

# Incentives in Ridesharing with Deficit Control

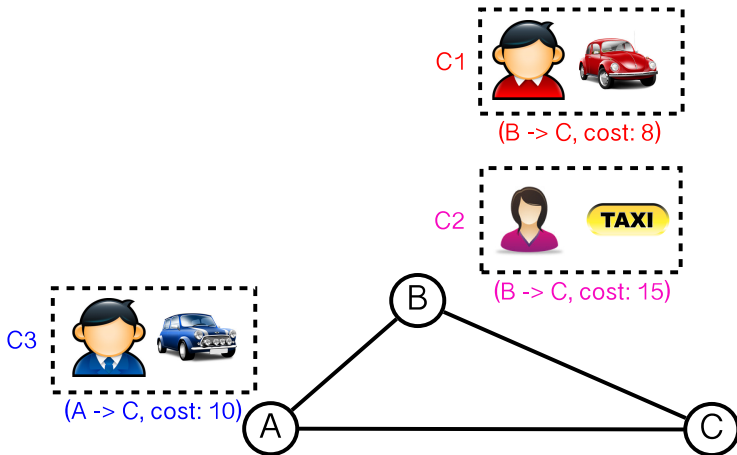
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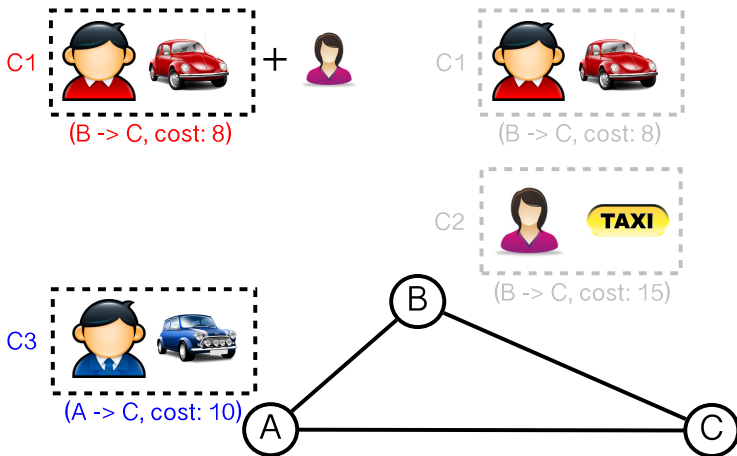
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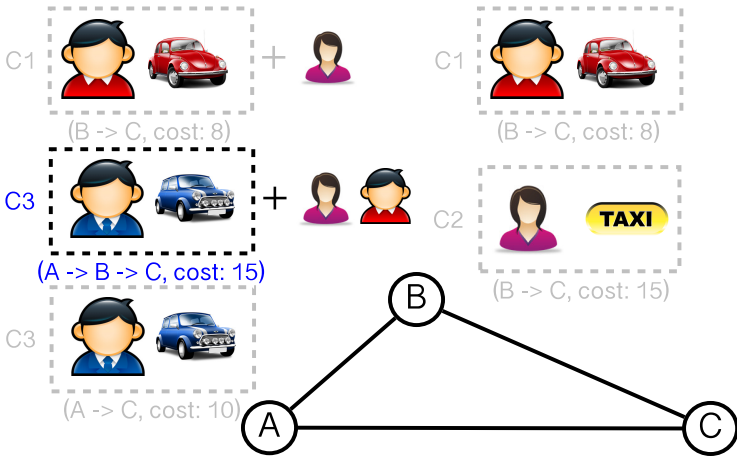
# Ridesharing Example



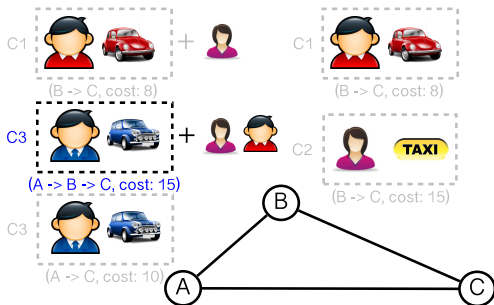
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## Questions:

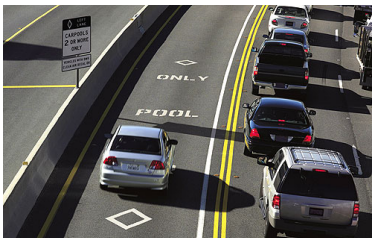
- How to arrange the sharing?
- How much should they pay/receive?

