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Spatial Pricing and Its Effect on Product Transportability*

The issue of what resources to devote toward making a product more transportable is addressed within the standard spatial pricing model of the firm. The relationship between transportability and pricing mode is specifically examined. The impact of the firm's decision on buyers of the product is discussed using consumer surplus and social welfare measures. It is found that, under certain circumstances, the level of transportability can depend on the pricing mode, and that the profit-maximizing level need not maximize the welfare of the buyers.

I. Introduction

In most models of the firm located in economic space, spatial pricing is the topic of main concern. That is, the firm is assumed to take such things as consumer demand, production costs, and transport rates as given and then to select the price at the various distances in a profit-maximizing manner. Within this framework, three different pricing modes are often considered and compared with one another. The profits of the firm, the overall consumer surplus, and a variety of other such performance measures are used to make these comparisons. Beckmann (1976), for instance, gives a detailed analysis of the pricing behavior of a monopoly firm which must select a mill, uniform delivered, or discriminatory price. He then compares these three pricing modes using nine different performance measures. Capozza and Van Order (1978), Greenhut and Ohta (1972), and Holahan (1975, 1978) are examples of other work in this area.

An important issue not addressed in these spatial pricing models is the internal trade-off available to the firm involving production costs and

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transportation costs. Specifically not addressed is the issue of how the firm decides on the resources it should devote to making the product more transportable, that is, to lower its transport rate. It is clear that certain expenditures can be made by the firm in the manufacture and packaging of its product in order to reduce the cost of transporting the product from the firm to the buyer. Costly characteristics such as collapsibility or removable parts can be incorporated into a product's design, thereby reducing shipping charges but increasing the costs of manufacture. Similarly, by packaging a product in a more durable container, the firm can reduce the costs of breakage or damage in transit. Since these costs are usually considered to be costs of transport, one again has an example of a strategy available to the firm which allows it to reduce transport costs, but simultaneously to increase production costs.

The importance of the packaging process function to the spatial firm has been recognized in the literature on logistical management. Bowersox (1978) notes the trade-off among production, warehousing, and transportation costs involved in shipping products in assembled (low-density) as opposed to unassembled (high-density) form. He also discusses the balancing of degree of protection, broadly interpretable as transportability, and input costs in designing optimal packaging. Davis and Brown (1974) also recognize the packaging-cost/transportation-cost trade-off, particularly as it relates to the choice of transport mode. They cite the ability of firms to lower packaging costs by hiring private, as opposed to common carriers, and thereby to avoid federal packaging regulations. Our paper serves as a complement to the logistical analyses by considering the simultaneity of the transportability (packaging) and pricing decisions within the spatial firm's decision calculus.

The main goal of this paper is the development of a model which allows the issue of the optimal level of transportability to be addressed, and to examine specifically the relationship between the pricing mode and the level of transportability. The model is formulated in such a way as to be consistent with, and to build on, the array of spatial pricing research previously mentioned. In the analysis presented here, both the price at the various distances and the transport rate will be treated as choice variables. The market size will first be treated as fixed, but later allowed to be a choice variable. Prices will be assumed to be selected by the firm in a profit-maximizing manner. The transport rates that are considered will be those which maximize firm profits, consumer surplus, and social welfare. Furthermore, all of this will be done under the mill, uniform delivered, and discriminatory pricing modes.

Our findings indicate that the level of transportability associated with a product will, in general, depend both on how it is priced, and on whether profits, consumer surplus, or social welfare is maximized in selecting the transport rate. Under the assumption of a fixed market size, profit-maximizing firms would select different levels of transportability for their product, depending on the pricing mode being followed. This difference, however, is eliminated if market size is selected to maximize profits. That is, if firms are allowed to choose price, market size, and the level of transportability in a profit-maximizing manner, then the level of transportability selected does not depend on the pricing mode. In all instances, the level of transportability which maximizes profits differs from that maximizing consumer surplus or social welfare if mill pricing is the pricing mode. No such differences arise under either uniform delivered or discriminatory pricing. These findings can be used to compare the various pricing modes, and to discuss the circumstances under which packaging restrictions might prove useful in the protection of consumer or firm interests.

