Quantitative Methods in Transport

Lecture 4: Introduction, Theory and Properties of Cost Functions. Application: Rail Open Access Competition

March 12th-13th 2019, Brno Czech Republic

Professor Andrew Smith

Structure of the remaining three lectures

- Lecture 4: Introduction, Theory and Properties of Cost functions. Application: Rail Open Access Competition

- Lecture 5: Econometric estimation of cost functions. Application: Rail Competitive Tendering and Water Regulation

- Lecture 6: The Econometric Approach to Efficiency Analysis. Application: Economic Regulation

Policy context
Concepts
Methods
Application

At the end of the course students will be able to:

- Identify the economic principles underlying and the properties of cost/production functions
- Explain the regulatory and competition policy context and associated motivation for cost analysis
- Apply econometric techniques to cost/production analysis (e.g. COLS; SFA)
- Determine measurement of the extent of inefficient behaviour of firms
- Understand the links between econometric techniques and policy

Institutional Options for network industries

State-ownership model

- Vertically integrated company
- Natural monopoly argument
- Regulation via ownership

Privatisation

- Privatise with no restructuring
- Regulate private firm

→ **Restructure for competition** — "In the market"

→ **Introduce Competition** — "For the market"

→ **Threat of Competition** — "Contestable markets"

→ **Regulate** — IM only

Institutional Options for network industries

National Grid (electricity and gas transmission)

Telecoms (last mile)

→ Restructure for competition — "In the market"

State-ownership model

Privatisation

→ Introduce Competition — "For the market"

Vertically integrated company

Natural monopoly argument

Regulation via ownership

Privatise with no restructuring

→ Threat of Competition — "Contestable markets"

