The Broader Benefits of Transportation Infrastructure

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Plan of Talk

1. Framing the issue
2. Previous literature
3. Our approach
4. Caveats, future work, and summary
Introduction

- Transport infrastructure provision = visible, vital, costly public sector contribution to private economy
- Decisions about the level/allocation of infrastructure investments suffer from incomplete information
  - Micro-scale analyses do not capture full range of economic benefits induced by a project/program
  - Macro-scale analyses are too broadly defined to provide guidance on the relative benefits of specific projects/programs
- Motivation for “meso-level” analytical tools
  - Need assessments that are both comprehensive (in the economy-wide sense) and able to represent specific infrastructure capacity expansions
- Meso-scale analysis for infrastructure planning: 3 requisites
  1. Incorporate information about specific additions or improvements to transportation infrastructure networks (not necessarily as detailed as micro-scale analyses)
  2. Trace economic processes triggered by infrastructure improvements
  3. Feasible to implement using data available at reasonable cost
Our Focus

• Long-run developmental impacts
  – Agglomeration of economic activity
  – Structural transformation of the economy (e.g., changing spatial patterns of production, creation of new industries/inter-industry linkages; shifts in households’ preferences)
  – Non-market effects involving complex/ idiosyncratic interactions among economic, social, cultural and institutional factors

• Short-run general equilibrium impacts
  – Stable, arise from actions of a well-defined set of economic agents through the medium of markets
  – Myriad effects coursing through the economy consequent on the time and money savings induced by infrastructure improvements
  – Savings affect marginal costs of transport producers, individuals’ mobility and demand for goods and services
  – Ripple through market interaction mechanisms ⇒ endogenous changes in employment, output, and incomes
“Meso-Level” Analysis in Context

**Macro**
- **Aggregate Productivity/Multipliers**
- Econometric analyses

**Issue Scope**
- **Broad Feedback Mechanisms of Congestion**
- Derived demands for transport; Infrastructure ⇒ transformation of transport services into trips

**Micro**
- **Localized impacts of a specific investment**
- User equilibrium modeling

Spatial Scale:
- **Aggregate**
- **Sub-national/Regional**
- **Local/MSA**

Details of network structure, allocation of trips to modes/links as a f'n of congestion (endogenous)
The Circular Flow of the Economy and the General Equilibrium Effects of Transportation Infrastructure

Consumption of goods by households requires retail shopping trips.

Households’ labor supply to firms requires commuting trips.

Shipment of goods from firms to retail outlets creates demand for freight trips.

INFRASTRUCTURE
Related Literature: CGE Models of Congestion

• Simple “maquette” models
  – Mayeres-Proost (1997)
    • Model congestion as a direct f’n of passenger + freight transport activity
    • Reduces quality of passenger transport consumed by hholds, productivity of final goods producers
    • Households have dual money and time budget constraints
    • Transport services either enter utility f’n directly or are necessary to ship final good from firm to households
    • Substitutability of trips among a few, very aggregate travel modes

• Realistic large-scale models
    • Aggregate transport cost minimization ⇒ optimal level of infrastructure
    • Ratio of actual to optimal level of infrastructure capital ⇒ congestion
    • Congestion synonymous w/. capacity utilization: ↓ productivity of sector-specific transportation capital stocks
Main Stylized Facts

• A-spatial, macro-level analysis
  – No details of transportation network ⇒ unable to resolve effects of particular infrastructure projects/programs
• Largely static: no capacity to capture developmental effects
• Illustrates elements of transport’s GE effects
  – Economic activities create derived demand for trips
  – ↑ Trip volumes + fixed infrastructure capacity = congestion
  – Congestion ↑ time costs of consumption activity, ↑ pecuniary costs of shipping goods to sources of demand
• Infrastructure investments alleviate congestion, raising the “speed limit” on economic activity
• Needed: comprehensive approach to elaborate mechanisms at work
  – Relationship b/w. congestion, value of time in a GE sense, taking into account all relevant interactions
Our Approach: A Transport-Focused CGE Model

• **Aim:** incorporate congestion mechanisms within static GE framework
  - No developmental impacts, but prerequisite to their characterization
  - Focus on elaborating model structure, empirical implementation left to future work

