Freight Demand

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1.201 / 11.545 / ESD.210
Transportation Systems Analysis: Demand & Economics

Fall 2008

Outline

- **Background**
  - Volumes
  - Types
  - Econometric Indicators
- Freight demand modeling
  - Framework
  - Logistics choices
  - Model system
- Trends and Summary
- Appendices: Extensions, Activity Systems, Model System

Major Types of Freight

- Bulk
  - Coal
  - Oil, Gas
  - Ores, Minerals, Sand and Gravel
  - Agricultural
- General Merchandise
  - Supermarket grocery
- Specialized Freight
  - Automobile
  - Chemicals
- Small Package

Bulk

- Commodity Characteristics
  - Cheap
  - Vast quantities
  - Transport cost is a major concern
- Relevant Modes
  - Rail unit train and multi-car shipments
  - Heavy truck
  - Barge and specialized ships
  - Pipeline

General Merchandise

- Commodity characteristics
  - Higher value
  - Greater diversity of commodities
  - Many more shippers and receivers
  - Logistics costs are as important as transport costs
- Relevant Modes
  - Rail general service freight car
  - Intermodal
  - Truckload
  - LTL (Less-than-Truckload)

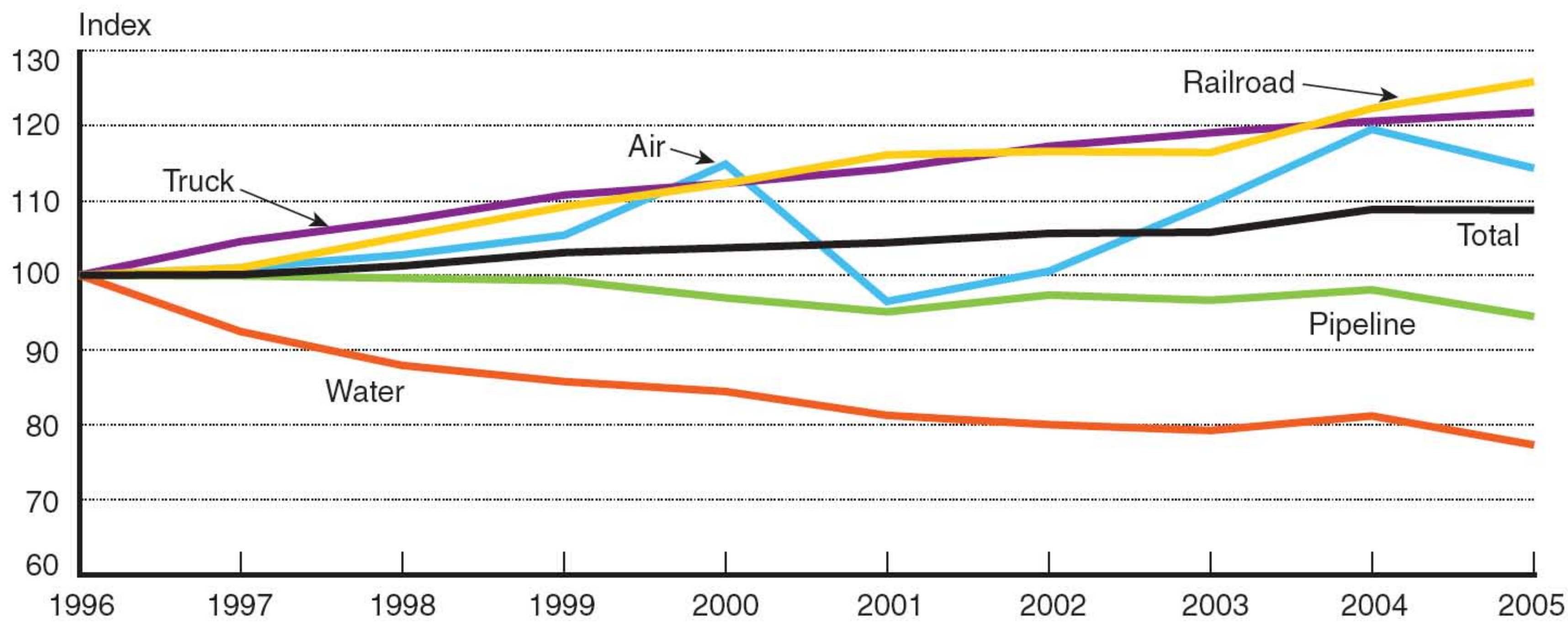
Specialized Freight

- Commodity Characteristics
  - Large volumes, relatively few customers
  - Specialized requirements to reduce risk of loss and damage
  - High value (can afford special treatment)
- Relevant Modes
  - Specialized rail (multi-levels, tank cars, heavy duty flats)
  - Specialized trucks (auto carriers, tank trucks, moving vans)
  - Air freight

Small Package

- Commodity Characteristics
  - Very high value
  - Logistics costs are more important than transport costs
  - Deliveries to small businesses or consumers
- Relevant Modes
  - LTL
  - Small packages services
  - Express services
  - Air freight

Growth in US Domestic Freight Ton-Miles by Mode: 1996 - 2005



SOURCE: U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics. BTS Special Report: A Decade of Growth in Domestic Freight, Table 1 (July 2007).

Freight Demand

- Freight transport demand is a derived demand
  - Related to the volumes of goods produced and consumed
  - Location of suppliers and consumers is critical
  - Freight flows shift with
    - New sources of and uses for materials
    - New locations for manufacturers and retailers
    - New products and specialized transport

Freight Elasticities

Model, elasticity type	Elasticity estimates	
	Rail	Truck
Aggregate mode split model [a]		
Price	-0.25 to –0.35	-0.25 to –0.35
Transit time	-0.3 to –0.7	-0.3 to –0.7
Aggregate model from translog cost function [b,c]		
Price	-0.37 to –1.16[d]	-0.58 to -1.81[e]
Disaggregate mode choice model [b,f]		
Price	-0.08 to –2.68	-0.04 to –2.97
Transit time	-0.07 to –2.33	-0.15 to –0.69

a. Levin, Richard C. 1978. "Allocation in Surface Freight Transportation: Does Rate Regulation Matter?" *Bell Journal of Economics* 9 (Spring): 18-45
b. These estimates vary by commodity group; we report the largest and smallest.
c. Friedlaender, Ann F., and Richard Spady. 1980. "A Derived Demand Function for Freight Transportation." *Review of Economics and Statistics* 62 (August)
d. The first value applies to mineral products; the second value to petroleum products.
e. The first value applies to petroleum products; the second value to mineral products.
f. Winston, Clifford. 1981. "A Disaggregate Model of the Demand for Intercity Freight Transportation". *Econometrica* 49 (July): 981-1006

Freight Value of Time (VOT)

	VOT estimates	
	Rail	Truck
(As percentage of shipment value)		
Total transit time (in days)	6-21	8-18

The lower value applies to primary and fabricated metals; the higher value applies to perishable agriculture products.

Source: Winston, Clifford. 1979. "A Disaggregate Qualitative Mode Choice Model for Intercity Freight Transportation." Working paper SL 7904. University of California at Berkeley, Department of Economics.

