SYNFUELS: JUSTIFICATIONS FOR AND CONSEQUENCES OF GOVERNMENT INTERVENTION

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I. Introduction

The recent cancellations of the Colony oil shale and Alberta tar sands projects have rekindled debate on the future of synthetic fuels. This debate has been under way for about fifty years, though it has gained much greater urgency since the Arab oil embargo of 1973 and the subsequent oil price shocks. It has been marked by recurrent rosy predictions followed by disappointments: in the thirties and fifties, as well as in more recent years, synthetic fuels were forecast to become profitable at prices 30 to 50 per cent higher than the prevailing oil price.

Governments have become increasingly involved in the discussion. In the U.S., Nixon's Project Independence and Carter's declaration of a moral-equivalent-of-war assigned important roles to various synthetic fuels. The Synthetic Fuels Corporation, created in 1980, is now empowered to use a variety of instruments, including price and loan guarantees, to encourage private development of synthetic resources; the SFC's budget for the next two years is $15 billion. In other countries, including Canada, Japan and Germany, governments have assumed partial or complete public ownership of synfuels projects.

Various arguments can be invoked to justify government intervention in the development and production of synthetic fuels. One important argument concerns monopsony power. For a nation that provides a significant fraction of the world demand for conventional fuels, the development of synthetic fuels as a substitute resource can reduce that nation's demands for conventional fuels and exert some downward pressure on the price of conventional fuels. The production of synfuels in the U.S., for example, could reduce the nation's demands for conventional fuels like crude petroleum and have some influence on the path of petroleum prices. The benefits to domestic consumers from a reduction in imported oil prices would not be taken into account in the profit-maximizing decisions of private firms contemplating synfuels production; thus we have here a potential justification for government involvement as a way of bringing about the optimal level of synfuels production (from the importing nation's point of view). It should be pointed out that the monopsony power issue has significance regardless of whether the world oil market is dominated by a cartel or is purely competitive, since in either case, synfuels production can potentially lower the path of conventional fuel prices.

Another justification for government intervention concentrates on capital market imperfections. The capital requirements for large plants are in the billions of dollars; potential investors in these projects face significant uncertainties associated with long lead times and untried technologies, as well as fundamental uncertainties regarding the behavior of foreign oil producers. Under these circumstances a shortage of private venture capital at the appropriate discount rate may develop, and government intervention may be appropriate. (See, for example, Arrow [1962].) Further complications arise, as Dasgupta, Gilbert and Stiglitz [1982] have demonstrated, when the owner of the synfuels patent also owns some of the competing exhaustible resource.

Other justifications for government involvement refer to the public goods aspects of R&D, and the potential national security benefits from a reduced dependence on imported oil brought about by domestic synfuels production. The first is not unique to synthetic fuels development, and has been elucidated by Hirshleifer [1971], among others. The basic point is that information is a public good; patents may not cover all the information gained in R & D and can lead to inefficiencies in the use of information even if they can be obtained. The national security argument invokes a nonpecuniary external benefit from synfuels production which is distinct from the pecuniary benefit stemming from monopsony power. (See, for example, Sweeney [1977].)

All of these justifications -- and especially the first two -- motivate the research in this paper. Our principal objective here is to investigate the desirability of alternative synfuels policies for a nation which is a major importer of conventional fuels. We shall examine how the government can implement synfuels programs which bring about the best strategic use of monopsony power. Here we shall take account of the substantial capital requirements of synfuel plants and the associated uncertainties facing potential investors.

Monopsony power arguments are often cited as justifications for tariffs on imported oil. In fact, many would regard an oil tariff policy as superior to a synfuels development program as a means of lowering imported oil prices (net of tariff) and enhancing social welfare. The argument is that, under the optimal tariff policy, consumers and domestic producers of both oil and synthetic fuels would face the "true" opportunity cost of importing oil, and that market forces would then determine the appropriate levels of production and consumption.

Yet a number of considerations indicate that it might be difficult to enforce the type of "optimal" tariff policy which would constitute a serious alternative to a synfuels program. To begin with, it may be quite difficult for the importing country to commit itself credibly to an optimal tariff program, especially when that program extends over a long period and involves different tariff rates at different points in time. In contrast, the construction of a synfuels plant constitutes a credible commitment to produce synthetic fuels. Furthermore, as pointed out by Newbery [1975] and Maskin and Newbery [1978], it is in the government's interest not to abide by the "optimal" tariff program which it announces. The solution of the game is not stable. This adversely affects the government's credibility, and can lead to preemptive behavior on the part of oil producers with adverse welfare implications. In addition, it may not be politically feasible or socially desirable, in many countries, to give special tariff protection to domestic energy producers. Other countries may retaliate on other products. Other domestic industries may demand, and receive, protection. In light of these considerations, Harberger [1980], among others, advocates a uniform tariff.

It therefore appears worthwhile to investigate the gains which might be obtained from government synfuels policies. We begin our paper by examining the optimal level of synfuels production for an importing country with monopsony power. Our approach is formally similar in certain respects to that of Dasgupta, Gilbert and Stiglitz [1981], who concentrate on the optimal timing of introduction, rather than the optimal quantity produced, a substitute resource. We shall consider the case where the imported resource is supplied by a cartel behaving as a profit-maximizing monopolist, and the case where suppliers are perfectly competitive. The government is assumed to commit itself credibly to the production of synfuels at some time in the future. The cartel or competitive producers maximize profits as a function of the level of synfuels production; propositions concerning this decision are developed in part A of Section II below. Realizing this dependence, the government optimizes the level of synfuels production; part B of Section II is devoted to an analysis of this decision.

In this paper, we regard synfuels as a perfect substitute for conventional resources, which are treated as exhaustible. The implications of the development of a substitute resource for an exhaustible conventional resource have been investigated by other authors. In many studies (e.g.

Nordhaus [1973]), the substitute is regarded as a "backstop technology" available in unlimited quantities at or above some "backstop price". In our analysis of synfuels, we do not assume a backstop technology; instead, we explicitly concern ourselves with the issue of the quantity of synfuels which should be made available. Given the long lead times, large capital requirements, and perhaps the exhaustibility of the synthetic fuel itself, this seems a reasonable approach. The limited availability of synfuels raises the possibility of market sharing between synthetic and conventional fuels. One of the issues we examine is the conditions under which market sharing will occur.

In Section III, we evaluate alternative synfuels policies, all suggested at one time or another, in terms of their effectiveness in bringing about socially optimal outcomes. A central result of this paper is that flexibility with respect to production of synfuels, in the absence of uncertainty, will often hurt, and almost never help, the importing government. Other policies considered include futures contracts, price guarantees, and loan guarantees against project failure or against firm bankruptcy.

Uncertainty regarding the levels of development and operating costs for the synfuel is introduced in Section IV. Here we also consider the case of asymmetric information between firms and the government regarding those costs. The possible advantage of flexibility in the presence of a particular type of uncertainty is shown. An incentive-compatible mechanism for solving the information problem is presented. The final section summarizes the results and discusses their significance.

II. The Model

We present here a partial equilibrium model in which the principal economic agents are foreign producers of an exhaustible resource and domestic producers of a synthetic substitute fuel. The case of exhaustible resource production by a cartel which acts as a profit-maximizing monopolist, as well as that of perfect competition among the resource producers, will be considered here. In this section we shall employ the model to explore the effects of government synfuels activity on the production decisions of owners of the exhaustible resource. In addition we shall examine what constitutes optimal synfuels production from the point of view of the importing country.

