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The Elasticity of Demand for Freight Transportation: The Case of Recyclable Commodities†

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ABSTRACT

THIS PAPER presents and generalizes a model of the rate elasticity of demand for transportation. Using the model, empirical results are presented showing the rate elasticity of demand for recyclable commodities. The model allows for the substitutability of recyclable and virgin materials and can be used to estimate the impact on recycling of a change in freight rate policy.

INTRODUCTION

As part of the 4-R Act of 1976 (Section 204), the Interstate Commerce Commission (ICC) was mandated to investigate the impact of changes in the level of freight rates on the volume of movements of recyclable vis a vis virgin substitute commodities. This investigation was undertaken in Ex Parte 319. The problem to be investigated is the classic economic problem of the measurement of demand elasticity.

It has often been alleged that the demand for freight transportation is inelastic or is biased toward inelasticity. The following paper presents a formal derivation of the elasticity of demand for transportation under the assumption that only one product is relevant and then under the assumption that another product, a potential substitute product, exists. The analysis is couched in terms of recyclable and virgin raw materials. However, the theoretical analysis is perfectly general.

THE THEORY AND RESULTS

This section follows the work of Samuelson (1952). Samuelson shows that spatial price equilibrium will occur when

$$(1) \qquad P_D(Q) = P_S(Q) + T$$

where

$P_D(Q)$ = The equilibrium excess demand price of the commodity at the destination (in transportation parlance — a delivered price, a C.I.F. [cost, insurance, freight] price)

$P_S(Q)$ = The equilibrium excess supply price of the commodity at the origin (in transportation parlance — an F.O.B. [free on board] price)

T = The transportation rate/unit of product (assumed to be independent of quantity [Q])

From the above relationship, the demand for transportation can be derived as a one to one mapping between T and Q. Since the demand for transportation is derived from the supply and demand relationships of the origin and destination, it has been termed a derived demand. Likewise, the elasticity of demand for transportation can be derived from the above demand for transportation and it is thus a derived elasticity—a function of the own price elasticity of demand (E_D) in the destination region, the own price elasticity of supply (E_S) in the origin region, and the relationship of the transportation rate to the delivered price at the destination.

The elasticity of demand for transportation, E_{DT}, is found (following Bennathan and Walters, 1969) by differentiating the arguments of (1) with respect to T which yields:

$$(2) \qquad \frac{\partial P_D(Q)}{\partial Q}\frac{\partial Q}{\partial T} = \frac{\partial P_S(Q)}{\partial Q}\frac{\partial Q}{\partial T} + 1$$

Solving for $\frac{\partial Q}{\partial T}$ and multiplying both sides of the equation by $\frac{T}{Q}$ yields

$$(3) \qquad E_{DT} = \frac{T}{Q}\left(\frac{\partial P_D(Q)}{\partial Q} - \frac{\partial P_S(Q)}{\partial Q}\right)^{-1}$$

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†Much of the work appearing herein is based on Allen and Nelson (1976).

Further algebraic manipulation yields:

$$(4) \quad E_{DT} = \frac{T}{P_D(Q)} \left(\frac{E_D \quad E_S}{E_S - (1 - \frac{T}{P_{D(Q)}}) E_D} \right) = \lambda \frac{E_D \quad E_S}{E_S - (1-\lambda) E_D}$$

where $\lambda = \frac{T}{P_D(Q)}$

Clearly some limits exist on the magnitude of E_{DT}. For instance, as either E_D or E_S go to zero, E_{DT} also approaches zero, e.g.,

$$(5) \quad \lim_{E_S \to 0} E_{DT} = \lim_{E_S \to 0} \frac{E_S \lambda}{\frac{E_S}{E_D} - (1-\lambda)} = \frac{0}{\lambda - 1} = 0$$

And

$$(6) \quad \lim_{E_D \to 0} E_{DT} = \lim_{E_D \to 0} \frac{E_D \lambda}{1 - (1-\lambda) \frac{E_D}{E_S}} = \frac{0}{1} = 0$$

Thus, if either the elasticity of demand for the commodity in the destination area or the elasticity of supply for the commodity in the origin area approaches zero, then the elasticity of demand for transport approaches zero, i.e., if the demand or supply of the commodity is insensitive to price, the demand for transport for that commodity will also be insensitive to price.

