Spatial Rents, Garage Location, and Competition in the London Bus Market

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Firm Location Matters

1. In many industries we study, where to locate affects profitability
   - Transportation costs / distance to consumers / product space / local monopoly rents
   - Economies of density
2. In urban context, actual spatial location matters
   - Congestion and pollution externalities of transporting goods & people across space
3. But models combining these features can quickly become intractable
   - See e.g., Oberfield, Rossi-Hansberg, Sarte and Trachter (Forthcoming)

We use characteristics of London bus market to estimate structural model of spatial location choice with competition and economies of density

What is this paper about?

1. Market for public bus transport in London: show that location of bus garages particularly important for firm's profitability
2. Structural model links value of Bus Garage to profits of Bus Route procurement, spatially — location in network of garages and routes
3. To estimate model: exploit changes in the garage-operator network since privatization of industry in 1994 — constructed from archival data and bus spotter sites
4. Use model estimates to quantify efficiency properties of garage ownership

London Buses are Privately Owned and Operated

Transport for London (TfL) procures bus route operation services from private firms.

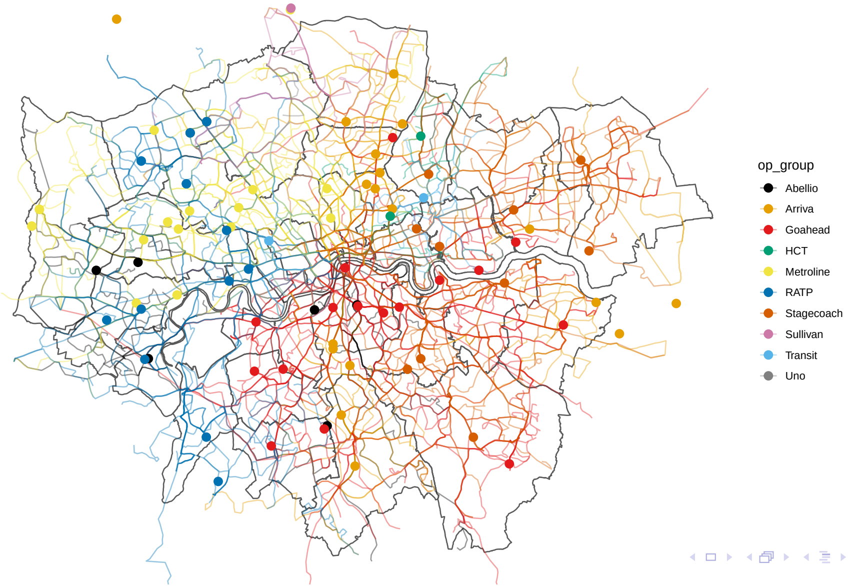
(a) GoAhead (b) Arriva and Metroline (c) StageCoach

Figure: Three examples in front of Drayton House (UCL Econ, Euston Road)

The London Bus Market

- London Buses transport 6m passengers on 675 routes per day.
- Since 1994, bus routes are tendered in recurring auctions.
- Procurement costs £273m per year.
- Today the market is dominated by a few large (international) transport firms

Garage operator network



Role of garages in procurement

- Contracts last for 5 years and specify *all* details of operations: route, frequency, vehicle type, minimum performance standards, etc.
  - See also Cantillon and Pesendorfer (2007)
- **Bid = Revenue** of operator
  - Demand-side is fixed here, no competition for passengers
  - Bus ticket fare goes to TfL
- Key source of competitiveness: **location of privately owned garage**
  - Dead Miles = driving empty between garage & route
  - Much lower for realized ($\sim$ 12 mins) than potential ($\sim$ 40 mins)
  - Descriptive evidence towards this end based on bid data

What are dead miles?

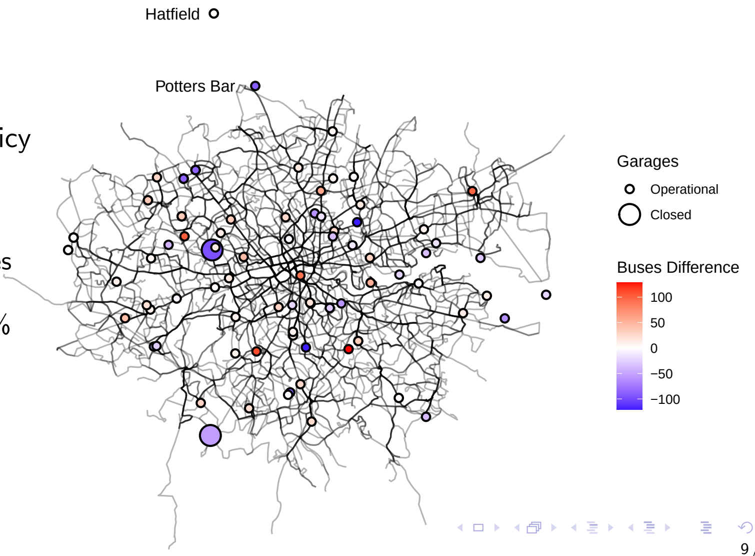
- *Distance travelled by revenue-gaining vehicles without carrying passengers*
- We find: 13% of London bus drive times are *dead*
- Empirically relevant for bids and route allocation

