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Abstract

The capital-theoretic model suggested for determining the price-quantity combinations does not hold in the case of most natural resources, including petroleum, since the inelastic demand function would vitiate the optimal solution. The specification of a dynamic demand function, with necessary attributes, no doubt, results in a valid optimal solution in period t, but that could be achieved only at the cost of sub-optimal solution in other periods. If the OPEC starts behaving as a discriminating monopoly, instead of as a pure monopoly, the optimal solution is assured in all markets and in all time periods.

The economists have, for long studied the world petroleum market as a competitive market, analogous to the U.S. petroleum industry, which consists of a large number of firms, big and small, and which apparently operates in a competitive market (Fisher, 1964; Erickson, 1968). As a reaction to the events of the past few years, both in the U.S. and abroad, the economists' view has completely reversed to treat the OPEC -- a loose association of a few major oil suppliers -- as a monopoly or a collusive cartel (Adelman, 1972; Akins, 1973; Danielson, 1976). Since there is considerable non-OPEC oil industry, a few others have attempted to characterize the world oil industry as a leader-follower or a dominant firm oligopoly, the 'strong' OPEC acting as the price-setter and the weak competitive fringe behaving as a price-taker and adjusting its output accordingly (Cremer-Weitzman, 1975).

In all these models the basic approach of optimization is as follows: The oil is a non-renewable natural resource. It is available in finite quantity which is known at the time of analysis, although further exploration holds the possibilities of expanded reserves. Given a constant discount rate or the interest rate, the producer would attempt to maximize the discounted stream of total revenues (or the total profits) he makes over the periods till the resource is completely exhausted, (Hotelling, 1931). In a perfectly competitive market the price of the resource will be growing at the discount rate. In a monopoly market the marginal revenue will grow at the discount rate as an optimal solution (Weinstein and Zechhauser, 1975, Rao, 1976). The output quantities will be given by the respective demand functions.

Delbruck (1976) has shown that this approach doesn't work in the case of most of the natural resources, including oil. Certain features associated with the petroleum demand function do not lend the objective function with an optimal solution. He has suggested a dynamic function to get an optimal solution in one period at the cost of sub-optimal solutions in other periods. A more satisfactory approach would be to obtain optimal solutions in all periods. This can be done by respecifying the demand function(s) in a discriminating monopoly situation.

In part II, the problem is presented in brief to, explain, on the lines of Delbruck, why the optimum solution is not possible in the case of oil. Part III presents an alternate model consisting of re-specified demand functions in a segmented market with price discrimination to show that optimal solution is possible in all periods. Part IV summarizes the discussion with a few comments on its social and international implications.

II

The objective of pricing strategy of a non-renewable natural resource, petroleum, is to maximize the discounted stream of the total revenues, neglecting any costs of production. Assuming that the quantity demanded in period t, (q_t), is a function of price of petroleum in that period, (p_t), and a constant c_t, which allows for shifts in the function due to changes in the national incomes and population growth the demand function can be specified as follows:

$$q_t = q_t\ (p_t,\ c_t);\ \frac{\partial q_t}{\partial q_t} < 0 \qquad (1)$$

The present value of the total revenues, discounted by a constant rate of discount, r, is given by

$$P.V. = \sum_t p_t \cdot q_t(p_t, c_t)(1+r)^{-t} \qquad (2)$$

Since the total quantity of petroleum in place (Q_t) is known, it is customary to impose a quantity constraint

$$\sum_t q_t \leq Q \qquad (3)$$

The Lagrangian of the problem is given by

$$L_1 = \sum_t p_t \cdot q_t(p_t, c_t)(1+r)^{-t} + \lambda(Q - \sum_t q_t) \qquad (4)$$

Applying Kuhn-Tucker conditions the following relations hold.

$$\frac{\partial L_1}{\partial q_t} = (p_t + q_t \frac{\partial p_t}{\partial q_t})(1+r)^{-t} \leq \lambda \qquad (5)$$

$$\sum_t q_t \frac{\partial L_1}{\partial q_t} = \sum_t q_t [(p_t + q_t \frac{\partial p_t}{\partial q_t})(1+r)^{-t} - \lambda] \qquad (6)$$

$$q_t \geq 0 \qquad (7)$$

$$\frac{\partial L_1}{\partial \lambda} = Q - \sum_t q_t \geq 0 \qquad (8)$$

$$\lambda \frac{\partial L_1}{\partial \lambda} = \lambda(Q - \sum_t q_t) = 0 \qquad (9)$$

$$\lambda \geq 0 \qquad (10)$$

(5) can be re-written as

$$p_t(1 + \frac{1}{\varepsilon_d})(1+r)^{-t} \leq \lambda \quad \text{where } \varepsilon_d = \frac{\partial q_t}{\partial p_t} \cdot \frac{p_t}{q_t} \qquad (5a)$$