The polar case to the one above is that of perfectly elastic demand or supply, i.e., E_D or E_S go to infinity. Under these circumstances, the limits of the elasticity of demand for transportation become,

$$(7) \quad \lim_{E_S \to \infty} E_{DT} = \lim_{E_S \to \infty} \frac{E_D \lambda}{1 - (1-\lambda) \frac{E_D}{E_S}} = \lambda E_D$$

and

$$(8) \quad \lim_{E_D \to \infty} E_{DT} = \lim_{E_D \to \infty} \frac{E_S \quad \lambda}{\frac{E_S}{E_D} - (1-\lambda)} = \frac{\lambda}{\lambda - 1} \quad E_S$$

Thus under conditions of infinite price sensitivity of commodity demand or commodity supply, the elasticity of demand for transportation becomes a function of only the elasticity which is not infinite and the ratio of transport cost to delivered price (λ).

Since the results of (7) and (8) represent polar cases to the results of (5) and (6), determining (7) and (8)'s tendency toward inelasticity will yield the worst possible case for the arguers of inelasticity of transport demand.

Another polar case involves the limits on λ. Clearly λ can only lie between zero and one. If λ is zero, (4) is zero and if λ is one, then (4) becomes E_D. Thus the elasticity of demand for transport can never exceed the own price elasticity of demand for the commodity. As shown in Table 3, the own price demand elasticities for the recyclable products in question in this paper are all inelastic and in most cases extremely so.

A search of the Philadelphia input-output matrix (Regional Science Research Institute, 1970)—a 640 by 640 matrix—reveals only 29 industries with a transportation coefficient greater than .04. Since a coefficient in an input-output matrix is the cents of the row input required to produce a dollar's worth of the column output, the input-output transporation coefficient can be regarded as an estimate of λ.

Under a worst possible scenario with $E_S = \infty$, the elasticity of demand would have to be 25 or more for all but 29 industry groups in the Philadelphia input-output matrix just to have $E_{DT} = 1$, i.e., unitary elastic. Any E_D's less than 25 would imply E_{DT}'s less than one, i.e., inelastic.

Likewise, under a worst possible scenario with $E_D = \infty$, the elasticity of supply would have to be 24 for all but 29 industry groups in the Philadelphia input-output matrix just to have $E_{DT} = 1$. Any E_S's less than 24 would imply E_{DT}'s less than one.

Estimates of elasticity of commodity demand compiled by Wold and Jureen (1952) and by Houthakker and Taylor (1970) seldomly show an E_D greater than two. Thus even under a situation where conditions are biased against transport demand inelasticity, i.e., $E_S = \infty$, it still seems rather unlikely that the elasticity of demand for the commodity is sufficiently elastic enough (note that it must be elastic since $\lambda < 1$) to offset λ to make E_{DT} greater than one.

Further evidence exists with respect to the magnitude of λ in a proceeding before the Interstate Commerce Commission-Ex Parte 295 (Sub no. 1) "Increased Freight Rates and Charges, 1973 —Proceedings, Recyclable Materials" decided October 29, 1974, at Tables I and J. Those tables yield estimates for iron and steel scrap, Great Lakes iron ore, secondary paper, virgin paper, secondary glass, virgin glass, secondary aluminum, virgin aluminum, secondary rubber, and virgin rubber, among others.

Table 1 yields the calculation from equation (7) of what the own price elasticity of demand would have to be for each recyclable and virgin commodity under the assumption that the commodity's own price elasticity of supply was perfectly elastic in order to yield an elasticity of transport demand for the commodity in question which was not inelastic, i.e., $E_{DT} \geqslant 1$. The equation form for such a calculation is:

$$(9) \qquad E_{Dmin} = \frac{1}{\lambda}$$

As can be seen from Table 1, most elasticities are at an unheard of level, with secondary glass the lowest at 2.262.

Although general evidence analogous to Wold and Jureen for elasticities of supply could not be found, calculations of equation (8) were made, i.e., assuming a worst possible case of the own price elasticity of demand of perfect elasticity, what is the minimum own price elasticity of supply which will make the elasticity of demand for transport non-inelastic? The resultant minimums are so high in many cases (as shown in Table 2) so as to render the possibility of elastic transport demand virtually impossible. The equation form for the calculation of Table 2 is:

$$(10) \qquad E_{Smin} = \frac{\lambda - 1}{\lambda}$$

It must be remembered that Tables 1 and 2 represent polar cases which bias the elasticity of demand for transportation away from inelasticity. The actual demand elasticity of transportation under the assumptions postulated at the beginning of the paper is given by equation (4) and depend on actual values of E_D and E_S. Table 3 shows the calculation of E_{DT} from (4) where estimates of E_D and E_S were available from secondary sources.

