SPATIAL COMPETITION A LA COURNOT

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N° 86 / 13

Director of Publication:

Charles WYPLOSZ, Associate Dean
for Research and Development

Printed by INSEAD, Fontainebleau
France

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Abstract

This paper considers oligopolistic competition in geographic space when firms take care of goods' delivery. Equilibrium sales (and prices) at each point in space are determined by a Cournot-Nash equilibrium.

We first analyze the properties of equilibrium spatial price schedules for given locations. Over the interval between two firms, the shedule is quasi-concave (quasi-convex) when transport costs are concave (convex). With linear transport costs (as noted by Greenhut and Greenhut (1975) and Phlips (1983)), the model predicts uniform delivered pricing. We show that uniform pricing can morever be obtained by a combination of increasing returns to volume in transportation together with concavity of unit transport costs in distance. Besides, in equilibrium firms' markets always overlap, a feature which accords with intuition and empirical observations.

We next consider location equilibria (contingent on Cournot competition at a later stage). For convex transport costs and sufficiently high consumer demand, there is a unique duopoly equilibrium at the centre of a linear market. Besides, there is always an agglomeration equilibrium at the centre, whatever the number of firms. If, however, transport costs are 'sufficiently' concave, equilibrium involves some differentiation between firms.

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INTRODUCTION

Hotelling's model appears as the dominant paradigm of spatial competition. In that framework, it is assumed that firms adopt an F.O.B. pricing policy, which implies that all consumers pay the same price, net of transportation costs. Hence, there is no discrimination between consumers, even though discrimination enlarges profit opportunities. The question then arises of whether firms do actually have the opportunity to charge different net prices to consumers located at different points in space. If so, Hotelling's model would be unduly emphasized and discrimination would deserve a more detailed analysis.

There is one instance in which discrimination is clearly difficult, or at least costly. When firms locate in a product (characteristics) space, instead of a geographical space, discrimination will require that consumers can be identified according to their willingness to pay for any particular product. This information can clearly not be gathered by direct observation as in the geographical paradigm. Screening devices can however be set up to sort consumers out indirectly and appropriate marketing techniques have been designed to achieve this goal (see....). Hence, information problems make discrimination more difficult but should not be compelling, even in the product differentiation analogue to spatial competition.

Second, it can be argued that F.O.B pricing is relevant when consumers go to the store, instead of being supplied at home. All consumers are then paying the same net price and there is no discrimination. However, most firms have distribution networks, which typically achieve some second degree price discrimination. For example, travelling to Wolksburg is not necessary for the purpose of buying a Wolkswagen. V.A.G dealers will also charge prices which reflect various proportions of the transportation cost from Wolksburg. Hence, it cannot be argued that discrimination is unimportant because consumers bear transportation costs in the real world. Rather, they bear some transportation cost. Besides, delivery is sometimes fully taken care of by the firms. Think (rather ironically) of ice cream vans, e.g.. Finally, it seems that even when consumers go to the stores, there is still some room for discrimination; firms can commit themselves to reimburse some proportion of the transportation cost. This is not as uncommon as it might sound; for example, visitors to Walibi (Belgian version of 'Disneyland'), can obtain a rebate on their train tickets, upon arrival. More generally, by providing free parking, banks or supermarkets support part of the cost associated with visiting their premises. Nearby customers (at walking distance from the outlet) are discriminated against while distant consumers are being subsidized.

All in all, it seems that some form of discrimination is likely to occur in most instances. It should be more frequent when firms locate in a geographical space (as opposed to a product space) and more fully implemented when firms take care of delivery. Hence, spatial discrimination deserves a detailed analysis. It should be a useful complement to Hotelling's approach of spatial competition.

Notwithstanding its empirical relevance, spatial discrimination has been relatively neglected so far in the literature, except for the case of a spatial monopoly (see e.g. Greenhut and Greenhut (1977), Holahan (1975), Norman (1977)). Spatial price discrimination in Cournot-type oligopoly has been considered solely by Greenhut and Greenhut (1975), Norman (1981) and Phlips (1983). These contributions assume that transport costs are linear in distance, an assumption we shall depart from. We shall allow for a more general form encompassing concave as well as convex transport costs. Assuming a linear bounded market and Cournot competition, we characterize (in Section 1), delivered price schedules corresponding to these various forms of transportation costs. Over the interval between two firms, the schedule is quasi-concave (quasi-convex) when transport costs are concave (convex). As already noted by Greenhut and Greenhut (1975) and Phlips (1983), the model predicts uniform delivered pricing when transport costs are linear in distance. Location tendencies of discriminating oligopolists have not been looked at either in the references mentioned above. We tackle this question in Section 2. In sharp contrast with the results obtained in Hotelling's model, we uncover a strong tendency for firms to agglomerate at the centre of the market.

In our model, discrimination results from a Cournot competition which takes place at each point in space. Alternatively, it can be assumed that firms set prices and thus compete in a Bertrand fashion. Discrimination arises as well and this route has been followed by Mac Leod, Norman and Thisse (1985) in a recent paper. Whether Cournot or Bertrand competition is more appropriate has been the subject of a long lasting debate. Puzzling features of both equilibrium concepts have been the point of focus; with Bertrand competition, two firms suffice to restore the perfect competition outcome (in absence of a spatial dimension). This feature clearly does not accord with empirical observations. At the opposite, as the number of Cournot competitors increases, the market equilibrium converges smoothly to the perfect competition outcome. On this ground, at least, Cournot competition is more appealling. However, the question then arises of how prices are determined if firms do not set them directly. Standard explanations will advocate the role of the "market". Prices will be defined, so it is argued, implicitly from demand. Appropriate equations are easy to write but the actual process which should take place is hard to figure out. Further insight into this question has been provided recently by Kreps and Scheinkman (1984). These authors consider a two-stage game in which firms decide on production capacity in the first stage and subsequently compete in prices. They show that equilibrium in this game coincides with the Cournot outcome of a single stage game. This observation makes Cournot equilibrium more appealling since it can now be interpreted as the outcome of a realistic decision process. Indeed, it seems reasonable to consider that, for example, automobile manufacturers make production plans far in advance, knowing that dealers will subsequently set prices. In a spatial context, additional arguments can be put forward. When firms compete in quantities at each point in space, their (spatial) markets will overlap (as shown below). This property fits nicely with empirical observations (see Phlips (1983)). In contrast, delivered price schedule resulting from Bertrand competition will mimic, at any point, the transportation costs from the firm which is furthest away (see Mac Leod, Norman and Thisse (1985)). This is so because the firm which is the most favourably positioned (closest) to serve a segment of the market charges a price ε below the transportation cost incurred by its competitor to serve that segment. It is accordingly a knife-edge equilibrium which generates connected market shares, without overlap. All in all, Cournot equilibrium over space has much in its favour. We shall prefer that assumption and now proceed with the model.