In view of (6) and for $q_t > 0$, the LHS of (5a) would be a negative quantity. This is so because $\varepsilon_d < 0$ and $|\varepsilon_d| < 1$ for petroleum which has been estimated as being between -·2 and -·15. There wouldn't, therefore, be any optimal solution to the problem and the price-quantity forecasts cannot be made using this model.

III

Assume that OPEC, the organization of major oil suppliers, dominates the competitive fringe to assign it a share of the market and a market price. In the remaining portion of the market the OPEC weilds a monopoly power, even to the extent of operating a discriminatory pricing policy. It could do so because the demand functions vary greatly in different areas. Let there be, for example, two markets with prices p_{1t} and p_{2t} in markets 1 and 2 in period t. p_{1t} is the same as the price obtaining in the portion of the market where the competitive fringe also operates. It is also assumed that intermarket trade is not possible and that the OPEC can enforce its dictate. Let the demand functions in the two markets be given by

$$q_{1t} = q_{1t}(p_{1t},\ p_{2t},\ c_t);\ \frac{\partial q_{1t}}{\partial p_{1t}} < 0;\ \frac{\partial q_{1t}}{\partial p_{2t}} > 0$$

$$q_{2t} = q_{2t}(p_{1t},\ p_{2t},\ k_t),\ \frac{\partial q_{2t}}{\partial p_{1t}} > 0;\ \frac{\partial q_{2t}}{\partial p_{2t}} < 0 \tag{11}$$

Quantity demanded in the first market as a function of its price is obvious, but that as a function of the price obtaining in the second market needs a little explaining. Given a certain total output in period t, constrained by the capacity of production, the consumers in the first market expect to buy a larger quantity at p_{1t}, if p_{2t} is higher. The rationale for this behaviour is the understanding that a higher than normal p_{2t} means a lower than normal q_{2t}, which leaves a larger output available in market 1 making the demand function in the 1st market shift upwards. The recent experiences about the initial success and later failure of the conservation efforts indicate the backward and forward shifts of the demand functions, due to lower and expanded supplies respectively in the market. The quantity to be maximized with the usual constraint would be

$$\text{P.V.} = \sum_t [p_{1t}\cdot q_{1t}(p_{1t},p_{2t},c_t) + p_{2t}\cdot q_{2t}(p_{1t},p_{2t},k_t)](1+r)^{-t} \tag{12}$$

and the Langrangean for this problem would be:

$$L_2 = \sum_t [p_{1t}\cdot q_{1t}(p_{1t},p_{2t},c_t) + p_{2t}\cdot q_{2t}(p_{1t},p_2,k_t)](1+r)^{-t} + \lambda[Q-\sum_t(q_{1t}+q_{2t})] \tag{13}$$

The K-T conditions for an optimum for this problem are as follows:

$$\frac{\partial L_2}{\partial q_{1t}} = \{[p_{1t}+ q_{1t}\frac{\partial p_{1t}}{\partial q_{1t}}] + [q_{2t}\ \frac{\partial p_{2t}}{\partial q_{1t}}]\}(1+r)^{-t} \le \lambda \tag{14}$$

$$\sum_t q_{1t}\ \frac{\partial L_2}{\partial q_{1t}} = \sum_t q_{1t}\ \{[(p_{1t}+ q_{1t}\ \frac{\partial p_{1t}}{\partial q_{1t}}) + (q_{2t}\ \frac{\partial p_{2t}}{\partial q_{1t}})]\ (1+r)^{-t} - \lambda\} = 0 \tag{15}$$

$$\frac{\partial L_2}{\partial q_{2t}} = \{[p_{2t}+ q_{2t}\ \frac{\partial p_{2t}}{\partial q_{2t}}] + [q_{1t}\ \frac{\partial p_{1t}}{\partial q_{2t}}]\}\ (1+r)^{-t} \le \lambda \tag{16}$$

$$\sum_t q_{2t} \frac{\partial L_2}{\partial q_{2t}} = \sum_t q_{2t} \{[(p_{2t} + q_{2t} \frac{\partial p_{2t}}{\partial q_{2t}}) + \tag{17}$$

$$(q_{1t} \frac{\partial p_{1t}}{\partial q_{2t}})](1+r)^{-t} - \lambda\} = 0$$

$$q_{1t} \geq 0 \qquad q_{2t} \geq 0 \tag{18}$$

$$\frac{\partial L_2}{\partial \lambda} = Q - \sum_t (q_{1t} + q_{2t}) \geq 0 \tag{19}$$

$$\lambda \frac{\partial L_2}{\partial \lambda} = \lambda[Q - \sum_t (q_{1t} + q_{2t})] = 0 \tag{20}$$