As is evident from Table 3, actual E_{DT}'s are quite low with high quality iron and steel scrap the highest at -.1598.

To allow directly for the possibility of substitution of recyclable for virgin commodities, equation (1) is now written:

$$(11) \qquad P_D{}^1 \ (Q_1, Q_2) = P_S{}^1 \ (Q_1, Q_2) + T_1$$

where

Q_1 is the recyclable commodity (good 1)

Q_2 is the virgin commodity (good 2)

T_1 is the transport rate for the recyclable commodity

Differentiating (11) with respect to

TABLE 1

Elasticity of demand required to yield a non-inelastic demand for transportation assuming infinite elastic supply for equivalent units of virgin and secondary materials

Equivalent Commodity	Mean transport price as a percent of delivered costs [source ICC (1974) Table I] $= \lambda$	Required minimum elasticity of demand in order to obtain a non inelastic demand for transport $= E_{Dmin} = \frac{1}{\lambda}$
Iron and Steel Scrap	30.7	— 3.257
Great Lakes Iron Ore	22.2	— 4.505
Secondary Paper	36.8	— 2.717
Virgin Paper	6.7	—14.925
Secondary Glass	44.2	— 2.262
Virgin Glass	41.3	— 2.421
Secondary Aluminum	5.7	—17.544
Virgin Aluminum	3.4	—29.412
Secondary Rubber	6.7	—14.925
Virgin Rubber	4.6	—21.739

TABLE 2

Elasticity of supply required to yield a non-inelastic demand for transportation assuming infinite elastic demand for equivalent units of virgin and secondary materials

Equivalent Commodity	Mean transport price as a percent of delivered costs [source ICC (1974) Table I] $= \lambda$	Required minimum elasticity of supply in order to obtain a non inelastic demand for transport $= E_{S\min} = \frac{\lambda - 1}{\lambda}$
Iron and Steel Scrap	30.7	2.257
Great Lakes Iron Ore	22.2	3.505
Secondary Paper	36.8	1.717
Virgin Paper	6.7	13.925
Secondary Glass	44.2	1.262
Virgin Glass	41.3	1.421
Secondary Aluminum	5.7	16.544
Virgin Aluminum	3.4	28.412
Secondary Rubber	6.7	13.925
Virgin Rubber	4.6	20.739

T_1, solving for $\frac{\partial Q_1}{\partial T_1}$, multiplying both sides of the resulting equation by $\frac{T_1}{Q_1}$, and performing the algebraic manipulations used to calculate (4), yields:

$$E_{D_1T_1} = \hat{\lambda} \frac{E_{D_1} E_{S_1}}{E_{S_1} - (1-\hat{\lambda}) E_{D_1}} \left[1 - \left(\frac{\partial P_D^1}{\partial Q_2} - \frac{\partial P_S^1}{\partial Q_2} \right) \frac{\partial Q_2}{\partial T_1} \right] \quad (12)$$

where

$E_{D_1T_1}$ = the elasticity of transport demand of the recyclable commodity (good 1) with respect to the transport rate, T_1

E_{D_1} = own price demand elasticity of good one

E_{S_1} = own price supply elasticity of good one

$\hat{\lambda} = \frac{T_1}{P_D^1}$

Denoting $\frac{\hat{\lambda} E_{D_1} E_{S_1}}{E_{S_1} - (1-\hat{\lambda}) E_{D_1}}$ as M and noting that M is the result obtained above in (4), by multiplying the term outside the parentheses in (12) by $\frac{P_D^1 T_1}{Q_2 T_1}$ and the terms inside the parenthesis in (12) by $\frac{Q_2}{P_D^1}$ and utilizing (11), equation (12) can be reduced to:

$$E_{D_1T_1} = M \left[1 - \frac{E_{DT_{12}}}{\hat{\lambda}} \left(\frac{E_{S_{12}} - (1-\hat{\lambda}) E_{D_{12}}}{E_{D_{12}} E_{S_{12}}} \right) \right] \quad (13)$$

where

$E_{DT_{12}}$ = the cross elasticity of transport demand for good 2 with respect to a change in T_1,