Section 1 : Spatial Price Discrimination

Assume that a simple geographical space can be represented by a segment of the real line [0,1]. x will denote a position along that segment. For the time being, we consider two firms, located at x_1, x_2 respectively and producing an homogenous good (with $x_1 < x_2$, w.l.o.g.). As illustrated below, the analysis can be easily extended to more numerous firms. Production takes place at constant marginal cost (zero, w.l.o.g.). Firms take care of goods' delivery, with the following transportation technology: at first, we assume that transportation costs are homogenous of degree one in quantity. Unit transport cost t(.) is then a function of distance (u) only. Quite naturally, we assume that this function is monotonically increasing, with a fixed point at zero ($t'(u) > 0$, $t(0) = 0$). Firms decide independently on the quantity ($q_i(x)$, $i = 1,2$) they wish to sell at each point in space. Demand is such that the market will always be fully served by both firms. It is characterized by an inverse demand function which is the same at each point (x). This is, $p(x) = p\,(q_1(x) + q_2(x))$, in which p(x) denotes the commodity's price at x. In order to guarantee existence of unique equilibrium, we shall assume that this inverse demand meets the following conditions:

$$\begin{aligned} & p''q_i + 2p' < 0 \qquad i = 1,2 \\ & p''Q + 3p' < 0 \end{aligned} \tag{1}$$

Existence of a unique equilibrium then follows from standard arguments (see Novshek (1984)). Under these assumption profits (Π_i, $i = 1,2$) can be written as follows:

$$\Pi^i = \int_0^1 [\ p\ (q_1(x) + q_2(x) - t(\lfloor x-x_i \rfloor)\ ]\ q_1(x)dx \qquad i = 1,2.$$

Equilibrium can now be characterized.

Proposition 1 : Assume that firms compete in a Cournot fashion at each point in space. The resulting delivered price schedule in between the firms, will be quasi-concave (quasi-convex) when transport costs are concave (convex). Linear transport costs give rise to uniform pricing. Outside the firms, delivered prices always increase.

Proof : Following first-order conditions are necessary and sufficient for a unique equilibrium (by (1)), at any point x:

$$\frac{\delta \Pi^1(x)}{\delta q_1(x)} = 0 \iff q_1(x) + p(x) = t(\lfloor x-x_1 \rfloor) \qquad (2)$$

$$\frac{\delta \Pi^2(x)}{\delta q_2(x)} = 0 \iff p' q_2(x) + p(x) = t(\lfloor x - x_2 \rfloor) \qquad (3)$$

Summing (2) - (3), one obtains :

$$P'Q(x) + 2p(x) = t(\lfloor x-x_1 \rfloor) + t(\lfloor x-x_2 \rfloor) \qquad (4)$$

Notice that (by (1)), the LHS of (4) is decreasing in Q. (This guarantees uniqueness of equilibrium). The RHS gives, at any point, the sum of firm's transportation costs to that point. Hence, if total transport cost goes up, equilibrium total quantity (Q) in the market goes down. Accordingly, price goes up.

Looking first at the interval in between the firms $x \in [x_1, x_2]$, (4) is rewritten :

$$P'Q(x) + 2p(x) = t(x-x_1) + t(x_2-x)$$

so that ,

$$\frac{\delta Q}{\delta x} = \frac{t'(x-x_1) - t'(x_2-x)}{p''Q + 3p'} \qquad (5)$$

where the denominator is negative (by (1)). The slope of the delivered price schedule is then given by (from(5)) :

$$\frac{\delta p(x)}{\delta x} = \frac{p'}{p''Q+3p'} \left(t'(x-x_1) - t'(x_2-x)\right) \qquad (6)$$

which is always zero at the midpoint between the two firms ($\bar{x} = \frac{x_1+x_2}{2}$).

Next, consider the delivered prices in the interval $[x_1,\bar{x}]$. By inspection of (6), it follows that :

- if $t'' = 0$, so that $t'(x-x_1) = t'(x_2-x)$, $\frac{\delta P(x)}{\delta x} = 0$. This is the case of linear transport costs, implying that total transport cost to any point in between the firms is constant. Accordingly, total sales do not vary over this interval. Pricing is uniform.
- if $t'' < 0$, transport costs are concave and $\frac{\delta P(x)}{\delta x} > 0$. Total transport cost decreases towards the midpoint ($\bar{x}$). Hence, total output increases and price goes down.
- if $t'' > 0$, transport costs are convex and $\frac{\delta P(x)}{\delta x} < 0$. Total transport cost increases towards the midpoint ($\bar{x}$). Hence, total output decreases and price goes up.

This interval $[\bar{x}, x_2]$ can be treated in the same way. Symmetry of total transport cost (around $\bar{x}$) will ensure that the delivered price schedule is symmetric (around $\bar{x}$). Since outside the firms total transport cost always increases, delivered prices will go up. The slope of the pricing schedules are given by:

$$\forall\ x < x_1, \qquad \frac{\delta p}{\delta x} = \frac{p'}{p''Q + 3p'}\left(-\ t'(x_1-x) - t'(x_2-x)\right) \tag{7}$$

$$\forall\ x > x_2, \qquad \frac{\delta p}{\delta x} = \frac{p'}{p''Q + 3p'}\left(t'(x-x_1) + t'(x-x_2)\right) \tag{8}$$

All in all, the various pricing schedules can be summarized as in Figures 1 to 3.

From this analysis, it appears that delivered prices follow closely total transport costs, namely the sum of both firms' transport costs to any point. This is in contrast with the discrimination enforced by Bertrand competition in which only the transport cost of the most distant firm actually matters. It is also related to the fact that in the present model, both firms serve the whole market (in equilibrium). As mentioned above, this market overlap is an interesting feature from an empirical point of view.

Predictions of the model for the case of linear transport can also be linked to specific empirical observations put forward by Phlips (1983). This author reports on uniform pricing observed for the cement industry in Belgium. This policy seems however to be enforced through a cartel. The prediction of uniform pricing obtained in this model, is clearly consistent with Phlips' observation, at least for the interval between the firms (which interestingly are located close to opposite borders of the Kingdom). Yet, the model points out that uniform pricing is not per se evidence of a cartel. Indeed, it seems that the cement cartel in Belgium 'enforces' the competitive solution !

The various pricing formula (6) - (8) given above can also be used to characterize the discrimination enforced by duopolists as compared to the monopoly outcome. It is well known that with linear demand and linear transport cost, a monopolist will absorb half of the freight. We can characterize freight absorption in duopoly under the same conditions by setting $p'' = 0$ and $t' =$ constant in (6) - (8). It turns out that outside the firms, 2/3 of total freight is being absorbed, a higher proportion than in monopoly. Total freight is however larger since it is the sum of firms' individual transport costs. Absolute values of net prices can thus not be compared. Nevertheless, consumers far away tend to be 'subsidized' by duopolists to a larger extent than in monopoly. Of course, in between the firms freight absorption is complete.

