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Holes in the Backstop: Optimal Contracts and the Saga of the U.S. Synthetic Fuels Corporation

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On June 30, 1980, Jimmy Carter signed into law the U.S. Energy Security Act, which delivered a Congressional mandate to develop a U.S. synfuels industry "to improve the nation's balance of payments, reduce the threat of economic disruption from oil supply interruptions, and increase the nation's security by reducing its dependence upon imported oil." The goal was an industry synfuel production level of 500,000 BOED by 1987 and 2 million BOED by 1992. Responsibility for directing this mammoth development program was given to the newly created United States Synthetic Fuels Corporation, a semi-autonomous federal agency directed by a full-time chairman and six board members.[1]

The Synthetic Fuels Corporation was empowered to provide financial incentives to synfuel projects in order to meet the development goals. These incentives include, in order of priority:

(i) price guarantees, purchase agreements, or loan guarantees;

(ii) loans; and

(iii) joint ventures.

The initial funding authorization for the Synthetic Fuels Corporation was approximately $15 billion. The Energy Security Act provided for possible additional funding up to a maximum of $68 billion pending a Congressional review of the Corporation's progress. A few strings were attached to the initial authorization. The Corporation was to avoid subsidies to projects that were not likely to become

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I am indebted to Kent Osband for many helpful conversations.

[1] Energy Security Act, Pub. 96-294, title I, 193, June 30, 1980, 94 Stat. 681.

commercially competitive. Initial loan guarantees and direct loans could not exceed 75% of the estimated project cost, and cumulative loan guarantees and direct loans over the life of the project could not exceed 250% of the initial cost estimate, adjusted for inflation. Participation in joint ventures was limited to no more than a 60% interest with no managerial function, and the equity interest was to be relinquished within five years following the initial production.

The Energy Security Act allowed the Synthetic Fuels Corporation to provide substantial financial incentives for synthetic fuel development while maintaining a minimal input into operational decisions. The Corporation was quickly inundated by applications for subsidies. The first solicitation by the Corporation, which concluded in March 1981, drew 63 responses for projects promoting coal liquefaction, coal gasification, oil shale, and other technologies.[2]

As of June 1983, the Corporation had committed less than $1 million of its multi-billion dollar budget, (in the form of a loan for engineering design to the First Colony peat to methanol project)[3]. More substantial in terms of eventual commitment, but without immediate budgetary impact, are the loan and price guarantees listed in Tables 1 and 2. The guarantees listed in the first table are firm obligations for the SFC, while those in the second table are in the final stages of negotiation. The levels of the price guarantees vary, but several are in the neighborhood of $11/mmBtu for synthetic gas and $60/bbl for oil.

The Synthetic Fuels Corporation has recently come under intense criticism. While much of the criticism has focused on alleged unethical behavior on the part of members of the SFC board, this is only incidental to widespread concern over the benefits of the SFC. At a time of soft energy prices and accelerating budget deficits, the $15 billion authorization of the SFC is a tempting target for budgetary reform. And indeed, a bill endorsed by the Reagan administration was introduced in Congress in the first quarter of 1984 to reduce the SFC budget by $9.5 billion, along with an imperative that funds should not be committed to projects whose products will cost significantly more than the anticipated

[2] "Synthetic Fuels Report," *Oil and Gas Journal*, June 29, 1981.
[3] "Synfuel Subsidies ......," *National Journal*, April 7, 1983.

Table 1. Synthetic Fuel Corporation Subsidies

Project	Type	Production	Assistance
Cool Water, California	Coal Gasification Low Btu	4,300 BOED for 106 mW electricity	Price Guarantees approx. $11/mmBtu (real) $120 million max.
Union Oil Parachute Creek, Colorado (phase I)	Oil Shale	10,400 BPD	Price Guarantees $400 million max.
Down Syngas, Louisiana	Coal Gasification Medium Btu	5,172 BOED	Price Guarantees approx. $11/mmBtu (real) $620 million max.
Total		19,872 BOED	$1.14 billion max.

market prices of competing fuels over the life of the project.[4] Even sterner budgetary measures have been proposed for the SFC.

The decline in world oil prices has stretched the pay-back period of many projects to the point where most are no longer economically feasible.[5] For example, in January 1982, the sponsors of the Great Plains Coal Gasification project indicated an expected profit of $1.2 billion over the first ten years of the venture. In March of 1983, their most likely forecast predicted a loss of $773 million, increasing to almost $1.8 billion if future oil prices are lower than expected.[6] In little over a year, anticipated profits fell by almost $2 billion. A notable example is Exxon, which withdrew its participation in the Colony Coal Liquefaction project by 1983.

The actual and potential commitments of the Synthetic Fuels Corporation listed in Tables 1 and 2 total almost $8 billion for a total synfuel production of about 116,000 BOED, or less than one percent of U.S. petroleum consumption in 1983. Assuming the synfuel plants last 20 years and that all commitments will be met in equal increments over the first five years, the levelized cost of these subsidies with a 15% discount rate is about $20/bbl. This is quite large relative to the market price of crude, which has averaged less than $30/bbl in 1984. Certainly this large subsidy gives cause to question the cost-

[4] "White House Synfuels Legislation to Congress," *Energy Daily*, May 30, 1984.
[5] An exceptional example is Kodak's methanol from coal plant, which is an economically successful synfuel project built with no direct government subsidy.
[6] "The Great Plains Project ....," *The Energy Daily*, April 11, 1983.

