Frictions in a Competitive, Regulated Market: Evidence from Taxis

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RESEARCH QUESTION

Close to textbook case of competitive market:

- *Firm = Driver + Car + Gasoline*.
- Low natural entry barriers: modest skill requirements.
- Limited room for product differentiation.
- Price taking behavior.

RESEARCH QUESTION

However:

- Restrictions on extensive margin (entry) and intensive margin (ownership rules) affect capital/labor utilization.
- Shift frictions.
- Prices are fixed.
- Search frictions.
- Network externalities.

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Question: Relative importance of these frictions?

Motivation

Broader Motivation

Entry restrictions:

- Occupational licensing.

Shift frictions:

- Flexibility of work arrangements.
- Overtime rules.

Search frictions:

- Labor markets, housing markets,...

Network externalities:

- Trading platforms, financial markets.

WHAT WE DO

Data and Setting: New York City Yellow Cabs

- Entire market (13520 medallions), every trip, driver/medallion id, earnings.

Structure: General equilibrium model.

- Supply: Drivers make entry and stopping decisions.
- Fixed fares: wait-time (for passengers) and search-time (for cabs) clear market.
- Matching process determines wait/search time and wages.

WHAT WE DO

KEY EMPIRICAL CHALLENGE

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- $s_1 = g(C_1, D_1), s_2 = g(C_2, D_2)$. If $C_2 = C_1$ and $s_1 > s_2 \Rightarrow D_2 > D_1$
- Problem: $g()$ is not known.

What we do

Key empirical challenge

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- Problem: $g()$ is not known.

Solution:

- Use geographical structure of Manhattan and **simulate** $g()$.

PREVIEW COUNTERFACTUAL RESULTS (I)

Regulation:

- Shift indivisibilities: strong differences in intra-daily labor supply elasticities.
- Entry: + 10% medallions
  - Consumer surplus: $+4.74\%$.
  - Drivers: -0.9%
  - Medallion Owners: -0.87%
- Similar results for regulations that affect intensive margin.

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Dispatch:

- Manhattan Dispatch
  - Consumer surplus: $+6.1\%$.
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  - Consumer surplus: -9.88%.
  - Passenger wait time: $+23.0\%$
  - Driver revenue: -5.4%

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Returns to density

- Brooklyn (relative to baseline):
  - Consumer surplus: -28.3%
  - Driver revenue: -17.5%
- Brooklyn Dispatch (relative to baseline):
  - Consumer surplus: -1.0%
  - Driver revenue: -1.6%

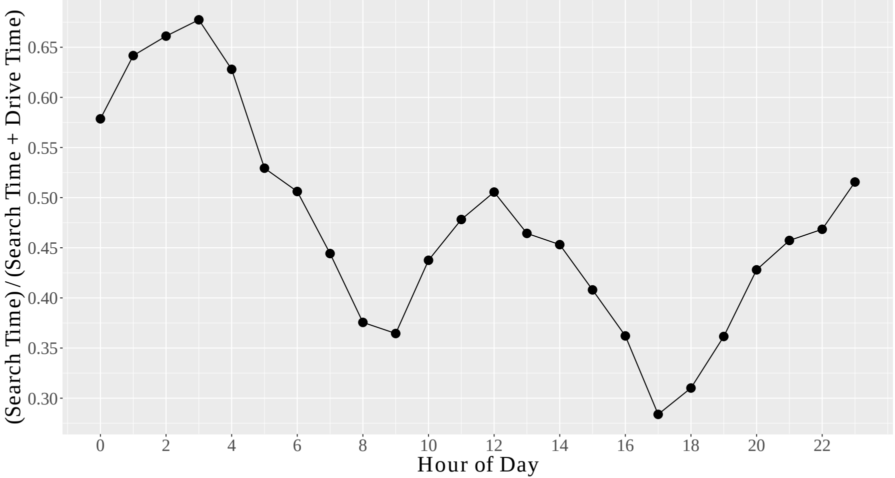
RELATED LITERATURES

Taxi/Rideshare: Camerer et al. (1997), Lagos (2003), Farber (2008), Crawford and Meng (2011), Haggag and Paci (2014), Buchholz (2015), Farber (2015), Cramer and Krueger (2016), Cohen et al. (2016), Hall and Krueger (2016), Angrist et al.(2017), Chen et al. (2017), Molnar (2017), Buchholz et al. (2017). Thakral and To (2017), Castillo and Weyl (2017), Cook et al. (2018).

Entry/Labour Supply of private contractors: Oettinger (1999), Bresnahan and Reiss (1991), Berry (1992), Jia (2008), Holmes (2011), Ryan (2012), Collard-Wexler (2013), Kalouptsidi (2014).

FRICTIONS: FRACTION OF TIME SPENT SEARCHING

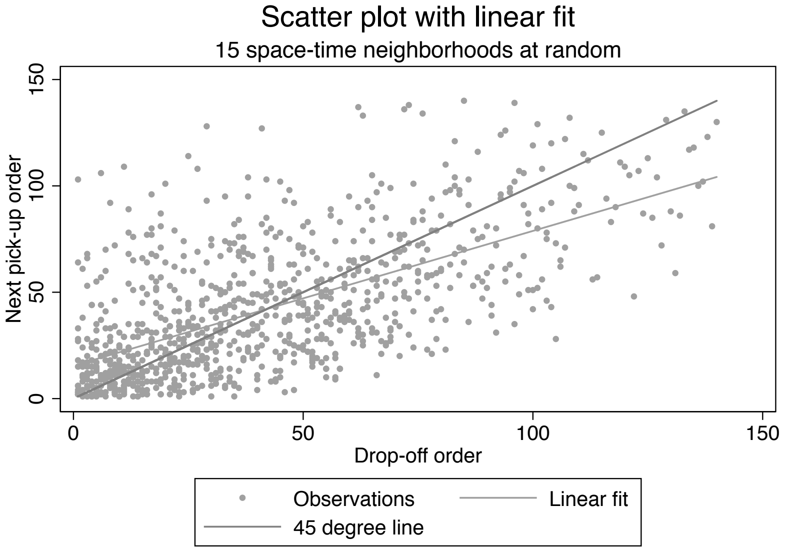
MARKET CLEARS ON SEARCH-TIME AND WAIT-TIME.