Regulate private firm

Electricity and gas distribution

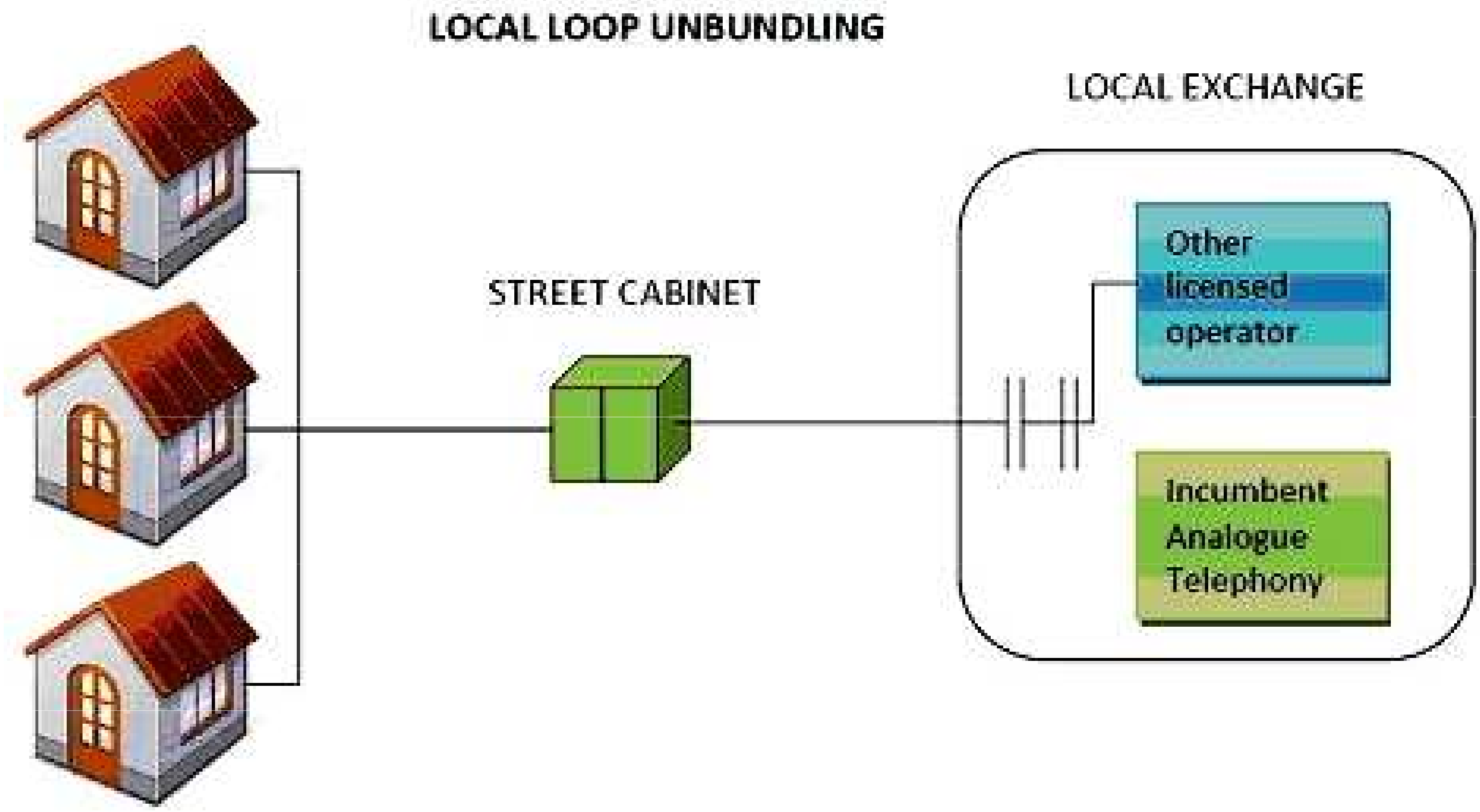
→ Regulate — IM only

Royal Mail delivery network

Rail infrastructure

Water and sewerage network

Telecoms



Source: http://images.huffingtonpost.com/2012-11-05-localloopunbundling.jpg

The purpose of modelling

Two main reasons: (1) understanding cost drivers and (2) measuring efficiency performance

(1) Understanding cost drivers

- Do economies of scale or density prevail – impact for policy?
- Forecasting – if traffic grows how much extra cost?
- Access charges – how much to charge for use of the network?
- How much does it cost for a marginal increase in quality?

[redacted]

Source

Professor Rod Smith, Imperial College London

Chief Scientific Advisor Department for Transport

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The purpose of modelling

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(1) Understanding cost drivers

- Do economies of scale or density prevail – impact for policy?
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- How much does it cost for a marginal increase in quality?

(2) Measuring efficiency performance

- Economic regulators require firms to be efficient
- Governments more widely interested in efficiency / VFM
- Impact of institutional model on cost?

Efficiency performance - examples

Benchmarking firms against their peers - efficiency

Economic regulation

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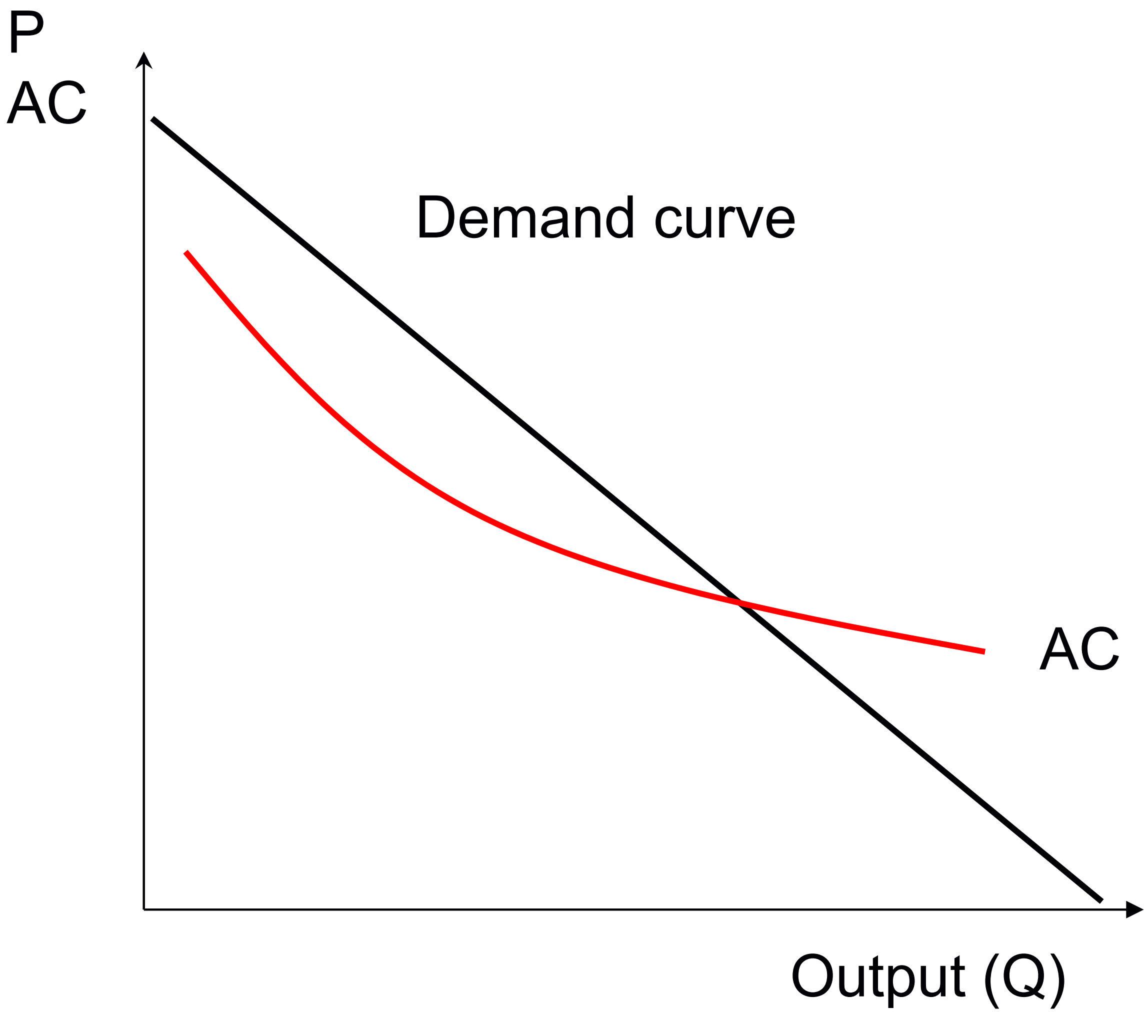
Other key sectors: energy, health, communications, postal services…