It follows that consumers should benefit from increased competition on two accounts. First, switching from monopoly to duopoly, all prices fall. Second, since freight absorption is larger, the 'benefit' from discrimination is enlarged: the effective spatial market (actually served by the firms), which increases because of discrimination, will increase more the higher is freight absorption.

With non-linear demand, freight absorption will vary over space. By inspection of (6) - (8), it is clear that, other things being equal, concave (convex) demand will lead to a freight absorption which decreases (increases) over space. Consumers far away, facing high prices will thus be 'subsidized' at a decreasing rate. This makes intuitive sense because, with concave demand, those consumers are relatively less price sensitive.

The results presented so far with regard to delivered price schedules can be extended in several ways. Henceforth, we shall consider two extensions that are of special interest from an empirical prospective. First, more numerous firms will be allowed for, while keeping the assumption of two production centres (x_1, x_2). Secondly, we attempt to model transportation technology more finely by introducing variable returns to volume.

(i) Oligopoly and two production centres

Suppose that there are n firms located at x_1 and m firms located at x_2 (with $m \geq n$). Focs for equilibrium are essentially the same as before. Each firm located in x_1, x_2 has a first-order condition given by (2) ((3)). Summing these conditions (as in (4)), one obtains for the interval $[x_1, x_2]$:

$$p'Q(x) + (n+m)p(x) = nt(x-x_1) + mt(x_2-x)$$

And the appropriate stability condition for a unique equilibrium is given by: $p''Q + (n+m+1)p' < 0$.

The slope of the delivered price schedule can be derived as in (6). It is written as follows :

$$\frac{\delta p}{\delta x} = \frac{p'}{p''Q+p'(n+m+1)} [n\ t'(x-x_1) - mt'(x_2-x)] \qquad (9)$$

with $p(x_1) \geq p(x_2)$ as $m \geq n$. (From Focs).

As already noted by Phlips (1983), we observe (from (9)) that with linear transport cost, delivered prices will decrease from the small centre (x_1) to the large one (x_2). From (9), it appears that a similar pricing schedule can be obtained with non-linear transport costs. Provided the difference in size (m-n) between the two centres is large enough (or T.C are close to linear), prices will decrease all the way from x_1 to x_2.

This schedule is of more than purely technical interest; it bears a strong resemblance with actual pricing arising out of a single basing point system. This was noted by Phlips (1983), who dealt with linear demand and linear transport costs. It is thus quite reassuring that the same result can be obtained with general demand and cost conditions.

(ii) Variable returns to volume

Day to day observation suggests that increasing returns to scale in transportation are commonplace. Think, for example, of a company delivering goods using trucks or small vans. High fixed cost are being incurred like the drivers' salary or the amortization cost of the van. The marginal cost of carrying extra units is probably rather small and can be regarded as constant. It would consist for example of the additional cost incurred in loading and unloading the van. Hence, it is likely that for any given distance, unit transport cost (this is, per unit of good) is decreasing with the total quantity being shipped. In what follows, we shall return to the duopoly model while introducing a transportation technology which allows for variable returns to volume. We shall assume that transportation cost per unit takes the following form:

$t(u,q) = uq^{\alpha}$ in which $\alpha > -1$, and u denotes a distance.

Unit transport cost is thus a linear function of distance but varies with the total quantity being shipped. If $\alpha > 0$ (< 0), there are decreasing (increasing) returns to volume, so that unit cost is rising (falling) with total quantity. The restriction $\alpha > -1$, guarantees that larger volumes always increase total transport costs (marginal cost is strictly positive).

We use the duopoly model presented above and characterize the delivered price schedule that will arise with this transportation technology. Derivatives with respect to $q_1(q_2)$ and x will be denoted by the lowerscript ^{1} (^{2}) and x.

Totally differentiating Focs ($\Pi^1_1 = \Pi^2_2 = 0$), one obtains :

$$\frac{\delta q_1}{\delta x} = - \frac{\Pi^1_{1x}}{\Pi^1_{11}} - \frac{\Pi^1_{12}}{\Pi^1_{11}} \frac{\delta q_2}{\delta x}$$

$$\frac{\delta q_2}{\delta x} = - \frac{\Pi^2_{21}}{\Pi^2_{22}} \frac{dq_1}{\delta x} - \frac{\Pi^2_{2x}}{\Pi^2_{22}}$$

Solving for $\frac{\delta q_1}{\delta x}$, $\frac{\delta q_2}{\delta x}$ and summing the resulting expressions :

$$\frac{\delta Q}{\delta x} = \frac{\delta q_1}{\delta x} + \frac{\delta q_2}{\delta x} = \left[\frac{\Pi^2_{21}\,\Pi^1_{1x} + \Pi^1_{12}\,\Pi^2_{2x} - \Pi^2_{2x}\,\Pi^1_{11} - \Pi^1_{1x}\,\Pi^2_{22}}{(\Pi^1_{11}\,\Pi^2_{22} - \Pi^1_{22}\,\Pi^2_{21})} \right] \qquad (10)$$

where Π^1_{11}, $\Pi^2_{22} < 0$ by the second-order conditions and the denominator is positive (stability condition). Evaluating the derivatives in (10) implicitly, one obtains:

$$\frac{\delta Q}{\delta x} = [1+\alpha]\, p' \,[q_1^\alpha - q_2^\alpha] + \alpha(1+\alpha)^2\, q_2^{\alpha-1}\, q_2^{\alpha-1}\, [(x-x_1)q_2 - (x_2-x)q_1]$$

Notice first that this expression cancells out for $x = \bar{x}$, where $q_1(\bar{x}) = q_2(\bar{x})$. Besides, for $\alpha = 0$, which implies constant returns to volume as assumed in the first section, $\frac{dQ}{\delta x} = 0$, and pricing is uniform.

Next, consider the interval $[x_1, \bar{x}]$; since $q_1(x_1) > q_2(x_2)$ (from Focs),

$q_1(\bar{x}) = q_2(\bar{x})$ and $\frac{\delta q_1}{\delta x} < 0$, $\frac{\delta q_2}{\delta x} > 0$, we have that $q_1(x) > q_2(x)$ in this

range. This is also to say that for $x \in [x_1, \bar{x})$:

$[x - x_1]q_2 < [x_2 - x]q_1$ (since $[x-x_1] < [x_1-x]$).

Using this inequality, it follows from (10) that :

- if $\alpha > 0$, $q_1^{\alpha} > q_2^{\alpha}$ and $\frac{\delta q}{\delta x} < 0$, $\frac{\delta p}{\delta x} > 0$

- if $\alpha < 0$, $q_1^{\alpha} < q_2^{\alpha}$ and $\frac{\delta q}{\delta x} > 0$, $\frac{\delta p}{\delta x} < 0$.

