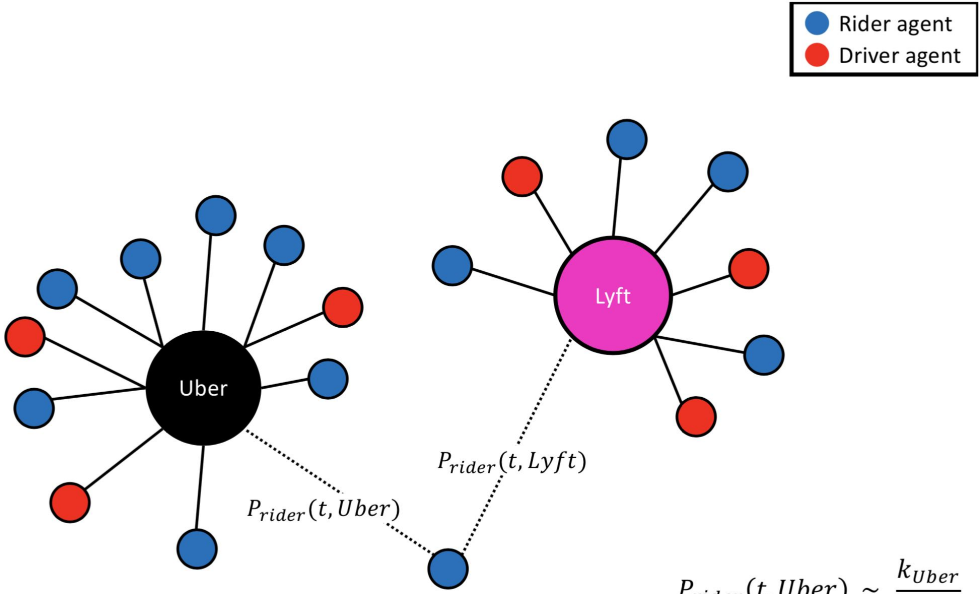


Statista Infographics. (n.d.). *Infographic: Ride-Hailing Apps Surpass Regular Taxis in NYC*. [online] Available at: https://www.statista.com/chart/13480/ride-hailing-apps-surpass-regular-taxis-in-nyc/ [Accessed 19 Jun. 2020].

What are the dynamics of this growth?

Network Effects: a key contributor

- More platform riders -> more drivers
- More drivers -> overall service is more appealing to riders
- Ride hailing platforms are known to have this dynamic [1]



$$P_{rider}(t, Uber) \sim \frac{k_{Uber}}{\sum_i k_i}$$

$$P_{rider}(t, Lyft) \sim \frac{k_{Lyft}}{\sum_i k_i}$$

[1] O'Connor, D., 2016. Understanding online platform competition: Common misunderstandings. *Internet Competition and Regulation of Online Platforms (May 2016), Competition Policy International*.

There seems to be an inherent limit...

- Unmitigated network effects lead to explosive growth

- Competition would be improbable **everywhere**

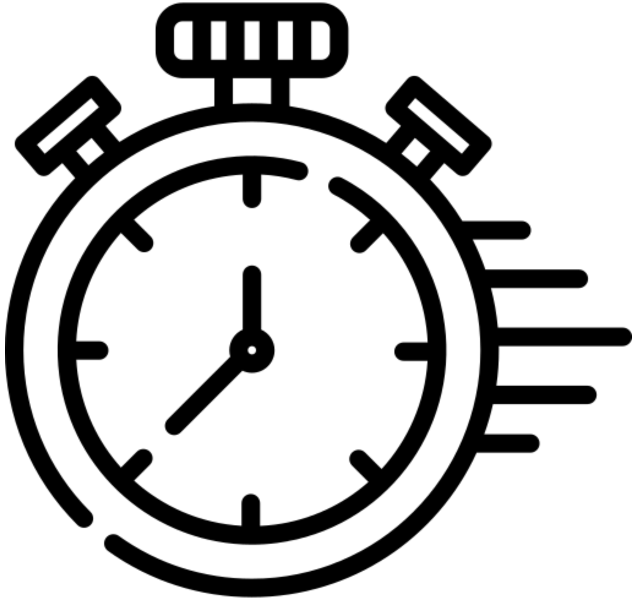
Because of their growth, it is assumed that a strong first-mover advantage prevails in the market.

This isn’t always the case and we study what could limit this.

Could the limit be the waiting time?

- Platforms have a key attractor: **waiting/idle time**

- Once it is low enough, is it still attractive?
    - 3 min vs 6 min
    - 1 min vs 2 min?
    - 30s vs 1 min??