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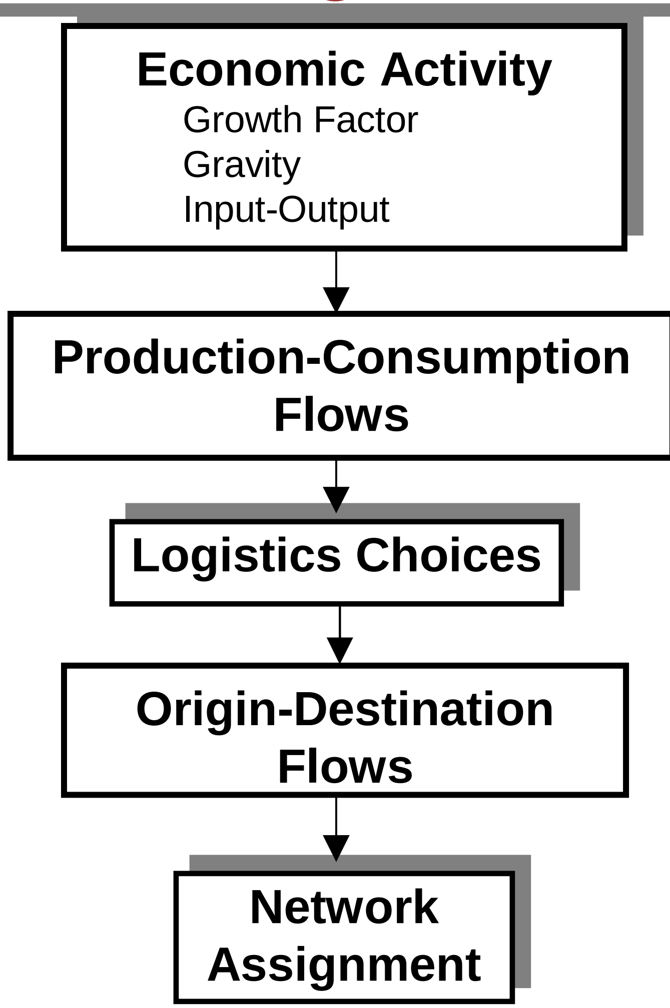
Freight Modeling Framework



Forecasting Freight OD Flows

- Growth Factors:
  - Factor an existing OD trip table of commodity flows to estimate future flows
- Gravity Models:
  - The distribution step in a 4-step model
- Economic Activity Models:
  - Trace the flows of commodities between economic sectors and between regions

Growth Factors

- Supply and Demand from a region are predicted using "Growth Factors"
- Iterative Proportional Fitting (IPF) technique is used
- Given the S_i , D_j and T^0_{ij} , calculate T_{ij} , α_i and β_j

$$T_{ij} = \alpha_i \beta_j T^o_{ij} \qquad i = 1,\dots, I \ and \ j = 1,\dots, J$$

$$\sum_j T_{ij} = S_i, \qquad i = 1,\dots, I$$

$$\sum_i T_{ij} = D_j, \qquad j = 1,\dots, J$$

Where, T_{ij} = predicted OD flow between region *i* and region *j*

T^0_{ij} = initial OD flow between region *i* and region *j*

α_i and β_j = balancing factors for regions *i* and *j* respectively

S_i = supply at region *i* and D_j = demand at region *j*

Gravity Model

- IPF with $$T_{ij}^{0} = S_i D_j f(C_{ij})$$

$$T_{ij} = \alpha_i S_i \beta_j D_j f(C_{ij}), \; i = 1,\ldots, I \text{ and } j = 1,\ldots, J$$

$$\sum_j T_{ij} = S_i, \quad i = 1,\ldots, I$$

$$\sum_i T_{ij} = D_j, \quad j = 1,\ldots, J$$

Where,

C_{ij} = generalized cost of shipping between regions *i* and *j*

$f(C_{ij}) = e^{-\theta C_{ij}}$ = generalized cost function

If $\theta \to \infty$, the model is equivalent to a linear programming problem:

$$Min \sum_i \sum_j T_{ij} C_{ij}, \quad s.t. \sum_j T_{ij} = S_i, \; \sum_i T_{ij} = D_j$$

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Logistics Chain

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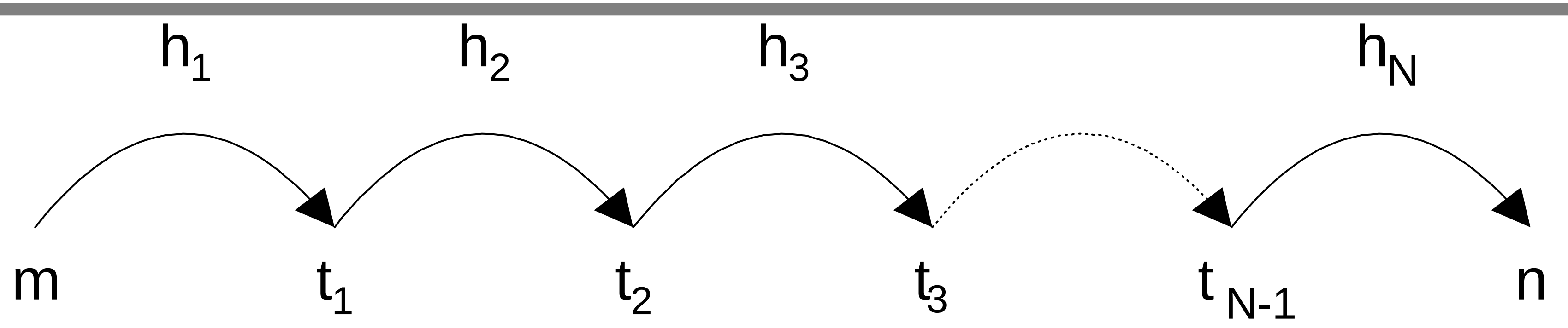
Multi-Leg Logistics Chain



N : number of legs in a logistics chain

m : sender

n : receiver

h : mode

t : transhipment location

Decision Maker

- No single decision maker
  - Producers
  - Wholesalers, Distributors
  - Consumers
  - Carriers
  - Logistics service providers

Logistics Choices

- Shipment size/frequency
- Choice of loading unit
  - e.g. container, pallet, refrigerated
- Formation of tours
  - consolidation and distribution, multi-stop deliveries, batching
- Location of consolidation and distribution centers

Logistics Choices (cont.)

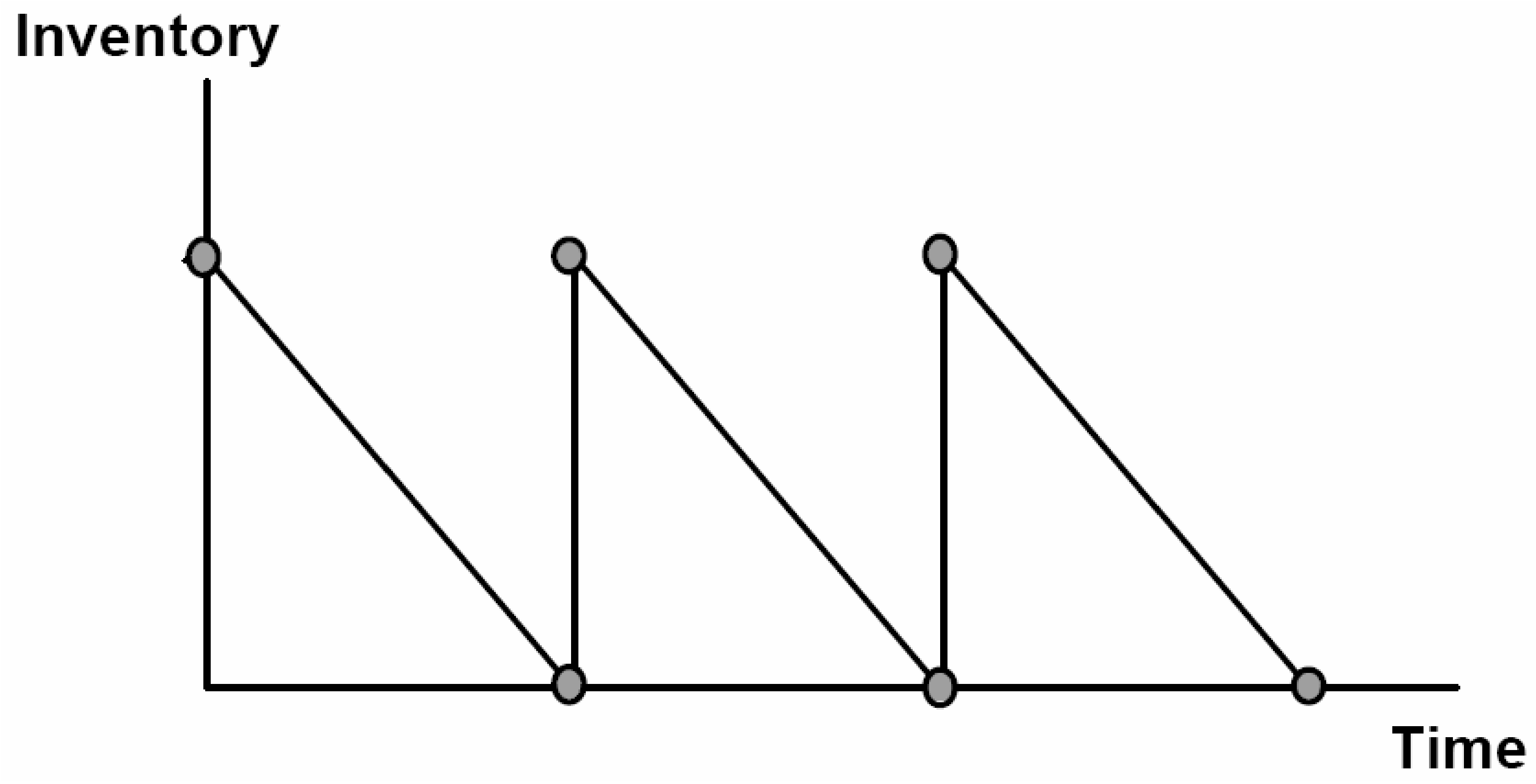
- Mode used for each tour leg
  - Road transport: vehicle types
  - Rail transport: train types
  - Maritime transport: vessel types
  - Air
- Shipment schedule