The interesting case is of course when $\alpha < 0$; it appears that increasing returns to volume generate the same pricing schedule as convex transportation cost (this is , convex in distance). The reason is that less volume is being shipped to location far away. Hence, less advantage is taken of increasing returns, effectively raising per unit transport costs.

It is often argued that transport costs in the real world are presumably concave (in distance). Hence, the case of convex costs, encompassed in the analysis above, might be considered as empirically irrelevant. Accordingly decreasing price schedules in between firms would be regarded as a technical oddity unlikely to be observed. However, the present analysis points out that the combination of linear costs (in distance) with increasing returns to volume, yields similar pricing schedules. This combination seems empirically reasonable and declining price schedules should therefore not come as a surprise. More generally, the effect of increasing returns to volume will be to depress prices in between firms. That is to say that concave transport cost and increasing returns to volume could presumably yield uniform pricing.

This concludes our analysis of delivered price schedules, locations being fixed. We shall now turn to location choices contingent on Cournot competition.

Section 2 : Location Choices

In this section, we look at a two-stage game in which firms select a location in the first stage and subsequently compete in a Cournot fashion. Three propositions will be put forward. First (i), we show that for general demand and transport costs, any duopoly equilibrium will involve symmetric positions. Second (ii), we restrict ourselves to linear demand and show that for convex transport costs and sufficiently high consumer demand duopolist will always agglomerate at the centre of the market. If transports costs are 'sufficiently' concave, equilibrium will involve some differentiation between firms. Finally, we further restrict ourselves to linear demand and linear transport costs. We show that whatever the number of firms, there is always an agglomeration equilibrium at the centre of the market.

Before turning to these propositions, it is however necessary to characterize further the Cournot equilibria which arise for any pair of locations. Specifically, we need to find out how equilibrium output (of individual firms as well as total output) changes at any point in space as locations are modified. For this purpose, it is useful to split the market segment into three connected intervals, s.t. :

$A = \{ x \mid 0 < x < x_1 \}$

$B = \{ x \mid x_1 < x < x_2 \}$

$C = \{ x \mid x_2 < x < 1 \}$

For each segment, we have computed by implicit differentiation of the FOC's given above (2) - (3), how duopolist's and total output (as well as prices) are affected by location changes. Results are summarized in Table 1.

We can now turn to Proposition 2 which asserts that equilibrium candidates can only be found among symmetric locations. This proposition is not altogether very surprising and the proof is rather tedious. It is however a prerequisite for Proposition 3, namely for showing uniqueness of the agglomeration equilibrium.

(i) Symmetric equilibrium

Proposition 2 : Assume that duopolists select their locations contingently on Cournot competition. Then, if equilibrium exists, it is symmetric.

Proof : Profit functions for the location game are written as follows :

$$\Pi^1 = \int_0^{x_1} q_1(x)\,[p(x) - t(x_1-x)]\,dx + \int_{x_1}^{x_2} q_1(x)\,[p(x) - t(x-x_1)]\,dx$$

$$+ \int_{x_2}^{1} q_1(x)\,[p(x) - t(x-x_1)]\,dx$$

$$\equiv \quad \Pi'_A + \Pi'_B + \Pi'_C$$

$$\Pi^2 = \int_0^{x_1} q_2(x)\,[p(x) - t(x_2-x)]\,dx + \int_{x_1}^{x_2} q_2(x)\,[p(x) - t(x_2-x)]\,dx$$

$$+ \int_{x_2}^{1} q_2(x)\,[p(x) - t(x-x_2)]\,dx$$

$$\equiv \quad \Pi_A^2 + \Pi_B^2 + \Pi_C^2$$

To shorten notation, the derivatives of firm i's profit function with respect to x_i, will be denoted $\tilde{\Pi}^i$, with $\tilde{\Pi}^i = \tilde{\Pi}_A^i + \tilde{\Pi}_B^i + \tilde{\Pi}_C^i$. Writing FOCs, one obtains:

$$\tilde{\Pi}^1 = \tilde{\Pi}_A^1 + \tilde{\Pi}_B^1 + \tilde{\Pi}_C^1 = \int_0^{x_1} \Big[p^A - t(x_1-x)\Big]\Big[\frac{dq_1}{dx_1}\Big]_A + q_1^A \Big[\Big[\frac{dp}{dx_1}\Big]_A - t'(x_1-x)\Big]dx$$

$$+ \int_{x_1}^{x_2} \Big[p^B - t(x-x_1)\Big] \Big[\frac{dq_1}{dx_1}\Big]_B + q_1^B\Big[\Big[\frac{dp}{dx_1}\Big]_B + t'(x-x_1)\Big]dx$$

$$+ \int_{x_2}^{1} \Big[p^C - t(x-x_1)\Big] \Big[\frac{dq_1}{dx_1}\Big]_C + q_1^C\Big[\Big[\frac{dp}{dx_1}\Big]_C + t'(x-x_1)\Big]dx \quad (11)$$

$$\tilde{\Pi}^2 = \tilde{\Pi}_A^2 + \tilde{\Pi}_B^2 + \tilde{\Pi}_C^2 = \int_0^{x_1} \Big[p^A - t(x_2-x)\Big] \Big[\frac{dq_2}{dx_2}\Big]_A + q_2^A\Big[\Big[\frac{dp}{dx_2}\Big]_A - t'(x_2-x)\Big]dx$$

$$+ \int_{x_1}^{x_2} \Big[p^B - t(x_2-x)\Big] \Big[\frac{dq_2}{dx_2}\Big]_B + q_2^B\Big[\Big[\frac{dp}{dx_2}\Big]_B - t'(x_2-x)\Big]dx$$

$$+ \int_{x_2}^{1} \Big[p^C - t(x-x_2)\Big] \Big[\frac{dq_2}{dx_2}\Big]_C + q_2^C\Big[\Big[\frac{dp}{dx_2}\Big]_C + t'(x-x_2)\Big]dx \quad (12)$$

Any equilibrium will be such that these FOCs are satisfied. In order to show that these FOCs can only be satisfied for symmetric locations, we exploit symmetry properties of (11) - (12). First, we show that $\tilde{\Pi}_B^1 = -\tilde{\Pi}_B^2$.