Dead Miles are inflated due to garage ownership constraints

Results from Companion Paper

We simulate an Unbundling Policy

- A Central Planner
  - Minimizing total dead miles
  - Respecting all constraints
  - Reduces dead miles by 14%



Dead Miles and Bidding Behaviour

Dead Miles Start-Stop (Minutes)	0.088***	0.095***	0.099***	0.019**	0.005
	(0.011)	(0.011)	(0.011)	(0.006)	(0.007)
Route Length	0.072***	0.077***	0.067**	-0.013	-0.022+
	(0.022)	(0.021)	(0.021)	(0.012)	(0.012)
Number of Bidders				-0.149***	-0.126***
				(0.029)	(0.029)
Peak Vehicle Requirement (PVR)				0.237***	0.225***
				(0.004)	(0.005)
Constant	1.330***	0.509+	0.172	-0.786***	-0.875***
	(0.209)	(0.272)	(0.332)	(0.207)	(0.223)
Closest Own Garage (mins)					-0.006+
					(0.004)
Dead Miles of Closest Competitor (mins)					0.043***
					(0.008)
Year FE	-	✓	✓	✓	✓
Winner FE	-	-	✓	✓	✓
Num.Obs.	1457	1457	1457	1457	1457
R2	0.059	0.146	0.196	0.748	0.754

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Outline

- Introduction
  - Garages, Bidding, Dead Miles
  - A Structural Model
- Data
- Garage Choice Model
  - Reduced Form
  - Estimation Results
- Counterfactual Simulations
  1. Efficiency Loss of Garage Hold Out
  2. Observed spatial clustering due to Market-Sharing?
- Conclusions & Literature

Introducing a Structural Model

Stages in period t:

1. Operators (i) observe current garage network and draw idiosyncratic cost shocks $\{\nu_{irt}\}_{r=1}^{R}$ for each route r

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3. Operators bid on bus routes, given (updated) network.

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Firm Behaviour

Operators infer value of a garage in stage 2 from knowledge about expected revenue from auctions in stage 3. *But:* myopic beyond current period t.

Introducing a Structural Model

Linking stage 2 garage location and stage 3 profitability

Cost to operate route r by operator i (from closest garage) in period t:

$$
\begin{aligned}
c_{irt} &= \text{RouteSpecificCosts}_{rt} + \beta \text{DeadMiles}_{irt} + \alpha \text{DensityGarages}_{it} + \nu_{irt} \\
&\equiv \delta_{irt} + \nu_{irt}
\end{aligned}
$$

where δ_{irt} deterministic and $\nu_{irt} \sim^{i.i.d.} F_{\nu}$ private information.

Introducing a Structural Model

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where δ_{irt} deterministic and $\nu_{irt} \sim^{i.i.d.} F_{\nu}$ private information.

- So the expected profits equal $\left(b_{irt} - c_{irt}\right) Pr(win|b_{irt})$,
- and the symmetric eqm. bid $\sigma^*(c_{irt})$ solves (Guerre et al. (2000))

$$b_{irt} = \sigma^*(c_{irt}) = c_{irt} + \frac{Pr(win|\sigma^*(c_{irt}))}{Pr'(win|\sigma^*(c_{irt}))}$$

Linking stage 2 garage location and stage 3 profitability

- With N_t bidders following $\sigma^*(\cdot)$, and with $c_{irt} = \sigma^{*-1}(b_{irt})$

$$Pr(win|b_{irt}) = 1 - \underbrace{\prod_{h \neq i \in \{1,\ldots,N_t\}} Pr(\nu_{hrt} + \delta_{hrt} \leq \sigma^{-1*}(b_{irt}))}_{\text{Pr any competitor has lower cost than } \sigma^{*-1}(b_{irt})}$$

- the expected procurement profit is decreasing in $DeadMiles_{irt}$ (if $\beta > 0$), and increasing in $DensityGarages_{it}$ (if $\alpha < 0$) and $DeadMiles_{hrt}$ of competitor h (if $\beta > 0$)

Linking stage 2 garage location and stage 3 profitability

In stage 2, infer **value of garage** j**,** π_{ijt} in stage 3 as:

$$\pi_{ijt} = \sum_r [(\sigma^*(c_{irt}) - c_{irt}) Pr(win|\sigma^*(c_{irt}))]$$

This shows that π_{ijt} is

- ... decreasing in distance to route network ($\beta > 0$)
- ... decreasing in distance to own garage network ($\alpha < 0$)
- ... increasing in distance of competing garages to route ($\beta > 0$)

"Spatial Rents" — local monopoly rents, dead miles transportation costs, and agglomeration benefits

Data

- We build a Garage-operator-route database.
  - Garage Ownership and which Routes operated from them
  - Provided by **London Omnibus Traction Society**
  - Complemented with bus spotter / hobbyist sites and geo-coded (`londonbusroutes.net`, `londonbuses.co.uk`, `countrybus.org`, `bus-routes-in-london.fandom.com`, `wikipedia.com`)
  - Locations of all bus stops from TfL
- TfL publishes tender data since 2003
  - For auxiliary analysis only — empirical results based on changes in operator-garage network (i.e., stage 2 of the structural model)

Garage-Operator-Route database

Which operator runs which route from which garage. Garage Capacity. Garage Names and Locatios.