Here synfuels do not represent a "backstop technology," since the quantity of synfuels available is limited by plant capacity, rather than infinitely available at or above some backstop price. We are explicitly concerned with the implications of the choice of plant capacity.

The date of introduction of the synfuel is exogenous: synfuel production begins at some future date, T, and continues for all time after T. This treatment contrasts with that of Dasgupta, Gilbert and Stiglitz [1981], who treat the date of introduction as a policy variable but regard the substitute resource as a backstop technology.

The presence of synfuels -- and, in some cases, the mere capacity to produce them -- affects the pricing strategy of resource producers, whether the latter are competitive or loyal to a cartel. Since synfuels are perfect substitutes for the exhaustible resource, additional production of synfuels increases the quantity of fuels (exhaustible resources plus synfuels) available and lowers the price which exhaustible resource suppliers can obtain for a given aggregate quantity of the resource. We regard the government as a Stackelberg leader: it takes into account the effect of the level of synfuels production on the pricing decisions of the resource producers.

The government represents an importing country which is regarded as the sole demander of the exhaustible resource and of the substitute, synthetic fuels. In our simplest model we assume that synfuels plants are built and operated by the government, and that the government is always committed to producing synfuels at capacity. The government selects a level of capacity, y, and announces that level to the producers of the exhaustible resource. It is assumed that the government can make its announcement credible in some way -- perhaps through an expenditure commitment or by initiating plant construction.

Define z_t as the quantity of the exhasutible resource made available by foreign producers at time t, and define q_t as the total quantity of the exhaustible resource and the synfuel available at that time.
When the government is committed to operating its synfuels plants at capacity, the quantity of synfuels available will be y, once the plants are operational. Thus

(1) $$q_t = \begin{cases} z_t, & 0 < t < T \\ z_t + y, & T \leq t < \infty \end{cases}$$

The demand for all fuels (the exhaustible resource plus synfuels) is given by the continuously differentiable function:

(2) $$q = f(p) \geq 0$$

where p is the price of fuels. It is assumed that $f'(p) < 0$. We define $p(q) \equiv f^{-1}(q)$. For analytical convenience, we make the useful assumption throughout that $f(p)$ is constant over time.

We shall arrive at an optimal level of synfuels production in two steps. First, we examine the response of resource producers to given values of y. Then we search for an optimal level of y, taking into account the response of resource producers.

A. The Resource Producer's Decision Problem

1. Cartel Case

Resource producers are regarded as attempting to maximize discounted profits. The resource is assumed to be costless to extract. The initial stock of the resource is designated as S_0. When the resource suppliers belong to a cartel, the maximization problem is:

(3) $$\max_{\{z\}} \int_0^T z_t \, p(z_t) \, e^{-rt} \, dt + \int_T^\infty z_t \, p(z_t + y) \, e^{-rt} \, dt$$

subject to

$$\int_0^\infty z_t dt \leq S_0$$

This represents a special case of the standard optimal extraction problem for monopolistically owned exhaustible resources. Here the monopolist faces different stationary demand functions in the intervals $[0, T)$ and $[T, \infty)$.

The demand function from $[T, \infty)$ is the one from $[0, T)$ shifted leftward by the quantity y.

The extraction path representing the solution to the maximization problem must satisfy the condition that marginal profit, at each point of time in which production occurs, will increase at the cartel's rate of discount, r. Denote the marginal revenue obtained by the cartel at time t as MR_t. Since the extraction cost is assumed to be zero, the solution requires that

$$MR_t = MR_0 e^{rt} \tag{4}$$

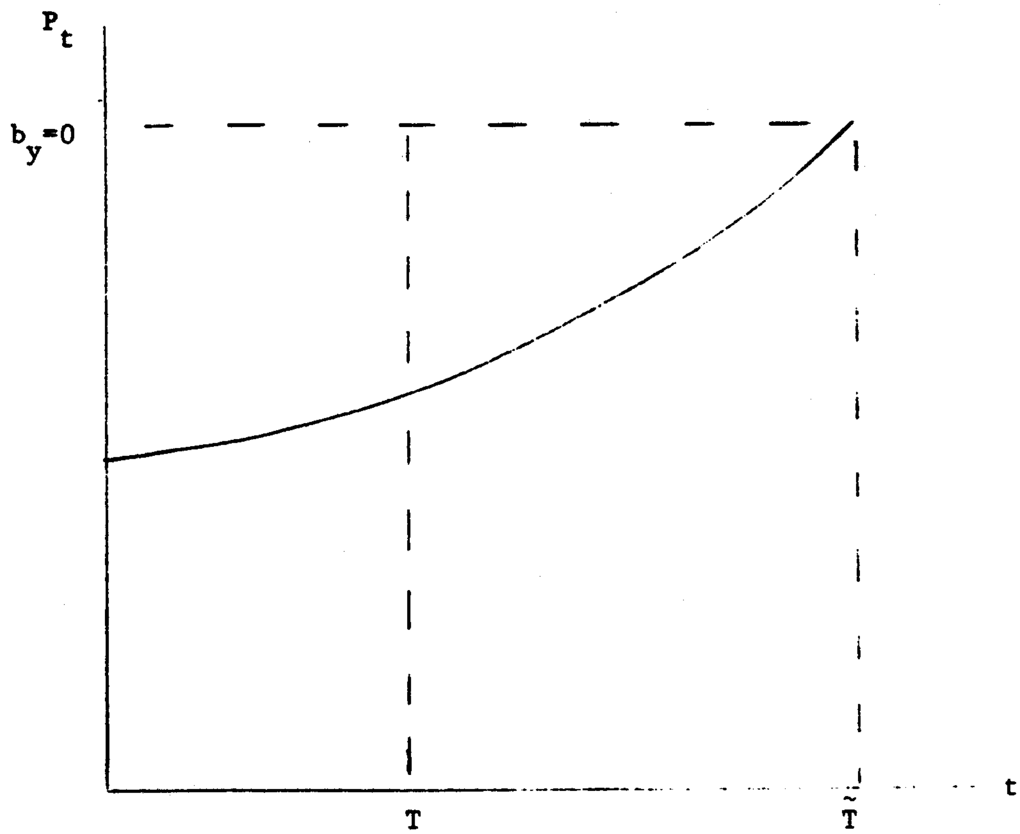
for all t in which $z_t > 0$.

In the extreme case when there is no synfuel capacity or production at anytime, $y = 0$. Then the cartel faces a single stationary demand curve over all time. Now we add the assumption that MR is a continuous, decreasing function of z. The requirement that MR increase at r means that z must decrease continuously over time, since the function $p(q) \equiv p(z+y)$ is continuous in z when $y = 0$.

Let $\tilde{T}$ represent the time at which exhaustion occurs on the optimal extraction path in the case of $y = 0$. Routine arguments show that $\tilde{T}$ is finite if there exists a choke-off price, that is, a price b such that $q(p) = 0$ for all $p \geq b$. Figure 1 characterizes the price path under $y = 0$ when b is the choke-off price. When y is greater than zero, the nature of the solution depends on the relationship of $\tilde{T}$ to T, the time of the introduction of synfuels.

Figure 1

Price Path in Cartel Ownership Case Under y = 0



($MR_t = MR_0 e^{rt}$ during $[0, \tilde{T})$.)

<u>Proposition 1</u>:

(a) If $T \geq \tilde{T}$, the level of synfuels production does not affect the extraction path of the cartel.