Studying the impact of reforms (efficiency / productivity)…

Impact of competitive tendering / privatisation?

Vertical separation or not?

Defining natural monopoly



AC=average cost; P=price

Single product case: average costs falling continuously over all levels of output (strong natural monopoly)

Market served most cheaply by one firm

Increasing returns to scale (or economies of scale)

Returns to scale

Increasing returns to scale (IRS)

- If all inputs (labour, materials, energy, capital) double then output more than doubles

Decreasing returns to scale (DRS)

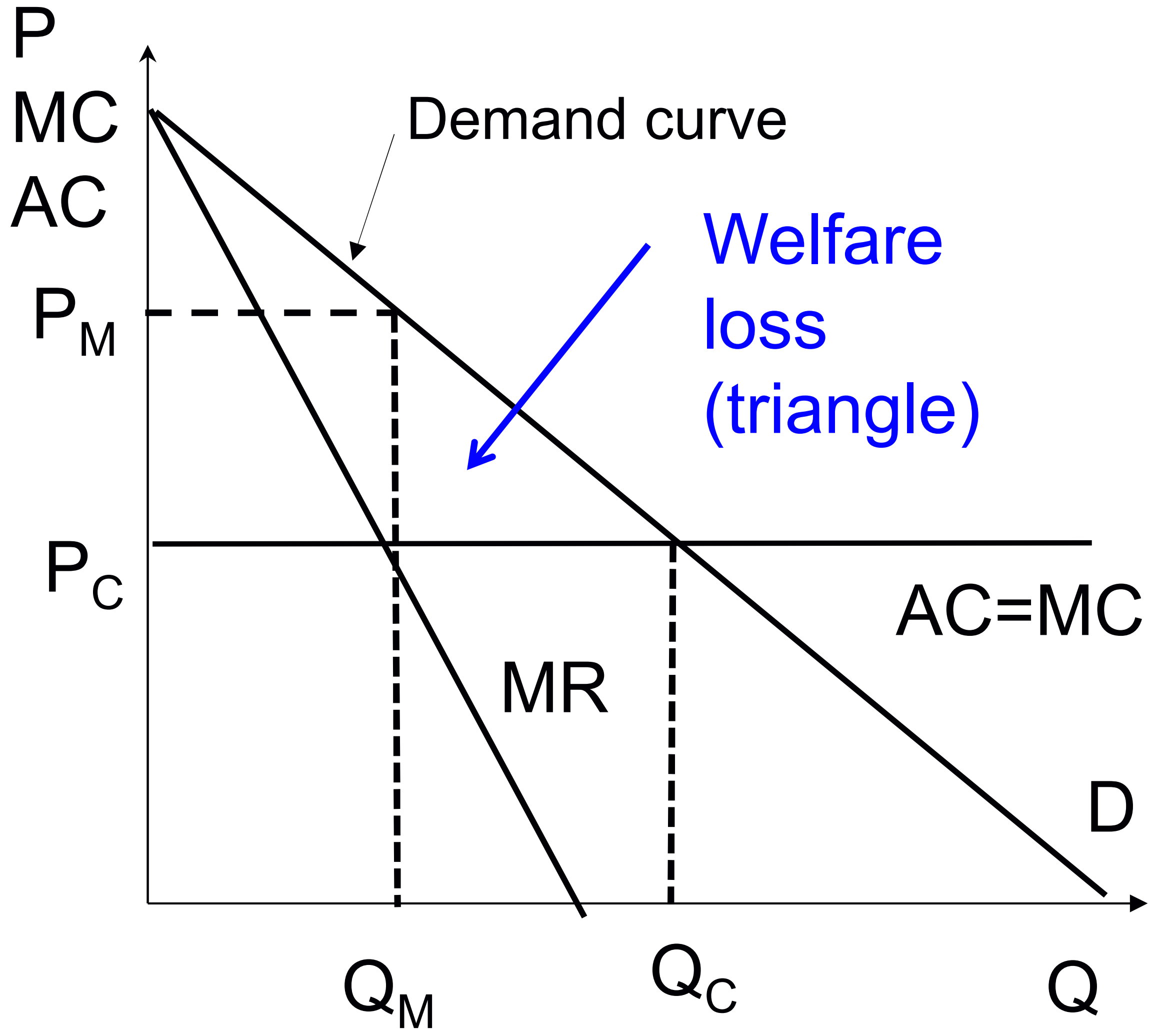
- If all inputs (labour, materials, energy, capital) double then output increases by less than double

