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

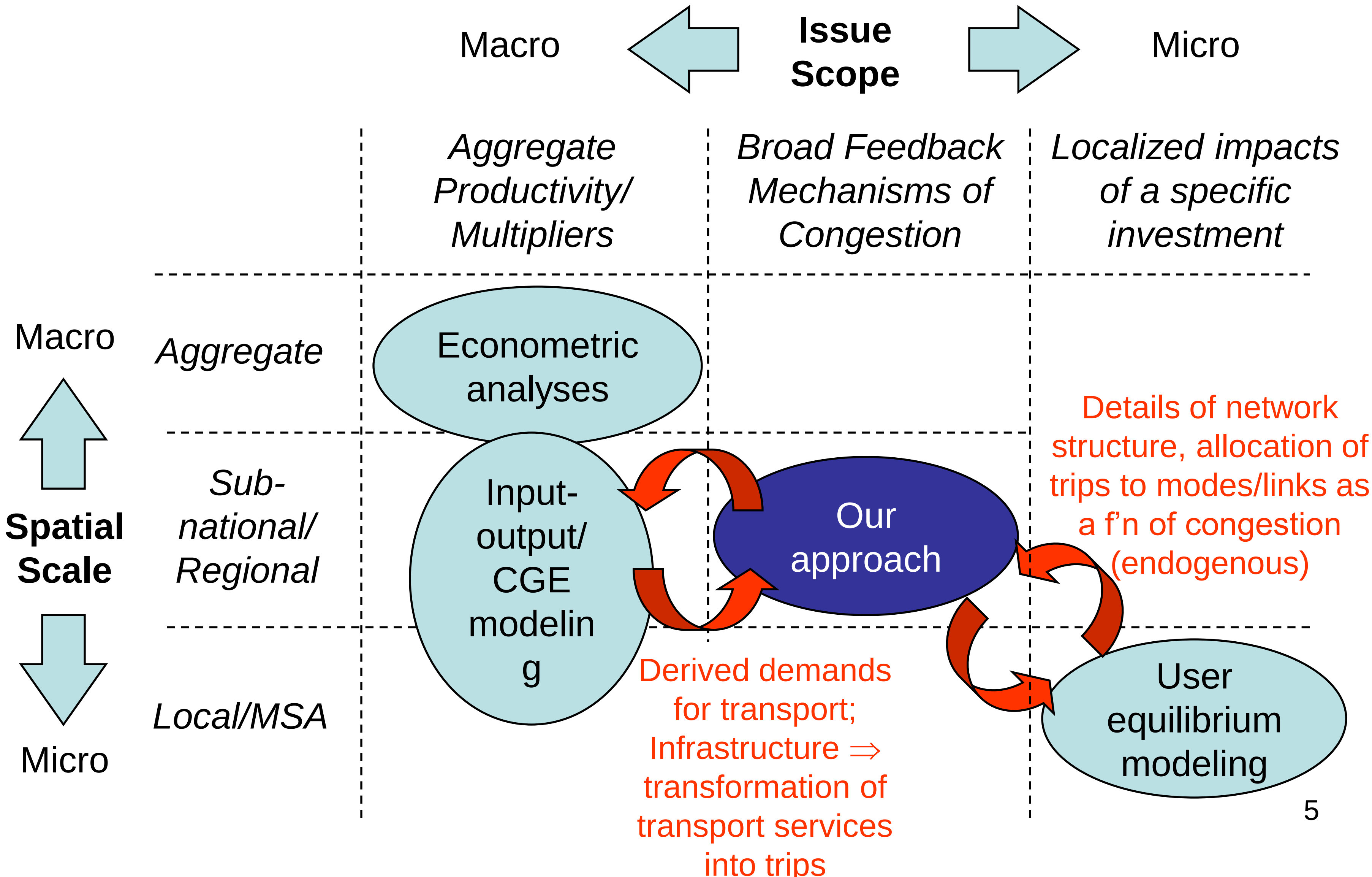
Introduction

- 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

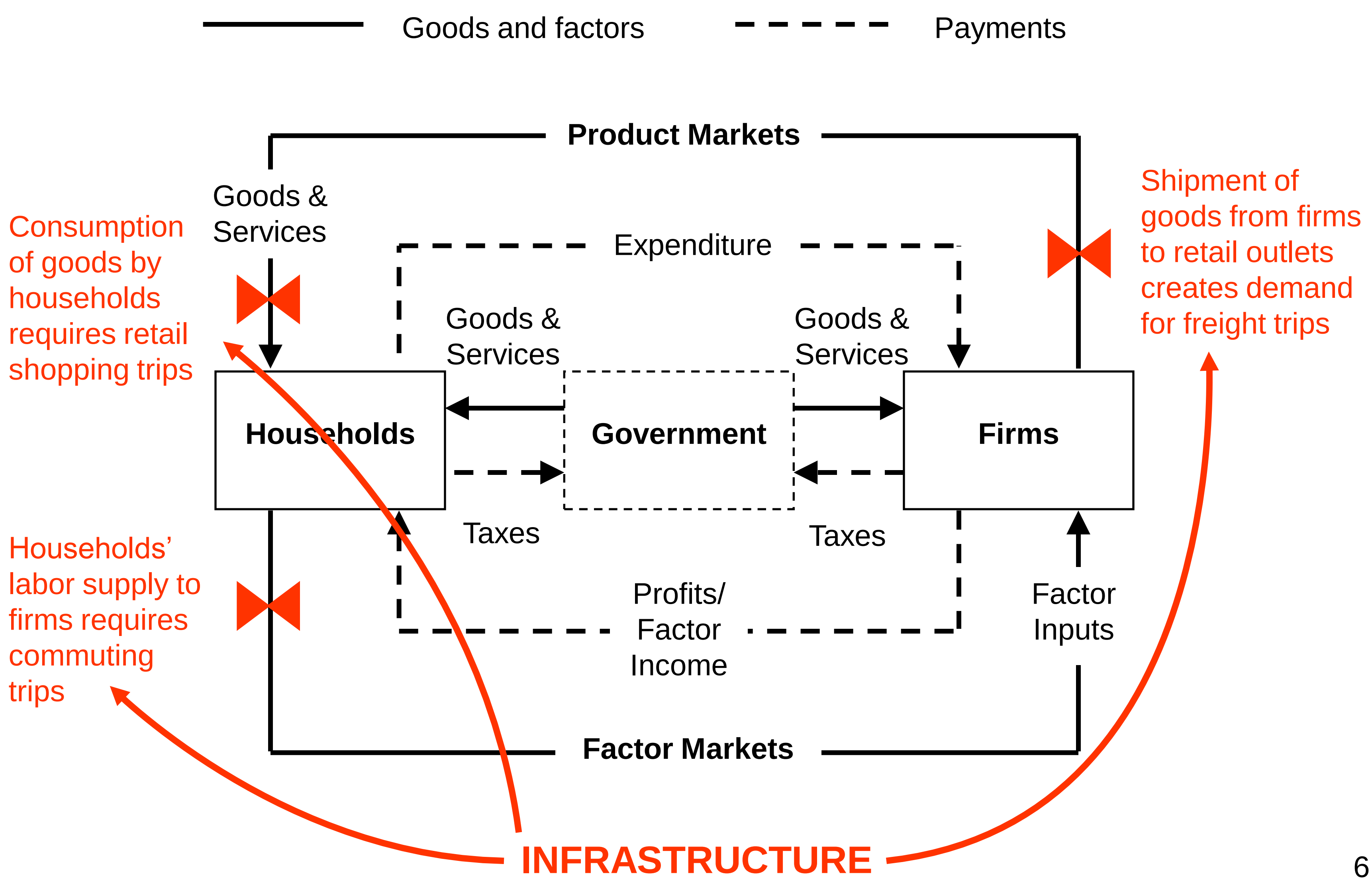
Our Focus

- 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 $\Rightarrow$ endogenous changes in employment, output, and incomes

“Meso-Level” Analysis in Context



The Circular Flow of the Economy and the General Equilibrium Effects of Transportation 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
  - Parry-Bento (2001, 2002)
    - 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
  - Conrad (1997), Conrad-Heng (2002)
    - Aggregate transport cost minimization $\Rightarrow$ optimal level of infrastructure
    - Ratio of actual to optimal level of infrastructure capital $\Rightarrow$ congestion
    - Congestion synonymous w/. capacity utilization: $\downarrow$ productivity of sector-specific transportation capital stocks

Main Stylized Facts

- A-spatial, macro-level analysis
  - No details of transportation network $\Rightarrow$ 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 $\Rightarrow$ derived demand for travel
  - Household consumption $\Rightarrow$ passenger shopping travel or retail delivery (*R*)
  - Household labor supply $\Rightarrow$ passenger commuting travel (*C*)
  - Goods movement $\Rightarrow$ 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 $\Rightarrow \downarrow$ avg. trip time $\Rightarrow \uparrow$ retail, commuting trip volumes $\Rightarrow \uparrow$ 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, = *f*(Link Capacity)