(b) If $T < \tilde{T}$, the presence of synfuels affects the cartel's extraction path, and for every initial exhaustible resource stock S_0 there exists a $\hat{y}$ such that:

(i) If the government chooses y less than $\hat{y}$, the cartel and synfuels producers will share the market from T until $T_x(y)$, the date of exhaustion of the conventional fuel. $MR(z_t)$ increases at the rate r during $[0, T_x)$. The fuel price rises continuously during $[0, T)$, takes a discrete drop at T, and rises continuously during $[T, T_x)$. The fuel price reaches p(y) at time T_x, and remains at p(y) thereafter. (See Figure 2.)

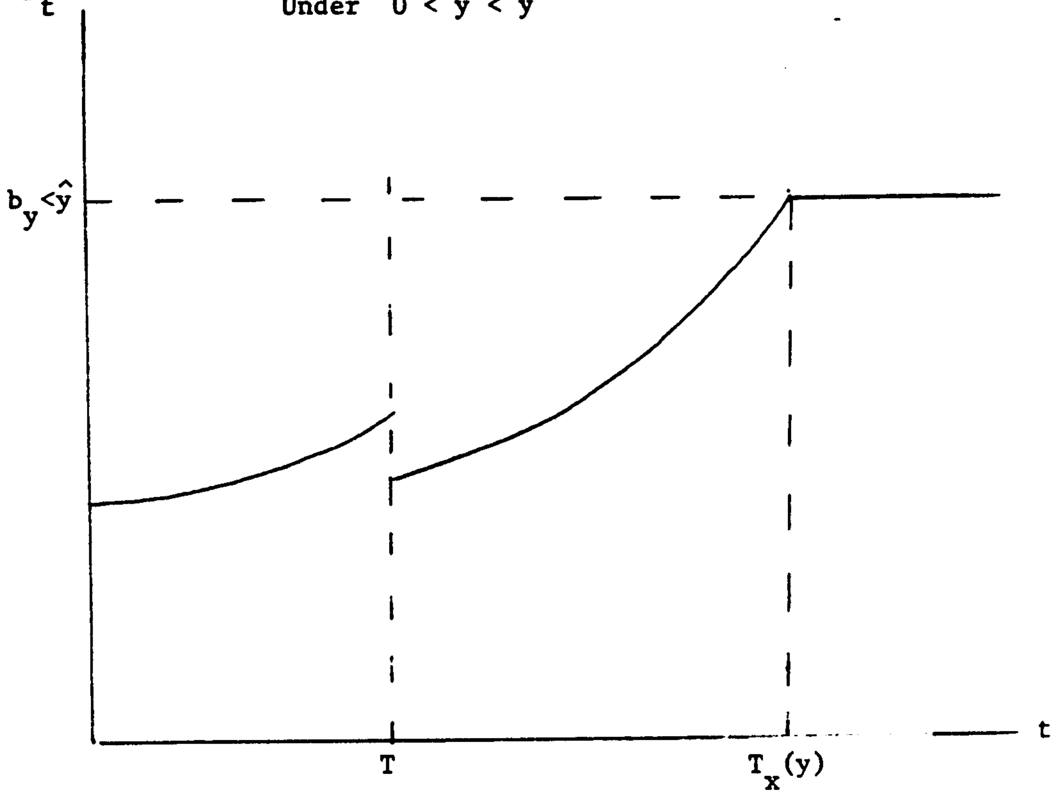
(ii) If the government chooses y greater than or equal to $\hat{y}$, conventional fuels will be exhausted at T. $MR(z_t)$ increases at the rate r during $[0, T)$. Th fuel price rises continuously during $[0, T)$ and remains at p(y) during $[T, \infty)$. The synfuels price p(y) is less than the fuel price just prior to exhaustion. (See Figure 3.)

<u>Proof</u>:

The proof of part (a) is straightforward. Any positive y reduces demands and hence the profitability of production at each point in time after T, but has no direct effect on the period before T. If $T \geq \tilde{T}$, resource owners were not producing after T in the absence of synfuels; <u>a fortiori</u>, they will not do so if synfuels are produced. Thus there is no effect on the extraction path if $T \geq \tilde{T}$, independent of the level of

Figure 2

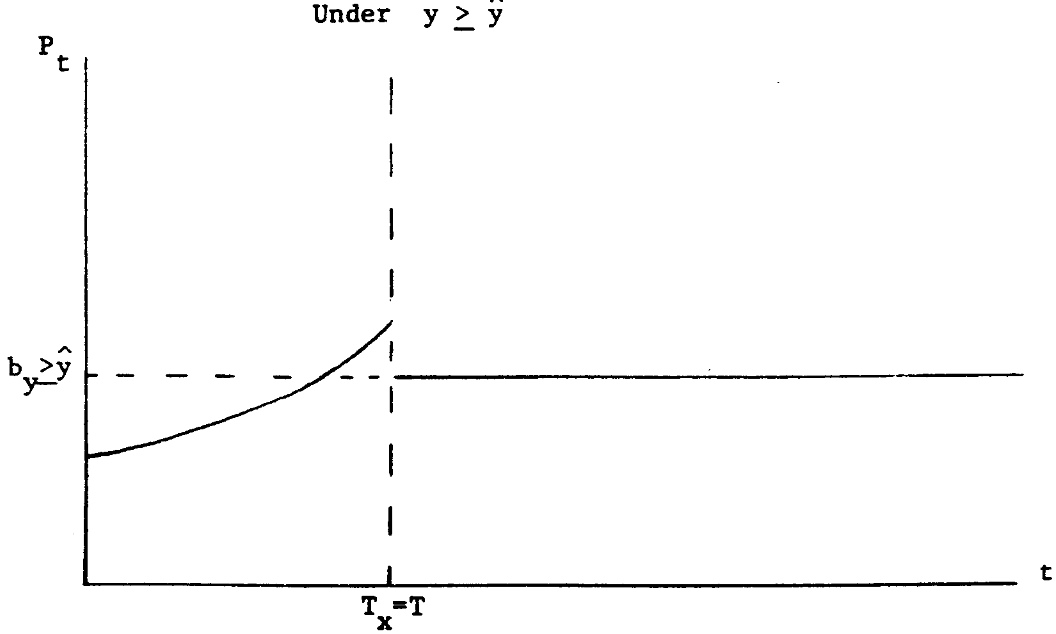
Price Path in Cartel Ownership Case
Under $0 < y < \hat{y}$



($MR_t = MR_0 e^{rt}$ during $[0, T)$ and during $[T, T_x)$. Conventional fuel and synfuels share market during $[T, T_x)$. $\partial z_t/\partial y > 0$ in $[0, T)$; $\partial z_t/\partial y < 0$ in $[T, \infty)$.)

Figure 3

Price Path in Cartel Ownership Case
Under $y \geq \hat{y}$



($MR_t = MR_0 e^{rt}$ during 0, T). No market sharing. $\frac{\partial z_t}{\partial y} = 0$.)

synfuels.

Part (b) requires more effort. Recall that the profit-maximizing extraction path requires that discounted marginal revenue, $MR_t(z_t)e^{-rt}$, be constant for all t in which $z_t > 0$. Consider the optimal solution to the monopolist's problem under the constraint that exhaustion must occur at time T. Call the value of discounted marginal revenue for this solution MR_0^*. It will be nonnegative if there is free disposal of the resource; its value is a function of the initial stock S_0, the shape of the demand curve, and T.