The paper is organized as follows. First, in the next section, the assumptions made are recorded. Those which are standard in spatial pricing models are stated with little comment, while the assumption concerning the transport rate and production costs is discussed in more detail. Section III summarizes a number of results currently available in the spatial pricing literature that are needed in later analysis. These are results concerning the profit-maximizing prices and the resulting profits, consumer surplus, and social welfare for a monopoly firm. In Section IV, the optimal level of the transport rate is derived for alternate goals of profit, consumer surplus, and social welfare maximization. This is done for each of the three pricing modes and for both a predetermined and a freely selected market area. As an aid in interpreting these results, the interests of each buyer located at the various distances from the firm are also examined. The results concerning the optimal levels of the transport rate under the different scenarios are summarized in table form.

II. Assumptions

The following list of assumptions specifies the model used here. Except for A2, the assumptions are essentially the same as those used by many researchers concerned with spatial pricing. The notation attempts to follow that used by Capozza and Van Order (1978).

A1.—There is a single commodity that can be produced in one-dimensional space with different transport characteristics.

A2.—The production-cost function depends both on the quantity produced and its transport rate in the following manner. There is a fixed cost and a marginal cost, which is a constant depending on the transport rate. That is, $C = f + c(t)X$, where X is total output; C is total cost of production; f is fixed cost; and $c(t)$ is marginal cost, which depends on the transport rate t. It is assumed that $c'(t) < 0$, and $c''(t) > 0$.

A3.—Transport cost per unit distance is identical between any two points and is denoted by t dollars per unit distance.

A4.—Potential customers occupy an unbounded line at uniform density D.

A5.—All customers are identical and have a demand curve for x that is linear in delivered price $x = a - bp = a - b(m + tu)$, where p is delivered price; m is mill price; u is distance to the firm; and $a, b > 0$.

In addition, one of the following three assumptions is used to specify the pricing mode that is being required or, in the case of discriminatory pricing, the lack of such a requirement.

A6A.—Firms set a mill price m, and transport costs are paid by the customers.

A6B.—Firms set a uniform delivered price p, and transport costs are paid by the firm.

A6C.—Firms are permitted to charge a price $p(u)$ which is a function of distance. Transport costs are paid by the firm.

Also, one of the following two assumptions will be assumed to hold with regard to the firm's market area.

A7A.—The firm is a monopolist serving a market of length R in each direction. R is restricted to satisfy $R \leq 2(a/b - c)/3t$.

A7B.—The firm is a monopolist serving a market of length R in each direction where R is selected to maximize firm profits.

Assumption A1 indicates that only one commodity can be produced, but that it can have different transport characteristics. Implicitly it requires the firm to be able to alter the transport properties of its product without altering the product itself as far as consumers are concerned. This seems reasonable for various packaging options, but less so for the design alternatives mentioned earlier. To keep the model simple, we will assume that the alternatives being considered by the firm which alter the transport rate of its product do not affect the product itself as far as buyers are concerned. Assumptions A3–A5 are standard and need no comment. Assumptions A6A, A6B, and A6C are simply the specification of each of the three possible pricing modes. Assumptions A7A and A7B concern the determination of the firm's market area. Under A7A, market area is given. The restriction on R insures that no matter what pricing mode is considered, negative demand is not observed at the profit-maximizing prices.

Assumption A2 is unique to this research. It specifies a relationship between the firm's production costs and the transport rate for its product. The particular specification used here has two desirable properties. First, it allows the firm to reduce the transport rate of its product only at the expense of increasing its production cost. Second, for a fixed transport rate, the cost assumption becomes the standard one made in spatial pricing models, namely, a fixed cost plus a constant marginal cost assumption. The latter property allows us to build on the results from existing spatial pricing models and to compare our conclusions with theirs.

The restrictions placed on the function $c(t)$ can be viewed as coming from a convex production-possibilities set in (t, c) space, with frontier $c(t)$. The assumption that $c'(t) < 0$ implies that reductions in the transport rate come about only by increasing the marginal cost of production. Furthermore, $c''(t) > 0$ implies that the rate at which one cost can be substituted for another declines as the substitution occurs; $c''(t) > 0$ is crucial in the second-order conditions for the maximizations examined later in the analysis.