Infrastructure Investment ⇨ {

- ↓ avg. trip time ⇒ ↑ freight trip volumes, goods shipments ⇒ ↓ commodity prices
- ↑ *T*-type firms' avg. factor productivity ⇒ ↑ Factor returns, household income

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 $\Rightarrow$ a practical tool for policy analysis
- Key features
  - Derived demands for trips due to production, consumption, labor supply
  - Hhold time budgets + transport producer time-based productivities $\Rightarrow$ 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
  - <u>Explain</u> 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*(Prices)
  - Firms max. profits $\Rightarrow$ Factor demands, Intermediate commodity demands = *f*(Prices)

Computable General Equilibrium: A Primer

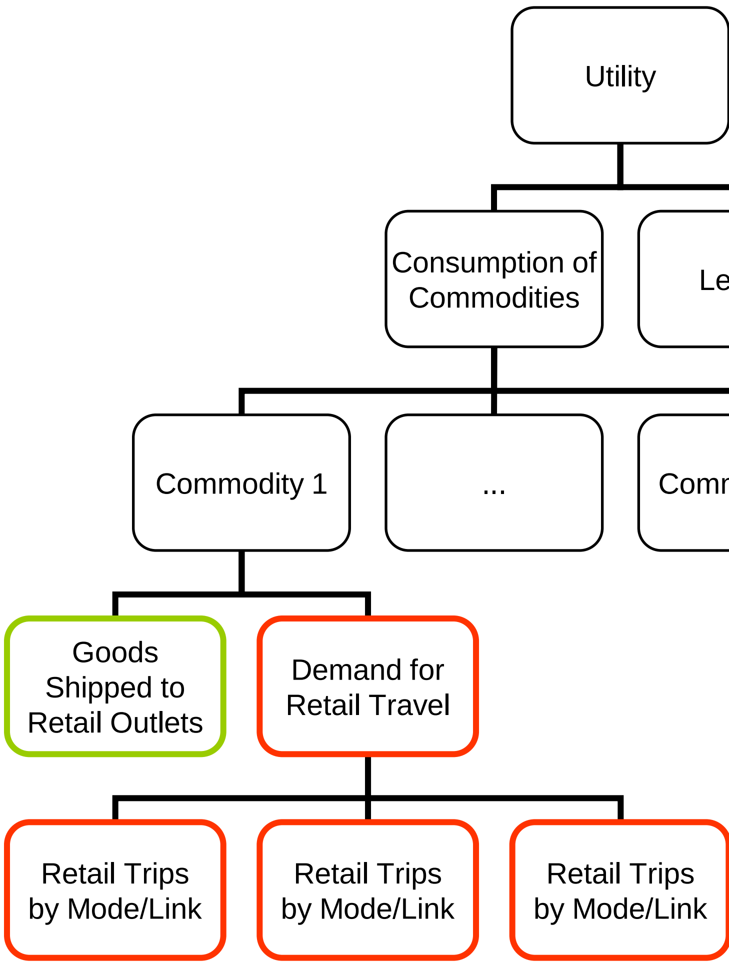
- CGE model in a nutshell

  MC: ∑ Factor demands = Factor endowment,
  ∑ Commodity demands = Commodity supply

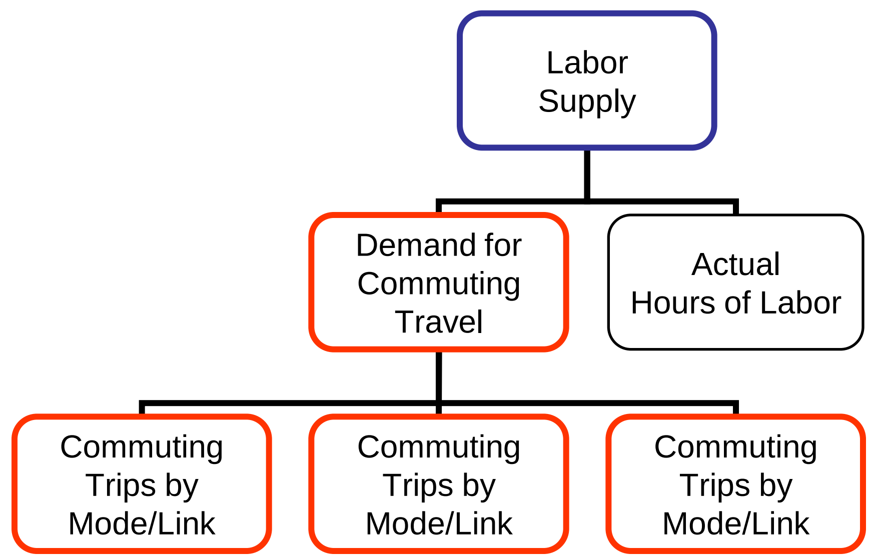
  ZP: Commodity price   Commodity supply =
  ∑ (Commodity prices   Intermediate demands)
  + ∑ (Factor prices   Factor demands)