Now consider the circumstances under which the cartel would prefer to extend production beyond T. Suppose that $MR_{T+\varepsilon}(0)e^{-r(T+\varepsilon)} < MR_0^*$, that is, the discounted margianl revenue, after synfuels are introduced, of the first unit of production is less than MR_0^*. Since, by assumption, MR decreases with z at any point in time, $MR_{T+\varepsilon}(0)$ is the highest marginal revenue obtainable at time $T + \varepsilon$. Further, since demands are identical at all points of time in $[T, \infty)$, then for all $t > T+\varepsilon$,

$$MR_{T+\varepsilon}(0)e^{-r(T+\varepsilon)} > MR_t(0)e^{-rt} > MR_t(z_t)e^{-rt}$$

for all $z_t > 0$. Therefore if $MR_{T+\varepsilon}(0)e^{-r(T+\varepsilon)} < MR_0^*$, the discounted marginal revenue (or discounted marginal profit, since marginal costs are zero) for the first unit or any successive unit of extraction at time $T+\varepsilon$ or afterward, will fall short of MR_0^*. This implies that shifting any production from $[0, T)$ into $[T, \infty)$ will lower discounted profits. Therefore the cartel will never wish to share the market with the synfuels producer if $MR_{T+\varepsilon}(0)e^{-r(T+\varepsilon)} < MR_0^*$. Thus, if the government wishes to assure no market sharing, it can do so by choosing $y = \hat{y}$, where

(5) $$\hat{y} = q\ (MR_0^* e^{rT})$$

This shifts the residual demand curve faced by the cartel inward in such a way that $MR_{T+\varepsilon}(0)e^{-r(T+\varepsilon)} < MR_0^*$, making production of the resource in $[T, \infty)$ disadvantageous. (See Figure 4.)

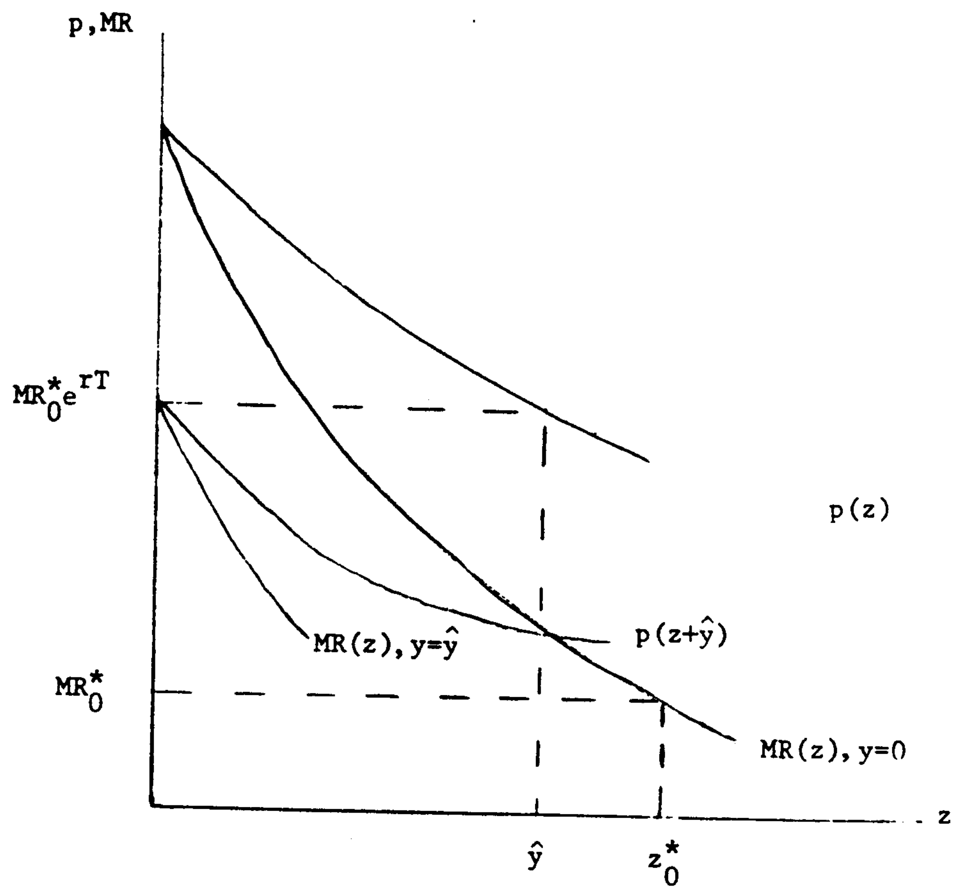
Clearly if $y > \hat{y}$, $MR_{T+\varepsilon}(0)^{-r(T+\varepsilon)}$ will be even lower, and resource extraction beyond T will not be optimal. On the other hand, if $y < \hat{y}$, $MR_{T+\varepsilon}(0)e^{-r(T+\varepsilon)} > MR_0^*$, and the deferment of at least one unit of extraction beyond T increases profits. Thus $\hat{y}$ is a critical value for y: if $y < \hat{y}$, the cartel will prefer to exhaust after T; if $y \geq \hat{y}$, the cartel will prefer to exhaust at T.

The characteristics of the price paths in the cases $y < \hat{y}$ and $y \geq \hat{y}$ remain to be shown. Optimality requires that marginal revenue (MR) increase continuously. In the interval $[0, T)$, output z is continuous and decreasing in MR (since, by assumption, MR is continuously decreasing in z). Price is also continuous and decreasing in z since during this interval the monopolist faces the continuous inverse demand function, $p(z)$. Thus the optimum implies that the resource price rises continuously in $[0, T)$. Similar considerations show that if production occurs beyond T (that is, if $y < \hat{y}$), the resource price rises continuously in $[T, T_x)$.

If $y < \hat{y}$, some of the resource is produced after T. Marginal revenue to the cartel must be the same just before and after the plant comes on line. Since there has been a horizontal leftward shift in demand at T, this is only possible if the price drops discretely at T (at any given price, marginal

Figure 4

Relationship of Conventional Fuel Demand and Optimal Synfuels Quantity, $\hat{y}$



revenue is greater after the shift than before). The intuition is that the cartel does not care about the effect of its output decision on the profits to the synfuel producer.

If $y \geq \hat{y}$, the conventional resource is exhausted at T. By the definition of $\hat{y}$, $p(\hat{y})$ is equal to the marginal revenue of the resource just before T when the cartel pursues the optimal path leading to exhaustion at T. Since marginal revenue is less than price, $p(\hat{y})$ is less than the cartel's price just before T. Since the conventional resource is not produced during $[T, \infty)$, $p(y)$ is the market price from T on. The larger is y, the smaller is $p(y)$ compared with $p(\hat{y})$, and the larger is the price drop at time T.

The proof is therefore complete. The next proposition relates changes in the level of synfuels production to changes in the cartel's extraction path.

Proposition 2:

Let T be less that $\tilde{T}$.

(a) If $y \geq \hat{y}$, $\dfrac{\partial z_t}{\partial y} = 0$

(b) If $y < \hat{y}$, $\dfrac{\partial z_t}{\partial y} \begin{cases} > 0 & 0 \leq t < T \\ < 0 & T \leq t < \infty \end{cases}$

Proof:

(a) If $y \geq \hat{y}$, the resource is exhausted at T. Since changes in y do not affect demands in $[0, T)$, then if Z is the optimal path under $y = y_1 > \hat{y}$, it is also optimal under $y = y_1 + \delta > \hat{y}$.