Logistics Costs

- Order management
- Transport
- Transshipment
- Loss and damage
- Capital tied up
- Inventory management
- Unreliability

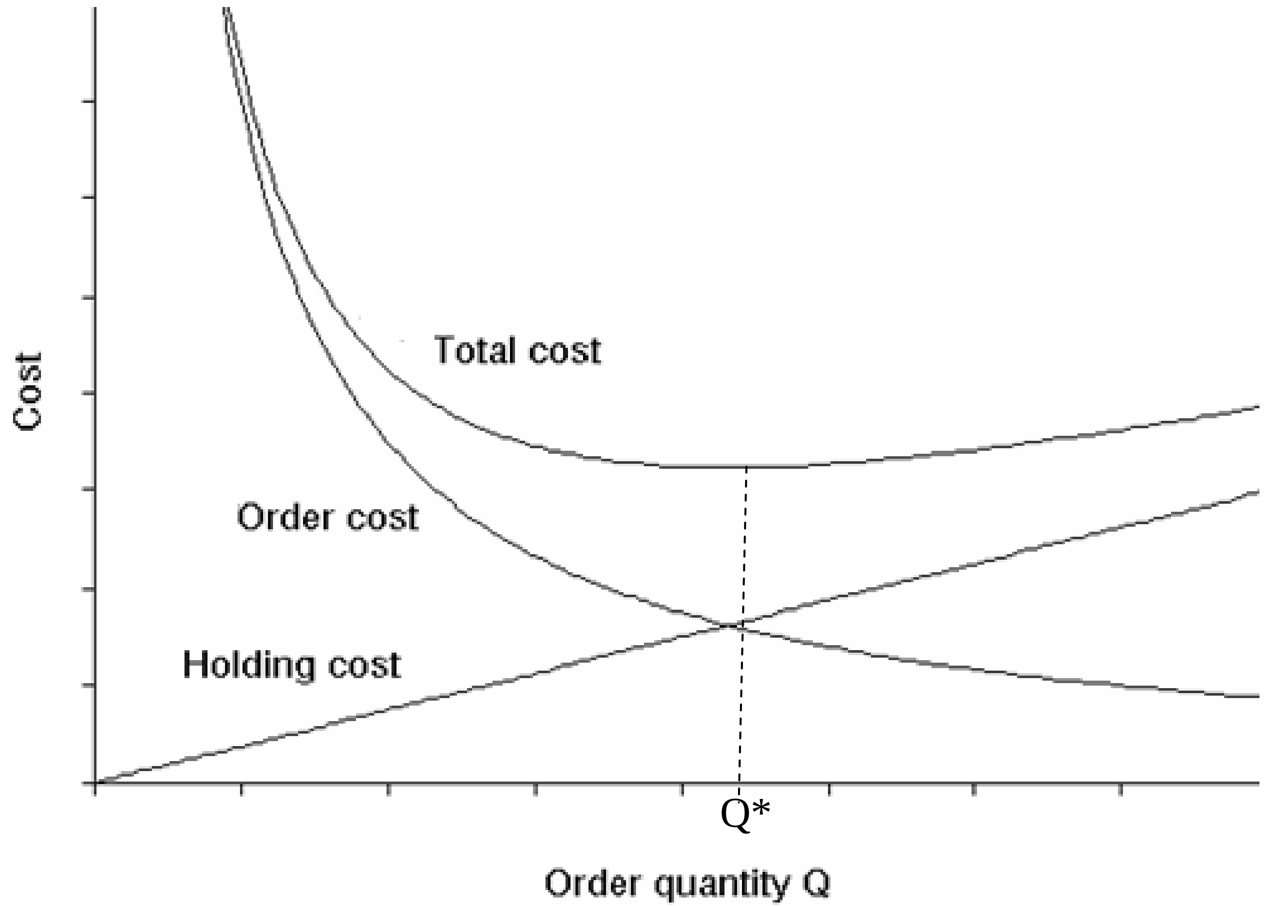
Factors Affecting Logistics Costs

Inventory Management



Factors Affecting Logistics Costs

Order Management



The optimal quantity Q* is also known as the Economic Order Quantity (EOQ)

Modeling Complexities

- Widely varying commodities with different requirements and characteristics
- Level-of-service attributes

  e.g. shipment time, cost, reliability
- Characteristics of the shipment

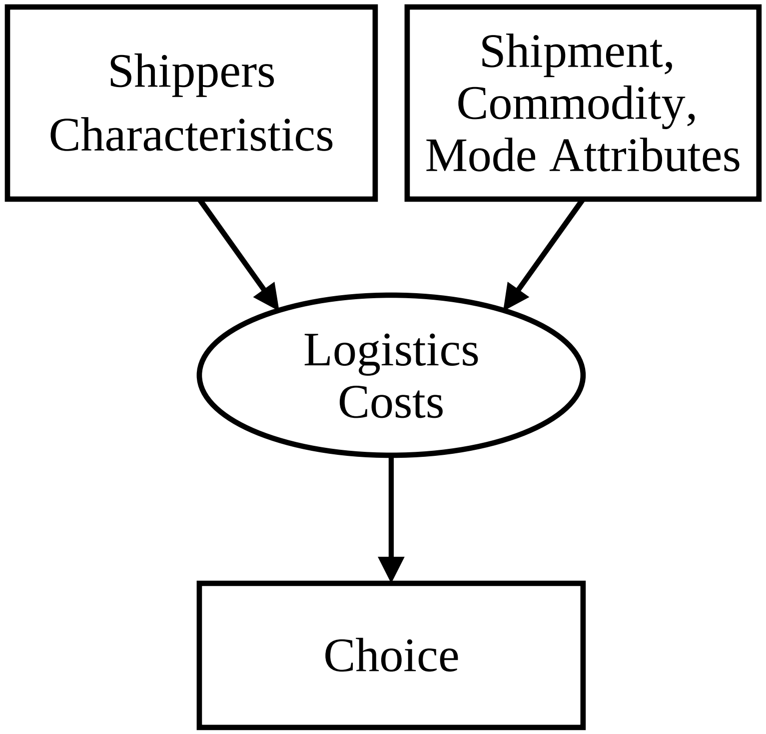
  e.g. size, frequency, goods typology (perishability, value)
- Characteristics of the firm

  annual revenue, availability of own trucks, availability of railway sidings

Data Requirements

- Size of firms by commodity and by region at production and consumption ends
- Shipments
- *Consolidation center* and *distribution center* locations, ports, airports, rail terminals
- Cost data
  - time and distance from network models combined with cost models

Freight Mode Choice Model



Model Specification

$$U_{in} = \mu(\text{ logistics cost}_{in}) + \varepsilon_{in}$$

$$\text{logistics cost}_{in} = C_{in} + W_{in}\theta + r(T_{in} + Z_{in}\gamma)$$

μ: negative scale parameter;

ε_{in}: error term that are i.i.d. standard normal;

C_{in}: transportation cost;

W_{in}: row vector that contains the mode-specific constant, mode-specific variables that capture the effects of ordering costs, on-time delivery and equipment availability;

T_{in}: daily value of in-transit stocks;

Z_{in}: discount rate related variables such as loss and damage costs and stock-out costs;

θ, γ: vectors of unknown coefficients;

r: discount rate.