What are the forces at play?

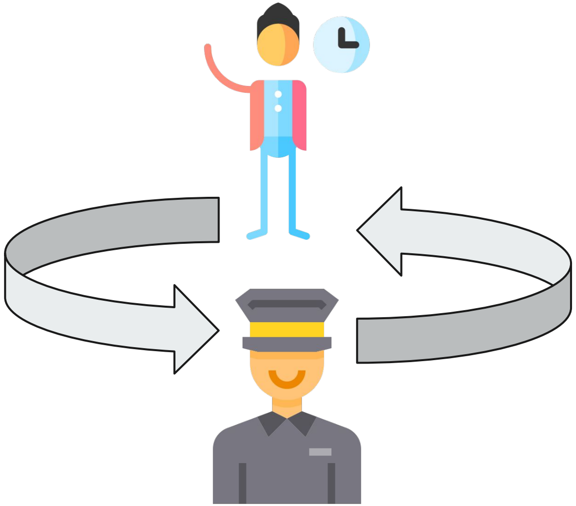
A high ride price is repulsive to riders

Agent	Scale	Sensitivity to ...	Cost efficiency
Riders	drivers	waiting time	ride prices
Drivers	riders	idle time	ride prices

green = positive factor | red = negative factor

A two sided feedback loop: agent based competition

- As a rider, drivers are a vital resource
- As a driver, riders become the resource
- This results in a two sided competitive feedback loop
    - competition among drivers (and riders)
    - competition for riders (and drivers)



Sun, M. and Tse, E., 2009. The resource-based view of competitive advantage in two-sided markets. Journal of Management Studies, 46(1), pp.45-64.

Summary of applicable models

Overview of modelling literature

	Agent based Model	Two-sided feedback loop	Competition for resources	Mathematically reproducible
Economics[1]	Mathematical Analysis			
Computational social science[2]			Isn’t modelled	
Biological processes[3]				

[1] Sun, M. and Tse, E., 2009. The resource-based view of competitive advantage in two-sided markets. Journal of Management Studies, 46(1), pp.45-64.
[2] Barabási, A.L. and Albert, R., 1999. Emergence of scaling in random networks. *science*, *286*(5439), pp.509-512.
[3] Delitala, M., Lorenzi, T. and Melensi, M., 2014. A structured population model of competition between cancer cells and T cells under immunotherapy. In *Mathematical Models of Tumor-Immune System Dynamics* (pp. 47-58). Springer, New York, NY.

Ride-hailing platforms in immunology?

Platform agents:		Human cells:
• agents compete amongst themselves for service (either rides or riders)	→	• Systematically compete amongst themselves for the body’s ressources
• As the population of agents increase, the effect of their respective waiting/idle times is magnified	→	• Overcrowding naturally hinders cell-growth

From immunology to ride-hailing platforms

- Directly models the population of two cell types (agents)
- Rigorous mathematical model
- Parameters can be mapped naturally to our situation
- Overcrowding and competition for resources are taken into account

A Structured Population Model of Competition Between Cancer Cells and T Cells Under Immunotherapy

Marcello Delitala, Tommaso Lorenzi, and Matteo Melensi

Delitala, M., Lorenzi, T. and Melensi, M., 2014. A structured population model of competition between cancer cells and T cells under immunotherapy. In *Mathematical Models of Tumor-Immune System Dynamics* (pp. 47-58). Springer, New York, NY.

The model's growth rate equations

Waiting/idle time sensitivities

$$R_{rider}(t, u_i) := \kappa_{driver}(t, u_i) - \mu_{waiting}\,\rho_{rider}(t, u_i) - \eta\rho_{rider}(t, u_i)$$

Price factors

$$R_{driver}(t, u_i) := \kappa_{rider}(t, u_i) - \mu_{idle}\,\rho_{driver}(t, u_i) + \eta\rho_{rider}(t, u_i)$$

with

$$\rho_A(t, u) = \frac{f_A(t, u)}{f_{rider}(t, u) + f_{driver}(t, u)} \qquad \kappa_A(t, u_i) = \frac{f_A(t, u_i)}{\sum_{j \neq i}^{U} f_A(t, u_j)} \qquad A \in \{rider, driver\}$$

Overpopulation factor

Barabasi like growth factors

Results

The data: NYC TLC*

- Monthly ride data from 2015 to 2019
- About 800 million individual rides
  - Spread out through 4 platforms: Uber, Lyft, Via and Juno
- Pickup/dropoff datetime (to the second)
- Location IDs:
  - LON/LAT for yellow/green cab
  - Split into neighbourhoods for our platforms

*Nyc.gov. (2018). *About TLC - TLC*. [online] Available at: https://www1.nyc.gov/site/tlc/about/tlc-trip-record-data.page.