Table 2. Letters of Intent to Provide Assistance Signed or Proposed by the Synthetic Fuels Corporation

Project	Type	Production	Assistance
HOP Kern River, California	Heavy Oil	3,600 BPD	Loan and Price Guarantees $100 million max. (proposed)
Cathedral Bluffs, Colorado	Oil Shale	15,160 BPD	Loan and Price Guarantees $2.19 billion max. (signed)
Union Oil Parachute Creek, Colorado (phase II)	Oil Shale	42,152 BPD	Price Guarantees $2.7 billion max. (signed)
Kentucky Tar Sand, Kentucky	Tar Sands	5,600 BOED	Price Guarantees $543 million max. (proposed)
Northern Peat, Maine	Wet Carbonization of Peat	2,745 BOED	Loan and Price Guarantees $365 million max. (signed)
Forest Hill, Texas	Heavy Oil	1,870 BOED	Loan and Price Guarantees $60 million max.
Seep Ridge, Utah	Oil Shale	1,000 BPD	Loan and Price Guarantees $45 million max.
Great Plains, North Dakota	Lignite Gasification High Btu	24,180 BOED	Price Guarantees $790 million max.
Total		96,307 BOED	$6.793 billion max.

benefit ratio of the synfuels program.

The synthetic fuels program cannot be justified as a measure to increase energy supply. Many conventional sources of energy are capable of far larger contributions to domestic energy supply at far less cost. The "hidden energy source" — conservation — has been the most successful contributor to reduced dependence on foreign oil in recent years and should not be overlooked as a means to lessen dependence on vulnerable energy supplies in the future at less cost than by production of synthetic hydrocarbons.

A number of arguments advanced to justify subsidization of synthetic fuels also apply to conventional sources of energy. For example, to the extent that production from domestic sources of energy reduces the market power of foreign suppliers, there is a "monopsony premium" that applies to all domestic energy sources. The size of this premium may increase substantially in an oil supply disruption, during which the market power exercised by foreign producers can be particularly large.

Although the concept of a monopsony or vulnerability premium applies to all domestic energy sources and warrants a price subsidy for domestic production, the size of the subsidy may vary for different energy sources. This may seem surprising, since the value of a barrel of oil is independent of its source. Yet it is not just the production of oil that has value in offsetting the market power of foreign producers. As important is the effect of the production on the elasticity of demand perceived by foreign producers.

The demand for foreign production is the difference between total demand and domestic supply. Hence the elasticity of demand for foreign oil is a weighted difference of the elasticity of total demand and the elasticity of domestic supply, the weights being the shares of total demand satisfied by foreign and domestic supply. A cardinal rule in resource economics is that a producer will allocate production until the marginal revenue from each barrel is equal in present value. Thus today's production decision will depend on tomorrow's marginal revenue. Since marginal revenue depends on the elasticity of domestic supply as well as on the elasticity of total demand, different energy sources will have different impacts on the production decisions of foreign producers with market power if they have different supply elasticities.

This point has been established by Gilbert and Richels [1982] and by Hoel [1983]. If a new technology tends to increase the supply elasticity in the neighborhood of the market price (for example, if the technology is capable of wide fluctuations in output in response to changes in prices), this will increase marginal revenue in the future. This in turn will lead to a higher marginal revenue in the near term if producers act to balance present-value marginal revenues over time. Price in the near term also will increase if marginal revenue decreases with output, since then a higher marginal revenue means a lower output and therefore, a higher price. The opposite will occur if a new technology leads to a decrease in the supply elasticity in the neighborhood of the market price. Both marginal revenue and price in the near term will tend to fall.

Figures 1a and 1b use a simple two-period model to illustrate the consequences of new technologies with different supply elasticities for foreign producers' marginal revenues and prices. The horizontal axis measures total foreign supply, S. It is assumed that the resource will be exhausted over both periods; hence if X is consumption of foreign oil in the first period, consumption in the second period is $S - X$. The diagram shows first period consumption measured from the left and second period consumption measured from the right. In the absence of a new technology, price and marginal revenue curves in the first and second periods would be (almost) mirror images.

Figure 1a illustrates the case of a new technology available in the second period with a horizontal (infinitely elastic) supply function at the price $\overline{p}$. The supply function chops off the second period demand for foreign oil at the price $\overline{p}$ and marginal revenue in the second period is discontinuous at the point X. For values of first period consumption larger than X, second period marginal revenue (which is $\overline{p}$, discounted to the present), exceeds first period marginal revenue, while the opposite is true if first period consumption is less than X. Thus X is an equilibrium point and P_o is the corresponding initial price. Note that if the technology had been absent, marginal revenues would have been equal at a larger first period output. Therefore the first period price would have been lower without the new technology available in the second period.

Figure 1b is similar, only here the new technology allows a fixed production independent of price. This shifts both the price and marginal revenue curves in the second period to the right by the amount of the fixed production. At any value for first period consumption, second period price and marginal revenue will be lower than they would have been without the technology. Thus it is necessary to produce more in the first period in order to equate first period marginal revenue to second period marginal revenue. The result is a lower price in the first period than would have occurred without the availability of the new technology.