Example of Estimation

- Data:
  - Survey of 166 large US shippers (1988)
  - Alternatives: Truck, Rail, Intermodal
  - Commodities: Paper, Aluminum, Pet food, Plastics and Tires.

Adapted from : Park, J. K. (1995). “Railroad Marketing Support System Based on the Freight Choice Model”, PhD Thesis, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology

Example of Estimation (cont)

- **Estimated logistics cost functions:**

$$Truck\ Cost = -0.138 + (Transportation\ cost) + 0.372(Distance) - 0.811(Delivery\ time\ reliability)$$
$$-4.35(Equipment\ usability) - 0.0980(Value/ton) + 0.456[(In\ transit\ stock\ holding\ cost)$$
$$+0.169(Safety\ stock\ costs) + 1.65(Loss\ and\ demage)]$$

$$Rail\ Cost = (Transportation\ cost) - 0.811(Delivery\ time\ reliability)$$
$$-4.35(Equipment\ usability) + 0.456[(In\ transit\ stock\ holding\ cost)$$
$$+0.169(Safety\ stock\ costs) + 1.65(Loss\ and\ demage)]$$

$$Intermodal\ Cost = 1.64 + (Transportation\ cost) - 0.811(Delivery\ time\ reliability)$$
$$-4.35(Equipment\ usability) + 0.456[(In\ transit\ stock\ holding\ cost)$$
$$+0.169(Safety\ stock\ costs) + 1.65(Loss\ and\ demage)]$$

Sources of Heterogeneity

- Inter-shipper
  - Attitudes
  - Perceptions of service quality
  - Awareness of modal alternatives
- Intra-shipper
  - Shipment type (regular vs. emergency)
  - Customer (large vs. small)

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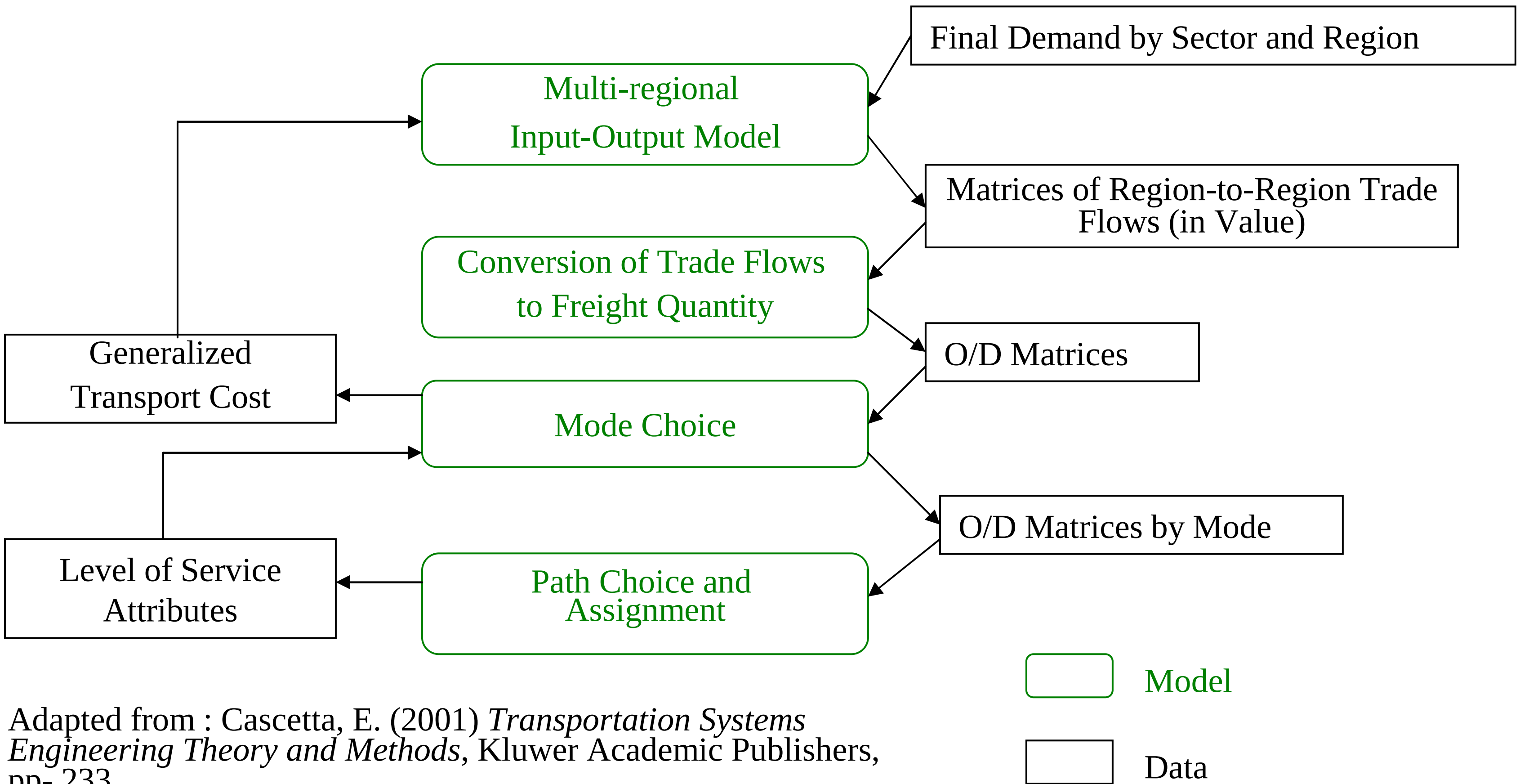
Model System



Adapted from : Cascetta, E. (2001) *Transportation Systems Engineering Theory and Methods*, Kluwer Academic Publishers, pp- 233

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Trends in Freight Modeling

- ***EMERGING ISSUES:***

  Smaller Inventories, Shorter lead time, Consolidation

- ***DATA:***

  Commodity Flow Surveys → Automated Data Collection (e.g. AVI, Remote Sensing)

- ***MODELING METHODS:***

  Aggregate Models → Disaggregate Models

- ***APPLICATION/FORECASTING:***

  Aggregate Forecasting → Disaggregate Forecasting

- ***BEHAVIORAL REPRESENTATION:***

  Homogeneous → Heterogeneous (commodity types, supply-chains)

Summary

- Freight demand is expected to continue to grow at a steady rate
- Discrete choice models are useful to predict intermodalism in freight demand with explicit treatment of heterogeneity and perceptions
- Estimation requires detailed shipment data, not all of which are available
- Aggregate data can be used to calibrate the overall freight model system in absence of detailed shipment data

Appendix A

Extensions of logistics choice modeling

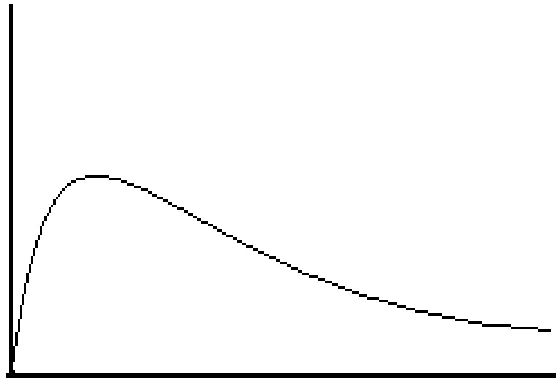
Extension 1: Distributed Discount Rate

- Shippers use *Discount Rate* (*r*) to calculate costs of inventory
- *Discount rate* varies significantly among shippers and shipments
- Model Specification:

$$r \sim log\,normal(\mu, \sigma^2)$$

$$\mu = -0.715, \sigma = 0.481$$

$$\bar{r} = 0.549, \sigma_r = 0.280$$



Distribution of Discount Rate

Extension 2: Shipper-Specific Discount Rate

- Multiple observations of the same shipper
- Shipper-specific discount rate captures correlation between observations from the same shipper
- Model Specification:

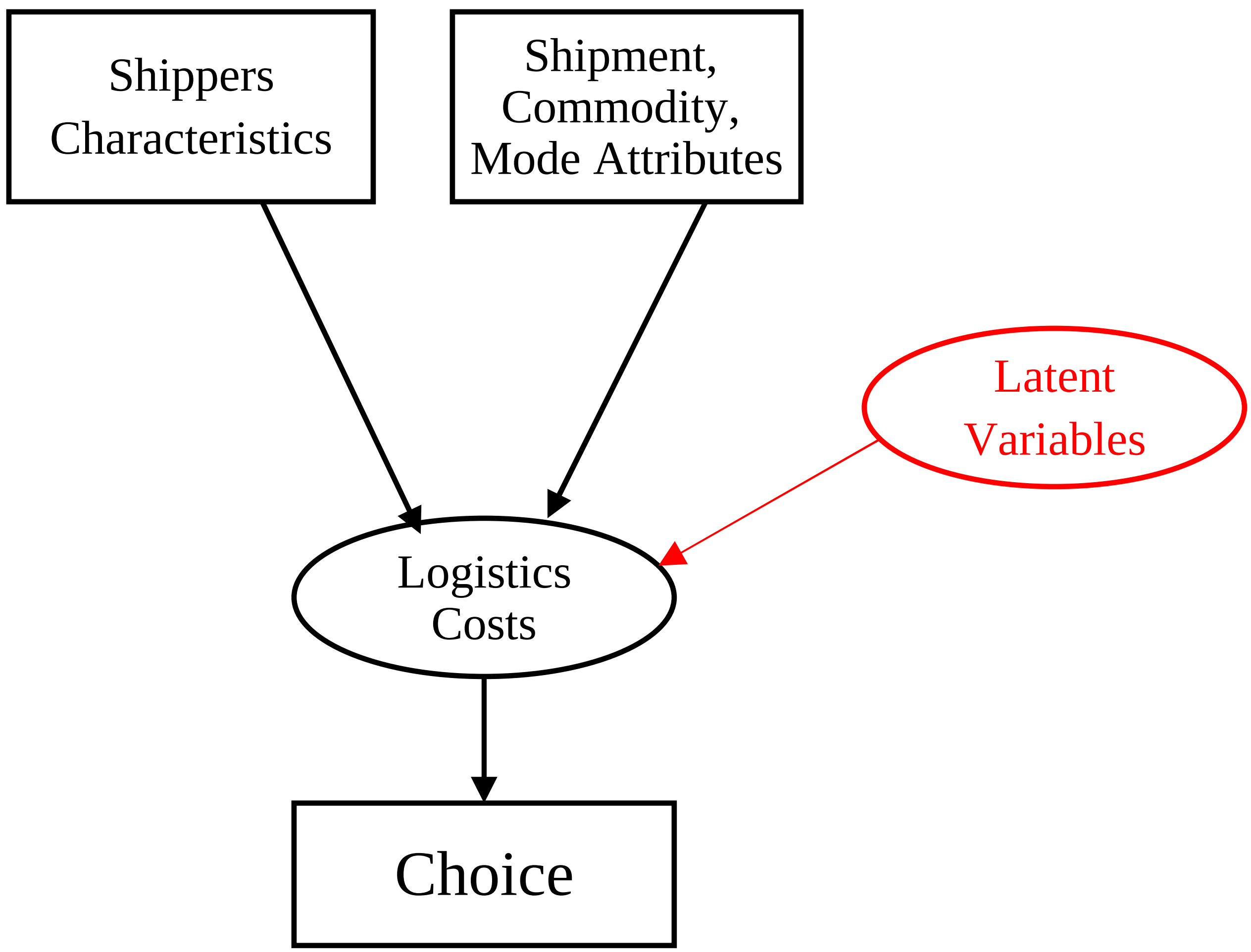
$$U_{int} = X_{int}\beta + Z_{int} r_{nt} + \varepsilon_{in}$$