The Simulation

At each timestep X agents are generated and become riders with probability *p*

- Agents choose which platform to join w.r.t. their type's rate equations

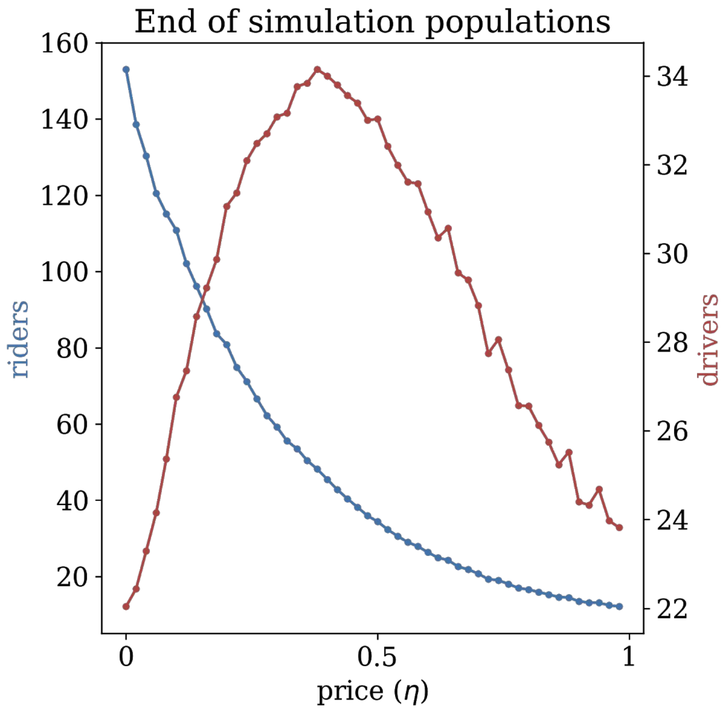
$$P_A(t, u_i) = \frac{R_A(t, u_i)}{\sum_j R_A(t, u_j)}$$

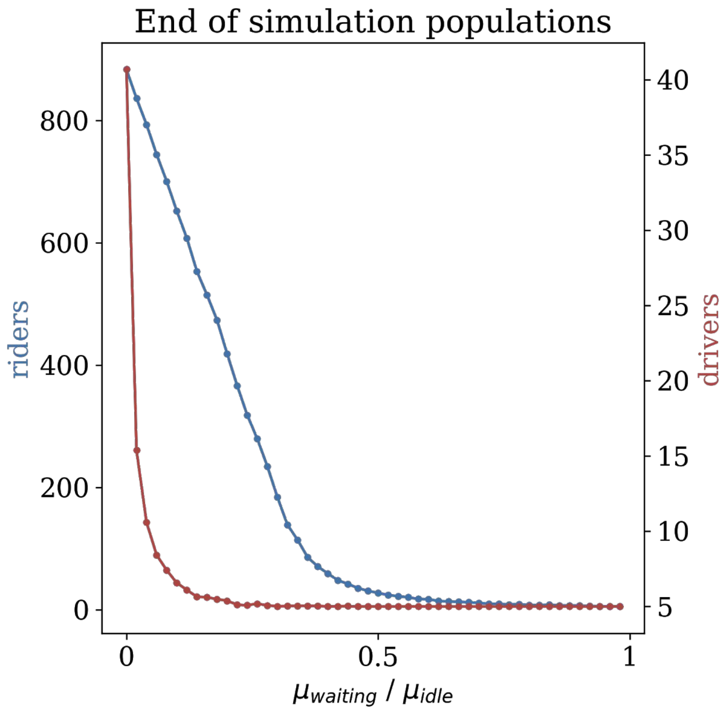
The three* free parameters are:

- $\boldsymbol{\mu}_{\text{waiting}}$ the sensitivity of riders on waiting time
- $\boldsymbol{\mu}_{\text{idle}}$ the sensitivity of drivers on idle time
- ***p*** the proportion of agents that are riders / drivers