III. Pricing Behavior

In the model posed here, the firm chooses the price at each point in its market area in accordance with the particular pricing-mode assumption being made, and does so in a profit-maximizing manner. By design, the problem is presented in such a way that the pricing behavior can be determined as a function of the transport rate. The profit-maximizing price can be explicitly solved for as a function of t. Thus, even though the price and the transport rate are both choice variables, the selection can be made in two steps. First, the price is determined as a function of t, and then t is selected to maximize the objective function, whether it be profits, consumer surplus, or social welfare. Furthermore, the results concerning the profit-maximizing prices and the resulting profits, consumer surplus, or social welfare for a given level of the transport rate have been derived previously by other researchers in the spatial pricing field. This section states, with only brief discussion, those results from the research of others that are needed in the present analysis.

The profit functions for a firm serving to a distance R in each direction under each of the three possible pricing-mode assumptions are given below. The variable m is used to designate a mill price, p a uniform delivered price, and $p(u)$ the discriminatory price at each distance u:

$$Y_m(m,t) = 2D \int_0^R (m - c)\,[a - b(m + tu)]\,du - f, \tag{1}$$

$$Y_p(p,t) = 2D \int_0^R (p - c - tu)\,(a - bp)\,\mathrm{du} - f, \tag{2}$$

and

$$Y_d[p(u),\mathrm{t}] = 2D \int_0^R [p(u) - c - tu]\,[a - bp(u)]\,du - f. \tag{3}$$

Recall that in these expressions, c is actually a function of t. Treating t and, hence, c as fixed, the firm maximizes these profit expressions by choosing m, p, and $p(u)$, respectively. The familiar optimal values for these prices are given below:

$$m^* = \frac{a}{2b} + \frac{c}{2} - \frac{tR}{4}, \tag{4}$$

$$p^* = \frac{a}{2b} + \frac{c}{2} + \frac{tR}{4}, \tag{5}$$

and

$$p^*(u) = \frac{a}{2b} + \frac{c}{2} + \frac{tu}{2}. \tag{6}$$

Each of these profit-maximizing prices is optimal for any value of t, as long as the market-size restriction $R \leqslant 2(a/b - c)/3t$ is met.

One can now substitute these profit-maximizing prices into the profit expressions and simplify. If one does so, one obtains profit expressions for each of the pricing modes which depend on the transport rate t and the parameters of the models. The reader is again cautioned to recall that c is a function of t. Beckmann (1976), Holahan (1975, 1978) or Gronberg and Meyer (1981) give details of these derivations:

$$Y_m(m^*,t) = 2D\left[\left(\frac{bt^2}{16}\right)R^3 - \frac{(a - bc)tR^2}{4} + \frac{(a-bc)^2R}{4b}\right] - f, \tag{7}$$

$$Y_p(p^*,t) = 2D\left[\left(\frac{bt^2}{16}\right)R^3 - \frac{(a - bc)tR^2}{4} + \frac{(a - bc)^2R}{4b}\right] - f, \tag{8}$$

and

$$Y_d[p^*(u),t] = 2D\left[\left(\frac{bt^2}{12}\right)R^3 - \frac{(a - bc)tR^2}{4} + \frac{(a - bc)^2R}{4b}\right] - f. \tag{9}$$

These profit expressions will be used in Section IV to determine the profit-maximizing value of the transport rate.

In addition to the firm's profits, the consumer surplus which accrues to all buyers of the firm's product can also be written as a function of the transport rate. These functions and their derivation are available in the previously cited references as well. The letters CSM, CSU, and CSD are used to denote the consumer surplus under mill, uniform delivered, and discriminatory pricing, respectively:

$$\mathrm{CSM}(m^*,t) = 2D\left[\frac{7}{96}bt^2R^3 - \frac{(a - bc)tR^2}{8} + \frac{(a - bc)^2R}{8b}\right], \tag{10}$$

$$\mathrm{CSU}(p^*,t) = 2D\left[\frac{3}{96}bt^2R^3 - \frac{(a - bc)tR^2}{8} + \frac{(a - bc)^2R}{8b}\right], \tag{11}$$

and

$$\mathrm{CSD}[p^*(u),t] = 2D\left[\frac{4}{96}bt^2R^3 - \frac{(a-bc)tR^2}{8} + \frac{(a-bc)^2R}{8b}\right].(12)$$

If one adds firm profits and consumer surplus to get a social welfare measure, the welfare expressions *WM, WU,* and *WD* are those given below.