shipper specific discount rate

$$r_{nt} = r_n \ \forall t$$

$$r_n \sim log\,normal(\bar{r}, \sigma_r^2)$$

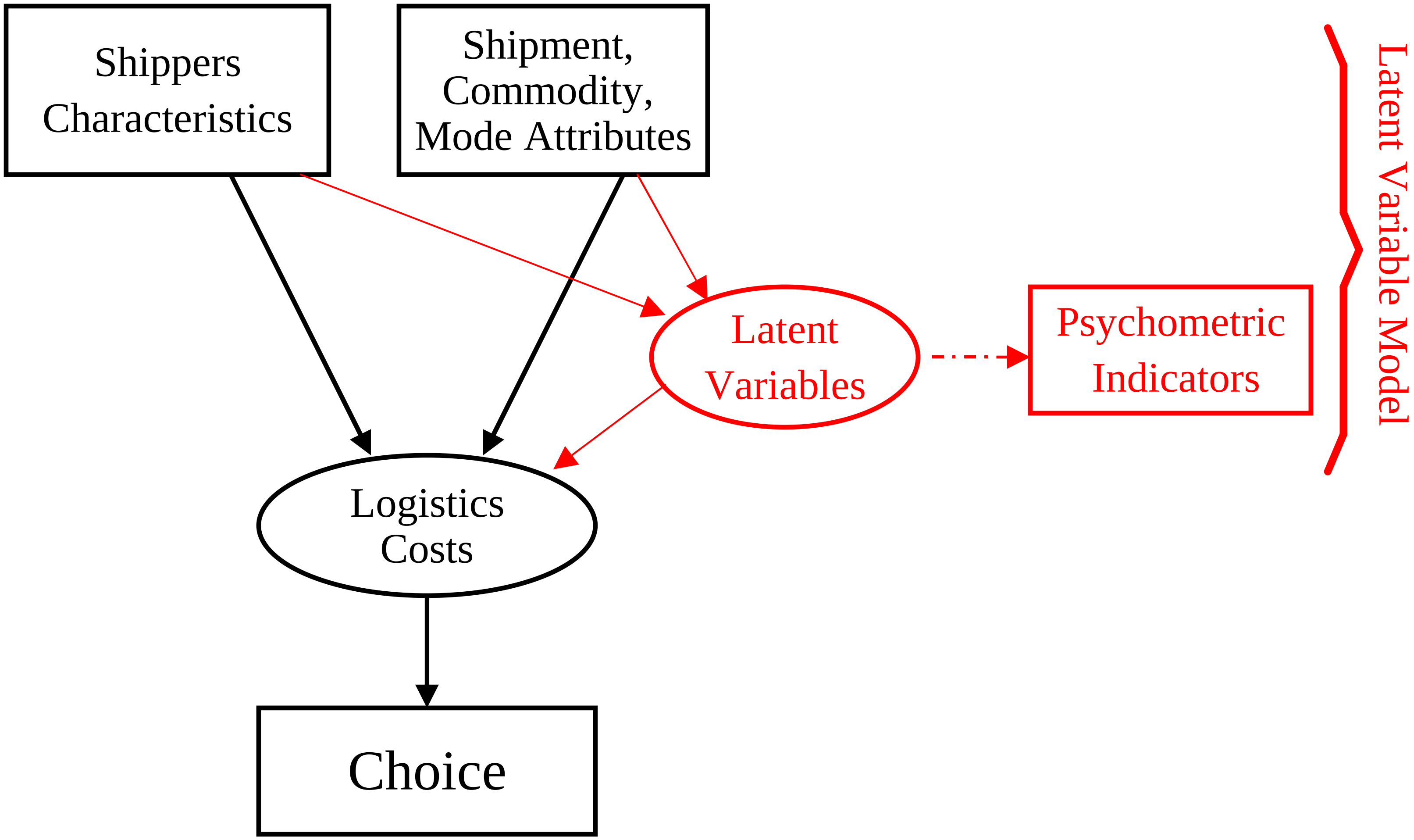
Extension 3: Latent Variable Models



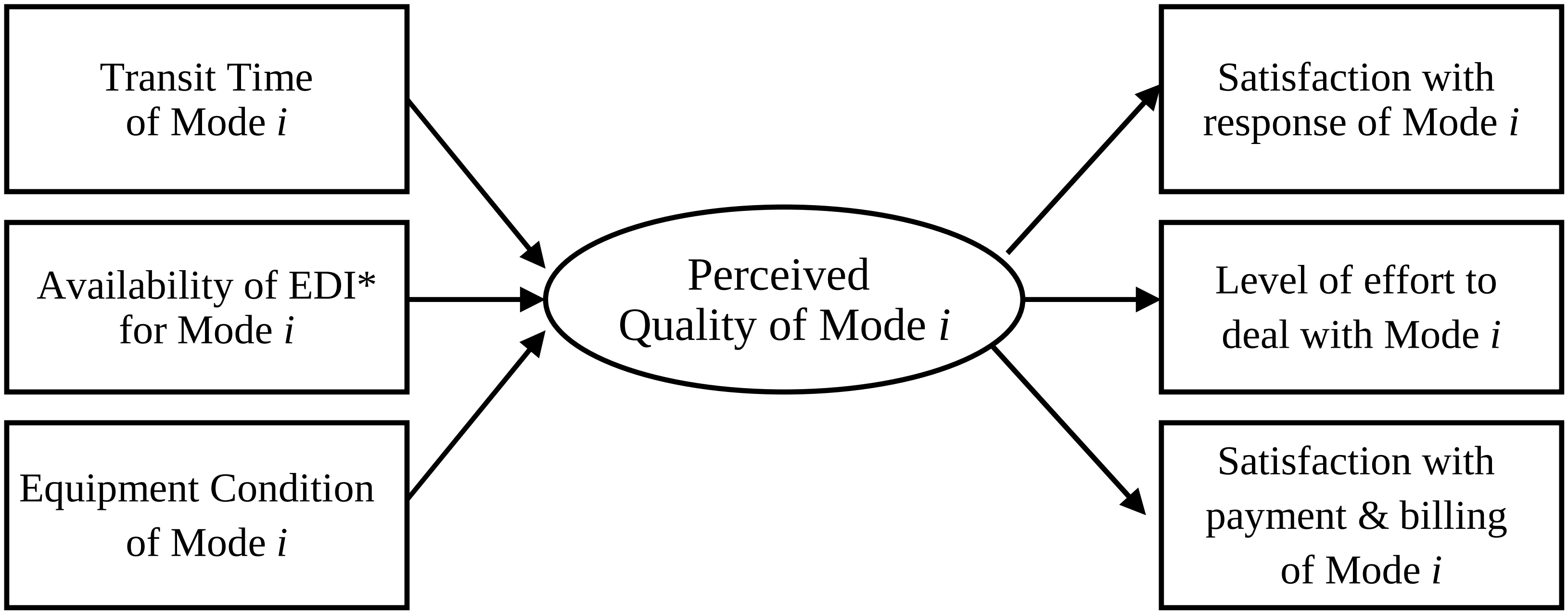
Latent Variable Models (cont.)

- "Qualitative Indicators" Provide Information on Latent Variables
  - Awareness
    - I could use rail as a substitute to truck service.
  - Sensitivity to Quality
    - I am willing to pay more for a mode with greater flexibility to accommodate emergency shipments.
  - Image
    - I like to use the most reliable technology

Latent Variable Model (cont.)



Latent Variable Model (cont)



*EDI: Electronic Data Interchange, which is a set of standards for structuring information that is to be electronically exchanged between and within businesses, organizations, government entities and other groups.

Latent Variable Model (cont)

- Significant improvement in log-likelihood
- Significant changes in some of the parameter estimates

$$
\begin{aligned}
Truck\ Cost = & -0.266 + (Transportation\ cost) + 0.627(Distance) - 0.905(Delivery\ time\ reliability) \\
& - 0.466(Value/ton) - 4.67(Equipment\ usability) \\
& + 0.356[(In\ transit\ stock\ holding\ cost) + 0.0970(Safety\ stock\ costs) \\
& + 2.28(Loss\ and\ demage)] - 0.769(Perceived\ Quality)
\end{aligned}
$$

$$
\begin{aligned}
Rail\ Cost = & (Transportation\ cost) - 0.905(Delivery\ time\ reliability) - 4.67(Equipment\ usability) \\
& + 0.356[(In\ transit\ stock\ holding\ cost) + 0.0970(Safety\ stock\ costs) \\
& + 2.28(Loss\ and\ demage)] - 0.769(Perceived\ Quality)
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$$

$$
\begin{aligned}
Intermodal\ Cost = & 1.65 + (Transportation\ cost) - 0.905(Delivery\ time\ reliability) - 4.67(Equipment\ usability) \\
& + 0.356[(In\ transit\ stock\ holding\ cost) + 0.0970(Safety\ stock\ costs) \\
& + 2.28(Loss\ and\ demage)] - 0.769(Perceived\ Quality)
\end{aligned}
$$

Extension 4: Combining Revealed and Stated Preference Data

- Features
  - Bias correction through explicit specification of stated preference model
  - Joint estimation with all available data

Combining Revealed & Stated Preferences Data (cont)

- Significant changes in parameter estimates and t-stats

	Estimates (t-statistics) RP&SP	Estimates (t-statistics) RP
Delivery time reliability	3.6(-7.8)	-0.91 (-1.0)
Equipment usability	-1.4 (-7.8)	-4.7 (-3.3)
Discount rate	0.20 (6.6)	0.36 (1.9)
Stock out costs	0.029 (0.1)	0.097 (2.9)
Loss and damage costs	5.0 (6.4)	2.3 (0.8)

References

- Ben-Akiva, M., Bolduc, D. and Park, J.Q. 2008, 'Discrete choice analysis of shipper's preferences', forthcoming in Ben-Akiva, M., Meersman, H. and Van de Voorde, E. (eds.), *Recent Developments in Transport Modelling: Lessons for the Freight Sector,* Emerald Group Publishing, United Kingdom, pp. 119-138.

Appendix B

Freight Economic Activity System Models

Economic Activity Models

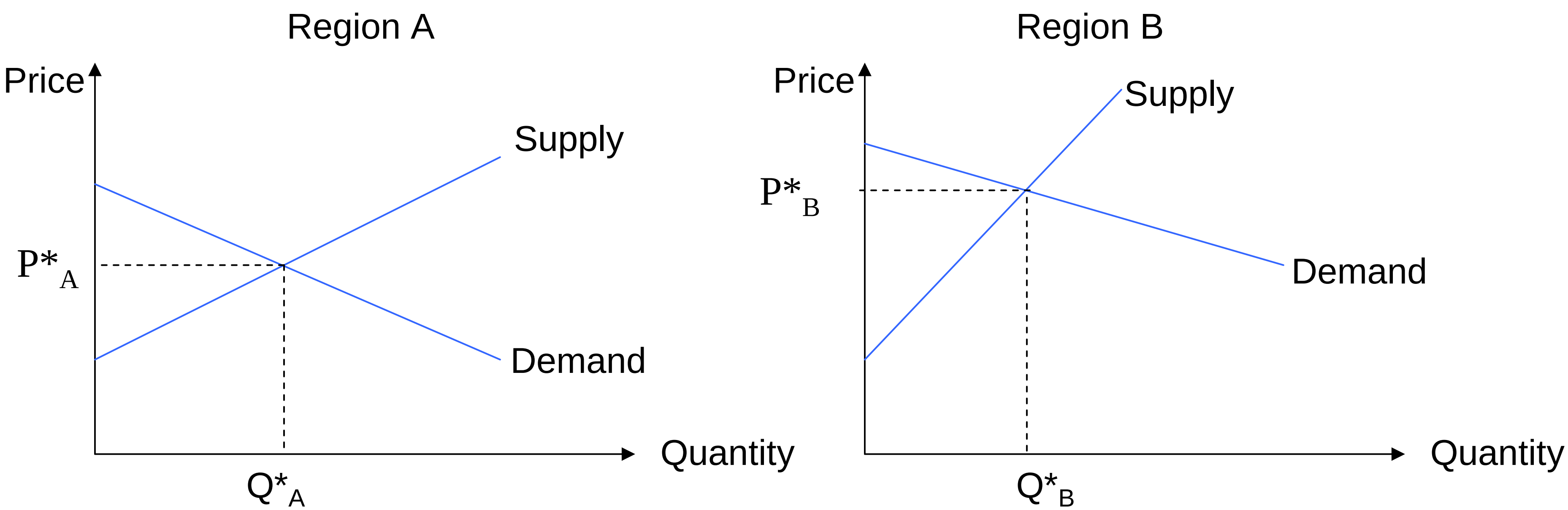
- Spatial Price Equilibrium (SPE)
- Multiregional Input Output (MRIO)