* There is also the effect of ride pricing, which we ignore in this initial work

Reproducing intuitive results

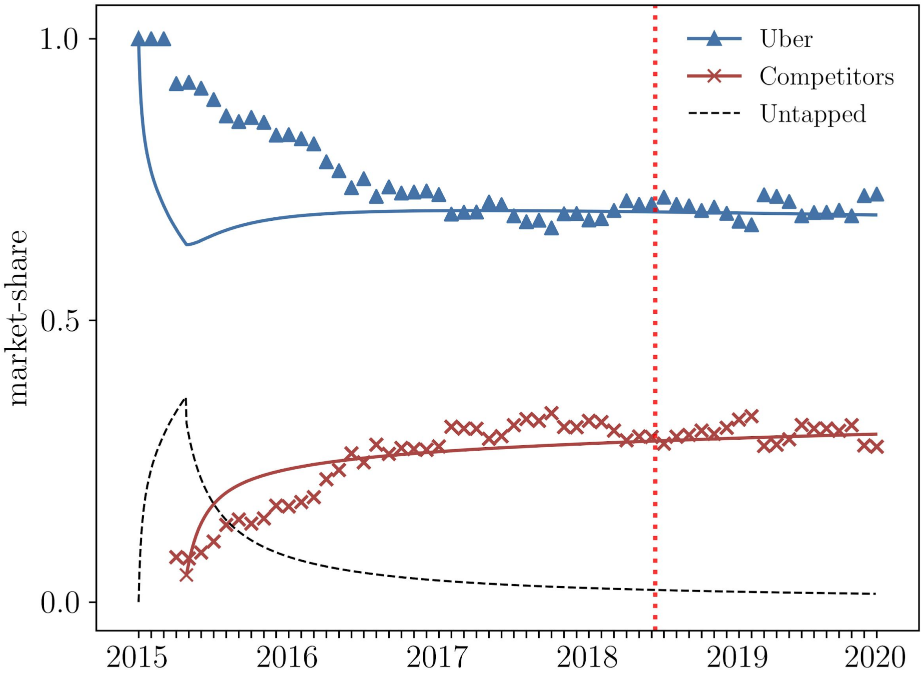




Market-share simulation results

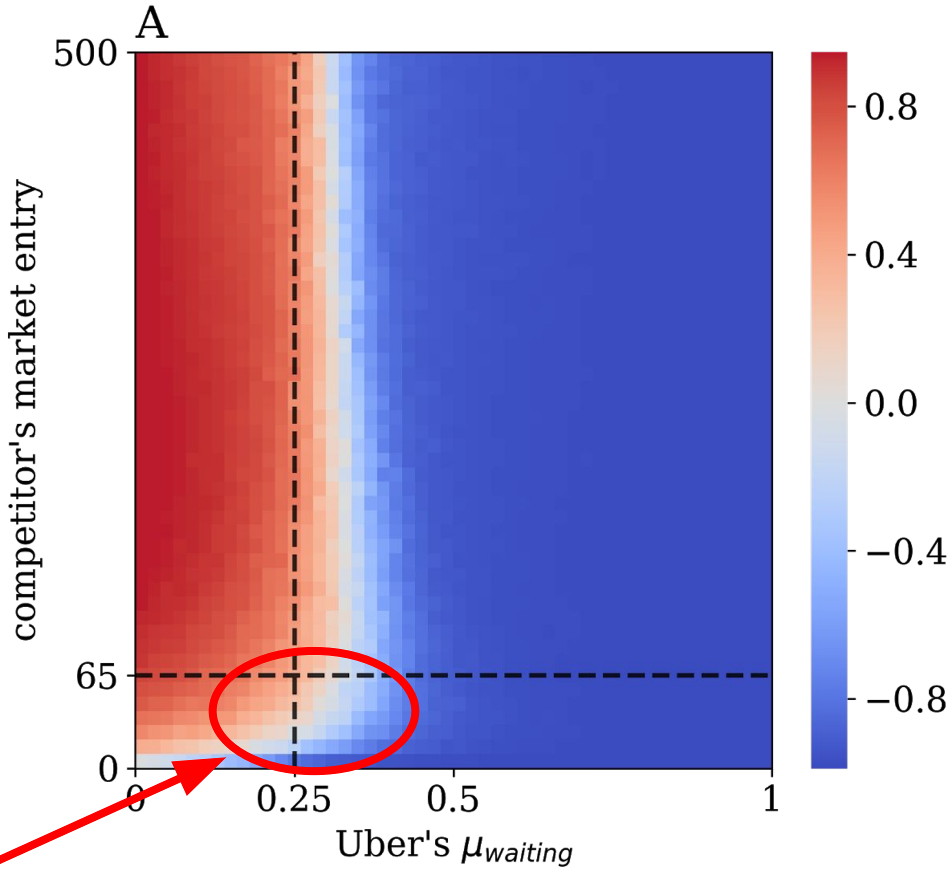
Solid lines are the simulation, markers are the real-world data

