Optimal Transport Networks in Spatial Equilibrium

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Introduction

- Large investments in infrastructure
  - 20% of World Bank spending
  - 6% of government spending around the world

- Large implications for welfare and growth
  - Transport of goods: lower prices, greater market access
  - Transport of people: access to jobs, diffusion of knowledge

- How should these investments be allocated in a transport network?
California Road Network and Current Infrastructure Projects

High Speed Rail

CALTRANS Capital Outlay Projects

Phase II
Phase I
Questions

1. Where should the investments be allocated?
2. How large should the overall network be?
3. What would be the productivity gains?

- Existing methods to analyze returns to specific investments
  - Duranton et al. (2014), Faber (2014),...

- But these questions require an efficient benchmark

- Challenges
  - Large investments in one segment affect rate of return in others
  - Reallocation of economic activity and trading routes
  - Large dimension of the problem
We study transport of goods: lower prices, greater market access.

We combine:

- **Quantitative trade model**
  - Cities trade differentiated goods
  - Differences in productivity and amenities
  - Workers choose where to live

- **Optimal transport** (e.g. Galichon, 2016)
  - Goods flow through a transport network (formally a graph)
  - Shipping companies choose best routes
  - Shipping cost on a link: \( \uparrow \) with quantity shipped, \( \downarrow \) with infrastructure

- **Optimal network problem.**
  - Choose infrastructure in every link
  - Given resources to grow the network
Application

- In the paper: application to road infrastructure in European economies
- Today: application to road network in California and across U.S. states
  - with Nicole Gorton (UCLA)
Graph

50 km x 50 km square network, 8 neighbors per interior node
Graph Representation of CA Cities and Highways

The problem of designing the network determines how much to build on each link
Parametrization

- Productivity and amenities by location to match GDP and population (G-Econ Dataset)
- Trading costs to match level of internal trade and elasticity of trade to distance
- Congestion to match response of travel time to vehicle-miles (Couture et al. 2018)
- Building costs are a function of terrain characteristics (Federal Highway Administration)
Optimal 10% Expansion of CA Road Network

- Annual cost: ~$0.4 billion
- Benefit (0.04% GDP): ~$0.7 billion
- Benefit / Cost = 1.6
- Optimal investments along
  - LA-Santa Barbara-San Jose (US 101)
  - LA-Bakersfield-Sacramento (US 99)

Notes:
- Cost: 10% of CA Network * 5% discount + 24k maintenance per lane-mile
- CA ~ 10% of Interstate Highways valued at $560 billion at 2007 prices (CBO)
- Benefit: 0.04% Gain * 70% Consumption Share * CA GDP at 2007 prices
Optimal 50% Expansion of CA Road Network

- Annual cost: ~$2.0 billion
- Benefit (0.08% GDP): ~$1.3 billion
- Benefit / Cost = 0.7

Optimal investments along:
- LA-Santa Barbara-San Jose (US 101)
- LA-Bakersfield-Sacramento (US 99)
- LA-San Diego (I5)

Notes:
- Cost: 50% of CA Network * 5% discount + 24k maintenance per lane-mile
- CA ~ 10% of Interstate Highways valued at $560 billion at 2007 prices (CBO)
- Benefit: 0.08% Gain * 70% Consumption Share * CA GDP at 2007 prices
Optimal Size of the Expansion

Analysis suggests CA road network should be 30% larger
How is population reallocated?

Note: green (red) locations grow (shrink) in the optimal 50% network expansion
How does the optimal expansion compare to existing projects?
Benefit-Cost Ratios across States

Note: figure show benefit-cost ratio of a 50% expansion of the road network of each state
Potential Applications

- New framework to study optimal transport networks in general equilibrium
  - Applicable using data on value added and population

- Many forces are not (yet) included:
  - Alternative modes of transport
  - International trade
  - Indirect effects through further investments (e.g., building structures)
  - Investments in trade hubs
  - Optimal investments around second best (e.g., distortions)
  - Agglomeration and spillovers in production
  - Dynamics

- Potential applications for future work
  - Optimal urban network
  - International trade facilitation
  - Developing countries
  - Political economy and competing planners