Constant returns to scale (CRS)

- If all inputs (labour, materials, energy, capital) double then output also doubles

Increasing returns also referred to as economies of scale. Means that unit costs fall as output rises

Monopoly pricing and welfare loss



AC=average cost; P=price; MC=marginal cost

- Simplified diagram to emphasise the point
- Monopoly charges where MR=MC
- Output too low; price too high
- **Implies that regulation is needed**

Alternative cost modelling approaches

What is the objective? To understand what happens to cost as output changes (or other cost drivers change):

- What is the marginal cost of an output change?
- What is the extent of economies of scale?
- What is the extent of economies of density?

1. Cost allocation models (top-down method)
2. Engineering models (bottom-up)
3. **Statistical (econometric) models (top-down)**

A starting point:
the Direct Cost Function

$$C = \sum_i W_i X_i$$

X_1= Labour input

X_2= Rolling stock capital

X_3= Infrastructure capital

X_4=Fuel input

W_i=input prices; C=cost; Q=output

Of course, the above is simply an accounting equation

Indirect Cost function example: Cobb-Douglas

Start with a Cobb-Douglas production function:

$$Q = aX_1^{b_1} X_2^{b_2} X_3^{b_3} X_4^{b_4}$$

The minimum cost way of producing a particular Q is found by minimising:

$$Z = \sum_i W_i X_i - \lambda(aX_1^{b_1} X_2^{b_2} X_3^{b_3} X_4^{b_4} - Q)$$

From this we derive an **indirect cost function** (Q is output; W = input prices)

$$C = f(w, Q)$$

Econometric approach – relate costs to traffic in regression model

$$C_{it} = f(Q_{it}, P_{it}, N_{it}, \tau_t; \beta) + v_{it}$$

- C_{it} is the cost measure – say, maintenance and renewal costs
- i is the unit of observation (e.g. operator; region; country; track section; maintenance unit); t is time period (year)
- Q_{it} - output measures (e.g. passenger tonne-km; freight tonne-km)
- β - parameters to be estimated – gives us % of cost variable with traffic and in turn, marginal cost

Notes: P_{it} - input prices (e.g. wage rate; price of materials); N_{it} - exogenous network characteristic variables (e.g. network length; linespeed capability; rail age; proportion of track in a curve; S&Cs); τ_{it} represent time variables capturing technical change over time

Properties of a cost function

Cost function takes **output and input prices as exogenously fixed** – and asks what is the minimum cost of producing that exogenously given output at a set of input prices

Assumes:

- Non-negative costs
- Non-decreasing in input prices
- Non-decreasing in output
- Linear homogeneity of degree 1 in respect of all input prices
- Concave in input prices

Theoretical properties that can be tested – linked also to engineering understanding

Not just a data fitting exercise – should be based on theory / engineering relationships

For further details see Coelli et. al. (2005)

The Cobb-Douglas (or double-log) Cost Function

Production Function: $Q = A K^a L^b$

Can be transformed into natural logarithms

$Ln\ Q = Ln\ A + a\ Ln\ K + b\ Ln\ L$

Likewise the cost function (dual to the production function) can be expressed in natural logarithms

$\mathbf{Ln\ C = b_0 + b_1\ Ln\ Q + b_2\ Ln\ W_1 + b_3\ Ln\ W_2}$

(where W_1 = labour price; W_2 = capital price)

Elasticity definitions

$Ln\ C = b_0 + b_1\ Ln\ Q + b_2\ Ln\ W_1 + b_3\ Ln\ W_2$

Elasticity of cost with respect to output:

$$Elasticity = \partial LnC / \partial \ln Q = b_1$$

$$Elasticity = \partial C / \partial Q * Q / C$$

$$= \frac{\partial C / \partial Q}{Q / C} = MC / AC$$

Obtaining scale properties from the cost function

$Ln\ C = b_0 + b_1\ Ln\ Q + b_2\ Ln\ W_1 + b_3\ Ln\ W_2$

Elasticity of cost w.r.t. output = $b_{1.}$ RTS = 1 / elasticity = $1/b_1$

If $b_1=1$, then constant returns to scale

If $b_1<1$, then increasing returns (economies of scale)