While a new technology with an elastic supply tends to increase current prices, a new technology with an inelastic supply has the opposite effect. The production of synthetic fuels has a large sunk

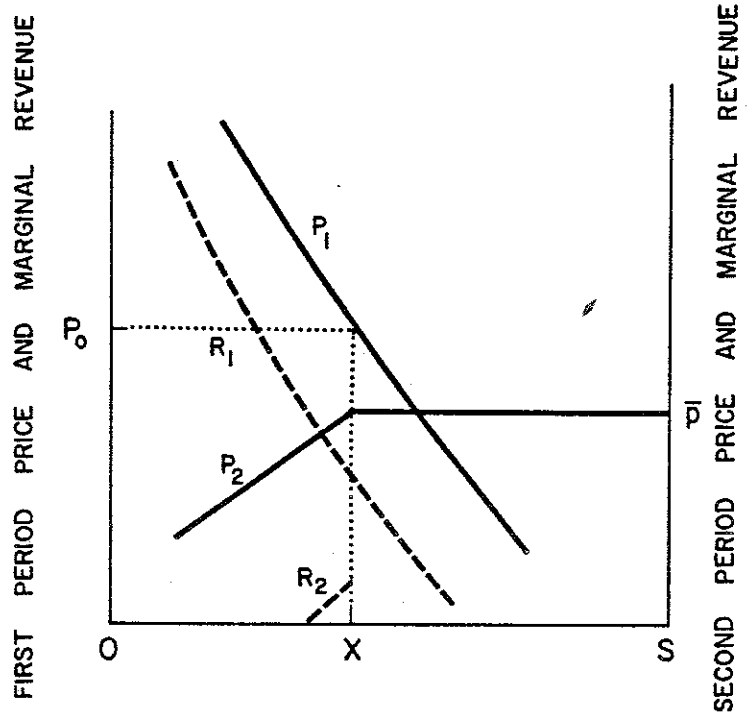

Figure 1a. Allocation of production with a perfectly *elastic* backstop technology in period 2.

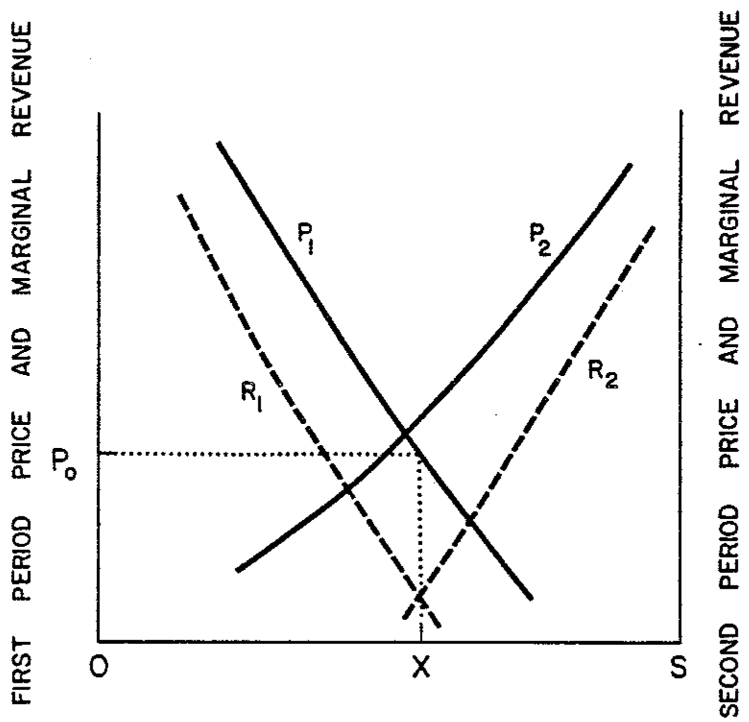

Figure 1b. Allocation of production with a perfectly *inelastic* backstop technology in period 2.

capital component, which suggests a relatively inelastic supply function at prices above the variable cost of the synthetic fuel feedstocks. While this might tend to make synfuels somewhat more valuable in holding down prices in the near term, the small amount of production involved suggests this benefit is only slight. The value of a synfuel program in merely establishing the existence of backstop technologies that could be commercially available at some future date is likely to be much more important.

Risk and infant industry arguments appeared frequently in the early debates over the desirability of subsidies for synthetic fuels. The infant industry argument is not unique to synthetic fuels, although one might argue that the magnitude of the risks involved, and the importance of the technologies to energy security, increase the importance of the infant industry consideration.

The possibility that a synfuel demonstration program might provide useful information about the possible contribution of these technologies to energy security is real, yet there is much disagreement about the state of development of these technologies. Some are relatively well-understood, while others represent new technological directions and their commercial value is more uncertain.

Given that few, if any, of the synfuel technologies are competitive at current energy prices, the main contribution of the program is in the production of information. Thus it would be desirable to design a synfuel demonstration program that maximizes the production of information about commercial feasibility.

Does the current synfuel program, or what remains of the program, succeed in maximizing the production of knowledge? The incentives offered to private industry do not appear to selectively reward those technologies that may provide more information. For example, consider two different technologies. Technology *A* has a known production cost of $60 per barrel, while technology *B* has a production cost that may be $80 with probability 1/2, or $40, also with probability 1/2.

A program that demonstrates the commercial feasibility of technology *B* has more information value than a program that demonstrates the commercial feasibility of technology *A*. However, the current program of synfuel subsidies may well select the first technology. The Synthetic Fuels Corporation offers price guarantees for new technologies which are as high as $65 per barrel over a period of several years. The first technology would be attractive given the price supports, although a demonstration program would prove little. The second technology may or may not respond to the price subsidy, depending on the sponsors' attitudes toward risk, although the potential for the production of useful information is much larger. Although the SFC selects projects for awards, the Corporation has only limited information about the technical possibilities, while the projects' sponsors have superior information and will apply for subsidies if they appear profitable.