Drivers spend 220% of the time it would take under **optimal**

FRICTIONS: FRACTION OF TIME SPENT SEARCHING

MORE EVIDENCE OF SEARCH FRICTIONS.



FRICTIONS: ENTRY

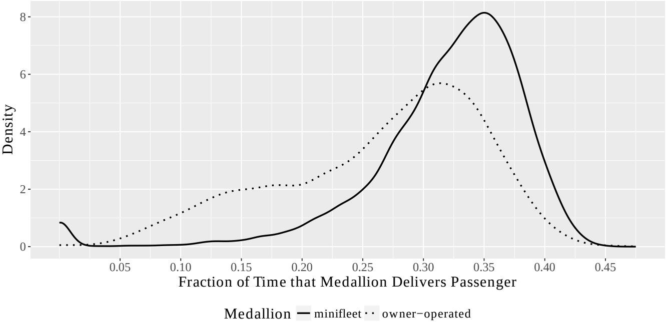
- High medallion prices: over \$500K in sample.
- No idle cabs: over 96% on weekdays.

OWNERSHIP FRICTION AND UTILIZATION RATES

Regulation: $\approx$ 40% must be **("owner-operated")**

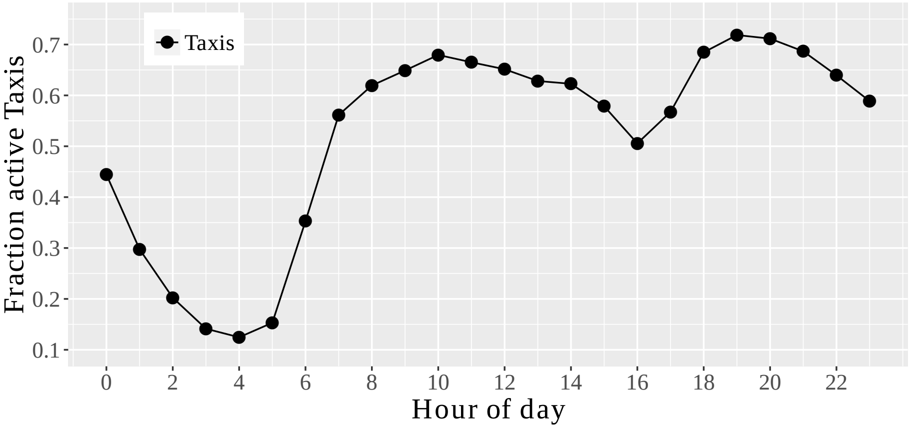
- Substantial time burden: 210 shifts per year.
- Effectively prevents corporate management.
- Big differences between owner-operated and corporate medallions.

FRICTIONS: UTILIZATION BY TYPE



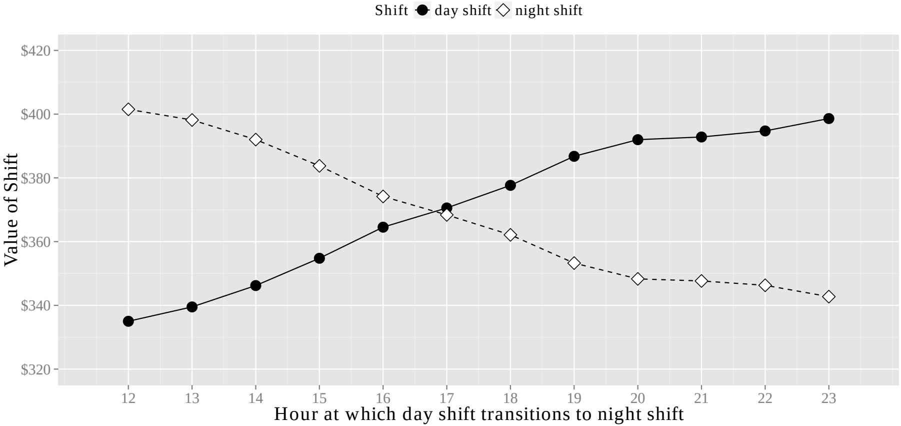
PATTERNS OF SUPPLY

INTRADAILY ACTIVITY



Shift Division

Income split



MODEL OVERVIEW

Supply Side:

- Drivers make daily entry and hourly stopping decisions.
- Compare value of outside option with earnings.
- Total number of entrants limited by number of medallions.
- Earnings depend on arrival rate of passengers and number of competing taxis.

Demand Side:

- Almost no fare variation.
- Number of passengers function of waiting time.

DEMAND

Two Steps:

- Recover unobserved demand.
- Estimate and deal with simultaneity.

FIRST STEP

Idea: Taxi search time informative about number of people waiting.

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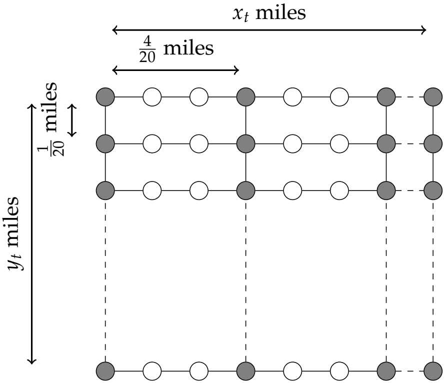
Use **geographical structure** of Manhattan to obtain:

$$\begin{pmatrix} s_t \\ w_t \end{pmatrix} = g(d_t, c_t, \phi_t)$$

- Simulate w_t and s_t for many $(d_t, c_t, mph_t, distance_t)$.
- Invert $g(.)$ to back out d_t and w_t.

Matching Simulation

A stylized representation of Manhattan



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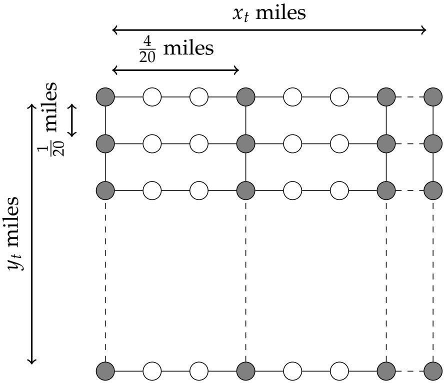

with $y_t/x_t = 4$ and $y_t \cdot x_t = a_t$

Baseline

- Turns only on grey nodes.
- No U-turns.
- Take turns randomly.
- Passengers stay put.
- Passenger abandon wait after 20 minutes.

