Transportation Costs

Moshe Ben-Akiva

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

Fall 2008

Review: Theory of the Firm

- Basic Concepts
- Production functions
  - Isoquants
  - Rate of technical substitution
- Maximizing production and minimizing costs
  - Dual views to the same problem
- Average and marginal costs

Outline

- **Long-Run vs. Short-Run Costs**
- Economies of Scale, Scope and Density
- Methods for estimating costs

Long-Run Cost

- All inputs can vary to get the optimal cost
- Because of time delays and high costs of changing transportation infrastructure, this may be a rather idealized concept in many systems

Short-Run Cost

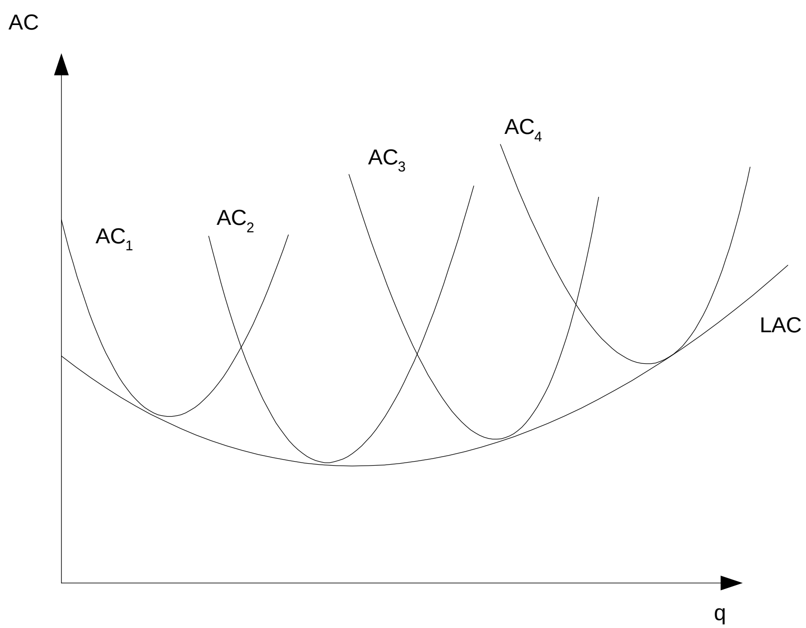
- Some inputs (*Z*) are fixed (machinery, infrastructure) and some (*X*) are variable (labor, material)

$$C(q) = W_Z Z + W_X X(W, q, Z)$$

$$MC(q) = \frac{\partial W_X X(W, q, Z)}{\partial q} \qquad \left(\frac{\partial W_Z Z}{\partial q} = 0 \right)$$

Long-Run Cost vs. Short-Run Cost

- Long-run cost function is identical to the lower envelope of short-run cost functions

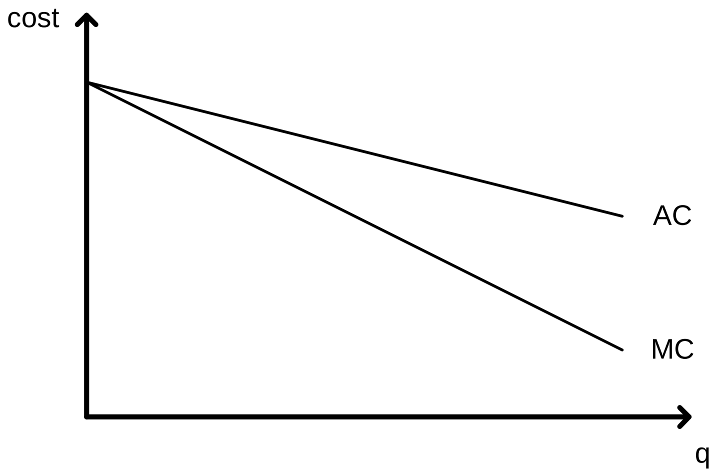


Outline

- Long-Run vs. Short-Run Costs
- **Economies of Scale, Scope and Density**
- Methods for estimating costs

Economies of Scale

$C(q+\Delta q) < C(q) + C(\Delta q)$



MC < AC

- Economies of scale are not constant. A firm may have economies of scale when it is small, but diseconomies of scale when it is large.

Example: Cobb-Douglas Production Function

Are there economies of scale in the production?