$$WM(m^*,t) = 2D\left[\frac{13}{96}bt^2R^3 - \frac{3(a-bc)tR^2}{8} + \frac{3(a-bc)^2R}{8b}\right], (13)$$

$$WU(m^*,t) = 2D\left[\frac{9}{96}bt^2R^3 - \frac{3(a-bc)tR^2}{8} + \frac{3(a-bc)^2R}{8b}\right], (14)$$

and

$$WD[p^*(u),t] = 2D\left[\frac{12}{96}bt^2R^3 - \frac{3(a-bc)tR^2}{8} + \frac{3(a-bc)^2R}{8b}\right].(15)$$

This concludes the listing of the results needed in later analysis. We now go on to the decision problem of selecting the optimal transport rate.

IV. Transport-Rate Selection

If the firm itself chooses the transport rate to maximize its profits, the value of t selected will depend on which pricing mode is being followed. For mill pricing, the firm's profits are given by expression (7) listed earlier. Differentiating this expression with respect to t and setting equal to zero, one obtains the following equation which implicitly defines t:

$$\frac{\partial Y_m(m^*,t)}{\partial t} = 2D\left[\frac{btR^3}{8} - \frac{(a-bc)R^2}{4} + \frac{bc'tR^2}{4} - \frac{2c'(a-bc)R}{4}\right]$$

$$= 2D\left(\frac{btR^2}{4} - \frac{(a-bc)R}{2}\right)\left(\frac{R}{2} + c'\right) = 0.$$

Since neither D nor $(btR^2/4 - (a-bc)R/2)$ are equal to zero given our assumption on R, this implies that $c'(t) = -R/2$. We also note that the second-order conditions for this maximization are satisfied at $c'(t) = -R/2$ as long as $c''(t) > 0$, as was assumed. Thus, $c'(t) = -R/2$ defines the profit-maximizing transport rate for the mill pricing firm, taking R as given. The mill pricing firm, even though it pays no transport charges itself, finds it optimal to select the transport rate at some value less than infinity, since it knows that the price it charges and the quantity it sells both depend on t. Thus, even though the transport charges are not paid directly by the firm, they are at least partially internalized through these mechanisms.

For the firm which selects a uniform delivered price, the profits expression as given in (8) is identical to that found for the mill pricing firm. Hence, without further analysis one can conclude that for this firm, the profit-maximizing transport rate satisfies $c'(t) = -R/2$ as well. Thus, the profit-maximizing behavior is the same independent of who nominally bears the transport charges.

Under discriminatory pricing, profits to the firm are higher than those for mill or uniform delivered pricing. Expression (9) gives these profits. Partially differentiating this expression with respect to t and setting equal to zero, one obtains the following after some simplification:

$$\frac{\partial Y_d[p^*(u),t]}{\partial t} = 2D\left[\left(\frac{btR^2}{4} - \frac{(a - bc)R}{2}\right)\left(\frac{R}{2} + c'\right) + \frac{btR^3}{24}\right] = 0.$$

This implies that $c' = -R/2 - btR^3/6[btR^2 - 2(a - bc)R]$. Now $btR^3 > 0$, and $btR^2 - 2(a - bc)R < 0$ under our assumption concerning R. This implies that the profit-maximizing value for $c'(t)$ is greater than $-R/2$. Since $c''(t) > 0$ was assumed, this means that the transport rate selected by a profit-maximizing price discriminator is larger than that chosen by either a mill or uniform delivered pricing firm. A price discriminator does less in the way of making his product transportable than does the mill or uniform delivered pricing firm, but he produces at a lower marginal cost than they do.

The preceding analysis considers the optimal transport rate when the firm itself selects t in a profit-maximizing manner. Buyer input to the decision concerning t enters only indirectly into the profit-maximization calculations. In the following analysis we examine the interests of individual buyers in the production cost/transportation cost trade-off decision.

For a buyer located at distance u from a firm known to charge the profit-maximizing mill price for his product, the delivered price to the buyer is given by: $DP_m(u) = a/2b + c/2 - tR/4 + tu$. Since a single buyer does not affect price and is a price taker, he wishes to minimize this delivered price. Doing so requires that $\partial DP_m/\partial t = c'(t)/2 - R/4 + u = 0$ or $c'(t) = R/2 - 2u$. Note that the second-order conditions for this minimization problem are satisfied.