(b) If $y < \hat{y}$, extraction continues beyond T. The value of any given resource stock remaining at time T declines continuously as y increases, by the assumption that marginal revenue is continuous and decreasing in q. Therefore, if y increases, it is in the cartel's interest to shift production from the period after T to the period before T. The requirement that marginal revenue must increase at the rate r within each period implies that when production is shifted from $[T, \infty)$ to $[0, T)$, it is reduced at every point in time in $[T, \infty)$ and increases at every point in time in $[0, T)$. Similar considerations apply for the case of a reduction in y.

2. Competition Case

Similar propositions hold for the case of perfectly competitive resource owners who do, however, know what the price path will be. Differences arise because the intertemporal optimality condition is that price, rather than marginal revenue, must rise at the interest rate. Since the proofs are similar to those of the cartel case, they are omitted.

Proposition 3:

(a) If $T \geq \tilde{T}$, the level of synfuel production does not affect the competitive extraction path.

(b) If $T < \tilde{T}$, the presence of synfuels affects the competitive extraction path, and for every intial resource stock S_0 there exists a $\hat{y}$ such that:

(i) If the government chooses y greater than or equal to $\hat{y}$, competitive resource owners and synfuels producers will share the market from T until $T_x(y)$, the date of exhaustion of the conventional resource. Price increases at rate r during $[0, T_x)$. The fuel price reaches

$p(y)$ at time T_x, and remains at $p(y)$ thereafter.

(ii) If the government chooses y greater than or equal to $\hat{y}$, the resource will be exhausted at T. Price increases at the interest rate during $[0, T)$, and is equal to $p(y)$ from T on. If $y > \hat{y}$, the price falls at T.

Proposition 4:

(Identical to Proposition 2, except that z_t is the output of the competitive producers instead of the cartel.)

Note that $\hat{y}$, T_x, and $\tilde{T}$ in the case of competitive producers are not the same as the corresponding values for the cartel, and that price falls at T only when $y > \hat{y}$.

In sum, if the government introduces synfuels prior to $\tilde{T}$, it will influence the extraction path.

If the level of synfuels production, y, is "small", market sharing will occur for a while. Higher values of y encourage the resource owners to extract more of the stock in the interval $[0, T)$.

For suitably large values of y, resource owners will extract all of its stock prior to the introduction of synfuels.

These summary remarks hold for both monopolistic and competitive ownership of the exhaustible resource, although the critical values of y will differ in the two cases.

B. The Government's Maximization Problem

The production of synfuels is assumed to involve a construction cost

$x(y)$ incurred at time 0. We assume that $x(y)$ is continuously differentiable and that $x'(y) > 0$. To avoid unnecessary corner problems, we assume that $x(0) = 0$ and $x(\infty) = \infty$. Synfuels are produced at a constant marginal cost, c.

Define $u(q) \equiv \int_0^q P(\xi)d\xi$ as the gross social surplus in the importing country when q is the rate of consumption of the resource or its substitute.

The usual caveats about the use of consumer surplus apply in this case. The analysis is largely unchanged if some externality, such as a national security premium, is included in the welfare function. We avoid this complication.

In this subsection we do not distinguish the cases of cartel ownership and competitive ownership of the exhaustible resource: the derivations are formally the same. Let V represent net social surplus. The government's objective is to:

(6) $$\max_y V = \int_0^\infty [u(q_t) - p(q_t)z_t]e^{-rt}\, dt - \int_T^\infty cye^{-rt}dt - x(y)$$

$$\text{where} \quad q_t = \begin{cases} z_t, & 0 \leq t < T \\ z_t + y, & T \leq t < \infty \end{cases}$$

Thus the government seeks to maximize gross social surplus less the resource import cost and the cost of producing synfuels. Note that q_t depends on z_t, which will be chosen by the resource producers as a function of y. Substituting for q, we can write

$$V = \int_0^T [u(z_t) - p(z_t)z_t]e^{-tt}dt$$

(7) $$+ \int_T^\infty [u(z_t+y) - p(z_t+y)z_t]e^{-rt}dt$$

$$- \frac{c}{r}ye^{-rT} - x(y)$$

Differentiating with respect to y gives

$$\frac{\partial V}{\partial y} = \int_0^T [u'\ (z_t)\ \frac{\partial z_t}{\partial y} - p(z_t)\ \frac{\partial z_t}{\partial y} - z_t p'(z_t)\ \frac{\partial z_t}{\partial y}] e^{-rt} dt$$

$$(8) \qquad + \int_T^\infty [-\ p(z_t+y)\ \frac{\partial z_t}{\partial y} - z_t p'\ (z_t+y)\ \frac{\partial (z_t+y)}{\partial y}\ ] e^{-rt} dt$$

$$+ \int_T^\infty [u'\ (z_t+y)\ \frac{\partial (z_t+y)}{\partial y}\ ] e^{-rt} dt - \frac{c}{r}\ e^{-rT} - x'(y) = 0$$

It is instructive to examine the above expression in two cases:

<u>Case 1</u>: $y \geq y$:

Recall that in this case, the extraction path leads to exhaustion at T, and $\frac{\partial z_t}{\partial y} = 0$. The first integral in the expression above reduces to 0. Using the fact that $\frac{\partial z_t}{\partial y} = 0$ and $z_t = 0$ in $[T, \infty)$, the second integral drops out and we can write the third integral as $\frac{1}{r}\ u'(y)e^{-rt}$. The entire expression therefore becomes

$$(9) \qquad \frac{1}{r}\ e^{-rT}(u'(y) - c) - x'(y) = 0$$

Note that $V''(y) = \frac{1}{r}\ e^{-rt} u''(y) - x''(y)$.

If marginal construction costs are constant or increasing in y, $V''(y)$ will be negative. Under these circumstances, if $V'(\hat{y}) < 0$, then any increase in $\hat{y}$ beyond y reduces social welfare. Expansion of capacity beyond $\hat{y}$ can only be justified if $V'(\hat{y}) > 0$, that is, if

$$(10) \qquad \frac{1}{r}\ e^{-rT} u'(\hat{y}) > x'(\hat{y}) + \frac{1}{r}\ e^{-rT} c.$$

The discounted marginal gross benefit from synfuels must exceed the sum of marginal construction costs and (discounted) marginal operating costs. If condition 10 holds, a local maximum exists for some $y > \hat{y}$ where $\frac{1}{r} e^{rT} u'(y) = x'(y) + \frac{1}{r} e^{-rT} c$. This may not be the global optimum, since another maximum may exist for some $y < \hat{y}$.

It should be noted that the optimality condition in equation 9 above is independent of both the price and quantity of the exhaustible resource. Since increases in y beyond $\hat{y}$ have no effect on the resource's extraction or its price path, these strategic considerations do not enter into the calculation of the marginal benefits and costs of increasing y beyond $\hat{y}$. Synfuels capacity should be expanded beyond $\hat{y}$ only if the additional output pays for itself.

It may also be noted that since $u'(y) = p(y)$ and marginal costs are nondecreasing, a necessary condition for expression 10 to hold is that synfuels production be privately profitable at $y = \hat{y}$.