(a) Stockwell Garage

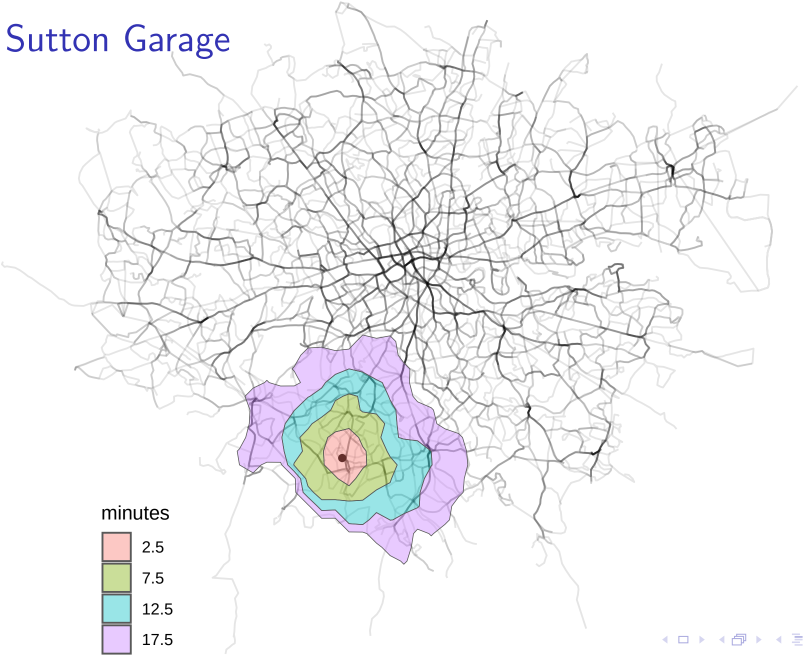
(b) Waterloo Depot

Measuring Distance: Drivetimes on London Streets

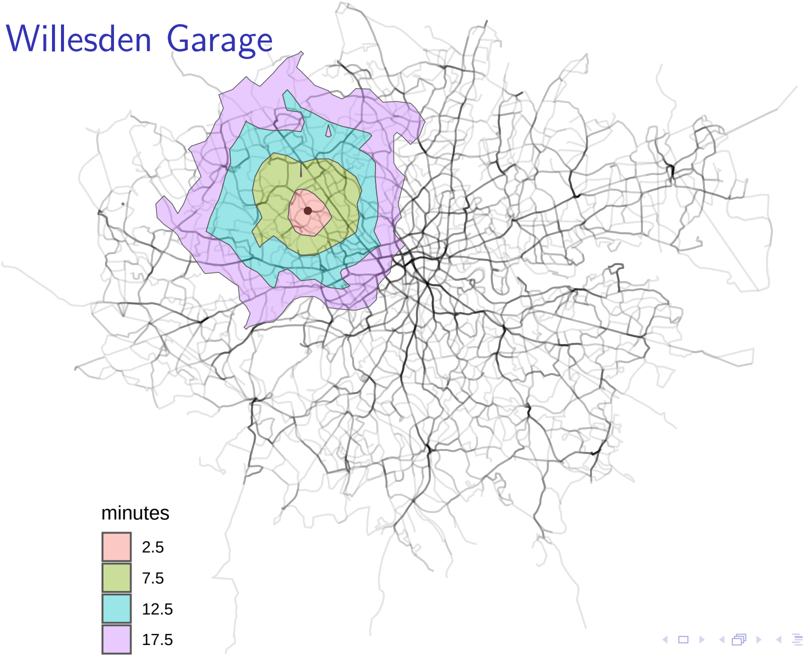
Use **actual drive time on the road** as our measure of distance:

- We compute the number of minutes it takes on London's street network from garage j to points of interest
- Points of interest: all (56K) bus stops, all other garages.
- Provides a realistic measure centrality of garage in route network, own- and competing- garage network
- We use the Open Source Routing Machine (OSRM) for this task. We compute 6.5m optimal routes (cost on google maps API ca USD 32,000)