Spatial Price Equilibrium (SPE) Models

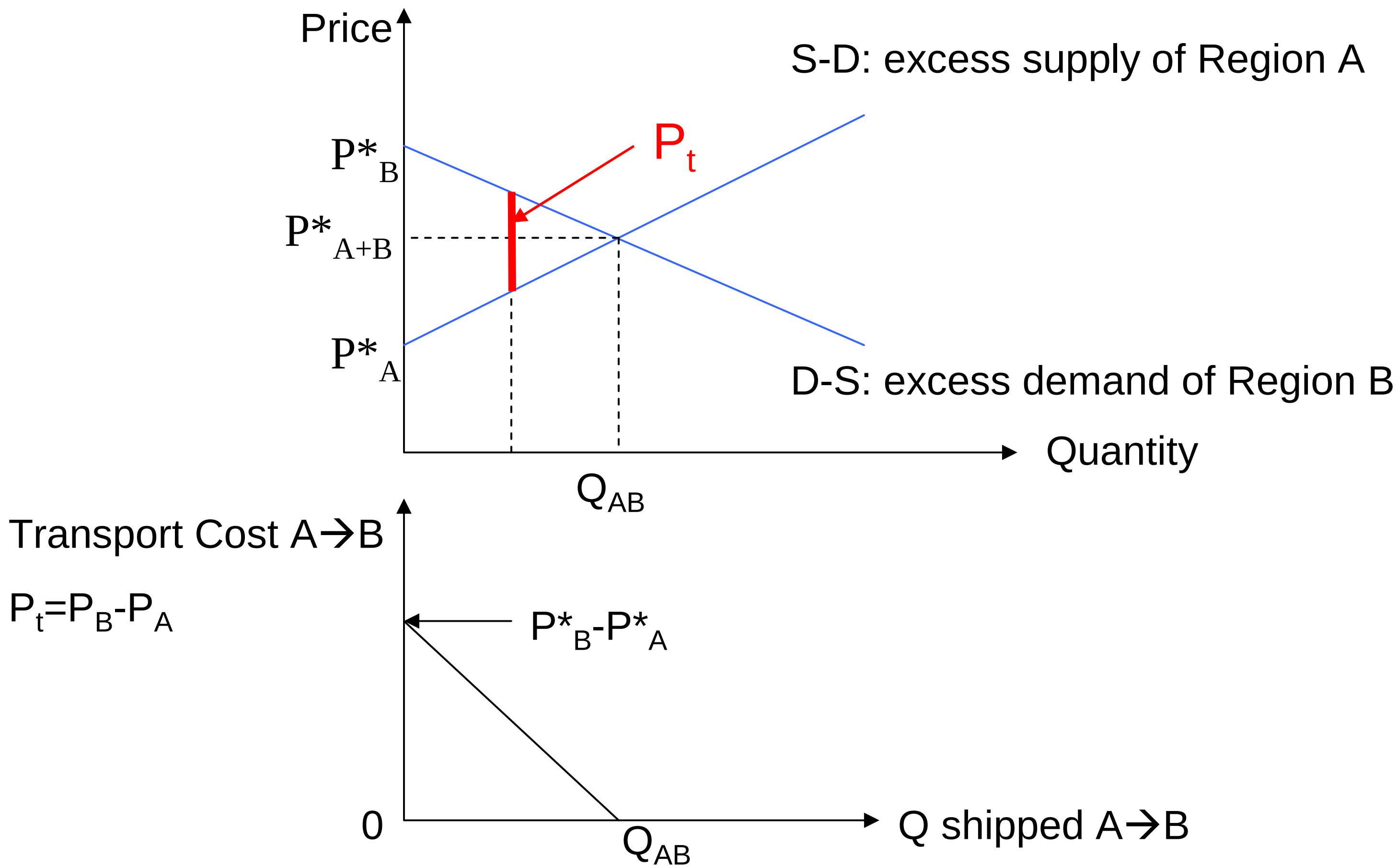
- Demand and supply curves of each region/economic sector
- Deterministic demand behavior: there is commercial exchange of goods between two regions only if the price in the origin region plus the transport cost is equal to the price in the destination region
- Freight flows may be concentrated to a small number of OD pairs due to the deterministic nature of the model

SPE Models (cont.)

Equilibrium quantities and prices in Region A and Region B:



SPE Models (cont.)



Multiregional Input-Output (MRIO) Models

- Application of economic production functions to freight demand
- Economic activities of production and consumption are classified into sectors:
  - Production
    - Goods manufacturing
    - Services
  - Consumption
    - Household
    - Public
    - Investments
    - Stock variations
    - Export

MRIO Models (cont.)

- Study area is divided into regions
- MRIO models also account for external (or 'international') trade

MRIO Models: Example of Sectors

- **The input-output tables available for Italy are disaggregated in 17 sectors (11 of physical goods and 6 of services)**

PHYSICAL GOODS

Agriculture and fishing
Energy
Ferrous/non-ferrous minerals and materials
Non-metal minerals and products
Chemical and pharmaceutical products
Machinery and metal products
Means of transport
Food and drink industry, tobacco
Textiles, clothing, leather and shoes
Paper, book trade, other industrial products
Wood, rubber

SERVICES

Civil constructions
Retail trade, hotels, public concerns
Transport and communications
Insurance and credit
Other sale-related services
Non sale-related services

MRIO Models: Inputs

- Input-output table (matrix of technical coefficients)
  - Characterizes intermediate demand (i.e. how much of sector *m* production is required for sector *n production*)
- Matrix of trade coefficients
  - Characterizes interregional trade.
- Final demand
  - The final demand of each sector in each region.
- Value of quantity coefficients
  - Used to transform flows in monetary units to physical quantities

MRIO Models: Steps

1. The following relationship is used to relate production and intermediate demand:

$$K_j^{mn} = a_j^{mn} X_j^{n}$$

Where,

K^{mn}_j = the value of the intermediate demand of the production in sector *m* (input) necessary for the production of sector *n* (output) in region *j*

a^{mn}_j = technical coefficient that depends on the production "technologies" available in region *j*

X^n_j = the value of the production of sector *n* in region *j*

MRIO Models: Steps (cont.)

