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The Impact of Rising Energy Prices on Transportation Costs and Industrial Location Patterns*

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Recent studies of the impact of rising energy prices on firms' location decisions generally assume that the rise of energy prices has no impact on transportation costs of raw materials, intermediate goods, and consumer goods. Leaving out the energy price factor in transportation cost functions may create some bias in the discussion of the optimum location of firms. In this paper, the transportation cost effect of rising energy prices is included explicitly in a model of bilateral monopoly. It shows that the optimum location of firms will be affected by rising energy prices when both the buyer's and the seller's production functions are constant returns to scale. The final outcome depends on the relative strength of the impact of rising energy prices on various transportation rates. These results are quite different from the ones obtained in the previous papers, namely, Sakashita (1980), Hwang and Mai (1987), and Cheng and Shieh (1991).

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1 . Introduction

Lately we have observed interest in the discussion of the impact of rising energy prices on firm's location decisions. In a recent paper,

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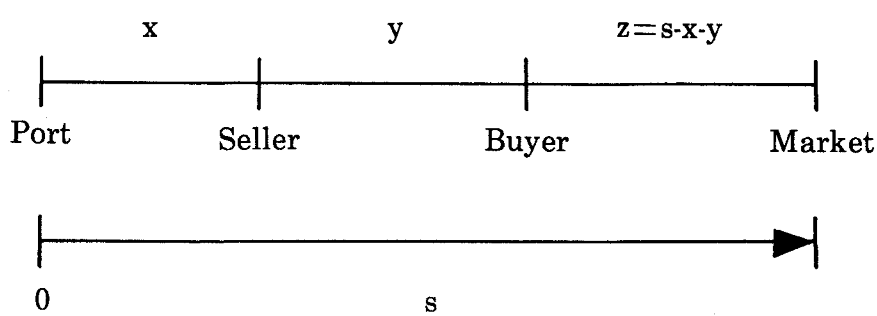
Sakashita (1980) develops a two-firm model on a straight line to discuss the firms' optimum location patterns and the impact of rising energy prices on firms' location decisions. Sakashita's analysis is confined to a case of perfectly competitive markets and constant transport rates, and it leads to the end-point location patterns. Meanwhile, by assuming negligible transport cost effect, he concludes that the rise of energy prices induces double location of firms instead of separate location. Hwang and Mai (1987) extend Sakashita's analysis to a case of bilateral monopoly. Assuming that the transport rate is a function of distance, they consider two non-cooperative cases: a monopoly solution and a monopsony solution. They show that there exists a possible intermediate location for both firms in the monopoly case, and in the monopsony case the seller definitely locates at the port, while the buyer may have an intermediate location. They also conclude that the impact of rising energy prices on the location of the buyer and the seller depends upon the nature of the buyer's production function only. Recently, Cheng and Shieh (1991) extend Hwang and Mai's analysis to a cooperative case where the firms' objective is to maximize their joint profit. Following the assumption that the transport rate is a function of distance, they show that there exists a possible intermediate location for both firms. As to the impact of rising energy prices on firms' location decisions, they conclude that the optimum locations of the firms are independent of energy prices when both buyer's and seller's production functions are constant returns to scale. However, in some other cases, the firms' location decisions will be affected by the rise of energy prices. In the above papers, it is generally assumed that the rise of energy prices has no impact on the transportation rates of raw materials, intermediate goods, and consumer goods. Nonetheless, the consensus is that changing energy prices should have some effect on transport costs, and the impact on different transport rates may be discriminating due to the different usable transportation systems for raw materials, intermediate goods, and consumer goods. For instance, transport by railroad may suffer less from rising energy prices than by trucking. A quotation from Sakashita's article (1980) explains this point very well: "······ the impact of rising energy prices on different transport rates is also discriminating ······ The raw material itself can be transported by the pipeline system for instance, which suffers least from the rise in energy prices. The intermediate good can be shipped by the railway but the consumer's good usually depends on trucking systems ·········" (P.428). Leaving out the transportation cost effect of changing energy prices may create some bias in the discussion of the impact of rising energy prices on the pattern of industrial location. In this paper, we attempt to correct the bias by incorporating the energy price factor in the transportation cost functions. We will extend Cheng and Shieh's model to analyze the impact of rising energy prices on industrial location patterns in a situation where transporation costs are functions of energy price and distance. It will be shown that the results derived in this paper are quite different from the ones obtained in the previous papers, namely, Sakashita (1980, PP.427-428), Hwang and Mai (1987, PP.261-262), Cheng and Shieh (1991).