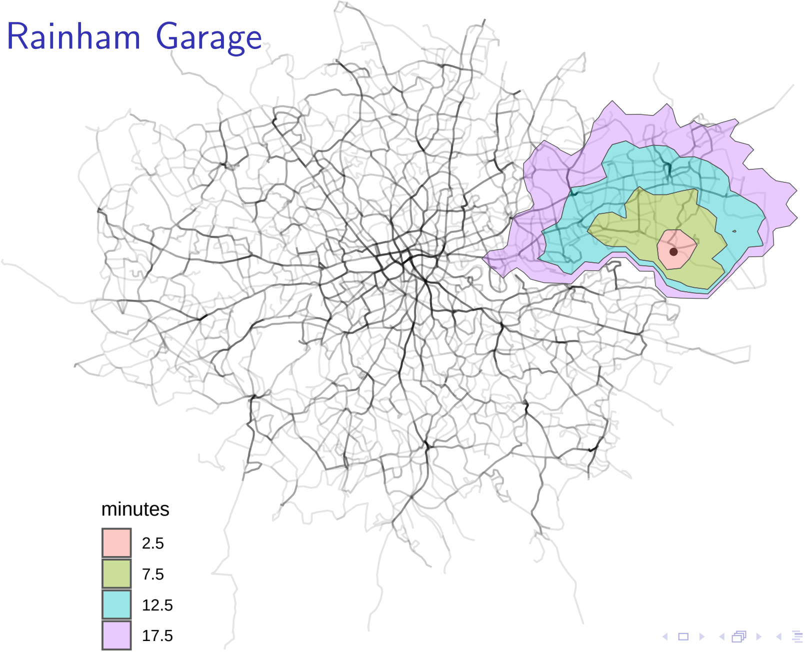
Drive times Sutton Garage



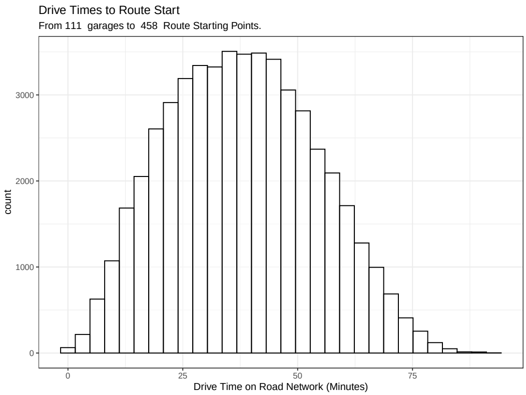
Drive times Willesden Garage



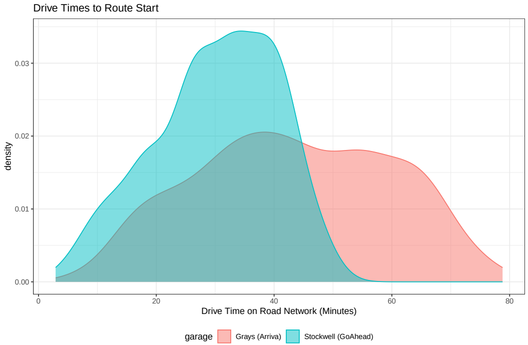
Drive times Rainham Garage



Data: Drive times vary by garage.



(a) Distribution of times

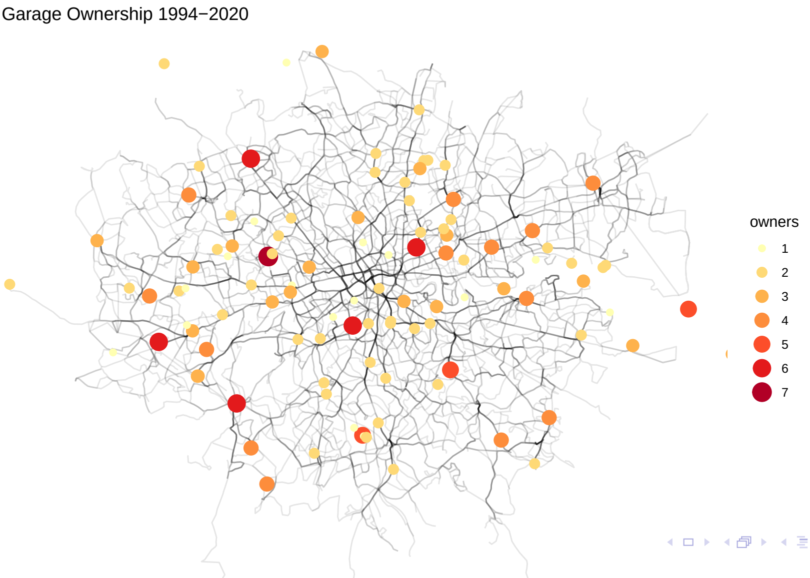


(b) Stockwell vs Grays

Garage Ownership (Changes)

- We observe 192 *garage-operator network changes* between 1995–2019 $\rightarrow$ taking place on *change-dates* (t)
- So, ownership changes are infrequent.
- We observe extremely few *new* garages (building restrictions) and assume those away – set of garages is fixed over time!
- We call a garage which does not exist anymore (or not yet): *vacant*.
- Some garages change owners very often – others never.