The question we pose in this paper is how can a subsidy program be designed to encourage the demonstration of those technologies which have the highest information value? There are two parts to this problem. First, a subsidy program must deal with the risks of new technologies and offer insurance so that risk averse investors are not turned away. Second, a subsidy program must selectively attract those technologies which have a high information value. Technologies with a low information value should find the subsidy program insufficient to warrant investment. While the first part of the subsidy design problem deals with insurance, the second addresses the problem of adverse selection.

For simplicity, I will examine the design of a subsidy scheme in a market with only two sources of uncertainty, prices for synthetic fuels and total costs of production. To further simplify the problem, I will assume that a synthetic fuel plant produces "one" (normalized) unit of output at a cost C, and I will initially allow prices and costs to each take on only two values. Thus there are four states of nature defined by the pair (P_i, C_j) $i, j = 1, 2$, with $P_1 < P_2$ and $C_1 < C_2$. These states are assumed observable by the government. That is, the government can verify the realized cost of a project.

The government will be assumed risk-neutral. Let V_i be the expected value to the government of a technology with a known cost C_i. Assume $V_1 >> V_2$ and if p_j is the initial probability that the government assigns to the outcome that technology j has cost C_1, then the expected value of the technology to the government is

$$\overline{V}_j = p_j V_1 + (1 - p_j)\ V_2\ . \tag{1}$$

The high cost technology need not be profitable at any foreseeable date. In that case the value of a demonstration project for that technology is zero and the expected value of technology j is $p_j V_1$. In this situation a demonstration project has the characteristic of an option. It has value only in the low cost state, and its expected value is proportional to the probability of that state.

The government can eliminate price risk by establishing a futures price for synthetic fuels. The government's expected marginal value of synfuels at some date t is the expected oil price at t plus any externalities associated with one more barrel of synthetic fuels. These externalities include, for example, the monopsony premium discussed above. They do not include benefits from the demonstration program because that value is associated with information about the technology and is only indirectly related to the production of one more barrel of synthetic fuel from a commercial plant.

The price guarantee offered by the Synthetic Fuels Corporation is not equivalent to a guaranteed futures price, as the price guarantee does not preclude sales at higher prices if spot prices exceed the obligated minimum.[7] While clearly more attractive than a futures price at the same level, the price floor does not eliminate risk. The guaranteed floor price also is not selectively more attractive to projects that have a higher probability of low cost production. It is the higher cost projects that stand to benefit proportionately more from the possibility that future prices will exceed the guaranteed floor. [8]

Assume the government eliminates price risk by offering a guaranteed future price of $\bar{P}$. There remains the risk associated with the cost uncertainty of a new technology. The government can reduce this risk by offering a contingent payment that is higher in the state corresponding to high costs. Let X_i be the payment in state i. Full insurance exists if

$$X_2 - X_1 = C_2 - C_1 \tag{2}$$

in which case the return to the firm is independent of the state of nature.

[7] Some contracts signed by the U.S. Synthetic Fuel Corporation provide for revenue sharing in the event that product prices exceed the guaranteed price.

[8] If a project's output depends on price or cost, profits are convex in these variables with the usual neoclassical assumptions (see Varian [1980]). Thus producers may desire some price or cost risk, although this effect is likely dominated by the variability in profits for a risk-averse investor. In any case, the assumption that the output of the project is fixed implies that utility is a strictly concave function of price and cost for a risk-averse investor.

It is not unreasonable to suppose that the proponent of a new technology has better information about its prospects, and therefore we assume that the probability that technology j is low cost, p_j, is known to the firm, but not to the government. In this case full insurance leads to adverse selection, since low probability technologies will receive the same net return, despite higher insurance costs.

Suppose the government wishes to identify and subsidize only those projects for which $p_j \geqslant \hat{p}$.

The expected utility of a firm with a type j technology is

$$E(U_j) = p_j U(\pi_1) + (1 - p_j) U(\pi_2) \tag{3}$$

with

$$\pi_i = \bar{P} - C_i + X_i \, . \tag{4}$$

Let $\bar{U}_j$ be the reservation utility level for the firm with technology j. A firm will accept the subsidy if and only if

$$p_j > \frac{\bar{U}_j - U(\bar{P} - C_2 + X_2)}{U(\bar{P} - C_1 + X_1) - U(\bar{P} - C_2 + X_2)} \tag{5}$$

Full insurance will not work, since then the payoff to the firm is a constant, $\bar{U}$, and the firm will accept the subsidy if and only if $\bar{U} > \bar{U}_j$. If better technologies imply higher reservation utility levels, firms with superior technologies may not accept the subsidy, while those with lessor technologies will. Partial, or co-insurance, with $X_2 - X_1 < C_2 - C_1$ can succeed in eliminating inferior technologies, but the optimal level of co-insurance depends on attitudes toward risk, which are difficult to determine. Also, since the reservation level is not observable, a particular insurance contract may not be acceptable to technologies with a low expected cost, as firms with these technologies may have particularly high reservation levels.

In what follows we present an alternative contracting mechanism which eliminates the problem of unobservable risk attitudes and allows for selection of technologies with any probability distribution on production costs.