• **Highlights**
  - Derived demand for travel modeled as an aggregation of trips
  - Trip volumes modeled as a good which is allocated across modes and links of transport network
  - Firms partitioned into non-transport goods producers (NT), transport producers (T)
    - *NT*-type firms are “mills” supplying commodities, which are then shipped to sources of demand
    - *T*-type firms supply transport services to *NT* firms, households
  - Trips generated from inputs of transport services, network capacity (a fixed factor)
The Demand Side

• Economic activity ⇒ derived demand for travel
  – Household consumption ⇒ passenger shopping travel or retail delivery ($R$)
  – Household labor supply ⇒ passenger commuting travel ($C$)
  – Goods movement ⇒ freight ($F$)

• Travel modeled as an aggregation of trips
  – Travel consumers substitute trips among different travel modes (e.g., air, rail, ground passenger/freight), transit network links
  – Transport consumers allocate trips among mode-link alternatives to minimize travel expenditure

• Households have time budget constraints
  – Captures GE feedback of simulated economic activities on pivotal value-of-time metric employed in traditional CBA
  – Infrastructure investment ⇒ ↓ avg. trip time ⇒ ↑ retail, commuting trip volumes ⇒ ↑ income, consumption
Household Utility Maximization, Labor Supply, and Derived Demand for Retail and Commuting Trips
The Supply Side

• Transport producers
  – Each firm corresponds to a single mode of transit
  – Firms do not possess a time budget
  – No direct production of trips, rather, generalized transportation services (vehicles on road, trains on track, planes in air, etc.)
  – Intra-firm capital stock determines service supply capacity

• Trips modeled as transformation of transport services
  – $T$-type firms allocate transport services among different payloads (freight, retail, commuting) and links to maximize revenue
  – Speed (inverse of avg. travel time) along any link necessary to transform transport services into trips, $\equiv f(\text{Link Capacity})$

$$\downarrow \text{avg. trip time} \Rightarrow \uparrow \text{freight trip volumes, goods shipments} \Rightarrow \downarrow \text{commodity prices}$$

$$\uparrow T\text{-type firms’ avg. factor productivity} \Rightarrow \uparrow \text{Factor returns, household income}$$

Infrastructure Investment
Production in Non-Transport Firms and Derived Demand For Freight Trips
Transport Producers and the Supply of Retail, Freight and Commuting Trips
Supply-Demand Linkage: Transport Network Detail

- Transportation network
  - Links, modes = abstract (a-spatial) network representation
  - Focus only on subset of alternatives suffering from congestion
  - Mode-link alternatives are imperfect substitutes, w/. differing marginal trip costs to transport consumers, marginal trip revenues to transport producers

- Congestion and effects of infrastructure improvements
  - For each mode-link combination, avg. trip time ↑ rapidly as
    \[
    (\sum R \text{Trips} + \sum C \text{Trips} + \sum F \text{Trips}) > \text{Link Capacity}
    \]
    (e.g., BPR capacity restraint formula)
  - Avg. trip time the key variable in hhold time budgets, transport producers’ ability to transform their output into trips
  - Infrastructure improvement synonymous w/. ↑ link capacity
  - Depending on which particular link(s) improved, impacts on trip volumes, economic variables can be very different
Data and Numerical Calibration: Implementational Issues

- Challenge: integrating incommensurate economic and transportation data
  - Normative question: what is the most appropriate geographic scale at which model should be specified?
  - Positive question: how to structure reduced-form representation of transit network?
  - Must be capable of being matched w/. relevant economic data, yet easy to calibrate

- Easy: calibrating of macroeconomic portion of model
  - Select substitution elasticity values for industries, representative hhold
  - Calculate technical coefficients of cost/expenditure functions using national- or regional-level social accounting matrix (SAM)

- Hard: calibrating elasticities + technical coefficients of trip aggregation, transformation functions
  - Substitution/transformation elasticities among trips
    - Drawn from literature vs. developed using our own econometric estimations
    - Quick & dirty approach: use Parry-Bento values
  - Need to aggregate key network characteristics, transport flows, input-output data to same geographic scale
    - Survey data on commuting and freight traffic flows available at MSA level
    - IMPLAN SAMs go down to county level
    - Possible solution: model major congested links in county aggregates which are coterminous w/. MSAs
  - Unsolved problem: details of defining network topology, assoc. traffic flows
Summary and Conclusions

• A contribution to the CGE literature on transportation infrastructure
  – Advance over existing “maquette” models in technical sophistication, overall scope
  – Comprehensive elaboration of relevant structure ⇒ a practical tool for policy analysis