Data: Number of owners per Garage



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Garage Choice Model

Setup

At time t we observe a **matching** of $\mathcal{N}$ operators to $\mathcal{J}$ garages. In reality, operators transact garages. However

1. Only one operator per garage
2. Observe changes sequentially (usually one change per t)
3. And recall that garage network is held fixed

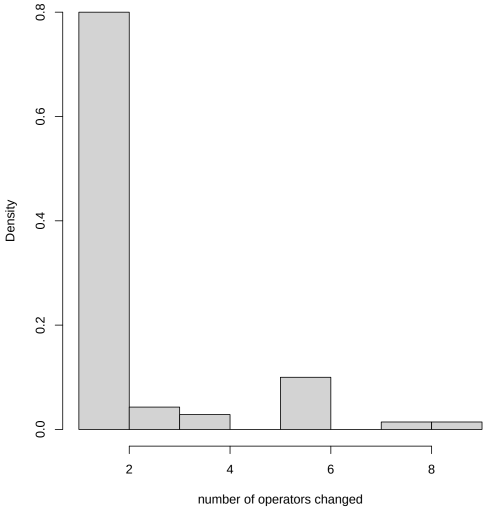
Garage Choice Model

Setup

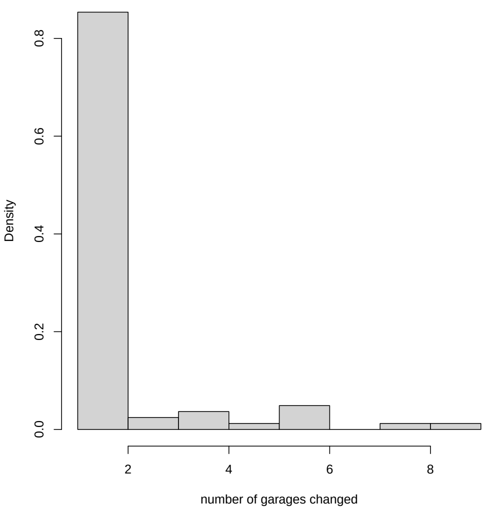
We can then flip the problem, to **garages choose operators**

1. Now, it's a multinomial choice problem
2. Garage j chooses among all operators the one that has highest π_{ijt}
3. Sequentially, given garage network at t
4. Market price to buy garage same for all operators, so cancels out
5. Vacant also $\in \mathcal{N}$, $i = 0$, mean utility normalized to 0
6. Key simplifications: static model, no bundled choice

(a) # Operators changing garage



(b) # Garages entered by operator



Garage Choice Model

Reduced form stage 2 garage network formation

- Model utility of garage j - operator i match as

$$\pi_{ijt} = \pi(\Gamma_j^X, \Gamma_{ijt}^C, \Gamma_{ijt}^O) + \epsilon_{ijt}$$

  - Γ_j^X: distance j to *route network* — (Dead Miles)
  - Γ_{ijt}^C: distance j to Competing garages — (Local Monopoly Rents)
  - Γ_{ijt}^O: distance j to Own garages — (Agglomeration Benefits)

- We parameterize π as a linear function and ϵ_{ijt} with nested logit structure (vacant, non-vacant)

Summary Statistics of Variables in Estimation

	Mean	SD	Min	Max
Choice entry	0.09	0.28	0.00	1.00
No. bus route starts within 10 min. drive time (Γ_j^X)	14.52	7.07	0.00	34.00
Min. drive time to any own garage (Γ_j^O)	28.08	17.06	0.00	86.40
Avg. drive time to any own garage (Γ_j^O)	38.75	14.48	0.00	86.40
Avg. drive time to any comp. garage (Γ_j^C)	38.87	5.98	28.32	57.89
No. comp. garages within 10 min. drive time (Γ_j^C)	1.72	1.55	0.00	7.00
No. garages owned	6.52	5.11	1.00	19.00
Years owned by previous operator (T_{jt})	3.24	4.24	0.00	23.00
Incumbency benefit ($\exp(-T_{jt})$)	0.46	0.47	0.00	1.00
Garage is not vacant	0.89	0.31	0.00	1.00

Estimation Results

	(1)
No. bus route starts within 10 min. drive time	0.025
No. bus route starts within 10 min. drive time (squared)	
Min. drive time to any own garage	-0.180***
Avg. drive time to any own garage	
Avg. drive time to any comp. garage	
No. comp. garages within 10 min. drive time	-0.618***
No. garages owned	
Incumbency benefit $[exp(-T_{jt})]$	
Garage is not vacant	
Inclusive value	2.583***
Num.Obs.	5184
Pr(highest-utility operator correctly predicted)	0.365
Mean AUC	0.912
Own garage proximity (mins) offsets extra comp. garage	3.436
McFadden's pseudo-R^2 w.r.t. Null Model (ρ_0^2)	0.468
Number of Choice Situations	192