To interpret this, observe that for buyers located at distances less than $R/2$ from the firm, the desired level of $c'(t)$ is greater than $-R/2$. Hence, these buyers prefer the firm to choose a higher t, that is, do less packaging and instead reduce the costs of production. On the other hand, those customers located beyond distance $R/2$ find that the firm selects too high a transport rate and, in these buyers' interests, should devote more resources toward making the product transportable. Only the buyer located at exactly $R/2$ agrees with the firm's selection concerning the transport rate. Thus, for the profit-maximizing mill pricing firm, virtually no buyers are pleased with the amount of resources devoted by the firm to improving the transportability of its product. Some think the firm overpackages and some think the firm underpackages its product.

In a similar manner we consider the interests of a customer located at distance u from a firm known to select the profit-maximizing uniform delivered price for its product. The delivered price to all customers is the same and given by $DP_u = a/2b + c/2 + tR/4$. Minimizing delivered price requires that $c'(t)/2 + R/4 = 0$ or $c'(t) = -R/2$. This is exactly the condition which defines this firm's profit-maximizing level of t. Hence, for the uniform delivered price case, all buyers would select the same level of t as the firm. No disagreement arises between buyers and seller concerning the amount of resources to be devoted to making the product transportable.

For the price-discriminating firm, the delivered price to a buyer located at distance u is given by the following expression: $DP_d(u) = a/2b + c/2 + tu/2$. Thus, the price-minimizing choice of the transport rate satisfies $c'(t)/2 + u/2 = 0$ or $c'(t) = -u$. Now the profit-maximizing level of $c'(t)$ is some number greater than $-R/2$. Hence, more than half of the customers, those located from some distance less than $R/2$ to the distance R, all think the level of t selected is too high. Only those located near the firm think that the profit-maximizing level of t is too low. Again the firm finds that the buyers do not agree with the selection of t made by the firm, but neither do they agree with one another.

Rather than examine individual buyers, one could discuss the issue of buyer welfare by considering the total consumer surplus generated across all buyers. Given the linear demand curves, the consumer surplus expression under each of the three pricing modes is rather easy to compute and was listed earlier in Section III. For a mill pricing firm which selects price in a profit-maximizing manner, the aggregate surplus is given below:

$$\mathrm{CSM}(m^*,t) = 2D\left[\frac{7}{96}bt^2R^3 - \frac{(a-bc)tR^2}{8} + \frac{(a-bc)^2R}{8b}\right].$$

Maximizing this expression with respect to t requires that

$$2D\left[\frac{7}{48}btR^3 - \frac{(a-bc)R^2}{8} + \frac{bc'tR^2}{8} - \frac{c'(a-bc)R}{4}\right] = 0.$$

This in turn reduces to $c'(t) = -R/2 - 4btR^3/6(btR^2 - 2(a - bc)R$. This is a value of $c'(t)$ which is greater than $-R/2$. To maximize consumer surplus in a mill pricing framework, the desired transport rate is higher than that which would be selected by the profit-maximizing firm. The goals of profit maximization and consumer surplus maximization do not yield the same level of the transport rate in a mill pricing world.

The case of uniform delivered pricing is analyzed in a similar manner. Consumer surplus was given earlier as expression (11). The value of t which maximized (11) satisfies $c'(t) = -R/2$. Since this is also the profit-maximizing value for t, the two goals yield the same selection of t in this model. This result is not unexpected, given the agreement between buyers and seller concerning the optimal t that was found earlier in the analysis of individual buyers.

For the price-discriminating firm, the aggregate consumer surplus measure is given by (12). Maximizing this expression with respect to t requires that $c'(t) = -R/2 - btR^3/6[btR^2 - 2(a - bc)R]$. This condition is exactly the condition found earlier when t was selected to maximize profits. Thus, for discriminatory pricing as well, the objective of profit maximization and consumer surplus maximization lead to the same amount of resources being devoted to reducing the transport rate for the product.