2 . MODEL

Consider a market for an intermediate good K, which is characterized by a single seller and a single buyer. The buyer uses K as its input to prodcue the consumer good Q, which is sold in the market center located at a fixed distance S from the port. The seller produces K by using an energy-related raw material input M (such as crude oil), which is imported from abroad and sold at the port at a given price m. Both firms locate along a straight line in the order of the port, the seller, the buyer, and the market center as illustrated in Figure 1. Let x be the distance between the port and the seller's location, and y be the distance between the seller's location and the buyer's location, then $z = s - x - y$ is the distance between the buyer's location and the market center.

Figure 1



The following assumptions are made in our model:

(a) The production function of the buyer is homogeneous of degree one:[1]

$$Q = K \tag{1}$$

(b) The production function of the seller is homogeneous of degree one.

$$K = M \tag{2}$$

(c) At the market center, the buyer faces a downward-sloping demand function.

$$P = P(Q), \qquad P_Q < 0 \tag{3}$$

(d) All transactions are based on f. o. b. mill pricing, i.e., buyers have to pay for the transportation costs.

(e) The buyer and the seller recognize their interdependence and are able to cooperate to maximize their joint profit.

(f) Transportation costs are functions of energy price m and distance with positive and increasing first derivatives.

The last assumption marks the main deviation of our model from Cheng and Shieh's analysis. The objective function of the cooperative seller and buyer can be specified as:

$$
\begin{aligned}
Max\pi &= \pi^S + \pi^B \\
&= kK - [m + C(x,m)]K + [P(Q) - A(z,m)]K - [k + B(y,m)]K \\
&= [P(Q) - A(z,m)]K - B(y,m)K - [m + C(x,m)]K \qquad (4)
\end{aligned}
$$

where $\pi^S = kK - [m + C(x,m)]K$ and $\pi^B = [P(Q) - A(z,m)]K - [k + B(y,m)]K$ are profit functions of seller and buyer respectively; $A(z,m)$, $B(y,m)$, and $C(x,m)$ are unit transport costs of Q, K, and M respectively. Here, we assume that transport rates decrease with distance and are sufficiently convex, thus $A_z > 0$, $B_y > 0$, $C_x > o$, $A_{zz} > 0$, $B_{yy} > 0$, and $C_{xx} > 0$.[2] It is also assumed that rising energy prices will cause the unit transport costs and the marginal transport costs of Q, K, and M with respect to distance to rise. Therefore, A_m, B_m, C_m, A_{zm}, B_{ym}, and C_{xm} will have positive signs. Also, k is the mill price of K, and x, y, K are choice variables.

The first order conditions for joint profit maximization are:

$$\partial\pi/\partial x = (A_z - C_x)K = 0 \qquad (5)$$

$$\partial\pi/\partial y = (A_z - B_y)K = 0 \qquad (6)$$

$$\partial\pi/\partial K = [MR(Q) - A(z,m)] - B(y,m) - [m + C(x,m)] = 0 \qquad (7)$$

where $MR(Q) = P + QP_Q > 0$. The second order conditions require that the principle minors of the relevant Hessian determinant alternate in sign:

$$\pi_{xx} < 0 \tag{8}$$

$$\begin{vmatrix} \pi_{xx} & \pi_{xy} \\ \pi_{yx} & \pi_{yy} \end{vmatrix} > 0 \tag{9}$$

$$D = \begin{vmatrix} \pi_{xx} & \pi_{xy} & \pi_{xK} \\ \pi_{yx} & \pi_{yy} & \pi_{yK} \\ \pi_{Kx} & \pi_{Ky} & \pi_{KK} \end{vmatrix} < 0 \tag{10}$$

where:

$$\begin{aligned}
\pi_{xx} &= -(A_{zz} + C_{xx})K \\
\pi_{xy} &= \pi_{yx} = -A_{zz}K \\
\pi_{Kx} &= \pi_{xK} = A_z - C_x = 0 \\
\pi_{yy} &= -(A_{zz} + B_{yy})K \\
\pi_{Ky} &= \pi_{yK} = A_z - B_y = 0 \\
\pi_{KK} &= 2P_Q + QP_{QQ} \equiv E
\end{aligned}$$

If the second order conditions are satisfied,[3] we can solve for K, x, y from equations (5), (6), and (7) in terms of m and s, and there exists a possible intermediate location for both industries.