- Competitors: Lyft, Via and Juno
- The untapped market: unassigned agents
- The model was fit with the RMSE values to the left of the vertical red line



Alternative worlds

- sensitivity to waiting time is different (X)
- the competitors enter the market at different times (Y)
- Red: Uber has more market share
- Dotted lines: the real world

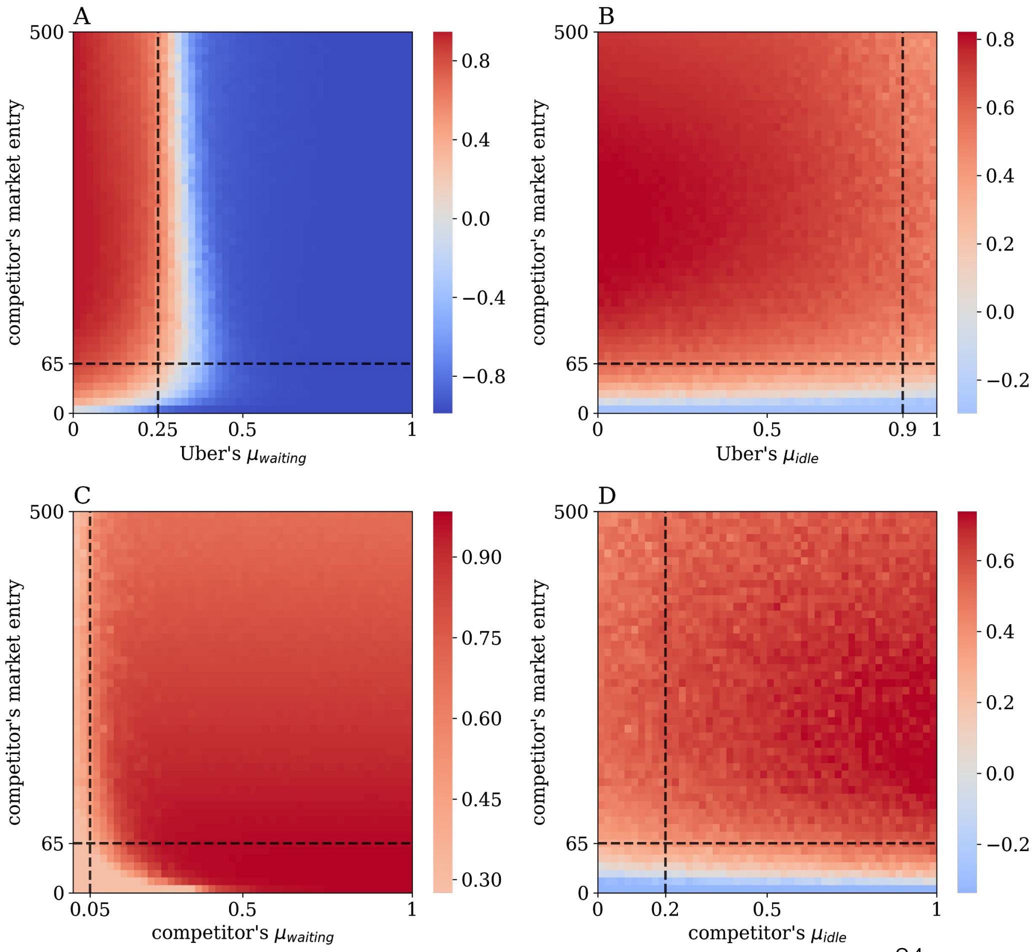


Waiting time can control first movers advantage

Sensitivity analysis

Extending this analysis we can see:

- **C:** a competitive boundary still exists
- **B, D:** the weakness of $\boldsymbol{\mu}_{\text{idle}}$



Future work

Improving rider/driver realism

- Increasing the complexity of the $\boldsymbol{\mu}_{\text{waiting}}$ and $\boldsymbol{\mu}_{\text{idle}}$ terms
  - Suggestion: model them as a distribution that changes over time
- Accounting for agent-level variance
  - Suggestion: sampling from a distributions of $\boldsymbol{\mu}_{\text{waiting}}$ and $\boldsymbol{\mu}_{\text{idle}}$

Improving platform realism

- Considering the geography of cities
  - Suggestion: model market-shares using an ensemble graph model (e.g. voronoi tessellation)
- Modelling the untapped market more accurately
  - Suggestion: Decrease the number of new agents over time

Studying the impact of price

- Study the impact of price
  - Suggestion: add η as a parameter in our model search / sensitivity analysis
- Increase the complexity of the η term
  - Suggestion: Sampling from a distribution for each agent, and have that distribution change over time