# History

- **Began** in the 1940s in North America
- Been **promoted** because of
  - fuel shortages, air pollution and traffic congestion
- **Peaked** in the US in 1970 with a commute mode share of 20.4%

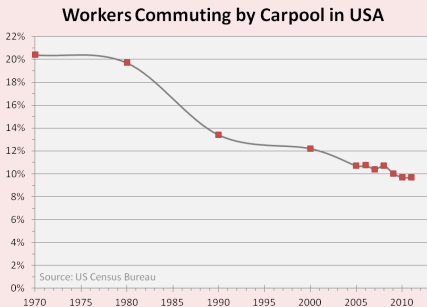


# Public and Private Promotions



# People are still NOT well motivated!

not going well...



- Australia (Queensland) will end ridesharing lanes
- The average car carries just 1.6 people



# What are the obstacles?

- Safety and Privacy
- Flexibility and Reliability
- ...

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- Flexibility and Reliability
- ...
- **Complicated join procedures**
- **No free market competition!**

# What we can do?

## Use Mechanism Design to build ridesharing:

- Automated ride matching
- Automated (profitable) price setting

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to answer...

### Questions:

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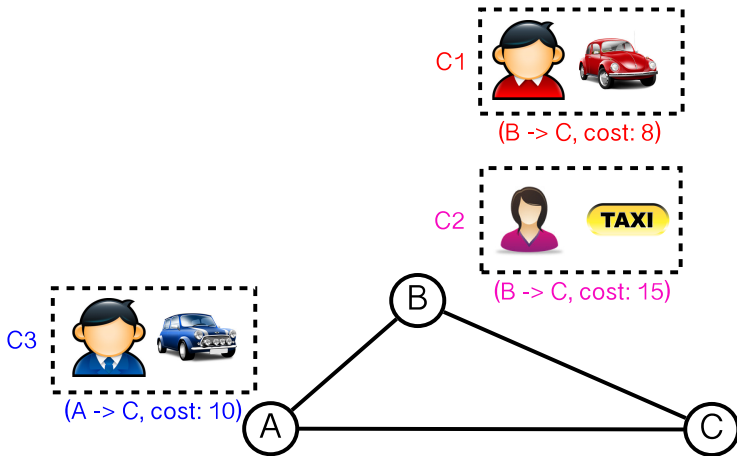
# Outline

- 1 The Model
- 2 Fixed-price Mechanisms
- 3 VCG with Reserve Prices
- 4 Conclusion

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- 1 The Model
  - Auction-based Ridesharing
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# System Overview



# System Overview

- Route map: a graph  $G = (L, E)$ ,
  - $L$ : stopping points/locations,
  - $E$ : routes between stopping points,
  - $w(e)$ : time required to travel via route  $e \in E$ .
- $i$ 's trip type:  $\theta_i = (l_i^d, l_i^a, t_i^d, t_i^a, c_i, q_i)$ 
  - $l_i^d, l_i^a \in L$ : departure and arrival **locations**,
  - $t_i^d, t_i^a$ : earliest departure and latest arrival **time**,
  - $c_i \in \mathbb{R}^+$ : travel **cost** to finish the trip,
  - $q_i \in \mathbb{N}$ : extra **seats available** on the trip.



# System Overview

- Allocation/Scheduling:
  - **driver**: drives and takes riders
  - **rider**: shares with drivers
  - **unmatched**: goes with his original preference
- Payments:
  - driver: receives money
  - rider: pays money
  - unmatched: no payment

# The Goal of the System

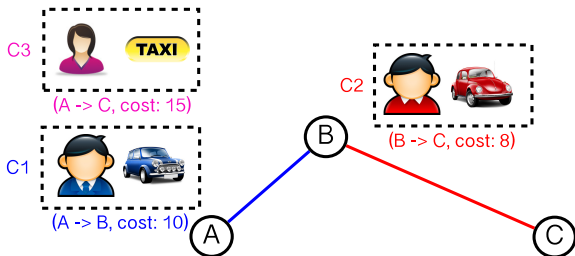
- Minimize the total travel costs (**efficiency**)
- Incentivize participation and against manipulations
  - Agents never receive negative utility (**individual rationality**)
  - Truthfully report their trip information is a dominant strategy (**truthfulness**)
- **Control deficit** (budget balance)
  - The system owner should not lose too much money

# Solution: Applying VCG Mechanism

- Efficient (cost minimizing)
- Individually rational
- Truthful
- High deficit ( $m$  times of the cost saved!)