Using Table 1 and FOCs for Cournot equilibrium, $\tilde{\Pi}_B^1$ and $\tilde{\Pi}_B^2$ can be rewritten (from (11) - (12)) as :

$$\tilde{\Pi}_B^1 = \int_{x_1}^{x_2} q_1(x)\ t'(x-x_1) \left[\frac{p''[2q_2+q_1]+4p'}{p''Q + 3p'} \right] dx$$

$$\tilde{\Pi}_B^2 = \int_{x_1}^{x_2} - q_2^B(x)t'(x_2-x) \left[\frac{p''[2q_1+q_2]+4p'}{p''Q + 3p'} \right] dx$$

using the change of variable $z \equiv x_2 - x$, these equations are further transformed as :

$$\tilde{\Pi}_B^1 = \int_0^{x_2-x_1} q_1(z+x_1)\ t'(z) \left[p''(x_1+z)\frac{[2q_2(x_1+z)+q_1(x_1+z)] + 4p'(x_1+z)}{p''(x_1+z)\ Q\ (x_1+z) + 3p'(x_1+z)} \right] dz \quad (13)$$

$$\tilde{\Pi}_B^2 = \int_{x_2-x_1}^{0} q_2(x_2-z)\ t'(z) \left[\frac{p''(x_2-z)\ [2q_1(x_2-z)+q_2(x_2-z)] + 4p'(x_2-z)}{p''(x_2-z)\ Q\ (x_2-z) + 3p'(x_2-z)} \right] dz \quad (14)$$

Finally, noticing from FOCs (2) - (3) that $q_1(x) = q_2\ (x_2+ x_1- x)$, $q_2\ (x) = q_1\ (x_2+ x_1 - x)$, $Q\ (x) = Q\ (x_2+ x_1 - x)$, $p(x) = p(x_2+ x_1- x)$, it follows that, using the change of variable :

$$q_1\ (z + x_1) = q_2\ (x_2- z)$$

$$p''\ (x_2 - z) = p''\ (x_1 + z)$$

$$p'\ (x_1 + z) = p''\ (x_2 - z)$$

$$q\ \ (x_1 + z) = q\ \ (x_2 - z)$$

These equalities are then used in (13) - (14) to compare the relevant terms. Simply by inspection, we obtain that $\tilde{\Pi}_B^1 = - \tilde{\Pi}_B^2$.

A second symmetry property of the FOCs (11) - (12) can be put forward. Assume, without loss of generality that $x_1 > 1 - x_2$, with $\tilde{x} = 1 - x_2$. The segment A can then be split in two regions, s.t. (see Figure 2).

$$A_a = \{ x \,/\, 0 < x < \tilde{x} \}$$

$$A_b = \{ x \,/\, \tilde{x} < x < x_1 \}$$

The argument presented above to show that $\tilde{\Pi}^1_B = - \tilde{\Pi}^2_B$, can be easily adapted to assert that $\tilde{\Pi}^1_{Ab} = \tilde{\Pi}^2_C$ and $\Pi^1_C = - \tilde{\Pi}^2_{Aa}$.

Using these symmetry properties, the FOCs (11) - (12) can be rewritten as :

$$\tilde{\Pi}^1 = \tilde{\Pi}^1_{Aa} + \tilde{\Pi}^1_{Ab} + \tilde{\Pi}^1_B + \tilde{\Pi}^1_C$$

$$\tilde{\Pi}^2 = - \tilde{\Pi}^1 + \tilde{\Pi}^2_{Aa} + \tilde{\Pi}^1_{Aa}$$

Since $\tilde{\Pi}^1_{Aa}$, $\Pi^2_{Aa} > 0$, $\tilde{\Pi}^2$ and $\tilde{\Pi}^1$ can only be equal to zero at the same firm if $A_a = \emptyset$, or $x_1 = 1 - x_2$. That is to say that FOCs can only be met for symmetric locations. Consequently, if equilibrium exists, it is symmetric.

As mentionned above, given the symmetry of firm's position, a symmetric outcome had to be expected. This property will be used in the following proposition.

(ii) Agglomeration in duopoly

<u>Proposition 3</u> : Assume that demand is linear and that both firms always serve the whole market. Suppose that the duopolists decide on their location knowing the Cournot equilibrium that will arise for each of their

choice. Then, if transport costs are convex, there is a unique location equilibrium such that both firms agglomerate at the centre of the market.

<u>Proof</u> : Equations (11) - (12) provide FOCs which are relevant to the present problem. Notice that when $x_1 = x_2 = 1/2$, the segment B disappears. In addition, by symmetry (see also proof of Proposition 2), we have that $\tilde{\Pi}^1_A = -\tilde{\Pi}^2_C$, $\tilde{\Pi}^2_A = \tilde{\Pi}^2_C$. It follows that FOCs are satisfied for $x_1 = x_2 = 1/2$. Next, we will look (a) at SOCs and show that provided transportation costs are convex, profits will be concave. Hence, for convex transport costs, $x_1 = x_2 = 1/2$ will be an equilibrium. Subsequently (b), uniqueness of this agglomeration equilibrium will be investigated. In what follows, we shall concentrate on firm 1. A similar reasoning can be held for firm 2 and will be omitted.

(a) Concavity of the Profit Function

We wish to show that $\frac{\delta^2 \Pi'}{\delta x_1^2} < 0$. When demand is linear $(p(x) = a - bQ(x))$, the (second stage) Cournot equilibrium can directly be computed as (see section 1) :

$$q_1(x) = \frac{a + t(\lfloor x_2 - x \rfloor) - 2t(\lfloor x_1 - x \rfloor)}{3b}$$

$$p\ (x) = \frac{a + t(\lfloor x_1 - x \rfloor) + t(\lfloor x_2 - x \rfloor)}{3}$$

$$Q\ (x) = \frac{2a - t(\lfloor x_1 - x \rfloor) - t(\lfloor x_2 - x \rfloor)}{3b}$$

and the resulting profit at any point x is then written as :

$$\Pi^1 = \frac{[a + t(\lfloor x_2 - x \rfloor) - 2t(\lfloor x_1 - x \rfloor)]^2}{9b}$$

Next, we derive the first-order derivative of firm 1's profit with respect to x_1 :

$$\frac{9b}{4}\ \frac{\delta\Pi^1}{\delta x_1} = -\int_0^{x_1}[a+t(x_2-x)-2t(x_1-x)]\ t'(x-x)\ dx$$

$$+\int_{x_1}^{x_2}[a+t(x_2-x)-2t(x-x_1)]t'(x-x_1)\ dx+\int_{x_2}^{1}[a+t(x-x_2)-2t(x-x_1)]t'(x-x_1)\ dx$$

