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)

\[
C(q) = W_Z Z + W_X X(W, q, Z)
\]

\[
MC(q) = \frac{\partial W_X X(W, q, Z)}{\partial q} \left( \frac{\partial W_Z Z}{\partial q} = 0 \right)
\]
Long-Run Cost vs. Short-Run Cost

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

![Graph showing AC curves and LAC curve]
Outline

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

\[ C(q + \Delta q) < C(q) + C(\Delta q) \]

- 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.

\[ MC < AC \]
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:

\[ C = \beta q^{\frac{1}{(a+b+c)}} W_K^{\frac{a}{(a+b+c)}} W_L^{\frac{b}{(a+b+c)}} W_F^{\frac{c}{(a+b+c)}} \]
Example (cont)

- The logarithmic transformation of the cost function:
  \[
  \ln C = d_0 + d_1 \ln q + d_2 \ln W_K + d_3 \ln W_L + d_4 \ln W_F
  \]
  
  \[
  d_1 = 1/(a+b+c) \quad d_2 = a/(a+b+c) \quad d_3 = b/(a+b+c) \quad d_4 = c/(a+b+c)
  \]

- 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

\[ C(q_1,q_2) < C(q_1,0) + C(0,q_2) \]

– 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

\[ C = C(q_1, q_2), \quad \frac{\partial MC_2}{\partial q_1} = \frac{\partial}{\partial q_1} \left( \frac{\partial C}{\partial q_2} \right) = \frac{\partial^2 C}{\partial q_1 \partial q_2} \]

- 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

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

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.
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).

\[ \text{Total cost} = \text{Fixed investment} + (\text{Variable Cost} \times \text{Number of Cycles}) \]

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 \(\rightarrow\) 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: \([w_1, \ldots, w_n]\)

\[
\ln C(q, w) = \alpha_0 + \sum_{i=1}^{m} \alpha_i \ln q_i + \sum_{j=1}^{n} \beta_j \ln w_j + \frac{1}{2} \sum_{i=1}^{m} \sum_{k=1}^{m} \alpha_{ik} \ln q_i \ln q_k
\]

\[
\text{Cobb-Douglas}
\]

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

<table>
<thead>
<tr>
<th>Explanatory variables</th>
<th>Coefficient</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue Output-Miles</td>
<td>0.805</td>
<td>23.6</td>
</tr>
<tr>
<td>Avg. Number Points Served</td>
<td>0.132</td>
<td>4.2</td>
</tr>
<tr>
<td>Price of Labor</td>
<td>0.356</td>
<td>178.0</td>
</tr>
<tr>
<td>Price of Capital Materials</td>
<td>0.478</td>
<td>239.0</td>
</tr>
<tr>
<td>Price of Fuel</td>
<td>0.166</td>
<td>166.0</td>
</tr>
<tr>
<td>Average Stage Length</td>
<td>-0.148</td>
<td>-2.7</td>
</tr>
<tr>
<td>Average Load Factor</td>
<td>-0.264</td>
<td>-3.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Selected Second Order Terms</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Output^2</td>
<td>0.034</td>
<td>.054</td>
</tr>
<tr>
<td>Points^2</td>
<td>-0.172</td>
<td>.152</td>
</tr>
<tr>
<td>Output x Points</td>
<td>-0.123</td>
<td>.064</td>
</tr>
<tr>
<td>Labor Price^2</td>
<td>0.166</td>
<td>.026</td>
</tr>
<tr>
<td>Fuel Price^2</td>
<td>0.137</td>
<td>.003</td>
</tr>
<tr>
<td>Labor x Fuel</td>
<td>-0.076</td>
<td>.022</td>
</tr>
<tr>
<td>Capital Price^2</td>
<td>0.150</td>
<td>.022</td>
</tr>
<tr>
<td>Capital x Fuel</td>
<td>-0.060</td>
<td>.005</td>
</tr>
<tr>
<td>Stage Length x Load Factor</td>
<td>-0.354</td>
<td>.190</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Returns to:</th>
<th>Trunk Carriers</th>
<th>Local Carriers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale</td>
<td>1.025</td>
<td>1.101</td>
</tr>
<tr>
<td>Density</td>
<td>1.253</td>
<td>1.295</td>
</tr>
</tbody>
</table>