Consider any project, j, whose cost is a random variable $\tilde{C}_j$ with probability density $f_j(C)$ defined over the interval $(\underline{C}, \bar{C})$. The government's expected value of the technology is

$$\bar{V}_j = \int_{\underline{C}}^{\bar{C}} V(C) f_j(C)\, dC. \tag{6}$$

The government's expected value for the technology depends on the probability density $f_j(\cdot)$, which is assumed known by the project's sponsor, but not by the government. Although knowledge of the entire density function is of value to the government, assume for now that the government's missing information is only the expected cost of the project

$$M_j = \int_{\underline{C}}^{\bar{C}} C f_j(C)\, dC \tag{7}$$

Later the analysis will be extended to allow the government to obtain information about other statistics.

The government can offer contract terms which lead firms to report M_j truthfully. Such contracts are incentive-compatible with respect to expected costs and according to the revelation principle (see Meyerson [1979] and Baron and Meyerson [1982]), incentive-compatible contracts can be designed which, according to any criterion of the government, weakly dominate other contracts. Thus restricting contract terms to those which lead to truthful reporting does not limit the government's set of feasible outcomes.

The analysis here of incentive-compatible contracts follows the work of Savage [1971] and Osband and Reichelstein [1984]. Let θ be the firm's reported expected cost, with the subscript j omitted to simplify notation. The actual costs are observable after the project is completed. Hence the contract terms can depend on the actual cost, C, and the firm's reported expected cost, θ. Let $Z(C, \theta)$ be the reward to the firm given that that the firm forecasts θ and realizes C.

Incentive compatibility requires

$$\int U(Z(C,\theta))\ f(C)\ dC \leqslant \int U(Z(C,M)\ f(C)\ dC \tag{8}$$

with equality only when $\theta = M$. The incentive compatibility condition must hold for any density $f(\cdot)$ with mean M. If the actual payoff is to depend only on M, then $U(Z(C,\theta))$ must have the form

$$U(Z(C,\theta)) = A(\theta) + CB(\theta) + D \tag{9}$$

Define

$$R(\theta, M) = \int U(Z(C,\theta)) f(C)\ dC \tag{10}$$

then

$$R(\theta,M) = A(\theta) + MB(\theta) + D. \tag{11}$$

and let

$$J(M) = R(M, M). \tag{12}$$

Theorem [Savage, Osband and Reichelstein]: A necessary and sufficient condition for an incentive-compatible contract is that $J(M)$ be convex and for each θ, $R(\theta, M)$ be a linear support of $J(M)$ at the point θ, and only there.

Two possible configurations for $J(M)$ and $R(\theta, M)$ are shown in Figures 2a and 2b. Since $R(\theta, M)$ must support $J(M)$ for any M, this implies that $J(M)$ must be convex. The linearity of $R(\theta, M)$ in M has been demonstrated from the incentive compatibility constraint. $R(\theta, M)$ can be downward or upward sloping in M, but $R(\theta, M)$ must equal $J(M)$ when $\theta = M$, and must lie below $J(M)$ whenever $\theta \neq M$.

It is clear from the figures that if $J(M)$ is differentiable, then

$$J'(M) = B(M) \tag{13}$$

Thus

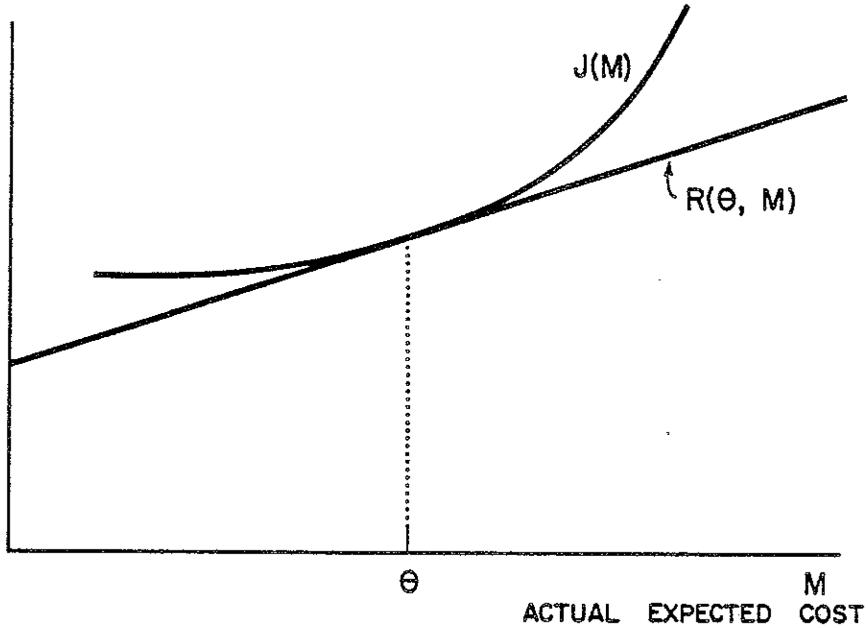

Figure 2a. Relation of $J(M)$ to $R(\theta, M)$ for incentive-compatibility — $R(\theta,M)$ *increasing* with M.