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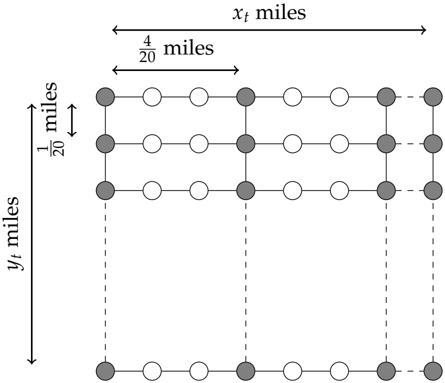

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Baseline

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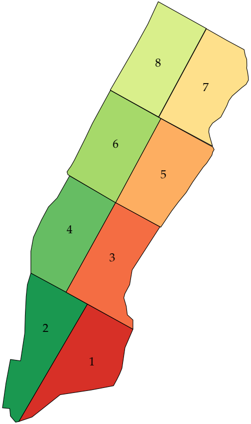
Dispatch

- Match **vacant** taxi to closest available passenger.

Matching Simulation

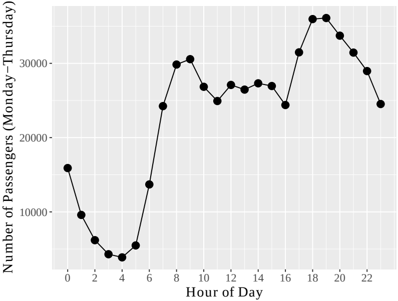
Homogeneity across Areas

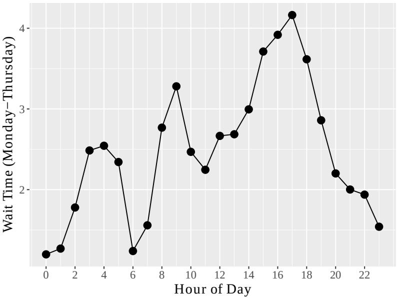


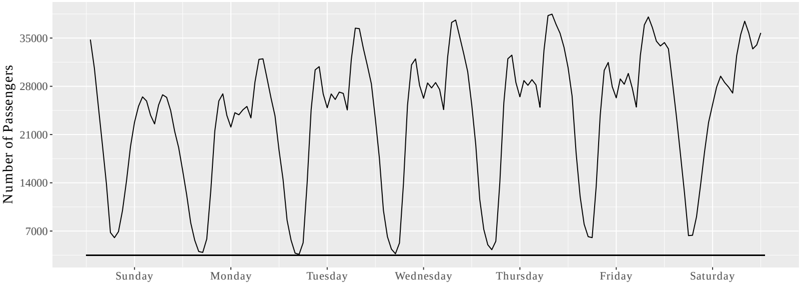
	Travel Distance	Search time
Area	Mean	Mean
1	2.67	11.64
2	2.08	9.15
3	1.88	8.6
4	2.06	9.21
5	1.74	8.34
6	1.85	8.79
7	1.94	9.68
8	2.41	11.42

- Use *observed distribution* of request and pickup locations in simulation.
- Demand estimation robust to smaller and bigger divisions.

DEMAND: RESULT







Demand: Result

Validation with weather data

Regress recovered demand and wait-time on **rainfall dummy**.

	(1)	(3)	(4)	(6)
	$log(d_t)$	$log(d_t)$	$log(w_t)$	$log(w_t)$
Rainfall	0.261**	0.247**	0.355**	0.463**
	(0.014)	(0.0083)	(0.011)	(0.0083)
Hour FE	No	Yes	No	Yes
Day of W. FE	No	Yes	No	Yes

DEMAND: ESTIMATE DEMAND FUNCTION

Constant elasticity, log-linear demand function:

$$d_t = exp(a + \sum_{h_t} \beta_{h_t} \cdot \mathbf{1}\{h_t\}) \cdot w_t^{\eta} \cdot exp(\xi_t) \Leftrightarrow$$

$$log(d_t) = a + \sum_{h_t} \beta_{h_t} \cdot \mathbf{1}\{h_t\} + \eta \cdot log(w_t) + \xi_t$$

DEMAND: ESTIMATES

Simultaneity:

- Drivers and passengers respond to unobserved shocks.
- $cov(\xi_t, w_t) \neq 0$

DEMAND: PREDICTABILITY

Supply rationed: hard to find supply side instruments.

Dependent Variable:	$log(w_t)$	$log(s_t)$	$log(w_t)$	$log(s_t)$
Observations	1428	1428	1428	1428
Hour FE	Yes	Yes	No	No
Hour x Day of Week FE	No	No	Yes	Yes
R^2	0.838	0.890	0.895	0.931

- Hour controls account for most variation.

DEMAND: INSTRUMENTS

Shift transition:

- Driven by supply side constraints.
- Long run demand adjusts.
- Possibly too coarse.

Trip Distance:

- Longer taxi trips lead to less supply.
- Use trip distance outside of Manhattan.

Number of active cabs in previous periods:

- Shift indivisibilities.

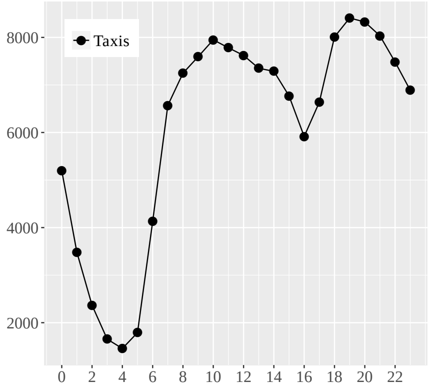
DEMAND: ESTIMATES

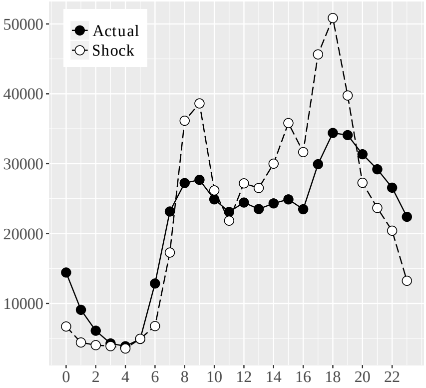
THREE DIFFERENT SPECIFICATIONS

	$log(d_t)$	$log(d_t)$	$log(d_t)$
	(1)	(2)	(3)
	lognump	lognump	lognump
logwait	-0.693**	-0.441**	-0.536**
	(0.0900)	(0.161)	(0.0315)
Observations	1531	1531	1531
Hour FE	Yes	Yes	No
2-Hour FE	No	No	Yes
R^2	0.950	0.964	0.948