If $b_1>1$, then decreasing returns to scale (diseconomies)

Scale elasticity example

See Excel spreadsheet example

Obtaining scale and density properties from the cost function

$\text{Ln } C = b_0 + b_1 \text{ Ln } Q + b_2 \text{ Ln } T + b_3 \text{ Ln } W$

T = Track-km; Q = train-km

Scale elasticity = what happens if operator runs more services over a bigger network (size of operation) = $\mathbf{b_1+b_2}$ **(RTS=1/($\mathbf{b_1+b_2}$)**

Density elasticity = what happens if operator runs more services down a fixed network = $\mathbf{b_1}$ **(RTD=1/$\mathbf{b_1}$)**

RTS and RTD Example

Suppose we have the following model results:

$$\text{Ln } C = 10 + 0.4 \text{ Ln } Q + 0.6 \text{ Ln } T + 0.2 \text{ Ln } W_1 + 0.8 \text{ Ln } W_2$$

Compute RTS =

Compute RTD =

RTS and RTD Example

Suppose we have the following model results:

$\text{Ln } C = 10 + 0.4 \text{ Ln } Q + 0.6 \text{ Ln } T + 0.2 \text{ Ln } W_1 + 0.8 \text{ Ln } W_2$

Compute RTS = **1/ (0.4+0.6) = 1**

Compute RTD = **1/0.4 = 2.5**

Example 2: Translog

$$\ln C = A + \alpha \ln Q + \sum_i \beta_i \ln W_i + \tfrac{1}{2}\delta(\ln Q)^2 +$$

$$\tfrac{1}{2}\sum_i \sum_j \gamma_{ij} \ln W_i \ln W_j + \sum_i \rho_i \ln W_i \ln Q$$

Where: C=total cost

Q=output

W_i=price of the i^{th} factor input

Allows returns to scale to vary with firm size

Translog example

See Excel spreadsheet example

Some candidate cost functions [1]