Key achievements

- ✓ Developed a simple graph-based model which captures micro-level intuitions and is capable of reproducing macroscopic behaviour
- ✓ Reproduced market-share growth from Uber and its competitors in NYC
- ✓ Sensitivity analysis based on the parameters that reflect the real-world situation
- ✓ Due to the model's origin, this work may shine a light on universal competitive dynamics (found both in ride-hailing platforms and in the human body)

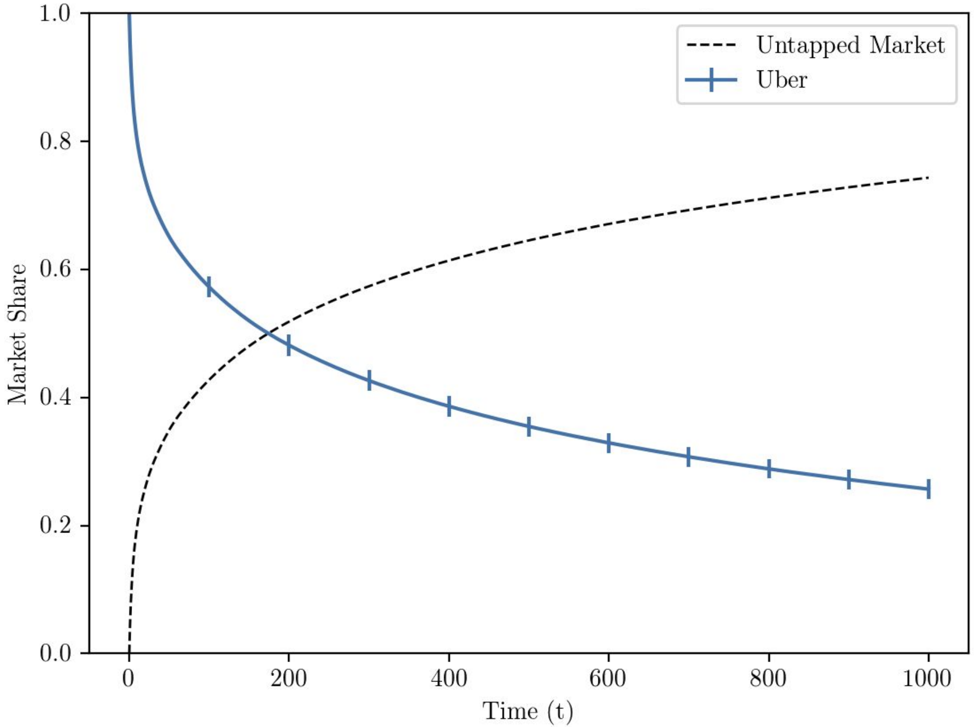
Questions?

Backup

Limits of the model

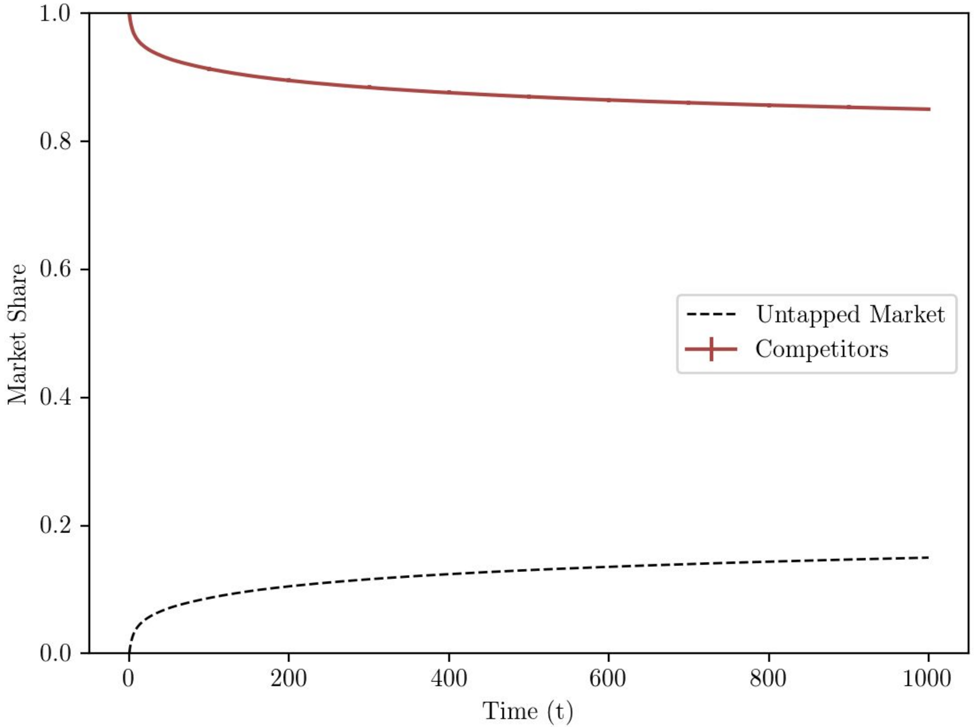
Limits of the simulation in a monopolistic setting