Note: $+\ p < 0.10$, $*\ p < 0.05$, $**\ p < 0.01$. All specifications include traffic speed as control. Standard errors clustered at

DEMAND: RESULT





SUPPLY SIDE: STOPPING PROBABILITIES

SUPPLY SIDE: STOPPING DECISION

Shift value of driver i at time t:

$$V(\mathbf{x}_{it}, \boldsymbol{\epsilon}_{it}) = max\{\epsilon_{it0}, \pi_t - C_{z_i,h_t}(l_{it}) - f(h_t, k_i) + \epsilon_{it1} \\ + \beta \cdot E_{\boldsymbol{\epsilon}}[V(\boldsymbol{x}_{t+1}, \boldsymbol{\epsilon}_{i,(t+1)})|\mathbf{x}_{i,(t+1)}]\}$$

With:

- $\mathbf{x}_{it} = (l_t, h_t), h_t \in \{0, 23\}$.

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- $\epsilon_{it0}, \epsilon_{it1} \sim T1EV\ iid$, $f_{z_i}(h_t, k_i) = f_{z_i} \cdot \mathbf{1}\{h_t \in h_{k_i}\}$: late fine.

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- $\pi_t = \pi_0 \cdot \frac{\mathbb{E}\left[DELIVERYTIME_t|h_t\right]}{\mathbb{E}\left[DELIVERYTIME_t|h_t\right] + \mathbb{E}\left[SEARCHTIME_t|h_t\right]}$: hourly earnings.

SUPPLY SIDE: ENTRY DECISION

Compare: $u_{ijt0} = \mu_{h_t,k_i} + v_{it0}$ w/
$u_{ijt1} = EV(\boldsymbol{x}_{t+1}|h_{t+1}) - r_{h_t} + v_{it1}$ under $v_{it0}, v_{it1} \sim T1EV\ iid$, variance σ_v^2

We obtain the probability of entry:

$$p^I(\mathbf{x}_{it}) = \frac{exp((EV(\boldsymbol{x}_{t+1}|h_{t+1}) - r_{h_t})/\sigma_v))}{exp((EV(\boldsymbol{x}_{t+1}|h_{t+1}) - r_{h_t})/\sigma_v)) + exp(\mu_{h_t}/\sigma_v)}$$

EQUILIBRIUM DEFINITION

Definition

A competitive equilibrium in the taxi market at time t is a set: $\{s_{h_t}, w_{h_t}, c_{h_t}, d_{h_t}, \pi_{h_t} : h_t \in H_t\}$, such that:

1. d_{h_t} results from the demand function $d(.)|h_t$ under the waiting time w_{h_t}.
2. s_{h_t} and w_{h_t} result from d_{h_t} and c_{h_t} under the matching function $g(.)|h_t$.
3. c_{h_t} results from optimal starting and stopping under π_{h_t}.
4. π_{h_t} results from s_{h_t}.

SUPPLY SIDE ESTIMATION

- Shift definition same as in Farber (2008).
- Estimation via **MPEC**.
- Different parameters for owner-operators and mini-fleet.
- Estimate for “average” weekday, Monday-Thursday.
- Match starting and stopping probabilities.

ESTIMATION: MPEC

$$\min_{\theta, p(\mathbf{x}_{it}), q(\mathbf{x}_{it}), EV(\mathbf{x}_{jt}|h_t)} \sum_{j\in J}\sum_{t\in T_i} d^A_{it}\cdot log(p(\mathbf{x}_{it})) + (1-d^A_{it})\cdot(log(1-p(\mathbf{x}_{it})))$$
$$+ d^I_{it}\cdot log(q(\mathbf{x}_{it})) + (1-d^I_{it})\cdot(log(1-q(\mathbf{x}_{it}))))$$

subject to:

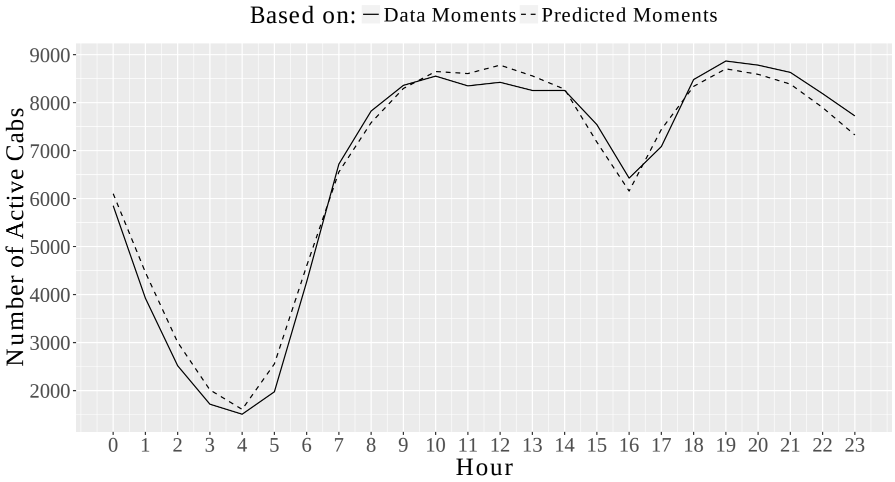
$$E_{\boldsymbol{\epsilon}}V(\boldsymbol{x}_t|h_t) = \sigma_\epsilon \cdot log\left(exp\left(\frac{1}{\sigma_\epsilon}\right) + exp\left(\frac{\pi_t - C_{\boldsymbol{x}_t}(\boldsymbol{x}_t) - f(\boldsymbol{x}_t) + E_{\boldsymbol{\epsilon}}V(\boldsymbol{x}_{t+1}|h_{t+1})}{\sigma_\epsilon}\right)\right) \quad \forall \boldsymbol{x}_{it}\in\boldsymbol{X}$$