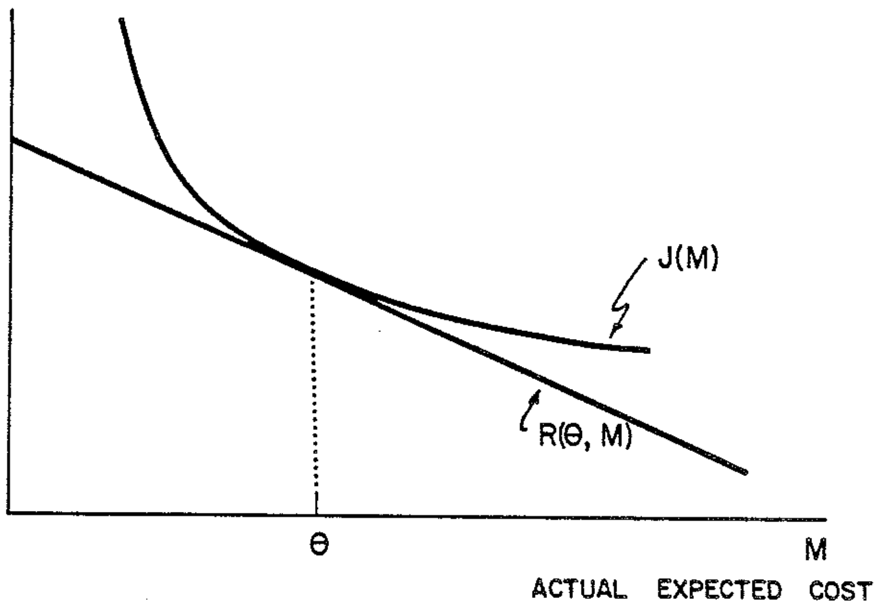

Figure 2b. Relation of $J(M)$ and $R(\theta, M)$ for incentive-compatibility — $R(\theta, M)$ *decreasing* with M.

$$J(M) = \int_{-\infty}^{M} B(x)\ dx + K \tag{14}$$

Also, from equations (11) and (12) with $\theta = M$,

$$J(\theta) = A(\theta) + \theta B(\theta) + D \tag{15}$$

Hence

$$A(\theta) = J(\theta) - \theta B(\theta) - D \tag{16}$$

and substituting (16) and (13) in (11) gives

$$R(\theta,\ M) = J(\theta) + B(\theta)(M - \theta)$$

$$= J(\theta) + J'(\theta)(M - \theta) \tag{17}$$

Since any convex function $J(\theta)$ can form the basis for an incentive compatible contract, it is useful to restrict the form of the contracts and narrow the class. One interesting property is that the expected loss function from failing to report truthfully,

$$L(\theta,\ M) = J(M) - R(\theta,\ M) \tag{18}$$

should depend symmetrically on $\theta - M$. Savage [1971] shows that this implies

$$J(M) = aM^2 + bM + d \tag{19}$$

and hence

$$R(\theta,\ M) = M(2a\theta + b) - a\theta^2 + d. \tag{20}$$

Until this point we have required only that $J(M)$ be convex. However, since we expect firms' reservation utility levels to vary inversely with M, and since we want to select those projects with lower expected costs, we require that $J'(M) < 0$ as in Figure 2b. Thus

$$J'(M) = B(M) = 2aM + b < 0 \tag{21}$$

for all feasible M. Let $\underline{M}$ be the lowest value and $\overline{M}$ the highest value for the expected cost of all projects. Then

$$2aM + b < 0 \tag{22}$$

for all M in $[\underline{M}, \overline{M}]$.

Now $J(M)$ must be convex, and consequently

$$J''(M) = 2a > 0 \tag{23}$$

Thus b must be negative and large enough in absolute value so that

$$2a\overline{M} + b \leqslant 0 \tag{24}$$

($J'(M) = 0$ at $M = \overline{M}$ is acceptable provided $J'(M) < 0$ for $M < \overline{M}$).

Condition (24) can be satisfied while still preserving ample flexibility in the behavior of $J(M)$. A larger value of a increases the curvature of $J(M)$. Increasing b in magnitude makes $J(M)$ decline more steeply with M, while the constant d translates the entire schedule up or down.

A firm will accept the subsidy program if

$$J(M) > U(M) \tag{25}$$

where $U(M)$ is the reservation level of utility for a firm with a technology whose expected cost is M. If the variation in $U(M)$ is known, and if it is monotone so that $U(M_j) > U(M_k)$ if $M_j < M_k$, a $J(M)$ can be chosen so that all firms with $M \leqslant \hat{M}$ will accept the subsidy, while those with $M > \hat{M}$ will reject the subsidy. This is possible because a and b can be selected to determine any (negative) slope for $J'(M)$. An example is shown in Figure 3.

One difficulty is that the function $U(M)$ must be known by the government. The revelation scheme cannot be used to reveal the function $U(M)$ because the reservation utility levels can only be

