Model of Price and Frequency Competition in Freight Transportation

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Key Freight Industry Characteristics

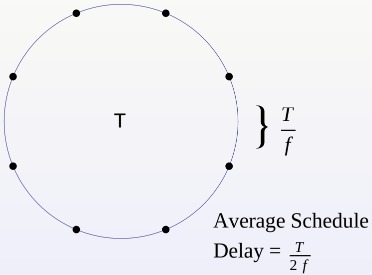
- numerous small players with low market concentrations
- spot market price competition coupled with short-term and long-term contracts between shippers and carriers
- crucial importance of timing of pick-ups and deliveries, especially for just-in-time production processes
- generalized model applicable to all modes of freight transport

Key Components of the Model

- Freight carriers competing in
  - price
  - frequency (service quality parameter)
- Producers of goods being transported
- Schedule delay : time gap between production and shipping
- Cost of schedule delay / cost of holding inventory
- Brand loyalty : preference of producers toward carriers

Modeling Cost of Schedule Delay

Preferred departure time drawn from a uniform distribution on a circle of circumference T



δ	inventory holding cost per unit output per unit time
$\frac{\gamma}{f} = \frac{\delta T}{2f}$	per unit cost of schedule delay
$p + \frac{\gamma}{f}$	full price per unit of transportation services

Producers' Problem

(Representative Firm)

Producers' Profit Function:

$$R = \left[r - p - \frac{\gamma}{f}\right] Q - E(Q)$$

Q	quantity of output produced
r	unit price of output
$p + \frac{\gamma}{f}$	full price per unit of transportation services
$E(Q)$	production cost as a function of output

Profit-maximizing Q and R are functions of $\left[r - p - \frac{\gamma}{f}\right]$

Producers' Problem

(Representative Firm) (contd.)

Producers' utility function:

$$u(R_i, a_i) = a_i R_i = a_i R\left[r - p_i - \frac{\gamma}{f_i}\right]$$

a_i brand loyalty parameter representing producer's preference for carriers $i = 1, 2 \ldots, n$

R_i profits of producer given its choice of carrier i

A producer chooses carrier i to ship its product iff

$$u(R_i, a_i) > u(R_j, a_j) \qquad j = 2, 3 \ldots, n$$

$$a_j < \frac{a_i R[r - p_i - \gamma/f_i]}{R[r - p_j - \gamma/f_j]} = \frac{a_i R_i}{R_j}$$

Carriers' Problem

(Representative Carrier)

Carrier i's objective function:

$$\max_{f_i, p_i, s_i} \pi = p_i q_i - f_i C(s_i)$$

$$\text{subject to } f_i s_i = q_i$$

q_i	total quantity of good transported by Carrier 1
$p_i q_i$	total revenue earned by carrier i
$C(s_i)$	cost of operation per vehicle
s_i	tonnage capacity of a vehicle
$f_i C(s_i)$	carrier i's total cost of operation

Functional Form Assumptions

- Producers's cost function

$$E(Q) = Q^\beta \qquad (\beta > 1)$$

resulting in

$$u(a_i, R_i) = a_i\delta\left[r - p_i - \frac{\gamma}{f_i}\right]^{\frac{\beta}{\beta-1}}$$

- Uniform distribution for brand loyalty
- Carriers' cost function

$$C(s_i) = \theta + \tau s_i$$

Substituting $s_i = q_i/f_i$ from capacity constraint,

$$\text{Carriers' total cost} = f_i\theta + \tau q_i$$

Optimization Problem

$$\pi_1 = \left(\frac{1}{\beta}\right)^{\frac{1}{\beta-1}} \frac{M(p_1-\tau)}{n} \frac{\left(r - p_1 - \gamma/f_1\right)^{\frac{(n-1)\beta+1}{\beta-1}}}{\prod_{j\neq 1}\left(r - p_j - \gamma/f_j\right)^{\frac{\beta}{\beta-1}}} - \theta f_1$$

- Take first order conditions with respect to p_1 and f_1
- Solve for a symmetric Nash equilibrium where

$$p_1 = p_2 = \ldots = p_n = p \quad \text{and} \quad f_1 = f_2 = \ldots = f_n = f$$

- Derive analytical results for the case when $\beta = 2$
- Simulate results for other values of β

Comparative Statics

Short-run Comparative Static Effects

Variable: Parameter:		Frequency (f)	Price (p)	Full Price $(p+\gamma/f)$	Capacity (s)
Market Size	(M)	+	+	-	+
Fixe Cost	(θ)	-	-	+	+
Marginal Cost	(τ)	-	+	+	-
Product Price	(r)	+	+	+	+
Cost of Delay	(γ)	+	-	+	-
Competitors	(n)	-	-	-	+

Model Extensions

- Solving for long-term equilibrium

$$\pi_{long-run} = 0 \qquad \text{and} \qquad \text{endogenous } n$$

- Comparing equilibrium results with socially optimal outcomes

$$p_{equi} > p_{opt} \qquad \text{and} \qquad f_{equi} < f_{opt}$$

- Explaining excess capacity (empty miles) as an equilibrium choice made by carriers
  - in the existence of a minimum capacity constraint, empty miles can only be eliminated through a reduction in frequency

Applications of the Model

The model framework can be used to analyze changing industry dynamics in several scenarios; examples:

- deregulation and its impacts on industry dynamics
- effect of outsourcing in the face of globalization
- adoption of just-in-time production processes
- changing tax and toll structures
- responsiveness to oil price changes