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Estimation Results

	(1)	(2)
No. bus route starts within 10 min. drive time	0.025	0.097***
No. bus route starts within 10 min. drive time (squared)		
Min. drive time to any own garage	-0.180***	
Avg. drive time to any own garage		-0.084***
Avg. drive time to any comp. garage		
No. comp. garages within 10 min. drive time	-0.618***	-0.520***
No. garages owned		
Incumbency benefit $[exp(-T_{jt})]$		
Garage is not vacant		
Inclusive value	2.583***	1.585**
Num.Obs.	5184	5184
Pr(highest-utility operator correctly predicted)	0.365	0.354
Mean AUC	0.912	0.916
Own garage proximity (mins) offsets extra comp. garage	3.436	6.209
McFadden's pseudo-R^2 w.r.t. Null Model (ρ_0^2)	0.468	0.455
Number of Choice Situations	192	192

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Estimation Results

	(1)	(2)	(3)
No. bus route starts within 10 min. drive time	0.025	0.097***	-0.011
No. bus route starts within 10 min. drive time (squared)			0.001
Min. drive time to any own garage	-0.180***		-0.209***
Avg. drive time to any own garage		-0.084***	
Avg. drive time to any comp. garage			0.039*
No. comp. garages within 10 min. drive time	-0.618***	-0.520***	-0.560**
No. garages owned			-0.151**
Incumbency benefit [$exp(-T_{jt})$]			
Garage is not vacant			
Inclusive value	2.583***	1.585**	2.709***
Num.Obs.	5184	5184	5184
Pr(highest-utility operator correctly predicted)	0.365	0.354	0.344
Mean AUC	0.912	0.916	0.917
Own garage proximity (mins) offsets extra comp. garage	3.436	6.209	2.676
McFadden's pseudo-R^2 w.r.t. Null Model (ρ_0^2)	0.468	0.455	0.478
Number of Choice Situations	192	192	192

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Estimation Results

	(1)	(2)	(3)	(4)
No. bus route starts within 10 min. drive time	0.025	0.097***	-0.011	0.056+
No. bus route starts within 10 min. drive time (squared)			0.001	
Min. drive time to any own garage	-0.180***		-0.209***	-0.198***
Avg. drive time to any own garage		-0.084***		
Avg. drive time to any comp. garage			0.039*	
No. comp. garages within 10 min. drive time	-0.618***	-0.520***	-0.560**	-0.695***
No. garages owned			-0.151**	
Incumbency benefit $[exp(-T_{jt})]$				2.061***
Garage is not vacant				
Inclusive value	2.583***	1.585**	2.709***	3.343***
Num.Obs.	5184	5184	5184	5184
Pr(highest-utility operator correctly predicted)	0.365	0.354	0.344	0.375
Mean AUC	0.912	0.916	0.917	0.915
Own garage proximity (mins) offsets extra comp. garage	3.436	6.209	2.676	3.514
McFadden's pseudo-R^2 w.r.t. Null Model (ρ_0^2)	0.468	0.455	0.478	0.486
Number of Choice Situations	192	192	192	192

$+$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Estimation Results

	(1)	(2)	(3)	(4)	(5)
No. bus route starts within 10 min. drive time	0.025	0.097***	-0.011	0.056+	0.025
No. bus route starts within 10 min. drive time (squared)			0.001		
Min. drive time to any own garage	-0.180***		-0.209***	-0.198***	-0.199***
Avg. drive time to any own garage		-0.084***			
Avg. drive time to any comp. garage			0.039*		
No. comp. garages within 10 min. drive time	-0.618***	-0.520***	-0.560**	-0.695***	-0.636***
No. garages owned			-0.151**		
Incumbency benefit $[exp(-T_{jt})]$				2.061***	2.624***
Garage is not vacant					1.858*
Inclusive value	2.583***	1.585**	2.709***	3.343***	2.755***
Num.Obs.	5184	5184	5184	5184	5184
Pr(highest-utility operator correctly predicted)	0.365	0.354	0.344	0.375	0.385
Mean AUC	0.912	0.916	0.917	0.915	0.916
Own garage proximity (mins) offsets extra comp. garage	3.436	6.209	2.676	3.514	3.205
McFadden's pseudo-R^2 w.r.t. Null Model (ρ_0^2)	0.468	0.455	0.478	0.486	0.491
Number of Choice Situations	192	192	192	192	192

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Estimation Results

- Statistically significant inclusive value, rejecting non-nested logit demand
  - More likely that two active operators have similar idiosyncratic values than the "the market" and another operator do
- Dead Miles relevant but statistically insignificant when accounting for agglomeration benefits through distance to nearest own garage
- Strong Agglomeration Benefit and Local Monopoly Rents
  - Surplus loss from additional competing garage within 10 minutes drive from j is offset by own garage being 3-4 minutes closer by
- Persistence through large incumbency benefit
  - Year 0: benefit offset with +4 competing garages within 10 mins
  - Year 1: benefit offset with +1.5 garages

Is That a *Good* Garage Choice Model?