3 . Impact of Rising Energy Prices on Optimum Location

In what follows, we will consider the comparative static effects of m on x and y by totally differentiating the first order conditions (5), (6), and (7). Via the Cramer's rule, we obtain:

$$\partial x/\partial m = (E/D)K^2[(A_{zz} + Byy)(A_{zm} - C_{xm}) - A_{zz}(A_{zm} - B_{ym})] \tag{11}$$

$$\partial y/\partial m = (E/D)K^2[(A_{zz} + C_{xx})(A_{zm} - B_{ym}) - A_{zz}(A_{zm} - C_{xm})] \tag{12}$$

The signs of equations (11) and (12) are difficult to determine except in the following cases:[4]

$$(i)\partial x/\partial m < 0 \quad \text{and} \quad \partial y/\partial m > 0 \quad \text{if} \quad C_{xm} > A_{zm} > B_{ym} \tag{13}$$

$$(ii)\partial x/\partial m > 0 \quad \text{and} \quad \partial y/\partial m < 0 \quad \text{if} \quad C_{xm} < A_{zm} < B_{ym} \tag{14}$$

$$(iii)\partial x/\partial m = 0 \quad \text{and} \quad \partial y/\partial m = 0 \quad \text{if} \quad C_{xm} = A_{zm} = B_{ym} \tag{15}$$

Equation (13) indicates that if the rise of energy prices has the strongest impact on the marginal transport cost of raw material and the weakest effect on the marginal transport cost of intermediate good, the seller will move its location closer to the port and the buyer will move its location away from that of the seller and closer to the market center as energy price rises. Equation (14) indicates that if the rise of energy prices has the strongest impact on the marginal transport cost of intermediate good and the weakest effect on the marginal transport cost of raw material, the seller will move its location away from the port and closer to that of the buyer, and the buyer will move its location closer to that of the seller and away from the market center as energy price rises. Obviously, the patterns of industrial location crucially depend on the relative strength of three forces: the raw material pull, the intermediate good pull, and the market pull.[5] Equation (15) indicates that if the rise of energy prices has the same effect on the marginal transport costs of raw material, intermediate good and consumer good, the firms' location decisions will not be affected by rising energy prices since the three forces mentioned above just cancel out one another. This result coincides with the conclusion made by Cheng and Shieh (1991), which is clearly focusing on a speical case in a more general model. The above results are also quite different from those obtained by Sakashita and Hwang and Mai. In Sakashita's paper (1980, P.428), he concludes that the rise in energy prices is likely to induce double location at the port or the market. Hwang and Mai assert that the distance between the location of the buyer and that of the seller will be invariant to any change in energy price if the production function of the buyer is constant returns to scale in the monopsony case (1987, P.262). They further argue that the location of the seller will move away from the port, and the location of the buyer will move closer to that of the seller and away from the market site as energy price rises if the production function of the buyer is constant or decreasing returns to scale in the monopoly case (1987, P.261).

4 . Conclusions

This paper has extended Cheng and Shieh's analysis to capture the transportation cost effect of rising energy prices. The model developed in this paper allows explicit discussion of the discriminating impact of rising energy prices on various transportation rates. The results derived in this paper show that the rise in energy prices will affect the firms' location decisions when both the buyer's and the seller's production functions are constant returns to scale. The final outcome depends on the relative strength of the impact on different transportation rates. If $C_{xm} > A_{zm} > B_{ym}$, the seller will move its location closer to the port and the buyer will move its location away from that of the seller and closer to the market center as energy price rises. If $C_{xm} < A_{zm} < B_{ym}$, the seller will move its location away from the port and closer to that of the buyer, and the buyer will move its location closer to that of the seller and away from the market center as energy price rises. These results are quite different from the ones obtained in previous papers. The upshot of this paper is that the inclusion of the transportation cost effect of changing energy prices has significant impact on firms' location decisions. Although the analysis is limited in scope, it is believed that even this simplified model can shed some light on the nature of industrial location patterns under different energy prices when the transportation cost effect of changing energy prices is taken into account.

Notes

1 The purpose of adopting a linearly homogeneous production function is for simplicity. However, it is easy to show that in the case of homogeneous production function, HM's and CS's results do not hold if transport costs are functions of distance and energy price. We leave this to the interested readers.

2 The assumption of $A_{zz} > 0$, $B_{yy} > 0$, and $C_{xx} > 0$ is made such that we can derive an interior solution in our model to carry out the comparative static analysis. Contrary to the general belief, this assumption does not require the existence of long-haul diseconomies. For example, if C is the unit transport cost of raw materials and a(x, m) is the unit transport rate of raw materials per mile, then:

$$C = a(x,m)x$$

$$\partial C/\partial x = a'(x,m)x + a(x,m)$$

$$\partial C^2/\partial x^2 = a''(x,m)x + 2a'(x,m)$$

To satisfy the assumption of $C_{xx} > 0$, we can have a combination of $a''(x,m)x > 0$ and $2a'(x,m) < 0$. So that even if the transport rate decreases with distance, as long as the transport rate function is sufficiently convex with respect to distance, the condition of C_{xx} being positive can be satisfied.