Uber in a monopoly
(with NYC parameters)



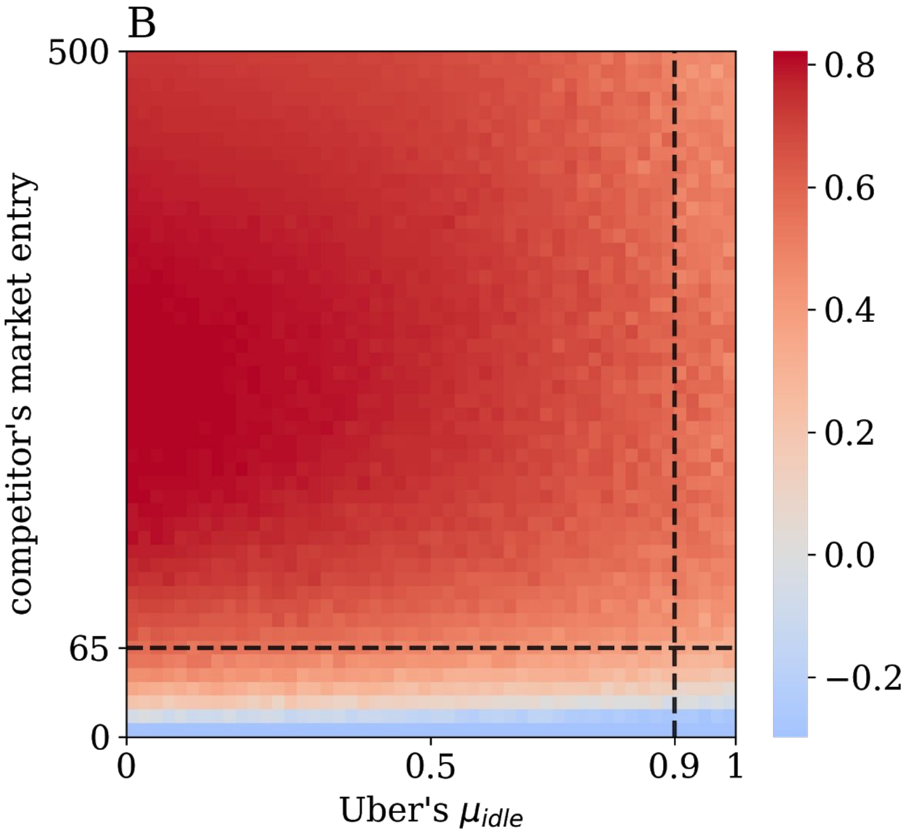
Limits of the simulation in a monopolistic setting

Competitors in a monopoly
(with NYC parameters)