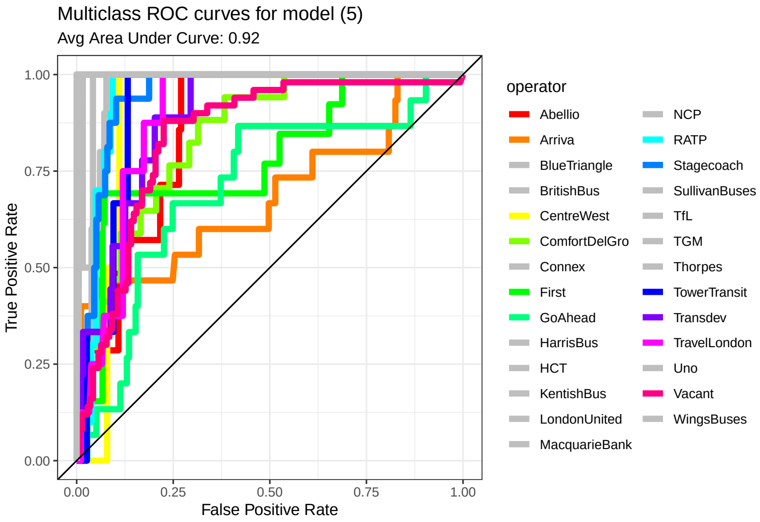
Ultimately, garage entry process is more complex. We abstract from dynamics, bundled choice, and —due observing only 192 choice situations— rely on simple representations of network variables.

But parsimonious model with 5 variables + nesting structure fits surprisingly well

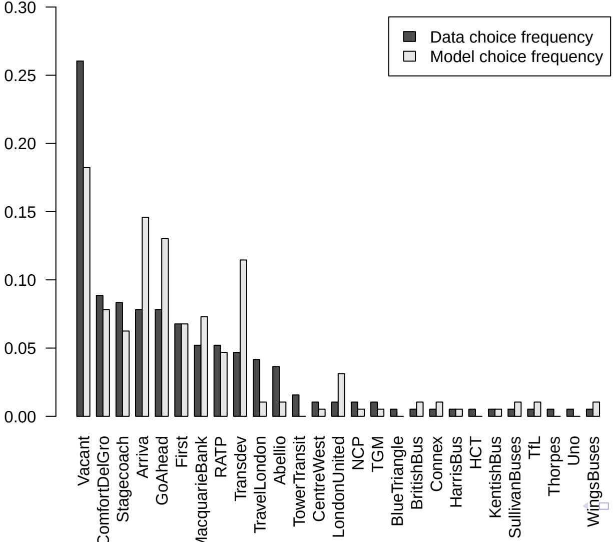
- McFadden's ρ^2's "excellent fit"
- *Identity* of highest-utility operator right in $\sim$ 40% cases
- Frequency-weighted *Area Under Curve* ~ 0.9
- Good average entry frequencies by operator

Model fit: Multi-class ROC curves

Top-left is best: high true positives and low false positives



Model fit: entry frequencies



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Application 1: Garage Hold Out Problem

Operators might be holding on for too long to their garages.

- Consider all garages where no change too place on date t.
- Compute utility difference with incumbent's utility: $\hat{\psi}_{ijt} = \max(0, \hat{\pi}_{ijt} - \hat{\pi}_{Ijt})$
- In 11% of cases, another operator would have benfited more from garage j than incumbent – we compute a measure of *efficiency loss*
  - Summing $\frac{\hat{\psi}_{ijt}}{\hat{\psi}_{Ijt}}$ across all operator-garage-time triples
- Given markup estimates, this loss represents 6.5% – 9.8% of the total London bus procurement cost
- Results from private ownership of garages

Providing a foundation for the Ownership Frictions found in companion paper

Application 2: Collusive market-sharing behavior *outside London*

UK Competition Commission 2011 report, on conduct bus operators outside London:

- *"[...] operator* **conduct by which operators avoid competing with other operators** *in 'Core Territories' (certain parts of an operator's network which it regards as its 'own' territory)* **leading to geographic market segregation***."*