3 To show that the second order conditions are satisfied, we will follow Hwang and Mai (1987, PP.258 and 260), Cheng and Shieh (1991) to assume that transport rates decrease with distance and are sufficiently convex, thus, $A_{zz} > 0$, $B_{yy} > 0$, $C_{xx} > 0$, and $E < 0$. Then, we obtain: (i)$\pi_{xx} = -(A_{zz} + C_{xx})K < 0$
(ii) $D_1 = \pi_{xx}\pi_{yy} - (\pi_{xy})^2 = (A_{zz}B_{yy} + A_{zz}C_{xx} + B_{yy}C_{xx})K^2 > 0$
(iii) $D = ED_1 < 0$

4 For cases other than those presented here, the signs of $\partial x/\partial m$ and/or $\partial y/\partial m$ are hard to determine. For example, if $C_{xm} > B_{ym} > A_{zm}$, $\partial x/\partial m < 0$, but the sign of $\partial y/\partial m$ is hard to determine. Because in this case the raw material pull dominates, thus the seller will get as close to the source of raw material as possible when energy price goes up. However, the impact of rising energy prices on the buyer's location is more difficult to determine due to the balancing factor of the three forces: the raw material pull, the intermediate good pull, and the market pull.

5 A thoughtful referee points out that equations (11) and (12) can be rewritten as:

$$\partial x/\partial m = E/DK^2[A_{zz}(B_{ym} - C_{xm}) + B_{yy}(A_{zm} - C_{xm})] \qquad (11')$$

$$\partial y/\partial m = E/DK^2[C_{xx}(A_{zm} - B_{ym}) + A_{zz}(C_{xm} - B_{ym})] \qquad (12')$$

It should be noted that as long as C_{xm} is greater (less) than B_{ym} and A_{zm}, $\partial x/\partial m < 0$ ($\partial x/\partial m > 0$). Similarly, as long as B_{ym} is greater (less) than A_{zm} and C_{xm}, $\partial y/\partial m < 0$ $(\partial y/\partial m > 0)$. Thus, the impact of rising energy prices on firms' location decisions depends solely on the relative strength of the raw matertial pull or the relative strength of the intermediate good pull. In other words, the raw material pull or the intermediate good pull becomes the dominating force in forming the firms' location decisions.

References

Cheng, D. and Y.N. Shieh

1991 "Bilatieral Monopoly and Industrial Location: A Cooperative Outcome", *Regional Science and Urban Economics* (in press).

Hwang, H. and C. C. Mai

1990 "A Simple Model of the Choice of Transport Mode and Plant Location", *The Annals of Regional Science* 24:197-210.

Hwang, H. and C. C. Mai

1987 "Industrial Location and Rising Energy Prices: A Case of Bilateral Monopoly", *Regional Science and Urban Economics* 17:255-264.

Sakashita, N.

1980 "The Location Theory of Firm Revisited-Impacts of Rising Energy Prices", *Regional Science and Urban Economics* 10:423-428.

能源價格上升對運輸成本和廠址選擇的影響

張光美

摘要

近來有許多探討能源價格上升如何影響廠商對廠址的選擇之研究。其中包括一九八O年Sakashita教授的著作，一九八七年黃鴻與麥朝成教授的作品，以及謝勇男與張光美教授一九九一年的文章。以上所有的研究著作都假定能源價格的上升不會影響各種運輸費率。然而在實際運作上，不論是那一種運輸方式均少不了要使用能源，因此，能源加價對運輸成本應當有其影響力。在本文中作者擬以一個生產函數為一階齊次式的生產模型，以及線型空間的廠址型態來探討在雙邊獨佔的市場模式下，能源價格上升對運輸成本以及廠址選擇所產生的影響。研究結果顯示，當我們把能源價格加入了運輸成本結構中，廠商的最佳廠址深受能源價格上升的影響。此一結果與謝張兩教授的結論不同。至於影響的方式則有視於能源價格上升對原料、中間財以及消費財的邊際運輸成本所產生的影響力大小而定。舉一例說明：如果運送原料的費用受到能源加價的影響最大，而對中間財運費的影響最小，則雙邊獨占市場的賣方就會盡可能將廠址移近原料的供應地以縮減運費，而買方就會盡量將廠址移往市場方向以節省運費。如果我們假定能源價格上升對各種運輸費率的影響完全相同，則能源加價對廠址選擇就沒有影響力了。因為各種運費會同時比例增加，廠商就不必變換廠址來節省運費。在此特例之下，本文的結論與謝張的結論就不謀而合了。