TABLE 3

Estimated elasticity of demand for transportation for selected recyclable materials from equation (4)

Commodity	Mean transport price as a percent of delivered costs [source ICC (1974), Table I] = λ	Estimate of E_D	Estimate of E_S	Estimate of $E_{DT} = \frac{\lambda E_D E_S}{E_S - (1-\lambda)E_D}$
No. 1 heavy melting iron & steel scrap (high quality scrap)	.307	−.5889(a)	3.1058(a)	−.1598
No. 2 bundles of iron & steel scrap (low quality scrap)	.307	−.1189(a)	6.787(a)	−.0361
Obsolete aluminum scrap	.057	−.0254(b)	.624(b)	−.0014
Obsolete paper scrap	.368	−.16 (c)	.55 (c)	−.0497
Copper scrap	.02 (d)	−.2131(e)	.3 (f)	.0025
Lead scrap	.058(g)	−.322(h)	∞ (i)	−.0187
Zinc scrap	.05 (j)	−.57(j)	∞ (i)	−.0285

a. calculated at the means from equations found in Adams (1974) pp. 124-138.
b. calculated at the means from equations found in Gordon et al (1972), pp. 169-75.
c. elasticities given in Anderson and Spiegelman (1976), p. 19.
d. given on p. 4-81 of ICC (1976).
e. given on p. 4-76 of ICC (1976).
f. given on p. 4-80 of ICC (1976).
g. given on p. 4-96 of ICC (1976).
h. given on p. 4-97 of ICC (1976).
i. not available, worst case shown.
j. given on p. 4-108 of ICC (1976).

i.e. $\frac{T_1}{Q_2} \frac{\partial Q_2}{\partial T_1}$

Es_{12} = the cross elasticity of supply for good 2 with respect to a change in $P_S{}^1$, i.e., $\frac{P_S{}^1}{Q_2} \frac{\partial Q_2}{\partial P_S{}^1}$

ED_{12} = The cross elasticity of demand for good 2 with respect to a change in $P_D{}^1$, i.e., $\frac{P_D{}^1}{Q_2} \frac{\partial Q_2}{\partial P_D{}^1}$

If recyclable and virgin commodities are perfect substitutes, then $ED_{12} = \infty$. Under such circumstances, the elasticity of demand for transport of recyclables becomes:

$$(14)\quad \lim_{E_{D_{12}}\to\infty} E_{D_1T_1} = \lim_{E_{D_{12}}\to\infty} M\left[1 - \frac{E_{DT_{12}}}{\hat{\lambda}}\left(\frac{\frac{E_{S_{12}}}{E_{D_{12}}} - (1-\hat{\lambda})}{E_{S_{12}}}\right)\right]$$

$$= M\left[1 + \frac{E_{DT_{12}}}{\hat{\lambda}}\frac{(1-\hat{\lambda})}{E_{S_{12}}}\right]$$

The magnitude of (14) relative to (4) depends on the signs and magnitudes of Es_{12} and $E_{D}T_{12}$ and the magnitude of $\hat{\lambda}$. If goods 1 and 2 are demand substitutes, then $E_{D\,T_{12}}$ is expected to be positive and if goods 1 and 2 are substitutes in supply, then $E_{S_{12}}$ is expected to be positive. Thus given complete substitutability between good one and good two (which does not exist in practice between recyclable and virgin materials, hence this is a polar case), the elasticity of transport demand for good 1 is inflated by $\frac{M E_{D\,T_{12}}(1-\hat{\lambda})}{\hat{\lambda}\, E_{S_{12}}}$ over the estimates in Table 3. No estimates of this inflation factor exist since no estimates of $E_{D\,T_{12}}$ and $E_{S_{12}}$ exist. It is suggested, however, that it is likely to be small because M is so small.