The second-order derivative ($\frac{\delta^2\Pi^1}{\delta x_1^2}$) is then computed as :

$$\frac{9b}{4}\ \frac{\delta^2\Pi^1}{\delta x_1^2} = -2[a+t(x-x)]t'(0)+\int_0^{x_1}-[a+t(x_2-x)-2t(x_1-x)]t''(x_1-x)+2[t'(x_1-x)]^2dx$$

$$+\int_{x_1}^{x_2}-[a+t(x_2-x)-2t(x-x_1)]t''(x-x_1)+2[t'(x-x_1)]^2\ dx$$

$$+\int_{x_2}^{1}-[a+t(x-x_2)-2t(x-x_1)]t''(x-x_1)+2[t'(x-x_1)]^2\ dx$$

Integrating by part, this expression becomes :

$$\frac{9b}{4}\ \frac{\delta^2\Pi^1}{\delta x_1^2} = -t'(x_1)[a+t(x_2)-2t(x_1)]-t'(1-x_1)[a+t(1-x_2)-2t(1-x_1)] \tag{15}$$

$$+\int_0^{x_1}t'(x_1-x)t'(x_2-x)\ dx-\int_{x_1}^{x_2}t'(x-x_1)t'(x_2-x)\ dx+\int_{x_1}^{1}t'(x-x_1)t'(x-x_2)\ dx$$

Notice that for $t''>0$ (convex transport costs) :

$$t'(x_1-x)<t'(x_1)\ \text{and}\ t'(x-x_1)\leq t'(1-x_1)\ .$$

Consequently, for $t''>0$,

$$\frac{\delta^2\Pi^1}{\delta x_1^2}\leq -t'(x_1)[a+t(x_2)-2t(x_1)]-t'(1-x_1)[a+t(1-x_2)-2t(1-x_1)]$$

$$+t'(x_1)\int_0^{x_1}t'(x-x)\ dx+t'(1-x)\int_{x_2}^{1}t'(x-x)\ dx$$

$$\leq -a[t'(x_1)+t'(1-x_1)] + 2t'(x_1)t(x_1) + 2t(1-x_1)t'(1-x_1) - t(x_2-x_1)t'(x_1)$$

$$\leq - t'(x_1)[a + t(x_2-x_1) - 2t(x_1)] - t'(1-x_1)[a - 2t(1-x_1)]$$

The right hand side of this expression is always negative when, as assumed above, the market is always served by both firms ($a > 2t(1)$). It follows that provided transport costs are convex, profits are concave and agglomeration is an equilibrium.

(ii) Uniqueness

We know (Proposition 2) that, if equilibrium exists, it is symmetric. Accordingly, we only have to investigate the set of symmetric locations. Hence, we evaluate the first-order derivative of firm 1's profit function with respect to x_1, at symmetric locations :

$$\frac{\delta\Pi^1}{\delta x_1}\Big|_{x_1=1-x_2} = - \int_0^{x_1} [a+t(1-x_1-x)-2(x_1-x)]\ t'(x_1-x)\ dx$$

$$+\int_{x_1}^{1-x_1} [a+t(1-x_1-x)-2t(x-x_1)]t'(x-x_1)\ dx + \int_{1-x_1}^{1} [a+t(x-1+x_1)-2t(x-x_1)]t'(x-x_1)\ dx \qquad (16)$$

We know that $\frac{\delta\Pi^1}{\delta x_1}\Big|_{x_1 = x_2} = 0$. At this point, ($x_1 = x_2 = 1/2$), (16) = 0, and we want to check that this is the only point for which (16) cancells out. A sufficient condition for this will be that (16) is monotonic in x_1,

or $\frac{d}{dx_1}\left(\frac{\delta\Pi^1}{\delta x_1}\Big|_{x_1 = 1 - x_2}\right) < 0.$

Differentiating (16) with respect to x_1, integrating by part and using $t'' > 0$, one can check that this derivative is always negative. (A more detailed derivation is available upon request from the authors).

All in all, we observe that with Cournot competition and convex transport costs, firms have a strong tendency to agglomerate, i.e. to minimize differentiation. This is sharp contrast with the results recently put forward for Hotelling's model. (see d'Aspremont et al. (1975), Neven (1985), and Anderson (1986)). In Hotelling's model, the incentive to relax price competition will lead the firms to move apart and in some cases even to maximize differentiation. In the present model, it seems that Hotelling's original intuition applies : firms have an incentive to enlarge the market segment in which they compete on favourable terms; i.e. outside their respective locations. In those segments, firms are better positioned since they incur less transportation cost than their competitor. They sell larger quantities and accordingly earn more profit. Hence, both firms have an interest to enlarge their 'outside' market. As a result, they agglomerate at the centre.

It should also be noticed that this result applies to a wider range of situations than the case of convex transport cost, stricto sensu. As mentionned above (Section 1), increasing returns to volume will mimic the role of convex transport cost. Accordingly, we should also expect the firms to agglomerate when concave transport costs are combined with substantial increasing returns to volume.

Let us now briefly consider location tendencies with concave transport costs. Some insight into this matter can be gained by looking at the second derivative of the profit function when both firms are located at the centre; estimating (15) at $x_1 = x_2 = 1/2$, one obtains :

$$\frac{9b}{4} \frac{\delta^2 \Pi^1}{\delta x_1^2} = - 2t'(1/2) [a - t(1/2)] + 2 \int_0^{1/2} [t'(1/2 - x)]^2 dx \tag{17}$$

When transport costs are concave ($t'' < 0$), $t'(1/2)$ is a lower bound to marginal transport costs. Hence, it can be arbitrarily small, so that the first term in (17) vanishes and the whole expression (17) is positive. Consequently, there exists parameter values for which profits are locally convex around the agglomeration position. Accordingly, firms have an incentive to move away from agglomeration and equilibrium will involve some differentiation between the firms. This results accords well with intuition; as compared with convex transport cost, concave functions lead to less intense competition in between the firms, as indicated by resulting quasi-concave delivered price schedules. In addition, concave transport cost will narrow the competitive edge of any firm in its 'outside' market. Differences in the transport cost incurred by the firms for those segments will be smaller with concave transport cost (than with convex schedules). As a result, firms have less incentive to enlarge their 'outside' market.

We shall now briefly examine whether the tendency towards agglomeration stands, when more firms are allowed for.

(iii) Agglomeration in oligopoly

Proposition 4 : Assume that demand is linear and transport cost too boot. Firms select their locations contingent on Cournot competition. Then, there is an agglomeration equilibrium at the centre of the market, whatever the number of firms.

Proof : Assume that n firms are being located at $x_2 = 1/2$. We wonder whether an additional firm $(n + 1)^{th}$ located at x_1 will choose to join the agglomeration ($x_1 = x_2$). If so, it follows by recurrence that there is an agglomeration equilibrium at the centre of the market.

We shall first (i) characterize the Cournot equilibrium that will arise in this situation. Subsequently (ii), we shall look at the location choice of the firm located at x_1 (say, firm 1).