Production function approach:

- K – capital
- L – labor
- F – fuel

$$q = \alpha K^a L^b F^c$$

Economies of scale: $a+b+c > 1$

Constant return to scale: $a+b+c = 1$

Diseconomies of scale: $a+b+c < 1$

Example (cont)

Long-run cost function approach

- The firm minimizes expenses at any level of production
- Production expense: $E = W_K K + W_L L + W_F F$

  W_K - unit price of capital (e.g. rent)

  W_L - wages rate

  W_F - unit price of fuel

- Production cost: $C(q) = \min E$

  $$s.t. \quad \alpha K^a L^b F^c = q$$

Example (cont)

- Finding the optimal solution:
  - Lagrangean function:

$$W_K K + W_L L + W_F F + \lambda(q - \alpha K^a L^b F^c)$$

  - Solution:

$$C = \beta q^{1/(a+b+c)} W_K^{a/(a+b+c)} W_L^{b/(a+b+c)} W_F^{c/(a+b+c)}$$

Example (cont)

- The logarithmic transformation of the cost function:

$$\ln C = d_0 + d_1 \ln q + d_2 \ln W_K + d_3 \ln W_L + d_4 \ln W_F$$

$d_1 = 1/(a+b+c)$ $d_2 = a/(a+b+c)$ $d_3 = b/(a+b+c)$ $d_4 = c/(a+b+c)$

- Properties:
  - Can be estimated using linear regression (linear in the parameters)
  - d_1 represents the elasticity of cost w.r.t output
  - Economies of scale if $d_1 < 1$ (i.e. a+b+c > 1)
  - Cost function is linearly homogenous in input prices

    Intuition: If all input prices double, the cost of producing at a constant level should also double

$$(d_2 + d_3 + d_4 = 1)$$

Economies of Scope

- Cost advantage in producing several different products as opposed to a single one

$$C(q1,q2) < C(q1,0) + C(0,q2)$$

  – The cost function needs to be defined at zero

Cost Complementarities

- The effect of a change in the production level of one product on the marginal cost of another product

$$C = C(q_1, q_2) \qquad \frac{\partial MC_2}{\partial q_1} = \frac{\partial\left(\partial C / \partial q_2\right)}{\partial q_1} = \frac{\partial^2 C}{\partial q_1 \partial q_2}$$

- Cost complementarities: $\frac{\partial^2 C}{\partial q_1 \partial q_2} < 0$
- Cost anti-complementarities: $\frac{\partial^2 C}{\partial q_1 \partial q_2} > 0$

Cost Complementarities and Economies of Scope in Transportation

- Generally, anti-complementarities and diseconomies of scope in transport services
  - Freight and passenger (railroad, airline and coach)
  - Truckload and less-than-truckload freight

Economies of Density

- Related to economies of scale, but used specifically for **networks** (such as railroads or airlines).
- A network carrier might:
  - Expand the *size* of the network (adding nodes/links) in order to carry more traffic, or
  - Maintain the existing network and increase the *density* of traffic on those links.
- Question: how will costs change?
- Important in merger considerations

Example: Scale Economies of Rail Transit

- From “Scale Economies in U.S. Rail Transit Systems” by Ian Savage in *Trans. Res-A* (1997)
- Transit networks display widely varying economies of size and density, depending on:
  - Total network size
  - Load factors
  - “Peak-to-base” ratio
  - Average passenger journey length

Scale Economies of Rail Transit (cont): Short-Run Variable Cost

- $ED = (\partial \ln SRVC / \partial \ln Y)^{-1}$
- $ES = ((\partial \ln SRVC / \partial \ln Y) + (\partial \ln SRVC / \partial \ln T))^{-1}$

where

ED:	Measure of economies of density
ES:	Measure of economies of network size
SRVC:	Short-run variable cost
Y:	Transit output (car-hours)
T:	Network size (way and structure)

- Economies of density for **car-hours** ranged from 0.71-2.04, with most in the range 1.0-1.5.
- Economies of network size ranged from 0.78-1.49, with most right around 1.0

Scale Economies of Rail Transit (cont): Total Cost

- When total costs considered:
  - ED ranged from 1.16-4.73
  - ES ranged from 0.91-1.17

Implications of the Rail Transit Study: Privatization

- Considerable economies of density:
  - Makes rail transit routes natural monopolies
- The constant returns to system size:
  - Suggests that there would be negligible cost disadvantage to breaking up firms into smaller component parts

Costing in Transport: Summary

1. High proportion of fixed costs
2. Vehicles and infrastructure dominate costs, but these appear fixed over short- and medium-term
3. Transportation shows economies of scope/scale/density more than most industries
4. Potential for “natural monopolies”

Outline

- Long-Run vs. Short-Run Costs
- Economies of Scale, Scope and Density
- **Methods for estimating costs**