Suppose that goods 1 and 2 were neutral goods, i.e., $E_{D_{12}} = 0$ then:

$$(15) \quad \lim_{E_{D_{12}} \to 0} E_{D_1T_1} = \lim_{E_{D_{12}} \to 0} M\left[1 - \frac{E_{D\,T_{12}}}{\hat{\lambda}}\left(\frac{\frac{E_{S_{12}}}{E_{D_{12}}} - (1-\hat{\lambda})}{E_{S_{12}}}\right)\right]$$

$$= M\left[1 - \frac{E_{D\,T_{12}}}{\hat{\lambda}}\left(\frac{\infty - (1-\hat{\lambda})}{E_{S_{12}}}\right)\right]$$

Thus $E_{D_1T_1}$ will be less elastic than M if the goods are neutral products.

If the cross elasticity of supply were perfect, i.e., $E_{S_{12}} = \infty$, then the elasticity of demand of recyclable commodities becomes:

$$(16) \quad \lim_{E_{S_{12}} \to \infty} E_{D_1T_1} = \lim_{E_{S_{12}} \to \infty} M\left[1 - \frac{E_{D\,T_{12}}}{\hat{\lambda}}\left(\frac{1-(1-\hat{\lambda})\frac{E_{D_{12}}}{E_{S_{12}}}}{E_{D_{12}}}\right)\right]$$

$$= M\left[1 - \frac{E_{D\,T_{12}}}{\hat{\lambda}\, E_{D_{12}}}\right]$$

Since $E_{D\,T_{12}}$ and $E_{D_{12}}$ are likely to be positive, the elasticity of transport demand is less elastic than (4) and as reported in Table 3. Since the negative entry is multiplied by M, the downward shift is not likely to be large. No estimates can be made because the magnitudes of $E_{D\,T_{12}}$ and $E_{D_{12}}$ are unknown.

The elasticities in (13) and (4) will be equal if $E_{D\,T_{12}} = 0$ or if $E_{D_{12}} = \frac{E_{S_{12}}}{1-\hat{\lambda}}$.

CONCLUSIONS

The theory of transport demand elasticity a lá Bennathan and Walters' has been derived and expanded upon in the context of virgin and recyclable commodities. Because of a lack of data availability, elasticities of transport demand in only the simplest case could be estimated. Elasticities from the more complex derivations can be related to the simpler ones on an a priori basis.

The elasticity of transport demand for recyclable commodities was shown (Table 3) to be extremely low indicating that attempts to encourage recycling by lowering transportation rates on recyclable commodities will be unsuccessful. Factors other than transport rates are inhibiting recycling.

Further tests of two polar cases (perfectly elastic demand and perfectly elastic supply—see Tables 1 and 2) yielded required supply and demand elasticities much larger than traditionally seen in empirical economic analysis, in order to obtain a situation where the elasticity of transport demand would exceed one, i.e., be elastic.

BIBLIOGRAPHY

1 Adams, R. L., *An Economic Analysis of the Junk Automobile Problem*, Washington, D.C., U.S. Department of the Interior, Bureau of Mines, 1973.

2 Allen, W. B. & J. R. Nelson, Verified statement before the Interstate Commerce Commission, Ex Parte 319, Investigation of Freight Rates for the Transportation of Recyclable or Recycled Materials, Washington, D.C., August 11, 1976.

3 Anderson, R. C., & R.D. Spiegelmen, "Tax Policy and Secondary Materials Use," Environmental Law Institute, Washington, D.C., 1976.

4 Bennathan, E. & A. A. Walters, *The Economics of Ocean Freight Rates*, Praeger Publishers, New York, 1969.

5 Gordon, R. L. et al, *Effective Systems of Scrap Utilization: Copper, Aluminum, and Nickel*, Washington, D.C., U.S. Department of the Interior, Bureau of Mines, open file report 18-72, 1972.

6 Houthakker, H. and L. Taylor, *Consumer Demand in the United States*, Cambridge, Massachusetts, Harvard University Press, 1970.

7 Interstate Commerce Commission, Ex Parte 295, "Increased Freight Rates and Charges, 1973—Proceedings Recyclable Materials," Washington, D.C., October 29, 1974.

8 Interstate Commerce Commission, *Draft Environmental Impact State-*

ment, Ex Parte 319, Office of Proceedings, Environmental Affairs Staff, Bureau of Economics, Washington, D.C., August 11, 1976.

9 Regional Science Research Institute, Philadelphia Input-Output Table, Mimeograph, Philadelphia, Pennsylvania, May, 1970.

10 Wold, H. & L. Jureen, *Demand Analysis: A Study in Econometrics*, New York, John Wiley & Sons, Inc., 1952.