To complete this analysis, it is worthwhile to consider a social welfare measure defined to be the sum of the firm's profits and the aggregate consumer surplus. Obviously, since for both uniform delivered and discriminatory pricing the same value of t maximizes both profits and consumer surplus, it must also maximize social welfare. For mill pricing one can show that the value of t which maximizes social welfare as given by expression (13) satisfies $c'(t) = -R/2 - 2btR^3/9[btR^2 - 2(a - bc)R]$. This implies a level of t somewhere between that which maximizes profits and that which maximizes consumer surplus.

In summary, table 1 gives the condition which t must satisfy in order to maximize either profits, consumer surplus, or social welfare under each of the three pricing modes. Define t_m, t_m^* and $\bar{t}_m$ to be, respectively, the profit-maximizing, consumer surplus–maximizing, and social welfare–maximizing levels of the transport rate under mill pricing and similar notation for uniform delivered pricing and discriminatory pricing. Then using the values listed in table 1 and recalling that $c''(t) > 0$, one can order these transport rates as follows: $t_m = t_u = t_u^* = \bar{t}_u < t_d = t_d^* = \bar{t}_d < \bar{t}_m < t_m^*$. Of course the associated levels of marginal cost of production are ordered in the reverse direction. The most important

TABLE 1 **Determination of Optimal Transportability within a Fixed Market Area**

Pricing Mode	Variable Maximized: Profits	Consumer Surplus	Social Welfare
Mill	$c' = -R/2$	$c' = -R/2 - 4K/6$	$c' = -R/2 - 2K/9$
Uniform delivered	$c' = -R/2$	$c' = -R/2$	$c' = -R/2$
Discriminatory	$c' = -R/2 - K/6$	$c' = -R/2 - K/6$	$c' = -R/2 - K/6$

NOTE.—$K = btR^2/[btR - 2(a - bc)]$.

observation to be made concerning these values is that they depend both on the pricing mode and the objective used in selecting t. Since packaging is often a regulated variable selected by a government agency or the shipper, this has obvious policy implications. It should be noted further that these results are independent of the assumption concerning market size. That is, even though the amount of transportability built into a product depends on R, the relative amounts across the various pricing modes, and under the various objectives, do not depend on the market size. This is a rather strong statement. It means that our results hold for small markets and large markets alike, as long as market size is fixed.

Relaxing the fixed-market-size assumption is our final variation on the overall problem of determining the amount of resources to be devoted to making a product more transportable. As indicated in the introduction, the freedom to select market size is sufficient to realign the profit-maximizing behavior of firms. With freely selected market areas, profit-maximizing firms no longer select different levels of transportability depending on the pricing mode being followed.

A firm choosing R to maximize the profit expressions (7), (8), and (9) listed earlier finds that the optimal R for the three pricing modes is given by: $R_m^* = 2(a/b - c)/3t$; $R_u^* = 2(a/b - c)/3t$; and $R_d^* = (a/b - c)/3t$. The results are well known and can be found in Holahan (1975). Each of these values depends on t, and the values for mill and uniform delivered pricing are the same and smaller than that for discriminatory pricing. The second-order conditions for this maximization are satisfied. Plugging these values for R into the expressions in table 1 one obtains table 2. The most significant change that occurs is that the profit-maximizing price discriminator now chooses the same level of t as does the mill and uniform delivered pricing firm. In fact, seven of the nine levels of t are now the same with only the mill pricing case showing variation in t under the different objectives. The freedom to select market size is sufficient to imply that firms choose the same level of transportability independent of the pricing mode being followed.

TABLE 2 **Determination of Optimal Transportability with Endogenous Market Area**

	Variable Maximized		
Pricing Mode	Profits	Consumer Surplus	Social Welfare
Mill	$c' = -H/3$	$c' = -H/9$	$c' = -7H/27$
Uniform delivered	$c' = -H/3$	$c' = -H/3$	$c' = -H/3$
Discriminatory	$c' = -H/3$	$c' = -H/3$	$c' = -H/3$

NOTE.—$H = (a/b - c)/t$.

V. Conclusions

The preceding analysis indicates that, for the monopoly case, how a product is packaged and designed can depend on the pricing mode under which it is priced. Furthermore, if a regulator or shipper is requiring a particular level of transportability for a product, how much to require depends in some cases on whose interests are being met. Given the variety of spatial pricing arrangements which prevail in the U.S. economy (see Greenhut, Greenhut, and Li 1980), recognition of intermodal variation in production/transportation trade-offs would seem important in policy formulation.

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