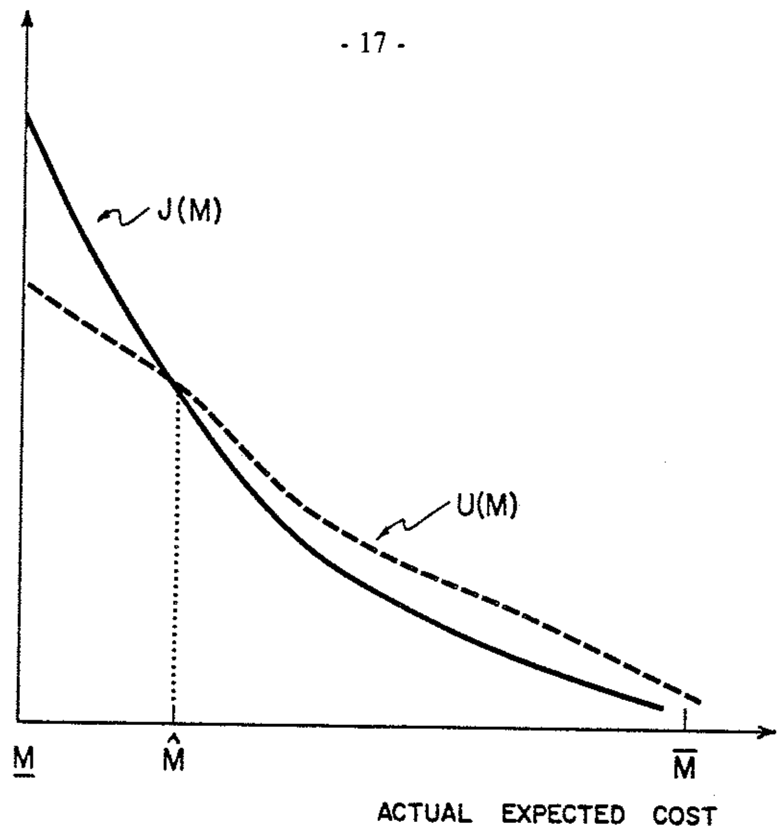

Figure 3. Relation of $J(M)$ and $U(M)$ for selection of only those projects with $M_j \leqslant \hat{M}$.

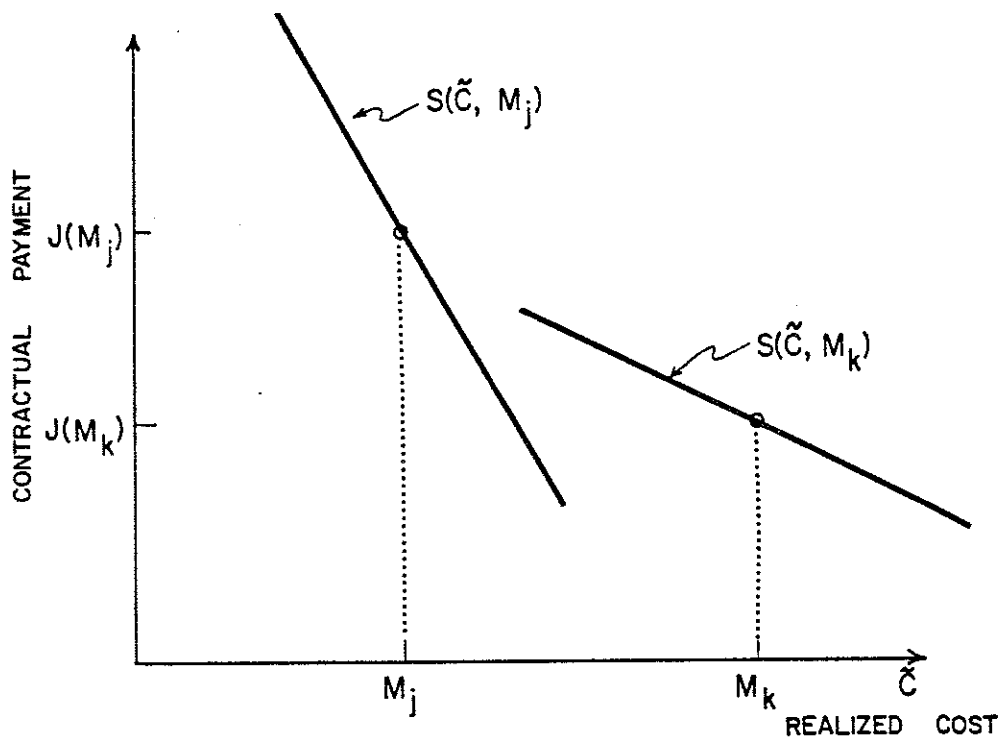

Figure 4. Contractual payments to technologies with realized costs $\tilde{C}$ when forecast expected costs are M_j and M_k.

inferred by offering a contract and observing the firm's behavior. But the decision to accept will depend on the contract terms, which in turn depend on the firm's decision to accept or reject the contract. This circularity prevents a solution using the techniques discussed here.

Some discussion of the form the incentive-compatible contracts would take in practice is in order. Note that the payoff conditional on the truthful report M and an actual cost outcome $\tilde{C}$ is

$$S(\tilde{C},M) = R(M,\tilde{C}) = J(M) + J'(M)(\tilde{C} - M) \tag{26}$$

The payoff is linear in $\tilde{C}$ with slope $J'(M)$. The slope is negative and larger in magnitude for smaller values of reported expected cost, M. Figure 4 shows two examples of $S(\tilde{C},M)$ for different values of expected cost $(M_j < M_k)$.

The implementation of these contracts is straightforward and takes the essential form of a productivity clause. The firm announces an expected cost of, say $40 per barrel. Based on the announcement, the government offers a payment which is a lump sum plus a bonus proportional to the difference between the forecast and realized cost. Both the lump sum and the bonus rate are larger if the firm forecasts a lower cost. In contrast to the incentives currently employed by the SFC, the incentive-compatible contract does not make use of a price guarantee. While current incentives guarantee a minimum gross revenue, the incentive-compatible contract offers a fixed net revenue (as a function of the sponsor's forecast expected cost) plus a variable net that depends on realized cost as well as on the forecast expected cost.

Note that the bonus provision should not be confused with the risk sharing present in insurance contracts designed to avoid adverse selection or moral hazard. The bonus takes into account risk aversion (see equation (9)-(11)) so that the realized utility of the firm is linear in the realized cost. The bonus provision is used to generate truthful reporting and its functional form is independent of attitudes toward risk.