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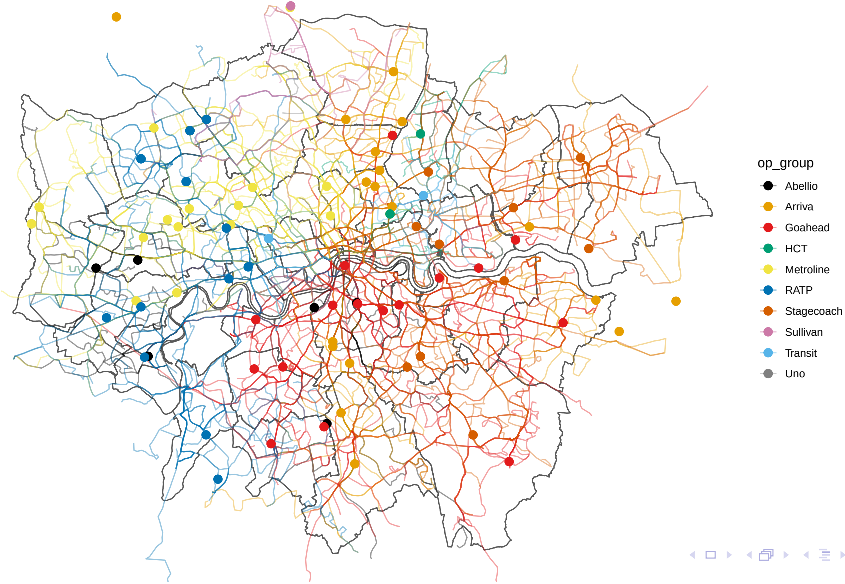
- *"We have seen* **retaliatory conduct** *in several areas, and* **consideration of retaliation** *elsewhere [...]"*
- *"[...] concerned that geographic market segregation might be a* **more widespread feature** *than we have identified"*

A More Widespread Feature Than We Have Identified?



Interpreting ψ as required *Punishment* to Sustain Collusion

1. We take the ψ's estimated in the preceding application.
2. Under a collusive agreement, side payments (or punishments) can rationalize the fact that operator l is in garage j, instead of operator i as our model predicts.
3. Relate the ψ's to theory when collusion more likely, to separate out signal from noise.

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4. Results suggest that $\psi \geq 0$, or *punishment*
   - Is more likely when there are fewer firms in the market
   - Increases during sustained periods without entry
   - Decreases when firms enter the market
   - Is higher for more isolated garages enjoying greater local monopoly rents

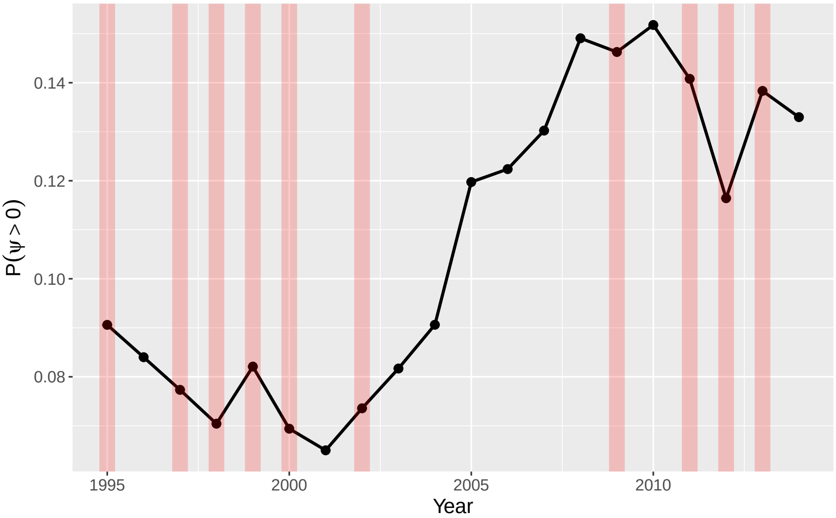
Theory: easier to collude in market with fewer firms

	$\psi : \psi > 0$	$\psi : \psi > 0$	$1(\psi > 0)$	$1(\psi > 0)$
(Intercept)	2.108***	2.967***	−1.377***	−1.068*
	(0.068)	(0.748)	(0.044)	(0.453)
No. alternatives	−0.002	−0.041	−0.058***	−0.059**
	(0.006)	(0.035)	(0.004)	(0.021)
Num.Obs.	8136	8136	71 775	71 775
R2	0.000	0.003		
R2 Adj.	0.000	0.000		
AIC	32 194.4	32 217.1	50 469.7	50 300.6
BIC	32 215.4	32 406.3	50 488.1	50 539.3
Log.Lik.	−16 094.175	−16 081.575	−25 232.855	−25 124.292
RMSE	1.75	1.75	0.32	0.32
Year-fixed effects?		✓		✓

- Fewer competitors = more gain per-firm and easier to coordinate
- Nr active firms varies over time, but finding consistent with year fixed effects

Theory: harder to collude when entry of new firms

Figure: Red bars indicate periods of high entry in market.



Spatial pattern of ψ measure

- More punishment for garages that are more isolated from competitors
- Higher local monopoly rents = greater incentive to protect position

Conclusions

1. Build custom dataset of London bus garage ownership and document spatial segregation of operators
2. Propose equilibrium model of garage choice
   - Linking garage value to route revenues, identifying spatial rents
3. Use model + data to estimate garage-operator utility function
   - Simple nested logit explains well changes garage-operator network
   - Important: own garage clustering, isolation from competing garages, incumbency benefit
4. Show that private garage ownership generates efficiency loss
   - Holdout Problem: amounting to 6.5-9.8% of procurement costs
   - Temporal pattern consistent with collusive market-sharing

References I

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