Engineering-Based Modeling of Scale Efficiencies in Telecommunications

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Spectrum Auctions and Market Structure Conference
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Plan

Elliott, J. T., Houngbonon, G. V., Ivaldi, M., & Scott, P. T. (2025). Market structure, investment, and technical efficiencies in mobile telecommunications. *Journal of Political Economy*, 133(5), 1401-1459.

- Sources of Efficiencies in JPE Paper
  - Path loss
  - Pooling
  - Base station fixed costs
- Results from JPE paper
- Sources of Efficiencies NOT in JPE Paper
  - Backbone network
- Econometric vs Engineering Approaches

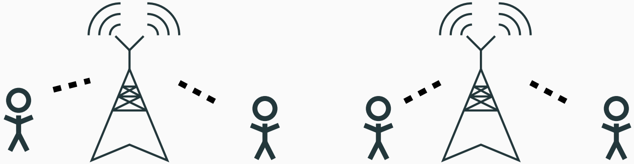
Why Do We Need Accurate Models of Efficiencies?

- Classic trade-off in merger analysis is market power vs scale efficiencies.
- Other market structure changes—e.g., through spectrum allocation or RAN sharing—have impacts through scale efficiencies.
- After building a model that captures scale efficiencies, we can quantify the value of spectrum in mobile telecom.

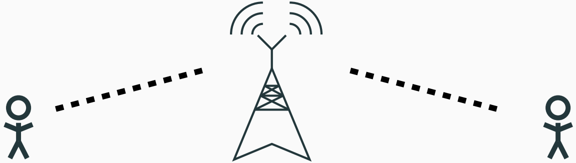
Path Loss

Path Loss and Population density

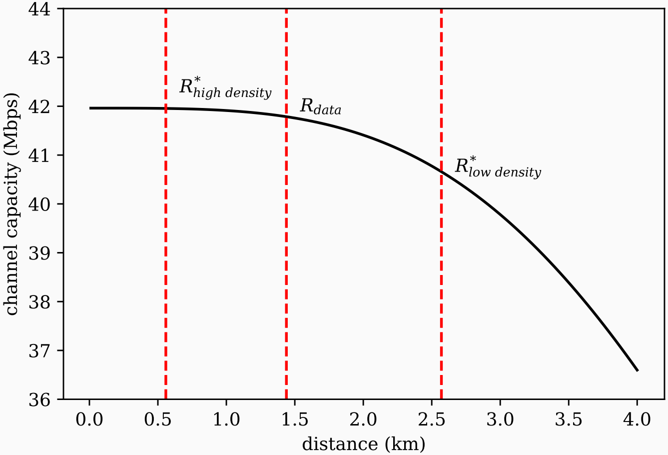
Urban Area:



Rural Area:



Channel capacity and cell size



Pooling

Economies of Pooling

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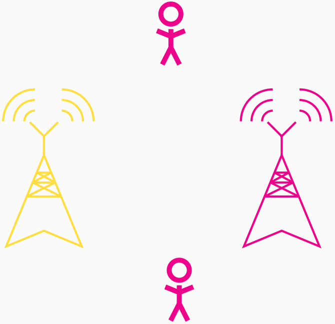
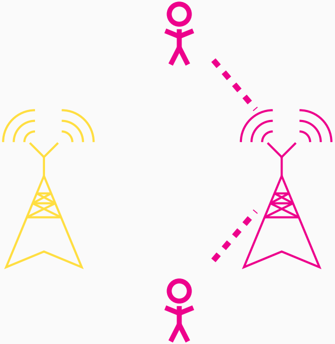
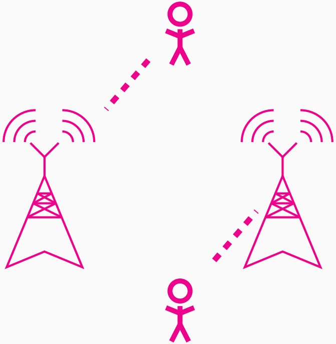