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## Question

How to control deficit?

# Our Solutions (Overview)

We propose...

Fixed-price Mechanisms :

- Flexible deficit control (outperforms VCG)
- Truthful and individually rational
- Very inefficient

VCG with Reserve Prices :

- Flexible deficit control (outperforms VCG)
- (Partially) truthful and individually rational
- Flexible efficiency control

# Outline

- 1 The Model
- 2 Fixed-price Mechanisms
  - $x^{fixed}(p^0, p^1)$
- 3 VCG with Reserve Prices
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$x^{fixed}(p^0, p^1)$ 

# Fixed Payments $x^{fixed}(p^0, p^1)$

Given predefined values  $p^0 \geq 0$  (for riders) and  $p^1 \leq 0$  (for drivers), fixed payments are defined

- Allocation independent
- Allocation dependent
  - location dependent (shortest path)
  - detour dependent
  - sharing dependent
  - ...



$x^{fixed}(p^0, p^1)$ 

# Dictatorship Mechanism

## Serial Dictatorship Mechanism with fixed payments

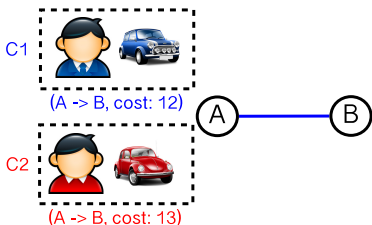
- 1 Predefine the set of (potential) drivers and riders
- 2 Order potential drivers and riders
- 3 Maximize drivers' utility according to the order
- 4 Each driver/rider gets the fixed payment

## Properties

- truthful and individually rational
- better deficit control than VCG
- very inefficient

$x^{fixed}(p^0, p^1)$ 

# Problems of Non-dictatorship Mechanisms



## Case I:

- `fixedPay = 10`
- both prefer drive
- potential problem for deterministic mechanisms

## Case II:

- `fixedPay = 1`
- both prefer ride
- potential problem for all mechanisms

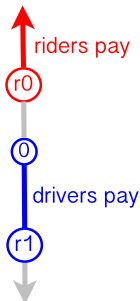
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- 1 The Model
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- 3 VCG with Reserve Prices**
  - $\mathcal{M}^{VCG}(r^0, r^1)$
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$\mathcal{M}^{VCG}(r^0, r^1)$ 

# VCG with Two-Sided Reserve Prices $\mathcal{M}^{VCG}(r^0, r^1)$

Predefined reserve prices  $r^0 \geq 0$  (for riders) and  $r^1 \leq 0$  (for drivers),



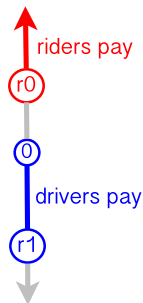
Note:  $r_0$  and  $r_1$  can be allocation dependent.

$\mathcal{M}^{VCG}(r^0, r^1)$ 

# Properties of $\mathcal{M}^{VCG}(r^0, r^1)$

$\mathcal{M}^{VCG}(r^0, r^1)$  is

- **truthful** iff  $r^0 \geq -r^1$ . Otherwise, the manipulation gain is bounded ( $\max(-r^1 - r^0, \delta_i^{\max}(-r^1 - r^0))$ ).
- weakly **budget balanced** without detour. Otherwise, deficit is bounded ( $-n_d \delta^{\max} r^1 - n_r r^0$ ).
- more **efficient** as  $r^0 + r^1$  decreases.



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- 1 The Model
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  - Done and ToDo

# What is NEW?

- The **first comprehensive ridesharing model** studied from a pure game-theoretic point of view.
- **Auction-based** ridesharing system incentivizing participation.
- Flexible **deficit control** rather than completely remove deficit.

# Future Work

- Tradeoff between deficit and efficiency (theoretically or simulations).
- The problem of finding optimal schedules is computationally hard (optimal in range).
- Allow agents to submit trips dynamically over time (online mechanism design).