$$p(\boldsymbol{x}_{it}) = \frac{exp\left(\frac{1}{\sigma_v}\right)}{exp\left(\frac{1}{\sigma_v}\right) + exp\left(\frac{\pi_t - C_{\boldsymbol{x}_t}(\boldsymbol{x}_t) - f(\boldsymbol{x}_t) + E_{\boldsymbol{\epsilon}}V(\boldsymbol{x}_{t+1}|h_{t+1})}{\sigma_v}\right)} \ \forall \boldsymbol{x}_{it}\in\boldsymbol{X}$$

$$q(\boldsymbol{x}_{it}) = \frac{exp\left(\frac{E_{\boldsymbol{\epsilon}}V(\boldsymbol{x}_{t+1}|h_{t+1}) - r_{\boldsymbol{x}_t}}{\sigma_v}\right)}{exp\left(\frac{E_{\boldsymbol{\epsilon}}V(\boldsymbol{x}_{t+1}|h_{t+1}) - r_{\boldsymbol{x}_t}}{\sigma_v}\right) + exp\left(\frac{\mu_{s_t}}{\sigma_v}\right)} \ \forall \boldsymbol{x}_{it}\in\boldsymbol{X}$$

▸ Go back

Model Fit


Based on: Data Moments Predicted Moments
Number of Active Cabs
9000
8000
7000
6000
5000
4000
3000
2000
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour

ESTIMATION RESULTS

Table: Parameter Estimates (standard errors in parentheses)

parameter	**description**	**minifleet** ($z_i = F$)	**owner-operated** ($z_i = NF$)
$\mu_{z_i,0}$	outside-option, 6pm-4am	299.59 (8.029)	311.33 (1.321)
$\mu_{z_i,1}$	outside-option, 5am-5pm	312.95 (7.249)	312.97 (2.343)
f_{0,z_i}	fine (nightshift)	87.25 (2.174)	90.58 (8.721)
f_{1,z_i}	fine (dayshift)	91.6 (2.897)	72.14 (7.759)
$\lambda_{0,z_i,0}$	fixed cost (1am-5am),	82.46 (11.62)	80.22 (14.956)
$\lambda_{0,z_i,1}$	fixed cost (6am-12pm),	62.15 (12.398)	44.96 (15.373)
$\lambda_{0,z_i,2}$	fixed cost (1pm-5pm),	47.81 (11.672)	43.45 (14.61)
$\lambda_{0,z_i,3}$	fixed cost (6pm-12am),	58.82 (11.142)	42.44 (14.204)
λ_{1,z_i}	linear cost coefficient	-14.08 (0.903)	-6.63 (0.428)
λ_{2,z_i}	quadratic cost coefficient	1.46 (0.09)	0.88 (0.052)
σ_ϵ	sd iid hourly outside option	59.1 (3.337)	59.1 (3.337)
σ_v	sd iid daily outside option	54.15 (2.954)	54.15 (2.954)

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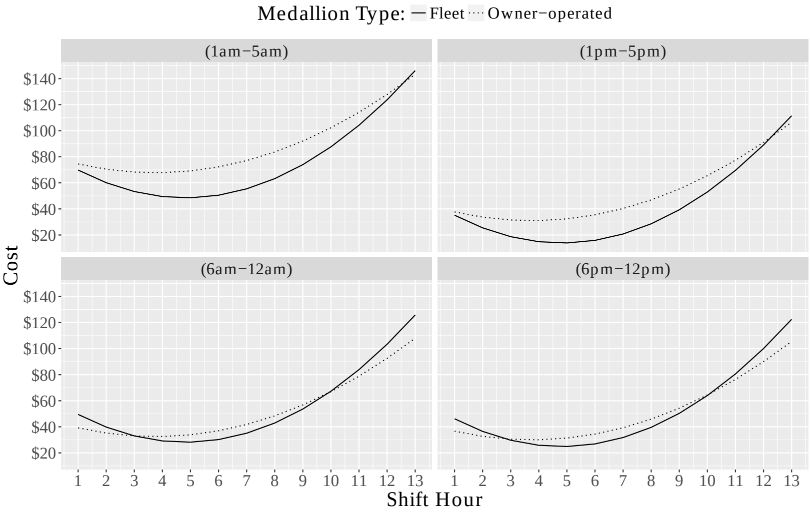
λ_{1,z_i}	linear cost coefficient	-14.08 (0.903)	-6.63 (0.428)
λ_{2,z_i}	quadratic cost coefficient	1.46 (0.09)	0.88 (0.052)
σ_ϵ	sd iid hourly outside option	59.1 (3.337)	59.1 (3.337)
σ_v	sd iid daily outside option	54.15 (2.954)	54.15 (2.954)

ESTIMATION RESULTS

Table: Parameter Estimates (standard errors in parentheses)