Economies of Pooling



Economies of Pooling



Queuing Theory and Pooling Efficiencies

- Q: delivered download speed
- $\bar{Q}$: channel capacity
- Q^D: demand arrival rate
- When consumers request data at the same time, they create congestion, reducing download speeds
- Assume M/M/1 queue and Poisson arrivals (open issue here!), then

$$\underbrace{Q}_{\text{delivered download speed}} = \underbrace{\bar{Q}}_{\text{channel capacity}} - \underbrace{Q^D}_{\text{demand arrival rate}}$$

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  - Demand model gives us Q^D, which depends on delivered download speed Q
  - Q and Q^D form a simultaneous system
  - Endogeneity of Q^D limits speed improvement in equilibrium, but there will still be improvement

Base Station Fixed Costs

Base Station Costs

- In our main specification, there are no cost synergies associated with fixed costs.
- Base station costs scale linearly with bandwidth, so the total costs of operating a base station are the same for
  - One firm operating B units of spectrum,
  - Two firms each operating $B/2$ units of spectrum at the same site.
- We also have a specification with duplicated fixed costs. In Peha (2017), cost synergies come exclusively from avoiding duplicated fixed costs.

Results from Elliot et al. (2025)

Demand Model Overview

- Consumers choose mobile plan (operator, price, data limit) and how much data to consume
- Quite standard: mixed logit model
- Not standard: download speed is an endogenous product characteristic
- Estimated using detailed data from Orange in France, 2015.
- Important aspects: how price sensitive are consumers, and how do they value data consumption and download speeds?

Supply Side

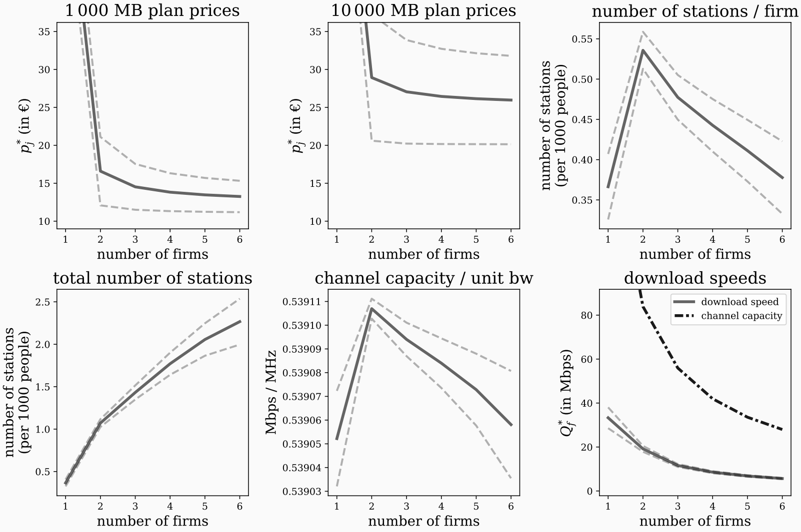
- Firms set prices and choose number of base stations (or cell size)
- Supply-side modeling is very engineering-based. Model of data transmission derived from
  - Path loss telling us how SINR depends on cell size/number of base stations
  - Shannon-Hartley Theorem telling us how SINR and spectrum allocation matter for channel capacity
  - Queuing model telling us how download speeds depend on channel capacity and consumer demand
- On supply side, only role for econometrics is to back out two cost parameters: cost per base station and cost per consumer.