(i) Cournot equilibrium

The FOC for the firm located at x_1 is given by :

$$a - b\,(nq_2 + 2q_1) = t\,\lfloor x - x_1 \rfloor \tag{18}$$

whereas each firm located at x_2 has a FOC of the following type :

$$a - b\,((n+1)q_2 + q_1) = t\,\lfloor x - x_2 \rfloor$$

Summing all FOCs, one obtains :

$$(n+1)a - b(n+2)Q = t\lfloor x - x_1 \rfloor + nt\lfloor x - x_2 \rfloor$$

so that

$$Q(x) = \frac{(n+1)a - t\lfloor x - x_1 \rfloor - nt\lfloor x - x_2 \rfloor}{(n+2)b} \tag{19}$$

$$p(x) = \frac{a + t\lfloor x - x_1 \rfloor + nt\lfloor x - x_2 \rfloor}{(n+2)} \tag{20}$$

As for the equilibrium quantity set by firm 1, from (18), it follows that :

$$\frac{a - t\lfloor x - x_1 \rfloor}{b} = q_1 + Q$$

so that, using (19),

$$q_1(x) = \frac{a + nt\lfloor x - x_2 \rfloor - (n+1)\,t\lfloor x - x_1 \rfloor}{(n+2)b}$$

The profit earned by firm 1 at any point is then computed (using (20) as :

$$\Pi^1(x) = \frac{1}{b}\left[\frac{a + nt\lfloor x - x_2 \rfloor - (n+1)t\lfloor x - x_1 \rfloor}{n+2}\right]^2$$

Assume that all firms serve the whole market ($a > (n+1)tl$), total profit earned by firm 1 is written :

$$\Pi^1 = \frac{1}{(n+2)^2 b} \Big[\int_0^{x_1} [a + nt(x_2-x) - (n+1)t(x_1-x)]^2 \, dx$$

$$+ \int_{x_1}^{x_2} [a+nt(x_2-x)-(n+1)t(x-x_1)]^2 \, dx + \int_{x_2}^{1} [a+nt(x-x_2)-(n+1)t(x-x_1)]^2 \, dx \Big] \qquad (21)$$

We can now turn to the location choice of firm 1.

(ii) Location choice

Taking first-order derivative of (21), with respect to x_1 yields the following expression :

$$\frac{\delta \Pi^1}{\delta x_1} = \frac{1}{(n+2)^2 b} \Big[\int_0^{x_1} -2[a+nt(x_2-x)-(n+1)t(x_1-x)](n+1)t \, dx$$

$$+ \int_{x_1}^{x_2} 2 \, [a+nt(x_2-x)-(n+1)t(x-x_1)] \, (n+1)t \, dx$$

$$+ \int_{x_2}^{1} 2 \, [a+nt(x-x_2)-(n+1)t(x-x_1)] \, (n+1)t \, dx \Big]$$

Notice that this function has a turning point for $x_1 = x_2 = 1/2$, so that FOC's will be met if firm 1 agglomerates. Checking concavity of the profit function, we write the second derivative of (21) with respect to x_1 :

$$\frac{(n+2)^2 b}{2(n+1)t} \, \frac{\delta^2 \Pi^1}{\delta x_1^2} = - 2[a+nt(x_2-x_1)] + \int_0^{1} (n+1) \, t \, dx$$

$$= -2a - 2nt(x_2-x_1) + (n+1)tl$$

Provided $a > (n+1)tl$, (as assumed above), this last expression is always negative, so that firm 1's profit is strictly concave in x_1, for any x_2.

Consequently, there is an agglomeration equilibrium at 1/2, whatever the number of firms.

The purpose of this section was to check whether the tendency towards agglomeration was not specific to duopoly. As it turns out, this tendency is quite robust to the number of firms, at least with convex (linear) transport costs.

There is however an assumption that we have maintained all along which is not innocuous. As indicated in the various proofs, it is compelling for our results that firms always serve the whole market. If demand is not high enough to guarantee this property, firms will presumably tend to differentiate themselves. The equilibrium configuration might then consist of a sequence of partly overlapping markets. This outcome would be quite appealing and would fit with Kaldor's original intuition that monopolistic competition results in a chain of partly overlapping markets. This seems an interesting topic for further research.

CONCLUSION

In this paper, we have investigated a model of spatial competition which is a complement to Hotelling's approach. It is not a substitute since arguably both frameworks should have empirical counterparts.

Nevertheless further progress with Hotelling's model will be limited by technical problems. As is well known, existence of a price equilibrium in that framework is quite problematic. In contrast, existence of equilibrium in the present model can be guaranteed under very general conditions. This will facilitate further extensions of the analysis. For example, two-dimensional spaces could presumably be dealt with. Applications of the model to international trade seem feasible at reasonable cost. As illustrated above, a more realistic description of actual transportation technology can also be incorporated without much trouble. All this suggests that the model has much potential for theoretical analysis.

The model seems to perform equally well when predictions are confronted with empirical observations. The various delivered price schedules described above seem to fit with the observations put forward by Phlips (1983) (uniform pricing, basing point system). In this respect also, the property that firm's market share overlap accords well with intuition and casual empiricism. Finally, the location tendencies that we uncover seem reasonable and flexible enough. Agglomeration is presumably more satisfactory, as a starting point, than maximum differentiation. Besides the model can also generate some differentiation between the firms with appropriate (concave) transport costs. Hence, it is flexible and should presumably be able to cover a wide range of situations.

TABLE 1

	A $x \leq x_1$	B $x_1 \leq x \leq x_2$	C $x_2 \leq x$
$\frac{dQ}{dx_1} =$	$\frac{t'(x_1-x)}{p''Q+3p'} < 0$	$\frac{-t'(x-x_1)}{p''Q+3p'} > 0$	$\frac{-t'(x-x_1)}{p''Q+3p'} > 0$
$\frac{dQ}{dx_2} =$	$\frac{t'(x_2-x)}{p''Q+3p'} < 0$	$\frac{t'(x_2-x)}{p''Q+3p'} < 0$	$\frac{-t'(x-x_2)}{p''Q+3p'} > 0$
$\frac{dQ_1}{dx_1} =$	$\frac{t'(x_1-x)}{p'} \frac{p''q_2+2p'}{p''Q+3p'} < 0$	$\frac{t'(x_1-x)}{p'} \frac{p''q_2+2p'}{p''Q+3p'} > 0$	$\frac{t'(x_1-x)}{p'} \frac{p''q_2+2p'}{p''Q+3p'} > 0$
$\frac{dq_2}{dx_2} =$	$\frac{t'(x_2-x)}{p'} \frac{p''q_1+2p'}{p''Q+3p'} < 0$	$\frac{t'(x_2-x)}{p'} \frac{p''q_1+2p'}{p''Q+3p'} < 0$	$\frac{t'(x-x_2)}{p'} \frac{p''q_1+2p'}{p''Q+3p'} > 0$