**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:

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

- 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

<table>
<thead>
<tr>
<th>Explanatory variables (logarithms except for dummy variables)</th>
<th>Coefficient</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car hours</td>
<td>0.688</td>
<td>6.14</td>
</tr>
<tr>
<td>Directional route miles</td>
<td>0.380</td>
<td>5.13</td>
</tr>
<tr>
<td>Load factor</td>
<td>0.592</td>
<td>2.75</td>
</tr>
<tr>
<td>Average journey length</td>
<td>-0.266</td>
<td>1.25</td>
</tr>
<tr>
<td>Peak-base ratio</td>
<td>0.209</td>
<td>0.91</td>
</tr>
<tr>
<td>Proportion at grade</td>
<td>4.337</td>
<td>1.95</td>
</tr>
<tr>
<td>Highly automated dummy variable</td>
<td>-0.272</td>
<td>5.01</td>
</tr>
<tr>
<td>Light-rail dummy variable</td>
<td>-0.199</td>
<td>3.72</td>
</tr>
<tr>
<td>Streetcar dummy variable</td>
<td>-0.278</td>
<td>3.50</td>
</tr>
<tr>
<td>Car hours(^2)</td>
<td>-0.076</td>
<td>0.52</td>
</tr>
<tr>
<td>Directional route miles(^2)</td>
<td>-0.159</td>
<td>0.62</td>
</tr>
<tr>
<td>Load factor(^2)</td>
<td>-1.052</td>
<td>1.82</td>
</tr>
<tr>
<td>Journey length’</td>
<td>0.485</td>
<td>2.49</td>
</tr>
<tr>
<td>Peak-base ratio(^2)</td>
<td>0.061</td>
<td>0.21</td>
</tr>
<tr>
<td>At grade(^2)</td>
<td>-0.129</td>
<td>1.69</td>
</tr>
<tr>
<td>Car hours x directional route miles</td>
<td>0.099</td>
<td>0.52</td>
</tr>
<tr>
<td>Car hours x load factor</td>
<td>0.421</td>
<td>2.30</td>
</tr>
<tr>
<td>Car hours x journey length</td>
<td>-0.163</td>
<td>0.79</td>
</tr>
</tbody>
</table>
## Estimation Results (cont)

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Coefficient</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car hours x peak-base ratio</td>
<td>-0.248</td>
<td>1.28</td>
</tr>
<tr>
<td>Car hours x at grade</td>
<td>-0.143</td>
<td>0.71</td>
</tr>
<tr>
<td>Directional route miles x load factor</td>
<td>-0.583</td>
<td>2.14</td>
</tr>
<tr>
<td>Directional route miles x journey length</td>
<td>0.410</td>
<td>1.59</td>
</tr>
<tr>
<td>Directional route miles x peak-base ratio</td>
<td>0.397</td>
<td>1.45</td>
</tr>
<tr>
<td>Directional route miles x at grade</td>
<td>0.200</td>
<td>0.63</td>
</tr>
<tr>
<td>Load factor x journey length</td>
<td>0.047</td>
<td>0.17</td>
</tr>
<tr>
<td>Load factor x peak-base ratio</td>
<td>0.800</td>
<td>2.34</td>
</tr>
<tr>
<td>Load factor x at grade</td>
<td>0.167</td>
<td>1.39</td>
</tr>
<tr>
<td>Journey length x peak-base ratio</td>
<td>-0.368</td>
<td>1.87</td>
</tr>
<tr>
<td>Journey length x at grade</td>
<td>-0.340</td>
<td>1.49</td>
</tr>
<tr>
<td>Peak-base ratio x at grade</td>
<td>0.068</td>
<td>0.38</td>
</tr>
<tr>
<td>Labor factor price</td>
<td>0.629</td>
<td>116.60</td>
</tr>
<tr>
<td>Electricity factor price</td>
<td>0.115</td>
<td>36.24</td>
</tr>
<tr>
<td>Car maintenance factor price</td>
<td>0.256</td>
<td>61.30</td>
</tr>
<tr>
<td>Labor factor price2</td>
<td>0.108</td>
<td>6.47</td>
</tr>
<tr>
<td>Electricity factor price2</td>
<td>0.059</td>
<td>9.13</td>
</tr>
<tr>
<td>Car maintenance factor price2</td>
<td>0.091</td>
<td>9.17</td>
</tr>
<tr>
<td>Labor price x electricity price</td>
<td>-0.038</td>
<td>4.37</td>
</tr>
<tr>
<td>Labor price x car maintenance price</td>
<td>-0.070</td>
<td>6.06</td>
</tr>
<tr>
<td>Electricity price x car maintenance price</td>
<td>-0.021</td>
<td>3.67</td>
</tr>
</tbody>
</table>
1.201J / 11.545J / ESD.210J Transportation Systems Analysis: Demand and Economics
Fall 2008

For information about citing these materials or our Terms of Use, visit: http://ocw.mit.edu/terms.