• Key features
  – Derived demands for trips due to production, consumption, labor supply
  – House time budgets + transport producer time-based productivities ⇒ travel time explicitly embedded in GE
determination of prices and quantities
  – Reduced-form transportation network representation: a set of capacitated mode-link combinations on which
trips competitively assigned
  – Focus on congestion, modeled as increase in travel time
  – Infrastructure investments’ mitigating effects based on a comprehensive, fully endogenous definition of the
value of time

• Difficult implementational issues have yet to be surmounted
  – Appropriate geographical scale for application, network specification
  – Reconciling economic and transport data, computing calibrated parameters

• Is it worth the effort?
  – Empirical question: are broader economic benefits captured by our model significant w.r.t. direct effects
captured by CBA?
  – Approach generates a range of information that cannot be obtained from existing analyses
    • Distribution of benefits: firms vs. households, among industries
    • Relative magnitude of hold benefits from consumption vs. time savings from commuting
    • Useful in assessing whether specific objectives that policy makers attach to a project are likely to be met.
    • Able to assess multiple, simultaneous capacity expansions: useful in identifying potential synergies among projects

• Ultimate value of approach
  – Elucidate a plausible set of economy-wide interactions triggered by infrastructure improvements
  – Explain relevant mechanisms rather than just quantify their impacts
  – Necessary to better understand economy-wide impacts of infrastructure, characterize developmental effects
Extra Slides
Computable General Equilibrium: A Primer

- **Circular flow = Walrasian equilibrium**
  - Market clearance (MC): supply = demand for each commodity/factor
  - Zero profit (ZP): each firm’s output price = marginal cost of production
  - Income balance (IB): hholds’ factor income from factor returns = expenditure on commodities

- **CGE models: algebraic expression of above**
  - Parameters numerically calibrated on real-world data
  - System of equations solved for vector of prices that supports equilibrium

- **Basic idea: imposition of producer and consumer optimization on the circular flow**
  - Hholds max. utility \( \Rightarrow \) Final commodity demands = \( f(\text{Prices}) \)
  - Firms max. profits \( \Rightarrow \) Factor demands, Intermediate commodity demands = \( f(\text{Prices}) \)
Computable General Equilibrium: A Primer

• CGE model in a nutshell
  \( MC: \sum \text{Factor demands} = \text{Factor endowment}, \)
  \( \sum \text{Commodity demands} = \text{Commodity supply} \)
  \( ZP: \text{Commodity price} \cdot \text{Commodity supply} = \)
  \( \sum \left( \text{Commodity prices} \cdot \text{Intermediate demands} \right) \)
  \( + \sum \left( \text{Factor prices} \cdot \text{Factor demands} \right) \)
  \( IB: \sum \left( \text{Commodity prices} \cdot \text{Final commodity demands} \right) = \sum \left( \text{Factor prices} \cdot \text{Factor endowments} \right) \)

• Solve for prices and quantities simultaneously
  – Find commodity/factor prices which satisfy above
  – Back substitute in demand functions to get quantities

• Our goal: integrate transport elements ( crave ) into above framework in a consistent fashion
Household Utility Maximization, Labor Supply, and Derived Demand for Retail and Commuting Trips

Utility

Consumption of Commodities

Commodity 1
- Goods Shipped to Retail Outlets
  - Retail Trips by Mode/Link

...  

Commodity N
- Demand for Retail Travel

Leisure

Demand for Commuting Travel

Labor Supply

Actual Hours of Labor

Utility Maximization

Labor Supply
Production in Non-Transport Firms and Derived Demand For Freight Trips

- Shipments of Product
  - Demand for Freight Travel
    - Freight Trips by Mode/Link
    - Freight Trips by Mode/Link
    - Freight Trips by Mode/Link
  - Production of Actual Good or Service
    - Intermediate Inputs
      - Intermediate Good 1
      - ... (omitted)
      - Intermediate Good N
    - Primary Factors
      - Labor
      - Capital
Transport Producers and the Supply of Retail, Freight and Commuting Trips

Freight Trips by Link

Retail Trips by Link

Commuting Trips by Link

Freight Trips

Retail Trips by Link

Commuting Trips

Intermediate Inputs

Intermediate Good 1

Intermediate Good N

Primary Factors

Labor

Capital