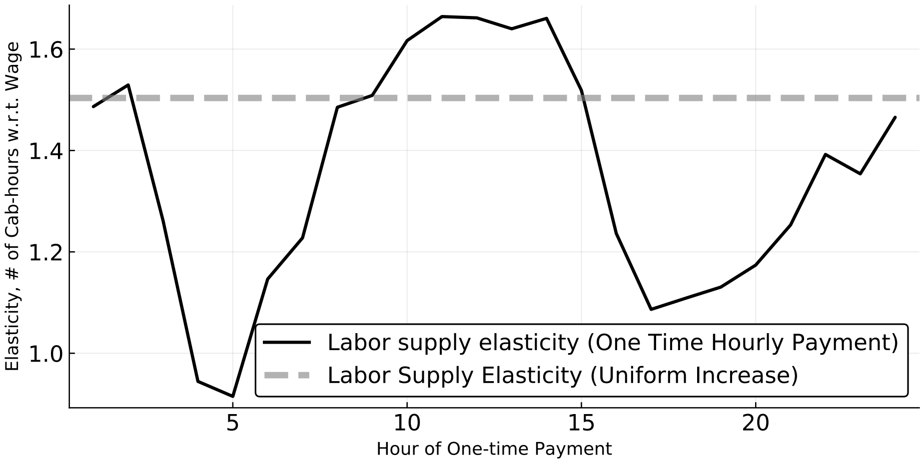
parameter	**description**	**minifleet** ($z_i = F$)	**owner-operated** ($z_i = NF$)
$\mu_{z_i,0}$	outside-option, 6pm-4am	299.59 (8.029)	311.33 (1.321)
$\mu_{z_i,1}$	outside-option, 5am-5pm	312.95 (7.249)	312.97 (2.343)
f_{0,z_i}	fine (nightshift)	87.25 (2.174)	90.58 (8.721)
f_{1,z_i}	fine (dayshift)	91.6 (2.897)	72.14 (7.759)
$\lambda_{0,z_i,0}$	fixed cost (1am-5am),	82.46 (11.62)	80.22 (14.956)
$\lambda_{0,z_i,1}$	fixed cost (6am-12pm),	62.15 (12.398)	44.96 (15.373)
$\lambda_{0,z_i,2}$	fixed cost (1pm-5pm),	47.81 (11.672)	43.45 (14.61)
$\lambda_{0,z_i,3}$	fixed cost (6pm-12am),	58.82 (11.142)	42.44 (14.204)
λ_{1,z_i}	linear cost coefficient	-14.08 (0.903)	-6.63 (0.428)
λ_{2,z_i}	quadratic cost coefficient	1.46 (0.09)	0.88 (0.052)
σ_ϵ	sd iid hourly outside option	59.1 (3.337)	59.1 (3.337)
σ_v	sd iid daily outside option	54.15 (2.954)	54.15 (2.954)

COST FUNCTION ESTIMATE



LABOR SUPPLY ELASTICITY

SHIFT INDIVISIBILITIES: EFFECTIVENESS OF TIME-VARYING WAGE INCREASES



COUNTERFACTUALS

COUNTERFACTUAL DESCRIPTION

- **Entry**: Increase number of medallions.
- **Ownership**: all medallions operated by fleet companies.
  - Importance of intensive margin.
- **Dispatcher**: empty cab dispatched to known location of closest passenger.
  - Full/partial dispatch.
  - Varying returns depending on market thickness.
  - Passenger choice of market (arbitrage).

COUNTERFACTUALS

EXTENSIVE MARGIN: MEDALLIONS

Entry: $+10\%$ medallions, from 13500 to 14850.

Table: Entry Counterfactual

	Baseline	Entry	Δ%
Consumer Surplus (million minutes/day)	2.00	2.09	4.7
Driver Revenue (hourly income)	\$39.54	\$39.19	-0.89
Medallion Revenue (PV in millions)	\$2.54	\$2.51	-0.97

Compensation through expansion of demand:

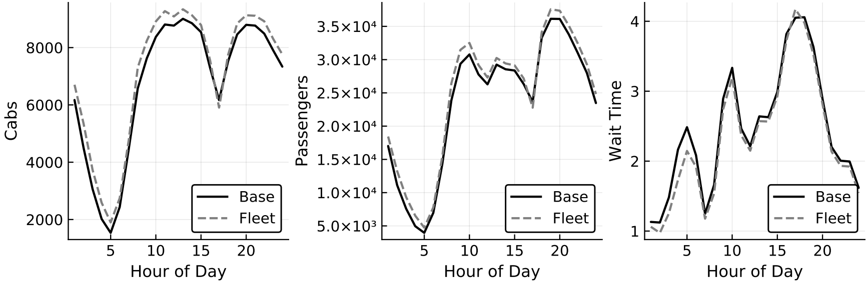
- Driver hourly income: 74%.
- Medallion owners: 70%.

COUNTERFACTUALS

INTENSIVE MARGIN: OWNERSHIP RULES

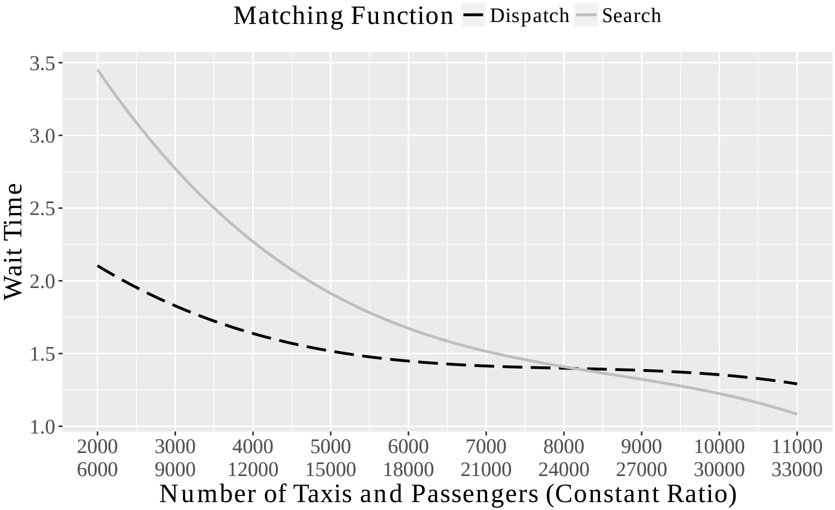
Ownership: All medallions operated by fleet companies.

	Baseline	Entry	Δ%
Consumer Surplus (million minutes / day)	2.00	1.8	2.13
Driver Revenue (hourly income)	\$39.54	\$37.39	-0.72
Medallion Revenue (PV in millions)	\$2.54	\$2.32	-0.62



COUNTER-FACTUALS

COMPARING MATCHING FUNCTIONS

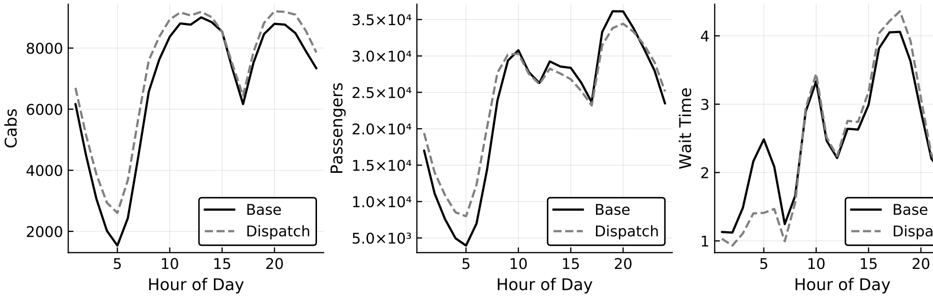


COUNTERFACTUALS

DISPATCH

Dispatch: Assign empty cab to closest passenger.