Methods of Estimating Costs

- Accounting
- Engineering
- Econometric

Accounting Costs

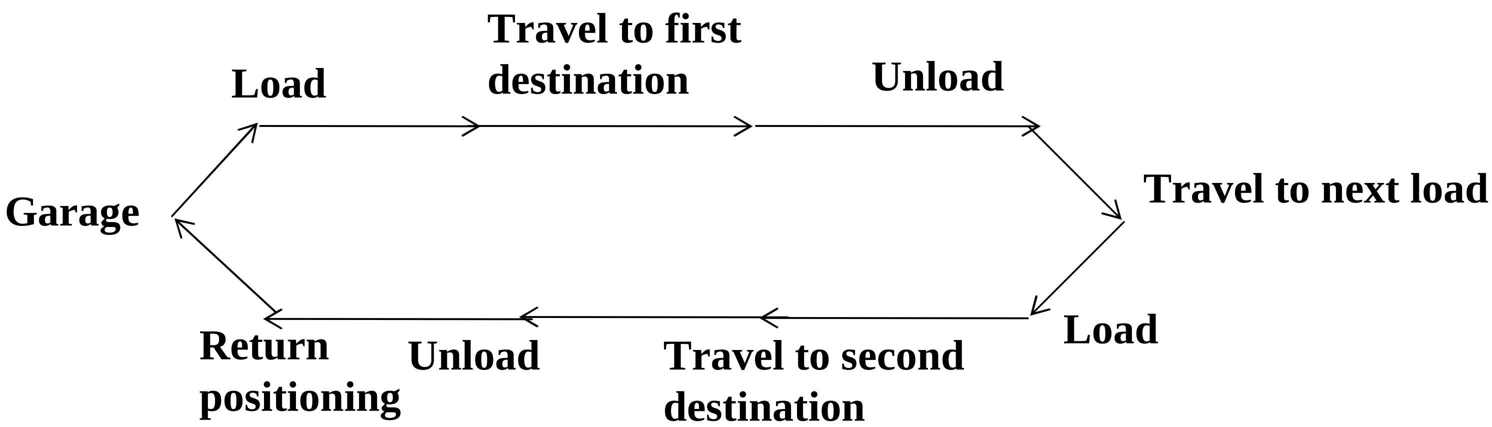
- Every company and organization has an accounting system to keep track of expenses by (very detailed) categories
- Allocate expense categories to services provided using:
  - Detailed cost data from accounting systems
  - Activity data from operations
- These costs are allocated to various activities, such as:
  - Number of shipments
  - Number of terminal movements
  - Vehicle-miles
- These costs are used to estimate the average costs associated with each activity
- Expense categories are either fixed or variable

Engineering Costs

- Use knowledge of technology, operations, and prices and quantities of inputs
- Examine the costs of different technologies and operating strategies, so historical costs may be irrelevant
- Engineering models can go to any required level of detail and can be used to examine the performance of complex systems

Engineering Cost Models: Example

- A trucking company
  - Vehicle cycle characterizes the activities of each truck in the fleet.



Engineering Cost Models: Example (cont)

- Components of this vehicle cycle:
  - Positioning time
  - Travel time while loaded
  - Travel time while unloaded
  - Load/unload time
  - Operational servicing time
  - Station stopped time
  - Schedule slack
  - Total vehicle operating cycle time (sum of all of the above)

Engineering Cost Models: Example (cont)

- Changes to the service or to the distribution of customers, for example, may affect some of the vehicle cycle components.
- This influences the utilization of each truck (i.e. the number of cycles that can be completed in a given period of time).

Total cost = Fixed investment + (Variable Cost*Number of Cycles)

Influenced by the various vehicle cycle components

- In engineering models, knowledge of technologies and operational details (such as the vehicle cycle) can assist in cost estimation.

Econometric Cost Models

- A more aggregate cost model
  - Estimated using available data on total cost, prices of inputs and system characteristics
  - Structured so that its parameters are in themselves meaningful, e.g. the marginal product of labor
  - Focus on specific parameters of interest in policy debates

Translog Cost Function

- Translog →Flexible Transcendental Logarithmic Function
- Provides a second-order numerical approximation to almost any underlying cost function at a given point
- Multiple Outputs : $[q_1, \ldots, q_m]$
- Multiple Inputs : $[w_1, \ldots, w_n]$

$$\ln C(q,w) = \underbrace{\alpha_0 + \sum_{i=1}^{m} \alpha_i \ln q_i + \sum_{j=1}^{n} \beta_j \ln w_j}_{\text{Cobb-Douglas}} + \frac{1}{2} \sum_{i=1}^{m} \sum_{k=1}^{m} \alpha_{ik} \ln q_i \ln q_k$$

$$+ \frac{1}{2} \sum_{j=1}^{n} \sum_{l=1}^{n} \beta_{jl} \ln w_j \ln w_l + \sum_{i=1}^{m} \sum_{j=1}^{n} \gamma_{ij} \ln q_i \ln w_j$$