<u>Case 2</u>: $y < \hat{y}$

Using $u'(z_t) = p(z_t)$, the first integral in equation 8 reduces to

$$(11') \qquad \alpha = \int_0^T -z_t p'(z_t) \frac{\partial z_t}{\partial y} e^{-rt} dt$$

This represents the change in consumer surplus in the interval [0, T) occasioned by an incremental increase in y. Since $\frac{\partial z_t}{\partial y} > 0$ in [0, T), α is positive; increases in y lower p in each instant in [0, T), and raise consumer surplus.

The relationship $u'(z_t+y) = p(z_t+y)$ can be used to reduce the second and third integrals in equation 8 to

$$(12) \qquad \int_T^\infty [u'(z_t+y)]\ e^{-rt}dt + \beta$$

where

$$\beta = \int_T^\infty [-z_t p'(z_t+y) \frac{\partial(z_t+y)}{\partial y}]\ e^{-rt}dt$$

The first term in expression 12 above is the marginal gross benefit from synfuels, equal to discounted revenue from synfuels production. The β term represents the change in consumer surplus in the interval $[T, \infty)$ from a change in y. This term will be positive if $\frac{\partial(z_t+y)}{\partial y} > 0$, or equivalently if $\frac{\partial z_t}{\partial y} > -1$, in $T, \infty)$. But this is always true for $y < \hat{y}$. It is obviously true after T_x, since $z_t = 0$. If it were not true in $[T, T_x)$, then the marginal value of the resource would be the same (actually higher in the case of cartel owenership) after the increase in y as it was before. Since the margianl value has fallen in $[0, T)$ due to the additional production in that interval, this could not be optimal.

Thus, equation 8 can be rewritten as

$$(13) \qquad \int_T^\infty u'(z_t+y)e^{-rt}dt + \alpha + \beta = \frac{c}{r}\ e^{-rT} + x'(y)$$

where the α and β terms represent the marginal benefits from synfuels production associated with monopsony power. Equation 13 indicates that a positive level of synfuels production may be desirable even if synfuels do not pay for themselves: at the margin, discounted synfuels revenue can fall short of discounted construction costs and operating costs. The change in net social surplus from building a synthetic fuels plant has two components: the marginal profit or loss on the plant itself and the change in discounted consumer surplus from changing the extraction path of the resource and reducing the price paid for it. The second component is always positive (equal to $\alpha + \beta$), so a loss on the synfuel can be overcome by the gain due to the lowered price of oil. This is true whether the resource is owned by a cartel or competitive producers. These results are summarized in Proposition 5. Part a was demonstrated under Case 1 above; parts b and c follow directly from $\alpha + \beta > 0$ for $y < \hat{y}$. The corollary follows directly from Proposition 5a and Proposition 1 (in the case of cartel ownership) or Proposition 3 (in the case of competitive ownership.)

Proposition 5:

(a) If marginal construction costs are non-decreasing, optimal y will be greater than $\hat{y}$ only if synfuels production is privately profitable.

(b) The optimal y may be greater than zero, even if synfuels producers always lose money.

(c) If the optimal level of y is greater than zero but less than $\hat{y}$, the synfuels producer will lose money on his production capacity at the margin.

Corollary to 5a:

If marginal construction costs are non-decreasing and synfuels are not privately profitable, then the optimal production of synfuels leads to market sharing with the exhaustible resource if synfuels are produced at all.

III. Evaluation of Synfuels Policies

Here we examine a number of synfuels policies with attention to their effectiveness in generating socially optimal outcomes. The analysis invokes a world of certainty, in which the government, exhaustible resource producers, and private synfuels firms have identical information. Cases of uncertainty and asymmetric information will be examined in the next section.

A. Government Construction and Operation of Synfuels Plants

1. Government Commitment to Operate at Capacity

This case follows most directly from the model described in section II. The model of the preceding section analyzed the welfare implications of synfuels development on the assumption that the extent of synfuels capacity and the level of synfuels production were identical. The results therefore apply to a circumstance in which the government credibly commits itself to developing a certain level y of synfuels capacity and to producing synfuels at capacity. The optimal policy under these circumstances is to develop the level of capacity $y = y^*$ which maximizes V according to the preceding model. The optimal y is a determinate function of the initial resource stock, S_0, the resource inverse demand function p(q), the synfuels construction cost function, x(y), and the marginal production cost of synfuels, c. These are all known.

2. Government Option to Shut Down at T

We now consider the case where the government commits itself in two stages: at time 0 it commits itself to capacity y ($0 \leq y \leq \infty$); then at time T it commits itself to a level of operation, either zero or y. We assume that the exhaustible resource producers are informed about the nature of the government's decision process and will believe the commitments at each stage. We thus have the following sequential game:

t=0: The government commits to a capacity level $\bar{y}$, based on S_0 and the anticipated responses of resource producers.

Resource producers respond to y, taking into account the effects of their response on the government's subsequent decisions at time T.

t=T: The government decides whether to operate or shut down, based on S_T and the anticipated responses of resource producers.

Resource producers determine their extraction path, based on the government's decision whether to operate.

Proposition 6

In a world of perfect certainty, the importing nation is never better off and may be worse off if the government has the option to shut down at time T rather than produce at capacity (V with shut down option $\leq$ V without option), if higher levels of the resource stock remaining at time T reduce the net gain to producing as opposed to shutting down.

This surprising result stems from the strategic influence given to oil producers when the government can shut down: producers may embark on a very conservative extraction program -- which can be very costly to the importing country -- in order to encourage the government to shut down at T and to allow themselves to dominate the market during $[T, \infty)$. Having the shutdown option opens up the possibility of strategic behavior on the part of resource producers which can be hazardous from the importer's point of view. The difference between the two integrals is net gain or loss from production:

$$(14) \qquad \int_T^\infty [(u(z_T'+y) - u(z_t)) - (p(z_t'+y)z_t' - p(z_t)z_t) - c_y]\, e^{-rt}dt$$

As S_T increases, both z_t and z_t' increase, but, unfortunately, the gain from producing relative to shutting down may increase or decrease. The first term represents the marginal value of the synfuels output, which will decrease as S_T increases. The second term reflects the gain from paying lower prices for oil, which probably will increase as S_T increases. The possibility that the second term decreases makes necessary the assumption which appears in the proposition. In the analysis which follows, we assume that higher values of S_T reduce the relative gain from production.

For a given extraction path, resource owners are always better off if the government shuts down. Let $\hat{S}_T$ be the value of the resource stock which makes the government indifferent between producing and shutting down. By assumption, the government will shut down if $S_T > \hat{S}_T$ and will produce at capacity if $S_T < \hat{S}_T$. First we shall consider the cartel.

Define Z_m as the optimal extraction path for the monopolist producer who knows with certainty that synfuels will not appear on the market under any circumstances. Define $S_T(Z_m)$ as the resource stock remaining at time T under path Z_m. Consider two cases:

Case 1: $S_T(Z_m) > \hat{S}_T$

In this case, pursuing the extraction path that would be optimal if synfuels technology did not exist causes the government to shut down, that is, prevents synfuels from being produced. The profits enjoyed by the cartel when it chooses the path Z_m are the same as the profits it would earn if synfuels technology did not exist, since synfuels do not appear on the market under Z_m. By the definition of Z_m, these profits must be at least as great as those provided by any other path which induces the government to shut down. Since any extraction path, given the appearance of synfuels, yields lower profits than the optimal path given the absence of synfuels technology, the cartel will prefer Z_m over any path which does not lead the government to shut down. Thus Z_m will be chosen by the cartel.