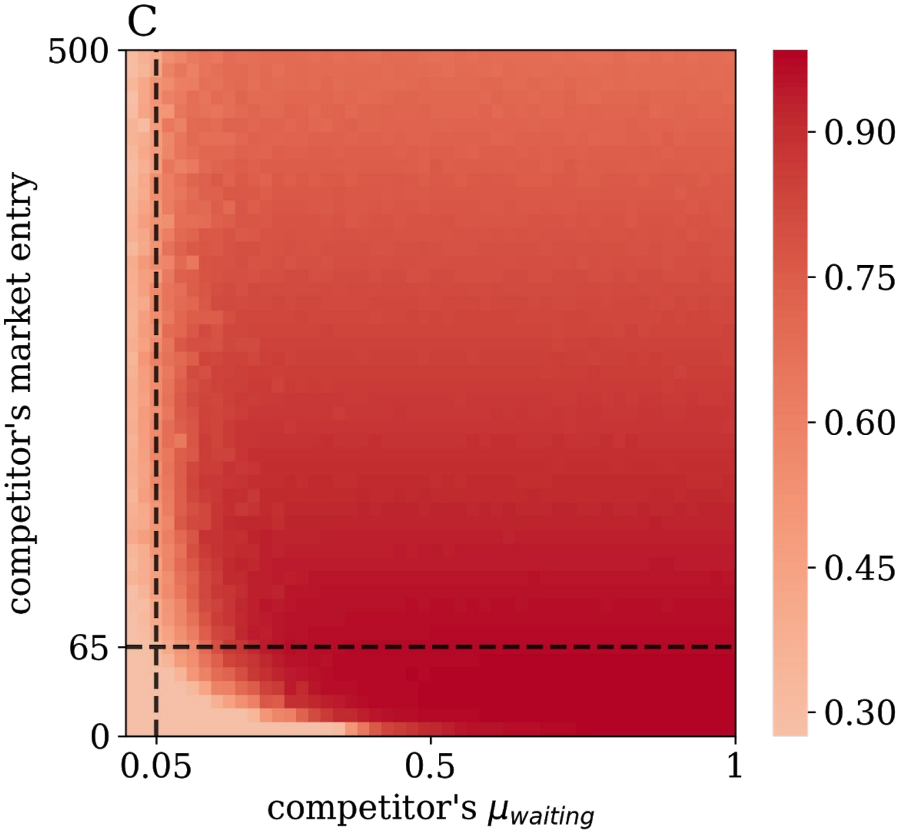


Individual sensitivity analyses

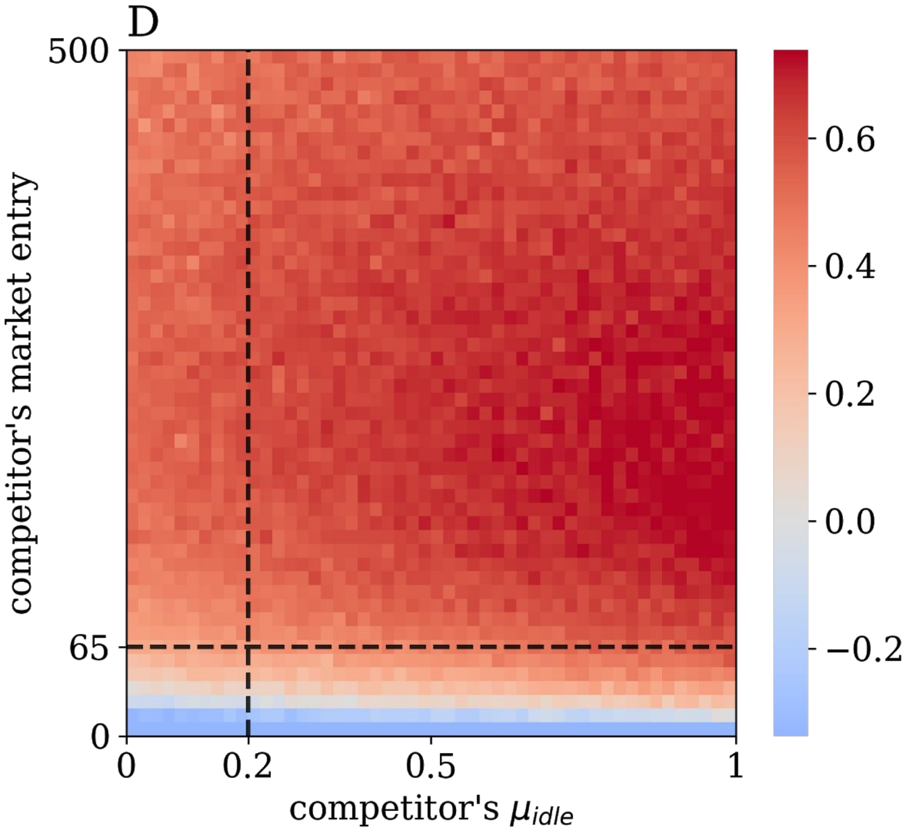
Uber’s sensitivity to idle time



Competitor’s sensitivity to waiting time



Competitor's sensitivity to idle time



The original cell population model

Population Model of Competition Between Cancer Cells and T Cells

$$R_C(t,u) := \underbrace{(\kappa_C - \mu_C \rho_C(t))}_{\text{cancer cell proliferation and competition for resources}} \underbrace{- \int_V \eta_{\theta_I}(|u-v|) f_I(t,v) dv}_{\text{action of T cells against cancer cells}},$$

$$R_I(t,v) := \underbrace{\left[\int_U \eta_{\theta_E}(|u-v|) f_C(t,u) du + \kappa_P c_P(t)\right]}_{\text{clonal expansion and boosting of T cell proliferation}} - \underbrace{\frac{\mu_I}{1+\mu_M c_M(t)} \rho_I(t)}_{\substack{\text{homeostatic regulation and} \\ \text{boosting of immune memory}}}. \tag{5}$$