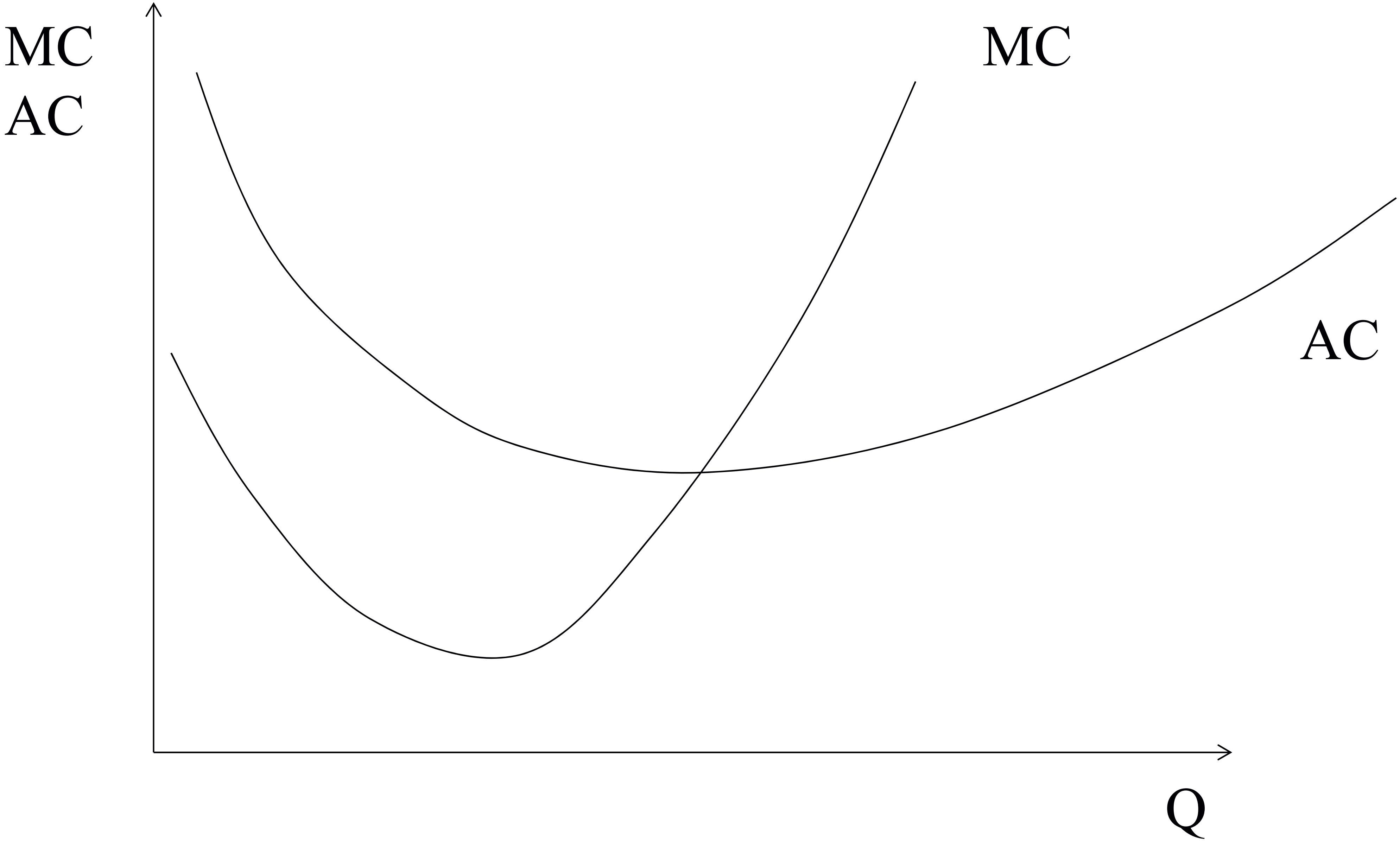
Linear Cost Function

$C = b_0 + b_1 Q$ ….

$$MC = \partial C / \partial Q = b_1$$

Very restrictive = implies that marginal cost is constant over all output levels

A standard cost function diagram



Some candidate cost functions [2]

Cobb-Douglas Cost Function

$\text{Ln C} = b_0 + b_1 \text{ Ln Q}$

$$Elasticity = \partial LnC / \partial \ln Q = b_1$$

More plausible in general (Box-Cox test can be carried out to test linear versus log-linear model).

However, log-linear model means elasticity constant over all output levels – still restrictive

The Translog Cost Function

Flexible functional forms - provides an approximation to any twice differentiable cost function.

Allows the elasticity and in turn the extent of scale economies to vary across different output levels.

$$LnC = b_0 + b_1 LnP + b_2 LnF + b_3 LnW + 1/2\, b_4 (LnP)^2 + 1/2\, b_5 (LnF)^2 + 1/2\, b_6 (LnW)^2 + b_7 LnPLnF + b_8 LnPLnW + b_9 LnFLnW$$

P=Passenger train-km; F = Freight train-km

The Translog Cost Function – deriving the elasticities

Differentiate with respect to output (e.g. passenger train-km):

$$Elasticity = \partial LnC / \partial LnP = b_1 + b_4 LnP$$
$$b_7 LnF + b_8 LnW$$

The elasticity is no longer constant. It is a function of the passenger output level, the level of other outputs (freight) and wages

We can test if the coefficients b_1, b_4, b_7 and b_8 are all zero (if so, we return to the (nested) Cobb-Douglas