	Baseline	Dispatch	Δ%
Consumer Surplus (million minutes / day)	2.00	2.12	6.11
Driver Revenue (hourly income)	\$39.54	\$41.63	5.27
Medallion Revenue (PV in millions)	\$2.54	\$2.68	5.42
Wait time (average in minutes)	2.7	2.66	-1.47

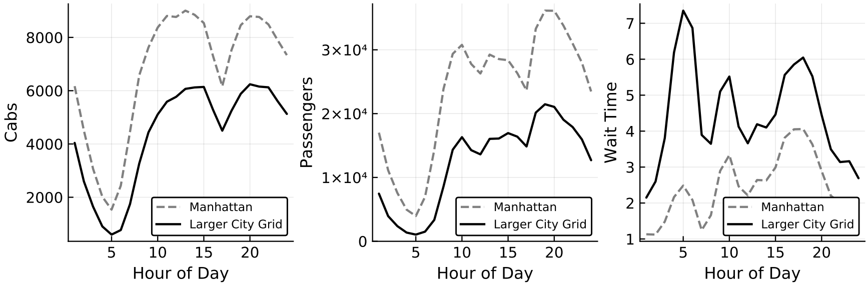


COUNTERFACTUALS

DISPATCH COMPARISON, BROOKLYN

Dispatch vs. **search** on an area of the size of Brooklyn.

	Baseline	Brooklyn	Δ%	Brooklyn Dispatch	Δ%
Consumer Surplus (million minutes / day)	2.0	1.43	-28.3		
Driver Revenue (hourly income)	39.54	$32.61	-17.54		
Medallion Revenue (PV in millions)	2.54	$1.97	-22.2		
Wait time (average in minutes)	2.7	4.33	60.4		

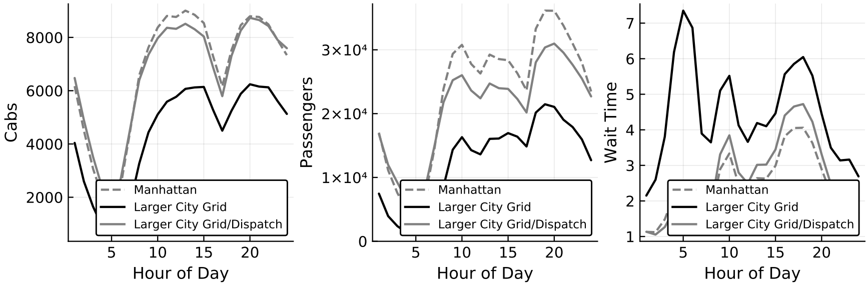


Counterfactuals

Dispatch comparison, Density

Dispatch vs. **search** on an area of the size of Brooklyn.

	Baseline	Brooklyn	Δ%	Brooklyn Dispatch	Δ%
Consumer Surplus (million minutes / day)	2.0	1.43	-28.3	1.97	-1.59
Driver Revenue (hourly income)	39.54	$32.61	-17.54	$39.12	-1.06
Medallion Revenue (PV in millions)	2.54	$1.97	-22.2	$2.52	-1.59
Wait time (average in minutes)	2.7	4.33	60.4	3.02	11.87



COUNTERFACTUALS

SEGMENTED MARKET

Segmentation: 50% dispatch, 50% search.

	Baseline	**Segmented**	$\Delta\%$	**Segmented Arbitrage**	$\Delta\%$
Consumer Surplus (million minutes / day)	2.00	1.8	-9.88		
Driver Revenue (hourly income)	\$39.54	\$37.39	-5.43%		
Medallion Revenue (present value)	\$2.54	\$2.68	-8.71		
Wait time (minutes average)	2.7	3.32	23.1		

COUNTERFACTUALS

SEGMENTED MARKET

Segmentation: 50% dispatch, 50% search.

	Baseline	**Segmented**	Δ%	**Segmented Arbitrage**	Δ%
Consumer Surplus (million minutes / day)	2.00	1.8	-9.88	2.02	0.9
Driver Revenue (hourly income)	\$39.54	\$37.39	-5.43%	37.19	-5.96
Medallion Revenue (present value)	\$2.54	\$2.68	-8.71	2.27	-10.66
Wait time (minutes average)	2.7	3.32	23.1	2.96	7.8

COUNTERFACTUALS

SEGMENTED MARKET

Segmentation: 50% dispatch, 50% search.

	Baseline	Segmented	Δ%	Segmented Arbitrage	Δ%
Consumer Surplus (million minutes / day)	2.00	1.8	-9.88	2.02	0.9
Driver Revenue (hourly income)	\$39.54	\$37.39	-5.43%	37.19	-5.96
Medallion Revenue (present value)	\$2.54	\$2.68	-8.71	2.27	-10.66
Wait time (minutes average)	2.7	3.32	23.1	2.96	7.8

Driver earnings difference over eight hour shift:

- Without passenger choice: \$35.2.
- With passenger choice: \$70.2.