Case 2: $S_T(Z_m) < \hat{S}_T$

Define Z_0 as the extraction path which is optimal for the monopolist producer when the government commits itself to both construction and operation at some level y. Define $S_T(Z_0)$ as the resource stock remaining at time T under path Z_0. Since $\frac{\partial z_t}{\partial y} > 0$ for all t in [0, T), $S_T(Z_0) < S_T(Z_m)$. Therefore $S_T(Z_0) < \hat{S}_T$. Therefore the extraction path Z_0, if undertaken when the government has the shutdown option, leads the government to operate the plants (in Case 2). Note that any given extraction path Z which leads the government to choose to operate the synfuels plants generates the same revenue as it would if the government had a prior commitment to generating the plants. Therefore path Z_0 must be preferred by the cartel to any other which leads the government to operate. The government doesn't exercise the shut down option and is indifferent to having it. However, there is another option for the cartel. It can produce even more slowly in [0, T) and have a large stock $\hat{S}_T$ remaining. This will cause the government to shut down. Under most circumstances, a cartel in the absence of synfuels is already producing too slowly (see Stiglitz [1975] or Weinstein and Zeckhauser [1974]). This outcome is therefore disastrous for the government, since it has pushed the cartel the wrong way and is out the construction cost besides.

When the producers are competitive, the situation is different. Since the producers cannot collude, there are only two potential stable equilibria: the producers following the extraction path they would choose in the absence of synfuels, Z_c, with the stock remaining, $S_T(Z_c)$, being large enough to cause a shutdown; or their following the extraction path they would choose if production were certain, Z_0, with the remaining stock being too small to discourage the government from producing. Since $S_T(Z_0) < S_T(Z_c)$, if $S_T(Z_c) < S_T$, the Z_0 path will be the only equilibrium; the government will produce and will be indifferent to having the shutdown option. If $S_T(Z_0) \geq \hat{S}_T$, the Z_c path will be the only equilibrium; the government will shut down and it will regret its construction expenses. The most interesting situation arises when $S_T(Z_0) < \hat{S}_T \leq S_T(Z_c)$. In this case there are two stable equilibria, one with higher profits for producers than the other. Yet the equilibrium with higher profits will not necessarily be chosen. In the terminology of game theory, no dominant strategy equilibrium exists.

Proposition 6 has now been proven for both cartel and competitive producers. The analysis is more complex if the difference to profits from producing rather than shutting down is not a decreasing function of S_T. First of all, no equilibria may exist. In the competitive case, this would happen if Z_c led to production and Z_0 to shutdown. Second, there may be a gain to the government from the shutdown option in the case of the cartel. If the option causes the cartel to reduce S_T in order to induce shutdown, the government may gain sufficient surplus to offset the lost construction costs.

However, if Z_m (for the cartel) or Z_c (for the competitive producers) leads to shutdown, that path is an equilibrium and the government will not benefit by having the option. In sum, it is very likely that the government is better off without the opportunity to change its mind.

B. Private Firm Participation in Synfuels

We now consider alternative policies in which synfuels development and construction is carried out by private firms.

Firms seeking to maximize discounted profits face the problem

$$(15) \qquad \max_{y} \Pi = \int_T^{\infty} [p(z_t+y)y - cy]\, e^{-rt}dt - x(y)$$

The first-order condition for this problem reduces to

$$(16) \qquad \gamma(y) = \frac{c}{r}\, e^{-rT} + x'(y)$$

where $\gamma(y)$ is equal to $\int_T^{\infty} [y \cdot p'(z_t+y) \frac{\partial(z_t+y)}{\partial y} + p(z_t+y)]\, e^{-rt}$ and denotes the discounted marginal revenue from synfuels production as a function of y. Equation 16 indicates that the firm equates discounted marginal revenue with the sum of discounted marginal production costs and marginal construction costs.

1. Futures Contract with Price a Function of Output

First we examine a futures contract between the government and private firms, where the futures price offered by the government is a function of y. From equation 16 above it follows that the government can induce the socially optimal level of synfuels production through such a contract: clearly, if the futures price can vary freely with y, it is possible to construct a futures contract so that discounted marginal revenue equals discounted marginal costs when and only when the optimal y, y^*, is produced. Since it will never be marginally profitable to produce more than y^* (see Proposition 5), the government need not fear the firm will sell additional output to another customer.

2. Futures Contract with Fixed Price

Under this policy, the government promises to purchase all synfuels from the private producer at the fixed price $\bar{p}$ during the interval $[T, \infty)$. If the firm accepts such a contract, its profit function becomes

$$\text{(17)} \qquad \Pi_f = \int_T^\infty (\bar{p} - c)ye^{-rt}dt - x(y)$$

$$= \frac{1}{r}(\bar{p} - c)e^{-rT} - x(y)$$

For the firm to be interested in this contract, we must have $\bar{p} > c$. Note that

$$\text{(18)} \qquad \frac{\partial \Pi_f}{\partial y} = \frac{1}{r}(\bar{p} - c)e^{-rT} - x'(y)$$

The term $\frac{1}{r}(\bar{p}-c)e^{-rt}$ is discounted marginal revenue net of marginal operating costs. This is independent of y.

The attractiveness of this policy depends on the nature of marginal construction costs. If marginal construction costs, $x'(y)$, are constant and less than $\frac{1}{r}(\bar{p}-c)e^{-rT}$, or if they are decreasing and not bounded from below by a number which exceeds $\frac{1}{r}(\bar{p}-c)e^{-rT}$, then for large y, $\frac{\partial \Pi_f}{\partial y}$ will be positive and both Π_f will increase without limit as y increases. The firm will have an incentive to expand indefinitely; this will not in general be optimal.

On the other hand, if marginal construction costs are increasing, the government can produce the socially optimal outcome by setting $\bar{p}$ such that

$$(19) \qquad \frac{1}{r}(\bar{p}-c)e^{-rT} = x'(\hat{y})$$

Since $x'(\hat{y}) > 0$, the optimal $\bar{p}$ satisfies $\bar{p} > c$. Here the government would need to prohibit the firm from selling additional synfuels to other customers.

3. Fixed Price Guarantee

Under this policy, the government promises to purchase synfuels from the firm at the fixed price $\bar{p}$ if the firm wishes to sell at the time. The firm will take this option at time t if $\bar{p} > p(z_t+y)$. The firm's profit maximization problem now becomes

$$\max \Pi_g = \int_T^{\infty} \{\max\ [p(z_t+y),\bar{p}] \cdot y - cy\}\ e^{-rt}dt - x(y)$$

Consider the case where $\bar{p} > c$. A lower bound for Π_g can be expressed by Π_f, the profits under the fixed-price futures contract, since the firm can always obtain at least $\bar{p}$ for its output. Thus the same arguments as those advanced in the case of the fixed-price futures contract indicate circumstances when the firm will have an incentive to expand indefinitely, and the policy will not be worthwhile.

If $\bar{p} < c$, there are several possibilities to consider. If the firm intends to produce $y \geq \hat{y}$, then the guarantee is worthless to the firm, since the firm loses money at the guaranteed price. Yet the firm may still find it profitable to produce if p(q) -- equal to p(y) in this case -- exceeds c. The price guarantee, however, has no effect on the firm's behavior.