Translog – pros and cons

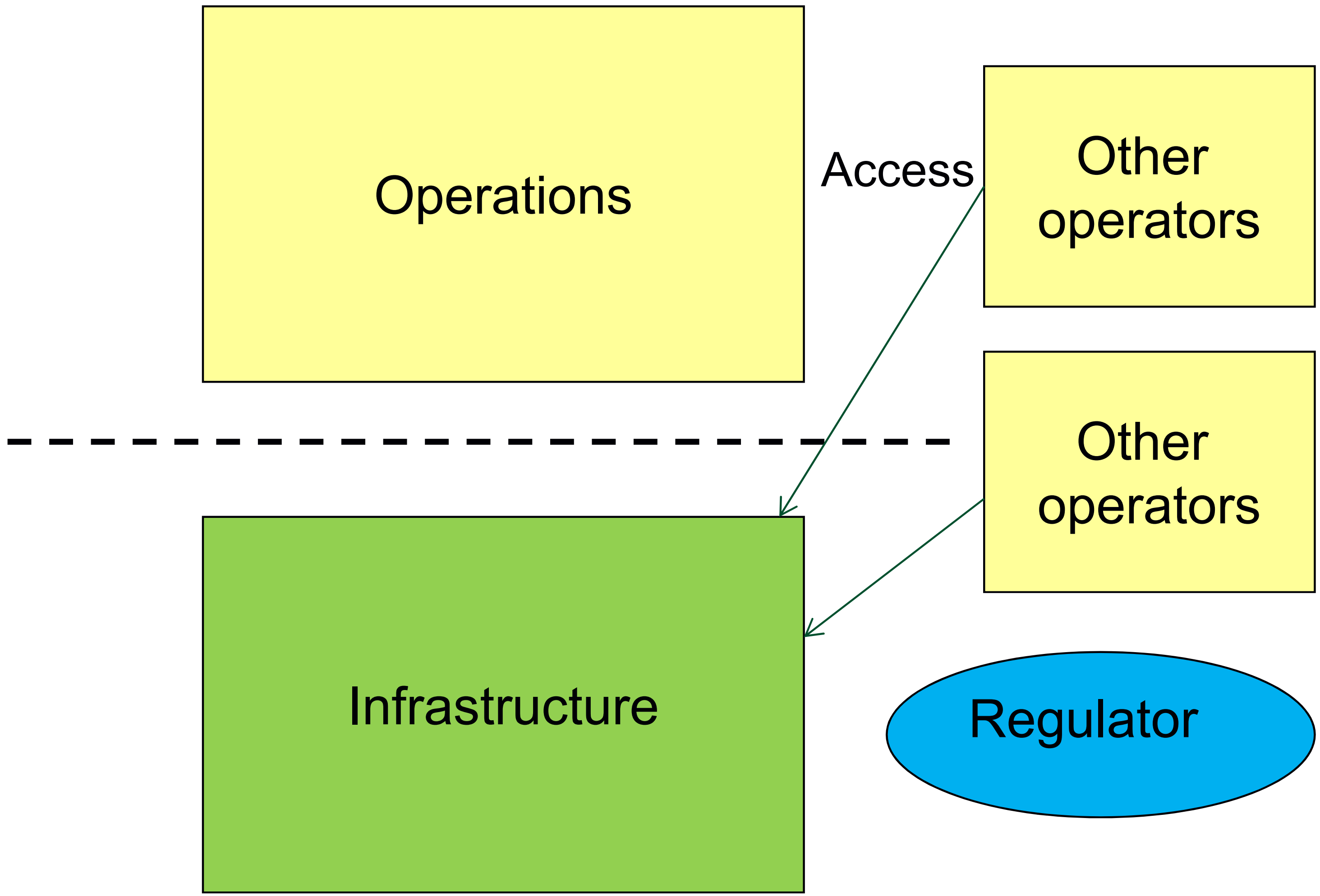
- Highly flexible form – permits varying degrees of returns to scale at different output levels
- Has become the standard in cost modelling and efficiency analysis
- It nests the Cobb-Douglas so permits statistical testing
- Drawbacks: uses a lot of degrees of freedom particularly where there are multiple outputs
- It may produce “unbelievable” elasticities away from the sample mean

Returns to scale and density

Rail evidence: vertically integrated

STUDY	Returns to Density	Returns to Scale
Keeler (1974)	**1.8**	1
Harris (1977)	**1.7**	0.9 - 1
Friedlander & Spady (1981)	**1.2**	0.9 - 1.1
Caves et al (1980)	**1.8**	1
de Borger (1992)	**-**	1
Sanchez and Villaroya (2000)	**-**	0.9
Graham et al (2003)	**1.3**	1
Smith (2006)	**2.9**	0.7

Vertically separated model



When to allow open access competition in rail?

Different considerations

OA may stimulate efficiency improvements – low cost model

OA may lead to loss of economies of density

OA may undermine cross-subsidy and lead to higher subsidy payments (increased cost to government)

Open access and economies of density

Cost Function

Ln Cost = 1+ 0.77*Ln Output

Case 1: one inefficient firm

Output	Ln Cost	Cost
100	4.545981	**94.3**

Case 2: 5 efficient firms (25% more efficient)

Output	Ln Cost	Cost Pre-saving	Cost Post-savings
20	3.306714	27.3	20.5
20	3.306714	27.3	20.5
20	3.306714	27.3	20.5
20	3.306714	27.3	20.5
20	3.306714	27.3	20.5
100.0		**136.5**	**102.4**

Cost increase from splitting up the industry **9%**

- Open-access operators need to be much more efficient in order to reduce costs overall because of loss of economies of density

When to allow open access competition in rail?

The Competition and Markets Authority commissioned Wheat and Smith (with Rasmussen) from Leeds University's Institute of Transport Studies to undertake research comparing the costs of open access operators with those of franchised train operators after controlling for a number of differences between the two types of operator.

https://assets.digital.cabinet-office.gov.uk/media/55a8cde240f0b6156000000b/Econometric_anaylsis_of_efficiencies.pdf

Surprising finding overall – OA operators may be cheaper despite their small scale / density

Evidence

- Increased open access? Research shows OA are surprisingly similar in terms of unit costs despite being very small – **appear to have a business model advantage** Wheat, Smith and Rasmussen (2018)