  IB: ∑ (Commodity prices   Final commodity demands)
  = ∑ (Factor prices   Factor endowments)
- 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 (⋈) into above framework in a consistent fashion

Household Utility Maximization, Labor Supply, and Derived Demand for Retail and Commuting Trips

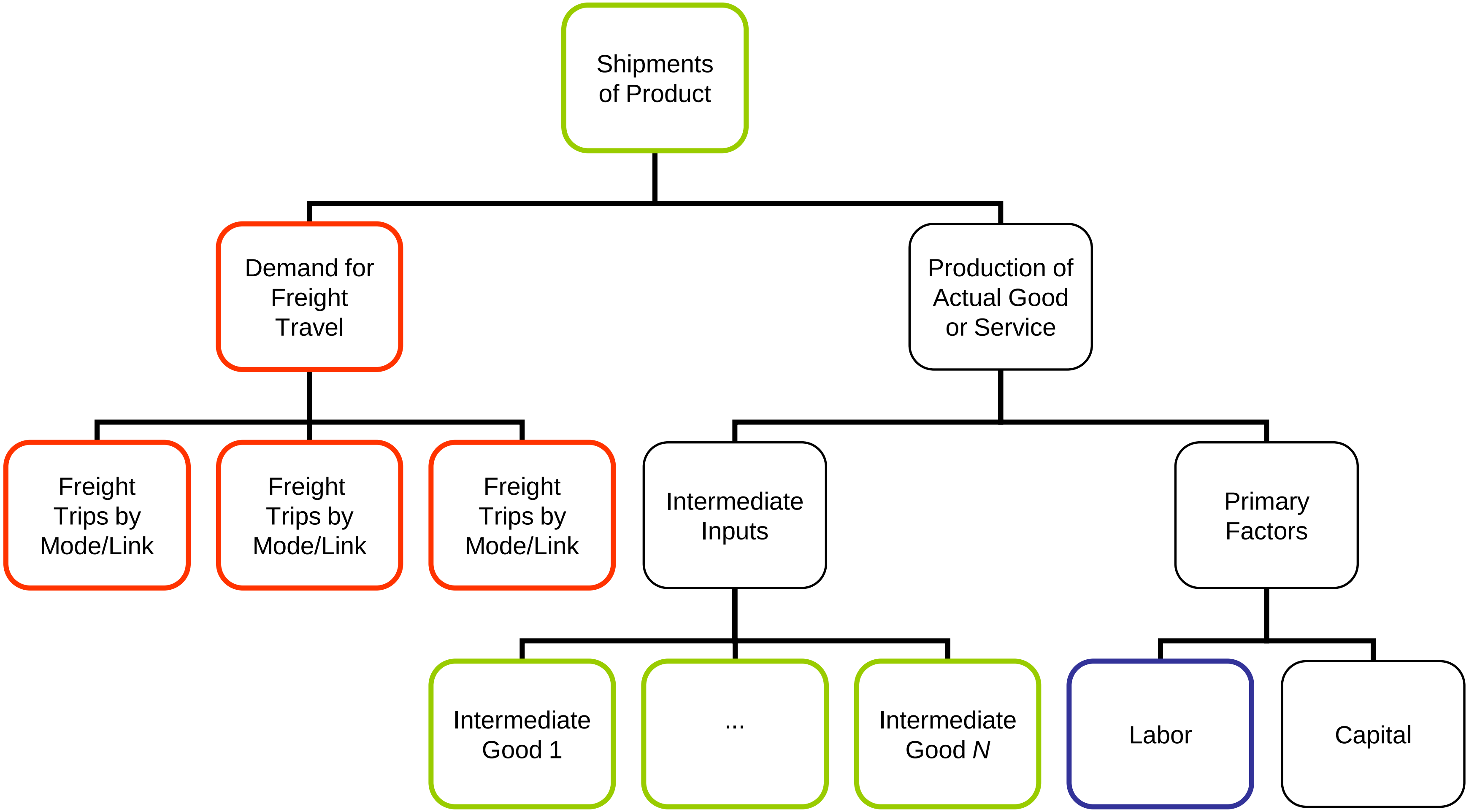


Utility Maximization



Labor Supply

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



Transport Producers and the Supply of Retail, Freight and Commuting Trips