Equilibrium Simulations

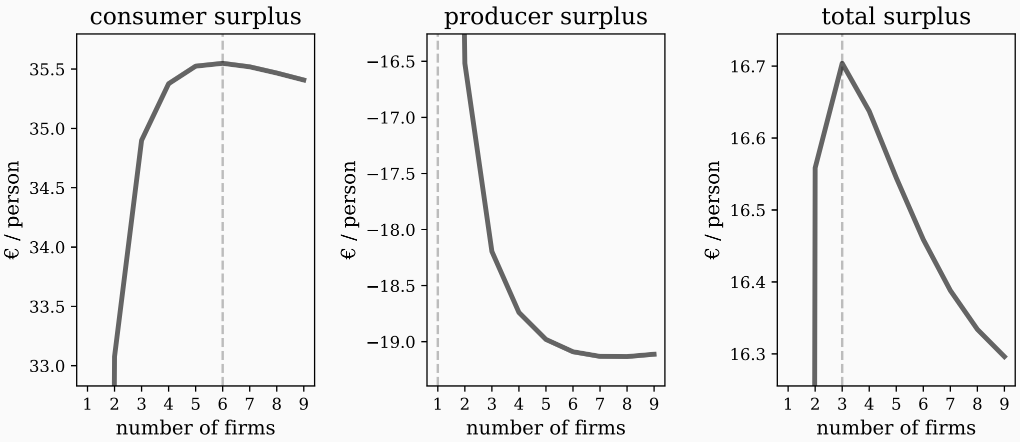
Two kinds of simulations:

- Vary number of firms, imposing symmetric firms
  - Total industry spectrum held fixed across simulations, spectrum divide evenly across firms
  - Many firms $\Rightarrow$ each firm has a small spectrum endowment
  - Number of base stations endogenously determined
- Bilateral merger simulations based on (asymmetric) market conditions in data
  - Base station network fixed, but merged firms combine the networks of the merging parties

Varying Number of Firms: Equilibrium Outcomes

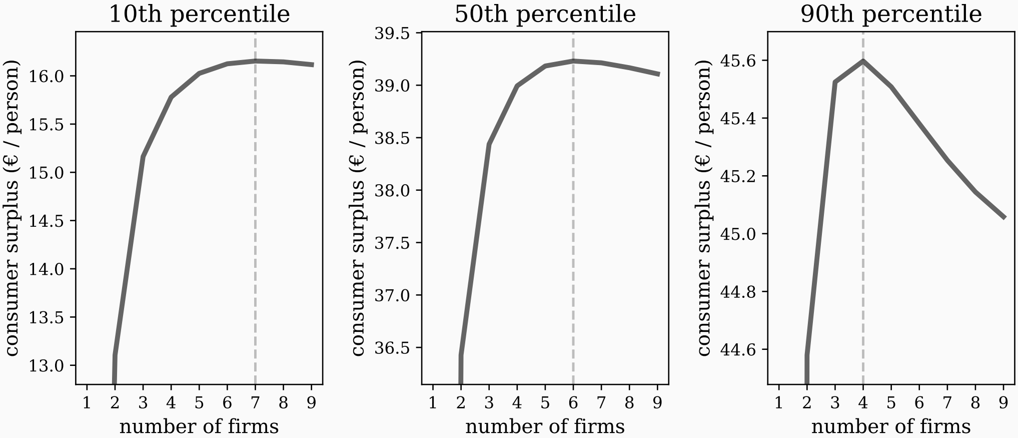


Varying Number of Firms: Welfare



Welfare levels are relative to monopoly case

Varying Number of Firms: Distributional Impact



Backbone Network

Optimal Transport/Allometric Scaling

- Suppose that the cost of a telecommunications network was proportional to the distance of connections, and that at a constant population density, the cost was linearly proportional to the area served.
- Then, the cost of a network will have the form

  $$C \propto D^{-1/2} A$$

  where C is cost, D is population density, and A is area served.
- However, there are many models in science and engineering where costs are less-than-linearly proportional to area served. For instance, we can derive an optimal transport model in which

  $$C \propto D^{-1/3} A^{2/3}$$

Econometrics vs Engineering

Optimal Transport/Allometric Scaling

- If our engineering model tells us that

$$C = \theta D^{-1/3} A^{2/3},$$

  then all we need from data is the value of θ, which can be determined from cost data, or potentially backed our from first-order conditions

- In contrast, old econometric studies of scale efficiencies in telecommunications estimated equations like

$$\ln(C/customers) = \theta_0 + \theta_1 D$$

- This comes with extra challenges:
  - Population density (and other RHS variables) may be correlated with unobservables. This can create bias in either direction.
  - Population density (and other RHS variables) is measured with error. This will tend to bias us towards having constant returns to scale.

Thank you!