Translog Cost Function (cont)

- Note that the first part is just Cobb-Douglas, (in logs, with multiple inputs and outputs)

$$\alpha_0 + \sum_{i=1}^{m} \alpha_i \ln q_i + \sum_{j=1}^{n} \beta_j \ln w_j$$

- The remaining coefficients allow for more general substitution between inputs and outputs

Example: Airline Costs and Production

- Study with 208 Observations of 15 Trunk and Local Airline Carriers

Explanatory variables	Coefficient	t-stat
Revenue Output-Miles	0.805	23.6
Avg. Number Points Served	0.132	4.2
Price of Labor	0.356	178.0
Price of Capital Materials	0.478	239.0
Price of Fuel	0.166	166.0
Average Stage Length	-0.148	-2.7
Average Load Factor	-0.264	-3.8
Selected Second Order Terms		
$Output^2$	0.034	.054
$Points^2$	-0.172	.152
Output x Points	-0.123	.064
Labor $Price^2$	0.166	.026
Fuel $Price^2$	0.137	.003
Labor x Fuel	-0.076	.022
Capital $Price^2$	0.150	.022
Capital x Fuel	-0.060	.005
Stage Length x Load Factor	-0.354	.190

Returns to:	Trunk Carriers	Local Carriers
Scale	1.025	1.101
Density	1.253	1.295
Operating Characteristics		
Average Number of Points Served	61.2	65.2
Average Stage Length (miles)	639	152
Average Load Factor	0.520	0.427

Case Study in:

McCarthy, P. Transportation Economics: Theory and Practice: A Case Study Approach. Blackwell Publishers, 2001

Summary

- Objectives of the firm
- Production functions
- Cost functions
  - Average and Marginal Costs
  - Long-Run vs. Short-Run Costs
  - Geometry of Cost Functions
- Economies of Scale, Scope and Density
- Methods for estimating costs

Coming Up: Midterm, then Pricing, then Maritime & Port…

Appendix

Full Results from Rail Transit Translog Study

Econometric Cost Models
Example: Rail Transit

- From "Scale Economies in U.S. Rail Transit Systems" by Ian Savage in *Trans. Res-A* (1997)
- Data: 13 heavy-rail and 9 light-rail for the period 1985-1991
- Outputs: Revenue car hour, passenger usage, load factor
- Inputs: Labor, electricity, maintenance
- Cost: (Total mode expense – Non-vehicle maintenance)

Estimation Results

Explanatory variables (logarithms except for dummy variables)	Coefficient	t-stat
Car hours	0.688	6.14
Directional route miles	0.380	5.13
Load factor	0.592	2.75
Average journey length	-0.266	1.25
Peak-base ratio	0.209	0.91
Proportion at grade	4.337	1.95
Highly automated dummy variable	-0.272	5.01
Light-rail dummy variable	-0.199	3.72
Streetcar dummy variable	-0.278	3.50
Car hours2	-0.076	0.52
Directional route miles2	-0.159	0.62
Load factor2	-1 .052	1.82
Journey length'	0.485	2.49
Peak-base ratio2	0.061	0.21
At grade2	-0.129	1.69
Car hours x directional route miles	0.099	0.52
Car hours x load factor	0.421	2.30
Car hours x journey length	-0.163	0.79

Estimation Results (cont)

Explanatory Variable	Coefficient	t-stat
Car hours x peak-base ratio	-0.248	1.28
Car hours x at grade	-0.143	0.71
Directional route miles x load factor	-0.583	2.14
Directional route miles x journey length	0.410	1.59
Directional route miles x peak-base ratio	0.397	I .45
Directional route miles x at grade	0.200	0.63
Load factor x journey length	0.047	0.17
Load factor x peak-base ratio	0.800	2.34
Load factor x at grade	0.167	1.39
Journey length x peak-base ratio	-0.368	1.87
Journey length x at grade	-0.340	1.49
Peak-base ratio x at grade	0.068	0.38
Labor factor price	0.629	116.60
Electricity factor price	0.115	36.24
Car maintenance factor price	0.256	61.30
Labor factor price2	0.108	6.47
Electricity factor price2	0.059	9.13
Car maintenance factor price2	0.091	9.17
Labor price x electricity price	-0.038	4.37
Labor price x car maintenance price	-0.070	6.06
Electricity price x car maintenance price	-0.021	3.67

1.201J / 11.545J / ESD.210J Transportation Systems Analysis: Demand and Economics
Fall 2008