14 and 15 can be rewritten as

$$p_{1t} (1 - \frac{1}{|\varepsilon_{d_{11,t}}|} + \frac{q_{2t}p_{2t}}{q_{1t}p_{1t}} \cdot \frac{1}{\varepsilon_{d_{12t}}}) \tag{14a}$$

$$(1+r)^{-t} \leq \lambda$$

$$p_{2t} (1 - \frac{1}{|\varepsilon_{d_{22,t}}|} + \frac{q_{1t}p_{1t}}{q_{2t}p_{2t}} \cdot \frac{1}{\varepsilon_{d_{21,t}}}) \tag{16a}$$

$$(1+r)^{-t} \leq \lambda$$

where

$$\varepsilon_{d_{ijt}} = \frac{\partial q_{it}}{\partial p_{jt}} \cdot \frac{p_{jt}}{q_{it}} ; \quad \varepsilon_{d_{iit}} = \frac{\partial q_{it}}{\partial p_{it}} \cdot \frac{p_{it}}{q_{it}}$$

For (14a) and (16a) to be valid the following conditions have to be fulfilled:

$$1 + \frac{TR_{2t}}{TR_{1t}} \cdot \frac{1}{|\varepsilon_{d_{12,t}}|} > \frac{1}{|\varepsilon_{d_{11,t}}|} \tag{21}$$

$$1 + \frac{TR_{1t}}{TR_{2t}} \cdot \frac{1}{\varepsilon_{d_{21,t}}} > \frac{1}{|\varepsilon_{d_{22,t}}|}$$

In actuality, this is not unlikely to be fulfilled, as it is reasonable to assume that the absolute cross elasticities are much smaller than the own elasticities of demand in the case of petroleum.

The rates of growth of prices in the two markets are given by

$$\frac{P_{1,t+1}}{P_{1t}} = \frac{[1 - \frac{1}{|\varepsilon_{d_{11,t}}|} + \frac{TR_{2t}}{TR_{1t}} \cdot \frac{1}{\varepsilon_{d_{12,t}}}]}{[1 - \frac{1}{|\varepsilon_{d_{11,t+1}}|} + \frac{TR_{2,t+1}}{TR_{1,t+1}} \cdot \frac{1}{\varepsilon_{d_{12,t+1}}}]} (1+r)$$

and (22)

$$\frac{P_{2,t+1}}{P_{2t}} = \frac{[1 - \frac{1}{\varepsilon_{d_{22,t}}} + \frac{TR_{1t}}{TR_{2t}} \cdot \frac{1}{\varepsilon_{d_{21,t}}}]}{[1 - \frac{1}{\varepsilon_{d_{22,t+1}}} + \frac{TR_{2,t+1}}{TR_{2,t+1}} \cdot \frac{1}{\varepsilon_{d_{21,t+1}}}]} (1+r)$$

Since the average revenue in the diseminating monopoly is larger than the average revenue in non-diseminating monopoly market, (unless equalization of $MR_1 = MR_2$ results in uniform price) the producers would get a larger average price for the output sold. It is obvious that $|\varepsilon_{d_{11t}}| > |\varepsilon_{d_{22t}}|$ implies $P_{1t} < P_{2t}$. The quantity changes can be forecast only after the respective quantities at which the equilibrium is reached is known.

IV

The model presented here has several favourable and unfavourable possibilities. It is not unreasonable to think that given the present status of the OPEC and its economic strength, it can operate as a discriminating monopoly, especially when it is obvious that the elasticities of demand for its product vary in different areas of the world. Under the economic pressures that several countries, both developed and the developing, are subjected to, it can ensure zero inter-market trade. If the new model results in a two tier price system, the developing countries would welcome the pratice and the OPEC will generate a large amount of political support, at the cost of the consumers in the other market where the absolute ε_d is relatively lower. But the two-tier price system, at least mathematically, ensures an optimal solution to the capital-theoretic model of natural resource depletion.

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