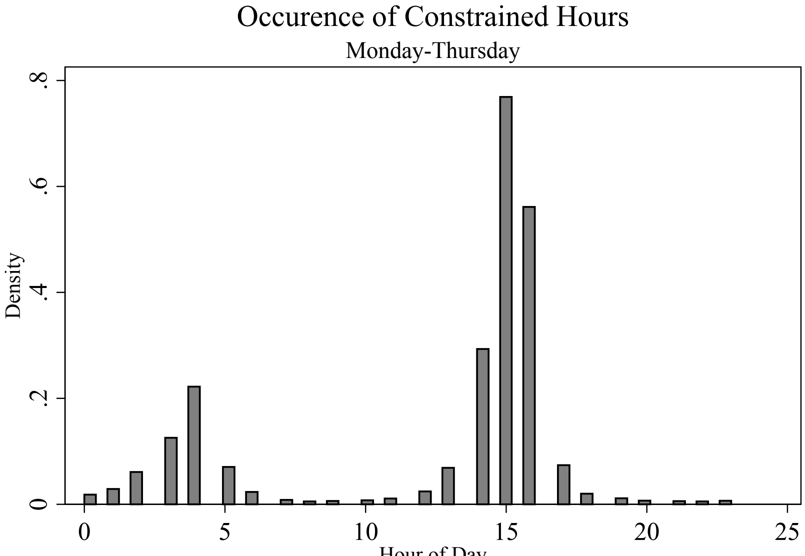
CONCLUSION

- Dynamic general equilibrium model with market clearing via wait/search time.
- Search frictions quantitatively important.
- Dispatch technology can be beneficial but market segmentation might undo these effects.
  - Dispatch can increase wait-times.
  - Dispatch technology vastly more efficient in thin market.
  - Demand side arbitrage beneficial to consumers but makes drivers worse off, exacerbates wage inequality.
- Removing restrictions to corporate management: feasible reform, importance of intensive margin.

THANK YOU FOR LISTENING!

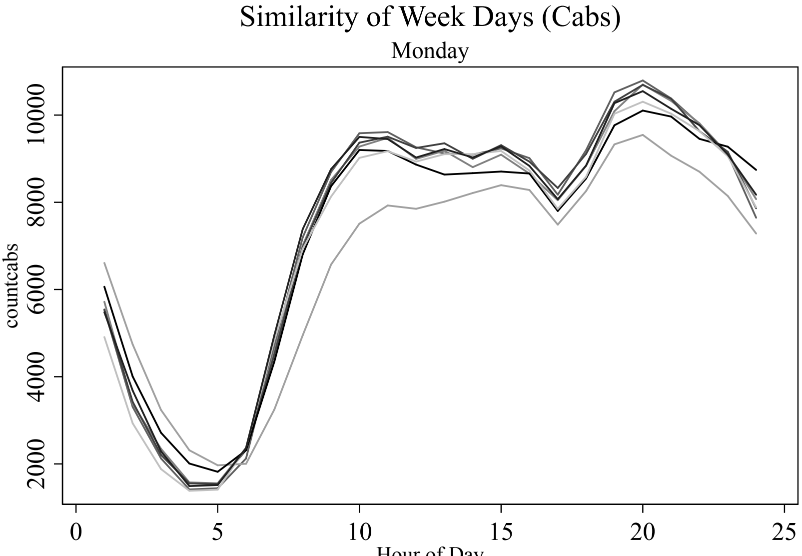
BACKUP SLIDES

OCCURRENCE OF CONSTRAINED HOURS



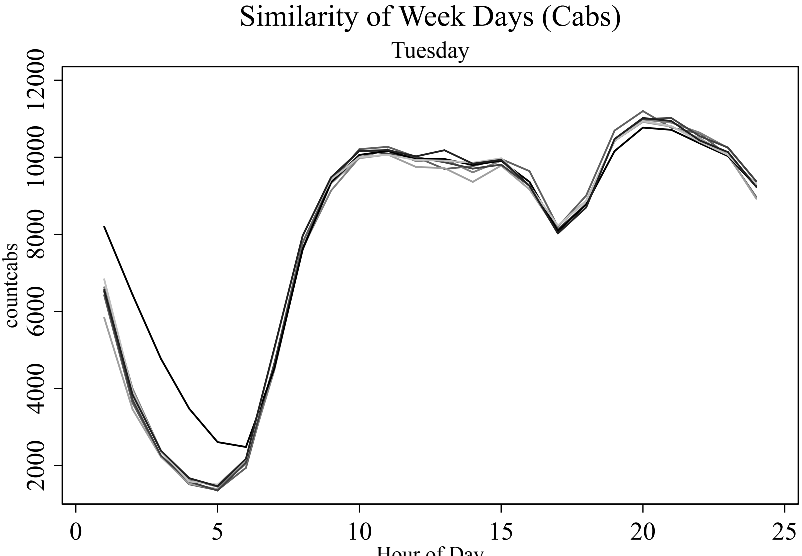
BACKUP SLIDES

MULTIPLICITY: MONDAY



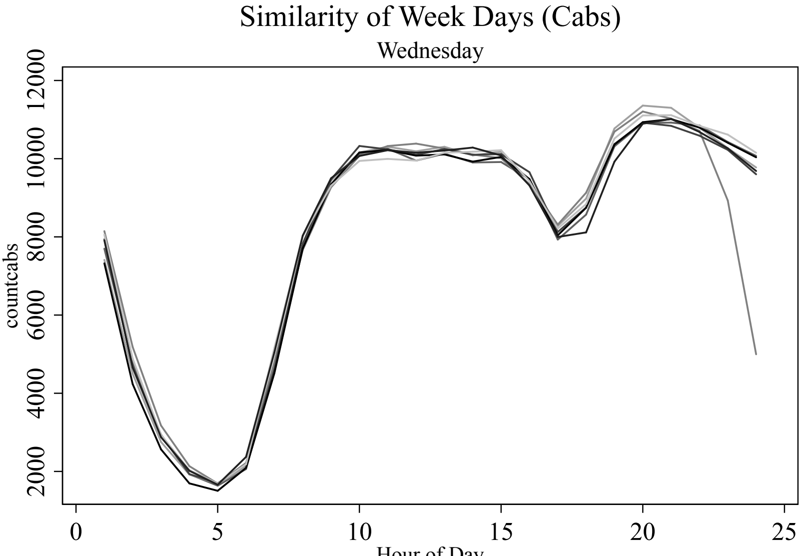
BACKUP SLIDES

MULTIPLICITY: TUESDAY



BACKUP SLIDES

MULTIPLICITY: WEDNESDAY



IDENTIFICATION

AN INTUITIVE EXPLANATION OF IDENTIFICATION.

- Parameters of the cost function: hazard rate out of a shift conditional on shift length.
- Fines: Higher stopping probabilities regardless of shift length at the times where shift change happens.
- Daily outside option: At this point $EV[0]$ is a known object, not pre-multiplied by a coefficient. This value together with starting and stopping probabilities identifies the the outside option and its variance like in a standard binary logit model.
- Standard deviations of shocks: earnings enter the stopping probability directly (without being pre-multiplied by a coefficient).