Option Values

One difficulty with the incentive-compatible contracting mechanism discussed in the preceding is that it succeeds in selecting projects only according to expected cost. Yet the value to the government is a highly nonlinear function of a technology's realized cost, with low cost technologies worth proportionately more than high cost technologies. A project with a high cost variance may have a considerable option value even if its expected cost is high, because there is a significant probability of a low realized cost and this can more than compensate for the high expected cost. Conversely, a project with a lower expected cost may be less valuable if it has a low variance and a correspondingly low probability of commercial success.

The contract mechanism discussed in the preceding section can be extended to select projects according to their expected value to the government. The government can inform firms of its value function, $V(C)$, and then simply require firms to report the expected value for their technologies,

$$\overline{V}_j = \int_{\underline{C}}^{\overline{C}} V(C) f_j(C)\, dC. \tag{27}$$

The requirements for an incentive-compatible contract are essentially the same as before. Let θ be a firm's forecast for the expected value $\overline{V}$ (with subscripts omitted) and let $V(\tilde{C})$ be the realized value. The government must offer a payoff conditional on the forecast θ and the outcome $V(\tilde{C})$ given by

$$S(V(\tilde{C}), \theta) = J(\theta) + J'(\theta)[V(\tilde{C}) - \theta] \tag{28}$$

If $J(\cdot)$ is convex and supported by the linear function

$$R(\theta, \overline{V}) = J(\theta) + J'(\theta)(\overline{V} - \theta) \tag{29}$$

at the point $\theta = \overline{V}$, then $S(V(\tilde{C}), \theta)$ will lead the firm to report $\theta = \overline{V}$ and hence will be incentive-compatible. The firm's expected payoff with the jth project is

$$\int_{\underline{C}}^{\bar{C}} S(V_j(\tilde{C}),\ \bar{V}_j) f_j(\tilde{C})\, d\tilde{C} = J(\bar{V}_j). \tag{30}$$

Thus if $J(\cdot)$ is increasing as well as convex, (as in Figure 2b), projects with a higher expected value to the government also will receive higher expected rewards. The government can use this condition to arrange a payment schedule which is attractive only to those firms whose technologies have values above some critical expected value, $\bar{V}_j$. This requires, as before, that the government have information about the firms' reservation levels.

Conclusions

The U.S. Synthetic Fuels Corporation has been an example of too much, too soon. The initial authorization of $15 billion cannot be justified as a means to increase the production of oil and gas. Assuming all projects currently under consideration are funded at the current maximum commitment levels and produce at designed capacities, the per barrel subsidies amount to about $20/bbl, far more than would be necessary to coax the same level of production from conventional energy sources, or to achieve the same level of demand reduction from conservation.

The rationale for a synthetic fuels program must be demonstration, not production. While it is almost certain that the U.S. Synthetic Fuels Corporation will not meet its original goal of 500,000 BOED by 1987 (given that current projects identified as eligible for subsidies from the SFC amount to only about 100,000 BOED), the program could succeed in providing valuable information about the commercial potential of synthetic fuel technologies.

Narrowing the goal of the U.S. synthetic fuels program to demonstration only without a production objective still leaves considerable cause for concern about the economic efficiency of the program. The contracting procedures employed by the SFC do not appear to select projects according to their probability of commercial success. Although the SFC has a responsibility to employ a wide diversity of feasible technologies, the contracting procedures appear to select projects based on their potential for production rather than on their potential for providing information about commercial possibilities. Put another way, the option values of these risky technologies appear to receive too little attention, and the subsidies do not reward technologies with high option values. While the SFC may attempt to choose technologies with high option values, the Corporation has only limited information about the expected cost characteristics of the technologies chosen for subsidies, and the contracting procedures employed by the Corporation do not take full advantage of the information known by the projects' sponsors.

How large should a synfuel demonstration program be? The answer depends on the risk characteristics of the technologies. A technology should be subsidized if the probability it will achieve costs lower than any other technology, multiplied times the value of the cost reduction, exceeds the cost of the subsidy (and assuming there is no other more cost-effective way to obtain additional energy). Thus information is needed about the extreme value statistics of projects' anticipated costs. It would seem, however, that with the limited number of truly independent technological directions, diminishing returns in the production of information are quickly encountered. A U.S. synthetic fuels program any larger in scope than the projects already under consideration therefore appears of little benefit and efforts to trim the budget of the U. S. Synthetic Fuels Corporation very likely represent a step toward a more balanced energy program.

References

Baron, D. P. and Meyerson, R. B. "Regulating a Monopolist with Unknown Costs." *Econometrica*, Vol. 50, No. 4, July 1982, pp. 911-930.

Gilbert, R. J. and Richels, R. G. "Technology Development, Energy Dependence, and Vulnerability." Chapter 9 in J. Plummer (Ed.) *Energy Vulnerability*, Ballinger, 1982.

Hoel, M. "Monopoly Resource Extraction Under the Presence of Predetermined Substitute Production." *Journal of Economic Theory*, Vol. 30, No. 1, June 1983, pp. 201-212.

Meyerson, R. B. "Incentive Compatibility and the Bargaining Problem." *Econometrica*, Vol. 47, 1979, pp. 61-74.

Osband, K. and Reichelstein, S. "Information Eliciting Compensation Schemes," University of California, Berkeley Working Paper EAP-4, January 1984.

Savage, L. J. "Elicitation of Personal Probabilities and Expectations." *Journal of the American Statistical Association*, Vol. 66, No. 336, December 1971, pp. 783-801.

Varian, H. *Microeconomic Theory*, Norton, 1980.