2. By definition, the total supply (production and import) of sector *m* in region *i* must be equal to the total demand (intermediate and final) of section *m* in region *i*. This leads to a system of simultaneous linear equations in which we solve for the value of production of each sector in each region
3. Given the trade coefficients, OD matrices of region-to-region trade flows are produced. The values in these matrices are all in monetary units
4. Given the value-of-quantity coefficients, the values in the region-to-region trade flow matrices are converted to physical freight units (e.g. tons or vehicles)

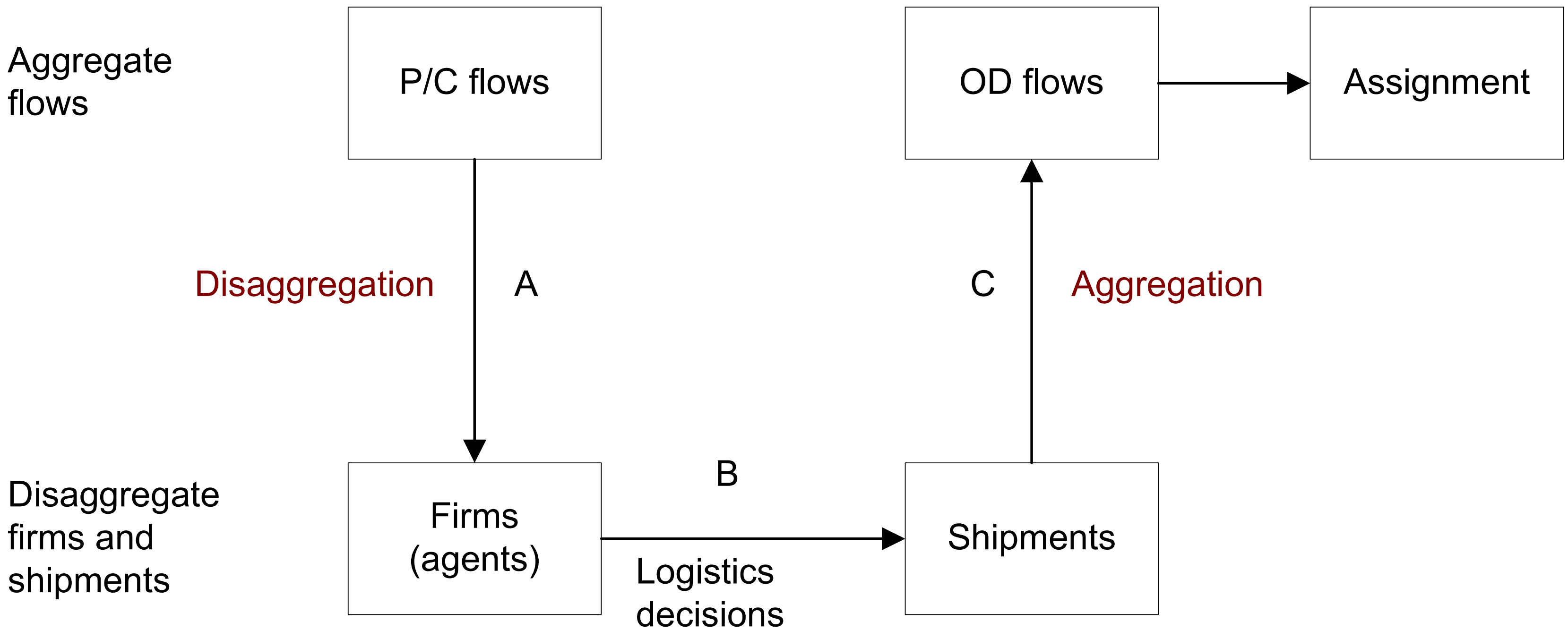
Appendix C

Aggregate/Disaggregate Modeling

References

- Ben-Akiva, M. and de Jong, G. 2008, 'The aggregate-disaggregate-aggregate (ADA) freight model system', forthcoming in Ben-Akiva, M., Meersman, H. and Van de Voorde, E. (eds.), *Recent Developments in Transport Modelling: Lessons for the Freight Sector,* Emerald Group Publishing, United Kingdom, pp. 139-162.

Combining Aggregate and Disaggregate Models



Modeling Steps

- Step A

  allocation of flows to individual firms at production (P) and consumption (C) ends

- Step B

  logistics decisions: chain type, mode, shipment size

- Step C

  aggregation of the individual shipments to OD flows for assignment

Step A: Allocation of Flows

- Aggregate P/C flows disaggregated to the level of decision-making unit
- General approaches:
  - Re-weighting
    - Use an existing sample or population and re-weight using marginal distributions
  - Synthetic
    - Draw from a sequence of conditional distributions
  - Hybrid
    - Begin with re-weighting and enrich the set of characteristics using synthetic draws

Step B: Logistics Chain Choice

Minimize: Total cost to transport a shipment of size *q* between firm *m* and firm *n* using logistics chain *k*

Step C: OD Flows for Assignment

- Shipments for the same commodity type aggregated to OD flows in vehicles
- Summation over shipments

Calibration and Validation

- Aggregate calibration
  - Concerns different equilibrium situations
  - Coefficients of sub models are adjusted to better match aggregate data
- Validation
  - Inputs from a different year is used and the predicted OD flows are compared against the actual flows
  - Major discrepancies may lead to readjustment of model coefficients

Application

- National model systems for freight transport in Norway and Sweden
- Previous models
  – Norway: NEMO, Sweden: SAMGODS
  – Multi-modal assignment with deterministic logistics model
- Proposed model
  – Aggregate-Disaggregate-Aggregate (ADA) freight model system

Freight Model System: Norway and Sweden

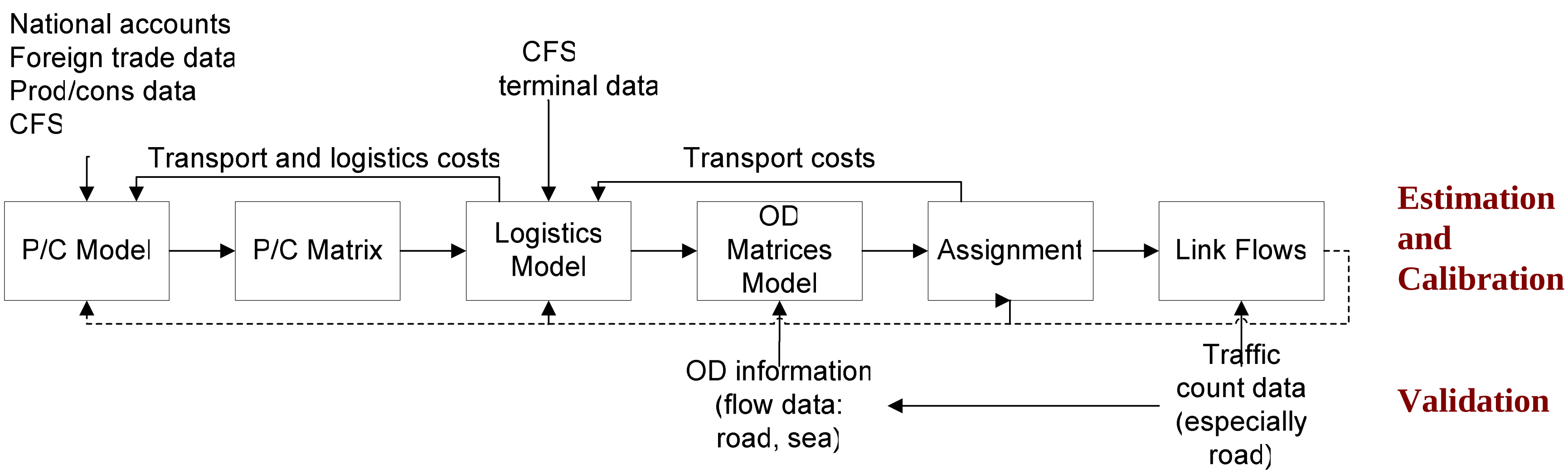
- Two-step logistics cost minimization:
  - Step 1:

    Determine the optimal transshipment locations for each type of transport chain and OD region.
  - Step 2:

    Determine the shipment size and transport chain.

Freight Model System: Norway and Sweden (cont.)

Estimation, Calibration and Validation of the Model System



Freight Model System: Norway and Sweden (cont)

- Shipment size (and frequency) and transport chain determined on the basis of deterministic costs minimization
  - 10 road vehicle types, 28 vessel types, 8 train types, 2 aircraft types
  - Container and non-container vehicle and vessel types
- P/C flows
  - Senders (P): more than 100,000 firms
  - Receivers (C): more than 400,000 firms
  - Result: 6 million firm-firm flows per year

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