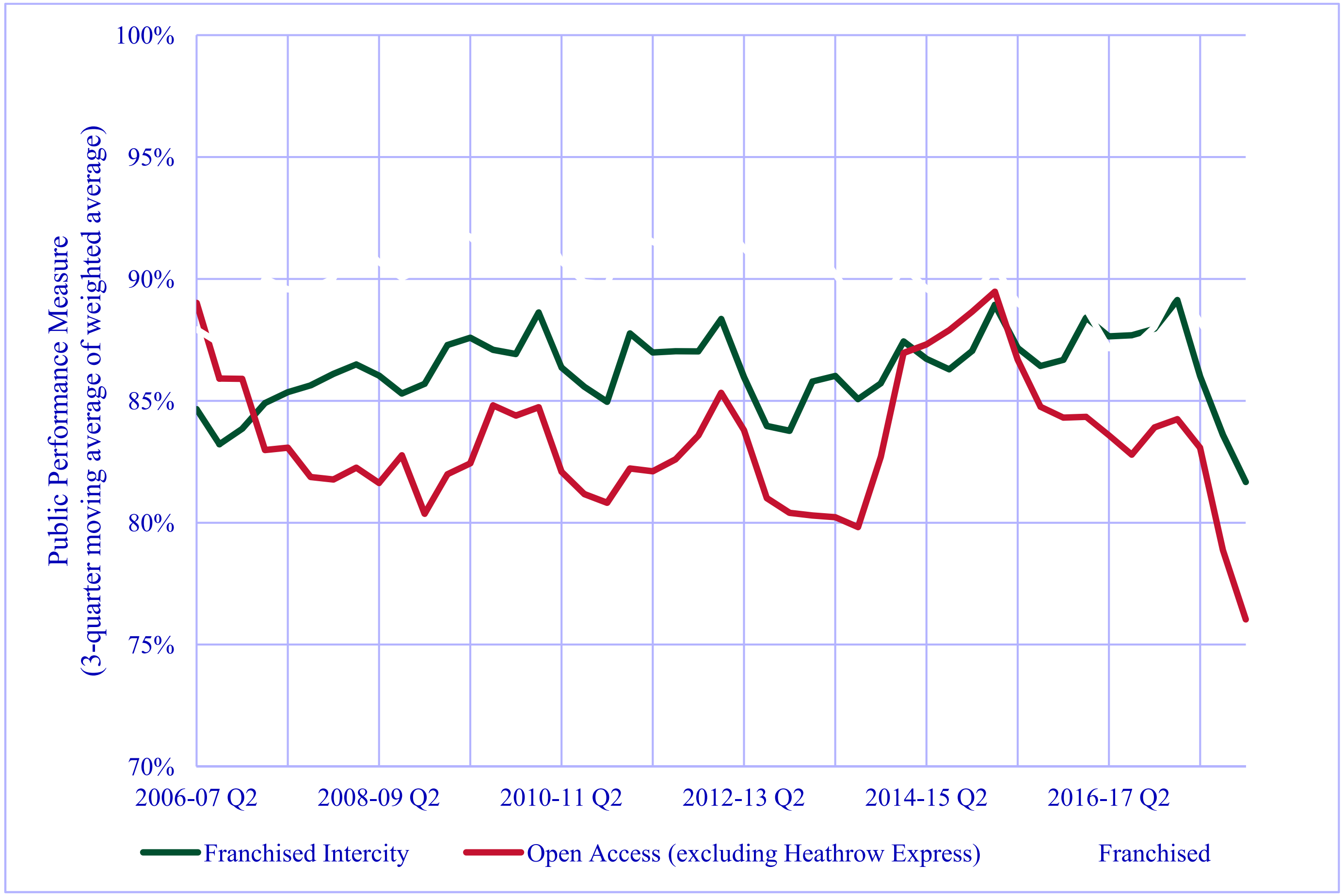
	Cost per train-hour	Cost per vehicle-hour
Open access	£552*	£308
Franchised	£670*	£286

* Statistically significant at 10% level

- But would they keep these advantages as they became larger?
- Do we know where their cost advantage comes from?

2019 update (Stead et. al., 2019)

- Confirms that open-access have similar unit costs to franchised operators, despite their small size
- But lower quality



Summary

- Regulatory / competition policy challenging - natural monopolies in industries of high social and economic importance
- Important to understand the cost structure when designing regulatory / de-regulatory interventions
- The econometric method produces new information for policy about the cost structure – based on actual data
- Cost function has some theoretical (testable) properties – useful to avoid data mining

Suggested readings

- Coelli, T.J., Prasada, R. O'Donnell, C.J. and Battese, G.E. (2005), An Introduction to Efficiency and Productivity Analysis, Chapter 2 (2.1, 2,2 and 2.4)
  [It is not necessary to understand all the maths, but to get the general concepts]

- You may also find the following useful: Varian, Intermediate Microeconomics (9th Edition) – Chapter 21 and sections 22.1-22.3 of Chapter 22 (earlier editions of Varian have similar chapters)
- Stead, A., Wheat, P.E., Smith, A.S.J. and Ojeda Cabral, M. (2019), Competition for and in the passenger rail market: Comparing open access versus franchised train operators' costs and reliability in Britain, mimeo.