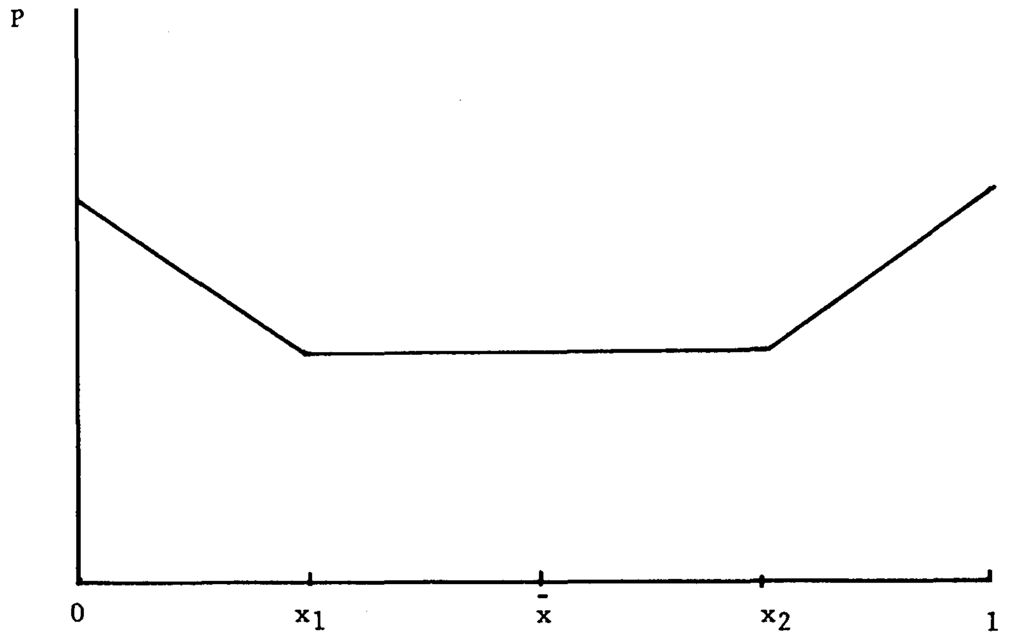

Figure 1 : Linear Transport Cost

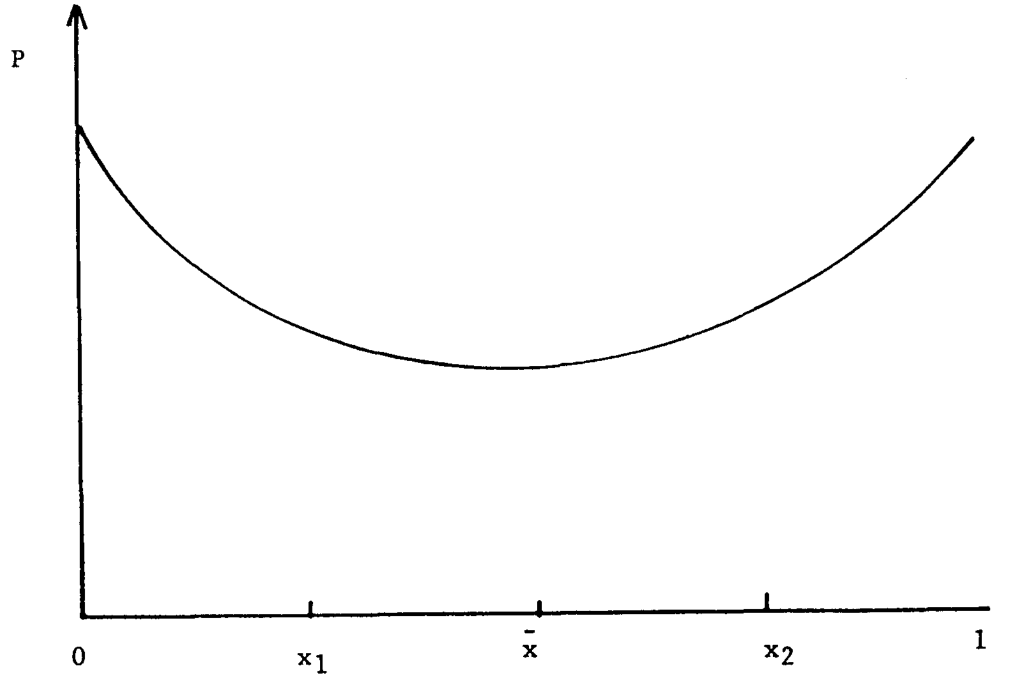

Figure 2 : Convex Transport Cost

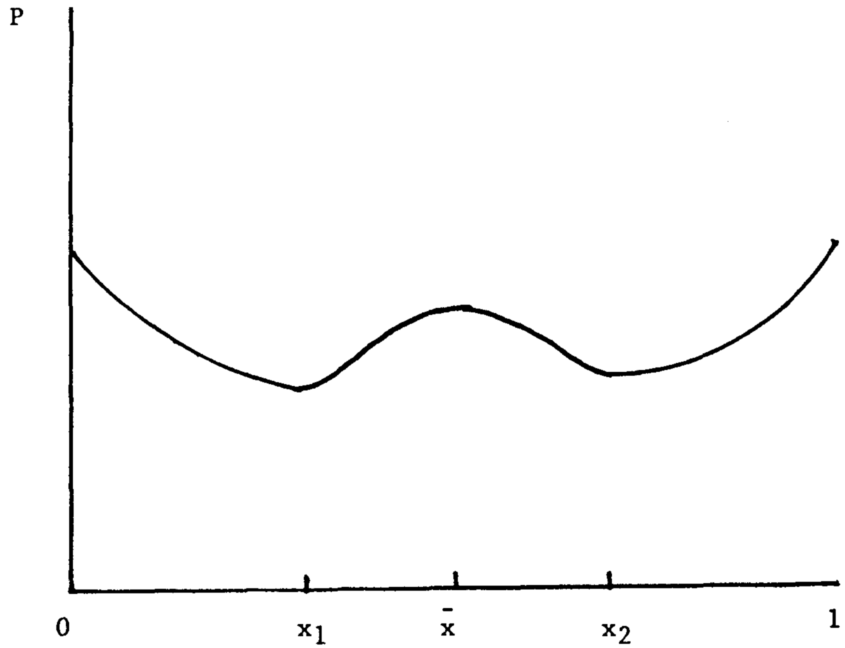

Figure 3 : Concave Transport Costs

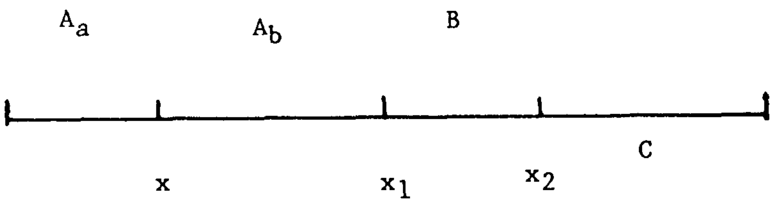

Figure 4

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