If $y < \hat{y}$, the firm's maximization problem is

$$\max_{y} \Pi = \int_{T}^{T'(y)} \bar{p}e^{-rt}dt + \int_{T'(y)}^{T_x(y)} p(z_t+y)e^{-rt}dt + \int_{T_x(y)}^{\infty} p(y)e^{-rt}dt$$

$$- \frac{c}{r} e^{-rT} - x(y)$$

where $T'(y)$ is the point in time where the market price overtakes the guaranteed price, and $T_x(y)$ is the time of exhaustion of the conventional resource. The analysis here is more complex than the analysis of the previously mentioned policies because the firm's optimizing behavior here directly depends on the behavior of resource producers and the market price of the conventional fuel. The possiblity emerges that resource producers will take account of their potential influence on the synfuels firm when determining their extraction paths. The result under these circumstances is a non-cooperative game between the synfuels firm and exhaustible resource producers, with no evident solution. The price guarantee policy therefore cannot be relied upon to generate the optimal outcome.

4. Loan Guarantee

4a. Loan Guarantee against Firm Bankruptcy

The policy described here would apply to an ongoing enterprise which is considering taking on synfuels as an additional one of its operations. Here the government guarantees the firm against bankruptcy "attributable" to the synfuels project; that is, if the firm sustains a loss on its synfuels operation and the overall net worth of the firm is negative, the government will assume the firm's debts in the amount A, where

$$A = \min \text{ (net loss attributable to synfuels, net indebtedness)}$$

This policy has little appeal in a world of certainty. Clearly if a synfuels project is privately profitable, then A equals zero and the loan guarantee is irrelevant to the firm. If synfuels are unprofitable, then there are two cases to consider: either the firm's net worth exclusive of the synfuels operation is positive, or it is not. In the latter case, the firm's outcome is the same regardless of whether it eschews synfuels or undertakes synfuels production with the government's guarantee. In the former case, the firm is made worse off by taking on synfuels, since the government's guarantee will only absorb the firm's debts, rather than restore the firm to the condition of positive net worth. Thus the attractiveness of synfuel operations ot the private firm is not improved by the government's offer of a loan guarantee against firm bankruptcy. The private firm will in general produce less than the socially optimal level of synfuels, y^*, at least when $0 < y^* < \hat{y}$, and the government's loan guarantee does nothing to improve the situation.

4b. Loan Guarantee Agaisnt Project Failure

Here the government guarantees to absorb any of the firm's losses from its synfuels operation. In a world of certainty, such a policy is essentially irrelevant to the firm: if synfuels are profitable, the guarantee is unnecessary; if the synfuels are unprofitable, the firm would do just as well to repudiate synfuels (as it would in the absence of the government's guarantee) as to produce synfuels at a loss and receive the government's bailout.

5. <u>Policies with Buyout Option</u>

By a buyout option we mean the right, reserved by the government, to cancel the project with compensation to the firm. In a world of certainty, such an option gains nothing. If the project is privately profitable, the firm will not enter into the agreement. If it is not, the government will be overseeing the project with an option to shut down; as shown in part A, it is usually a bad idea to have such an option. When uncertainty is considered, the inclusion of this option may be advantageous (see next section).

IV. Uncertainty and Asymmetric Information

A. Uncertainty

The only sorts of uncertainty we shall consider are those regarding the construction cost and the operating cost of the synfuels plant. The important complications arising from uncertainty regarding the size of the resource stock, the time of development of the synfuels plant, the level of future demands, and the security of property rights shall all be ignored. Additionally, the importing government, producers and firms are assumed to be risk-neutral.

If the government is committed to production once construction begins, the uncertainty with regard to costs has no effect on resource producers. They care only about the level of synfuels production, and that is known with certainty. If the uncertainty regarding costs takes the following simple form:

$$x(y) = x_e(y) + \varepsilon, \quad c = c_e + \eta, \quad E(\varepsilon) = E(\eta) = 0$$

the government can substitute expected values into equations of subsection II B to determine optimal y. (If the government wanted private firms to produce synfuels, it could induce the optimal level of synfuels production through a flexible futures contract of the type described in III B1 above.)

The addition of uncertainty is more interesting if the government has the option of shutting down. If the uncertainty were only with regard to construction costs, then the analysis of subsection IIIA would carry through since the government would learn nothing helpful to the second-stage problem in the course of construction. It would generally hurt to have the option of shutting down. In the case of uncertainty about operating costs, though, there is a benefit to having the option which can outweigh the disadvantages.

The option allows the synfuel project to stop if costs get too high. The value of that option obviously depends on the variance of operating costs, among other factors. Producers would be uncertain about shutdown. In the competitive case, a level of production intermediate between Z_c and Z_0 would be chosen.

B. Asymmetric Information

What if potential firms have better information regarding costs than the government? If both the government and the firm have the same expected value for costs, with the firm merely having a more accurate distribution, it is not necessary to worry, since the government can still determine and induce the level of production which is optimal *ex ante*.

In general, though, the firm will have a different expected value. As with most problems of this type, the incentive structure must be set up so that the agent with the private information makes the appropriate decision. One method to accomplish this is to offer the firm a fraction of the difference between the ex-post value of social surplus for the level of y chosen and the value of social surplus if no synfuel is produced. An optimal scheme must have this characteristic, though perhaps in disguised form (e.g. including a lump-sum transfer), since the payoff to the firm must be maximized at the maximum of V for all c and x.

V. Conclusion

In this paper we have examined certain justification for and consequences of government intervention in the production of synthetic fuels for a nation with potential monopsony power in the market for conventional exhaustible resources. The consequences of synfuels production are analyzed in the framework of a Stackelberg game involving the government of the synfuels producing nation and owners of the exhaustible resource; the government is the Stackelberg leader.

We find that the decision by owners of the exhaustible resource whether to share the market with synfuels or to exhaust the resource prior to the introduction of synfuels depends on the quantity of synfuels produced. In particular, there exists a critical quantity of synfuels $\hat{y}$ such that resource owners will share the marekt with synfuels if and only if the actual level of synfuels production is less than $\hat{y}$. These results hold in the case of monopolistic ownership of the exhaustible resource and the case of competitive ownership, although the critical quantity will differ in the two cases.

The optimal level of synfuels production, from the point of view of the synfuels producing nation, is analyzed formally in terms of the monopsony power benefits and other benefits associated with production of these fuels. We find that if marginal construction costs are non-decreasing, the optimal synfuels quantity will be greater than $\hat{y}$ -- and therefore will result in the conventional resource being exhausted prior to the introduction of synfuels -- only if synfuels production is privately profitable.

A two-stage game is developed in order to analyze alternative types of commitment to synfuels by the government. In the absence of uncertainty, a prior commitment to build <u>and operate</u> synfuels plants is shown to be preferable in general to a commitment simply to build which leaves the government with the option to shut down the synfuels plants after their construction. When the government reserves the option to shut down, it thereby grants exhaustible resource owners additional strategic influence which can result in their embarking on a very conservative extraction path in order to induce the government to shut down; this will generally have adverse consequences for the synfuels producing nation.

We examine various government policies influencing the development and production of synthetic fuels by private firms. In a world of certainty, a flexible futures contract appears the most attractive of the policies considered in terms of its effectiveness in bringing about the socially optimal production of synfuels.

Uncertainty regarding the development and operating costs of synfuels is also considered; we find that in the presence of a particular type of uncertainty, there is a possible advantage to the government's maintaining flexibility in its commitment to synfuels. The case of asymmetric intervention between firms and the government regarding synfuels costs is also examined, and an incentive-compatible mechanism for solving the information problem is presented.

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