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7 The U.S. Strategic Petroleum Reserve: An Analytic Framework

Jonathan Eaton and Zvi Eckstein

7.1 Introduction

The U.S. government pursues a number of policies affecting imports of oil. An excise tax is imposed on sales of gasoline, and the U.S. government maintains "strategic reserves" of oil in salt domes. There has been discussion of imposing a tariff on oil both to raise revenue and to improve the U.S. terms of trade.

Oil presents U.S. policymakers with a situation that is unusual in three respects. First, in most areas where a protectionist policy has been pursued by the government, the motivation has been primarily domestic, to maintain output and employment levels in different regions and sectors. The second-best nature of tariffs and quotas for these purposes is well known. In contrast, many of the existing and proposed policies toward oil have been justified partly on optimal tariff grounds; the United States is a large importer whose level of imports affects the world price. From a national perspective, restricting imports is a first-best policy. Indeed, the current level of protection may be too low.

Second, oil is an exhaustible resource. Imports in any period affect in an essential way not only the international price today but the world equilibrium in all future periods. The static framework of most trade-theoretic tariff analysis is inappropriate.

Third, the strategic behavior on the part of agents other than the U.S. government is important for the effects of policy. For one thing, the Organization of Petroleum Exporting Countries (OPEC) constitutes a

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large supplier. For another, U.S. policies affect the storage and extraction behavior of private agents in the domestic and world economies. The interactions of these groups must be taken into account. Again, a static framework assuming that all agents except the U.S. government are atomistic is inappropriate.

These three considerations make an analysis of optimal commercial policy in terms of traditional trade models difficult. Before an analysis of the welfare effects of the U.S. Strategic Petroleum Reserve (SPR) can be attempted, an analytic framework identifying its effects on U.S. welfare must be specified. Our purpose here is to develop such an analytic framework. The model we develop does not incorporate all aspects of the SPR that we believe to be important. Nevertheless, it suggests a set of considerations that necessarily arise in a strategic setting between a large importing country and a monopolistic supplier.

The remainder of the introduction provides a discussion of the background of the U.S. Strategic Petroleum Reserve and an outline of our analysis.

7.1.1 Background

The current pattern of general public concern about energy supplies is in sharp contrast to the prevailing pattern before 1973. In the early years after World War II, the United States was essentially self-sufficient with respect to crude oil supplies. Concern, largely by members of the petroleum industry, was focused not on problems of shortage but on price effects of abundance. As a result, the U.S. government imposed an oil imports quota in 1959 of 9 percent of the estimated domestic demand. However, imports gradually increased over time and reached approximately 23 percent of total domestic demand by 1972. In May 1973 import quotas were discontinued and a license fee system was substituted. The fee system soon became superfluous, however, with the subsequent quadrupling of world oil prices (Bohi and Russell 1978, 7, 230–35). Despite the quota, considerable excess capacity for crude oil production developed during the sixties, and regulatory federal and state agencies distributed production allocations to the various producers of crude petroleum. The real price of oil was continuously dropping during the sixties until October 1973.

Government storage of oil began in the United States in 1909 with the creation of the Naval Petroleum Reserves which serve exclusively the needs of the U.S. defense forces. As a result of the increase in oil imports to the United States and the Arab oil embargo in 1973–74, there were calls for government storage of petroleum to be held out of ground, available in the short run in relatively large amounts (Glatt 1982, 7–8). In 1973 President Nixon established Project Independence with the purpose of achieving domestic energy self-sufficiency. In the following year the

International Energy Agency (IEA) of oil consuming countries in the OECD established the International Energy Program (IEP). Participants in the program pledged to establish reserves equal to sixty days consumption (to increase to ninety days in 1980). These reserves were to include private storage (which at that time was sufficient to meet the requirements in all the participating countries). The Strategic Petroleum Reserves (SPR) program was established under the Energy Policy and Conservation Act (EPCA) of 1975 as the U.S. component of the IEA program.[1]

The EPCA is a broad piece of legislation designed to "increase domestic energy supplies and availability: to restrain energy demand (and) to prepare for energy emergencies" (Glatt 1982, 9). The act contains a detailed outline for the operation of the SPR. It explicitly claims that "the storage of petroleum products will diminish the vulnerability of the United States to the effects of a severe energy supply interruption and will provide limited protection from the short-term consequences in supplies of petroleum products." A somewhat different purpose of the SPR was suggested by Senator Henry Jackson, who was a strong supporter of the SPR: ". . . with a Strategic Petroleum Reserve, we will have greater credibility, as I see it, in dealing with this problem (oil prices), and we'll help to stabilize the price situation, which otherwise could be one of great havoc."[2]

The EPCA determined that the SPR could contain as many as 1 billion barrels but should have no less than 500 million barrels. It also required the establishment of Industrial Petroleum Reserves by the oil industry and Regional Petroleum Reserves. The Federal Energy Administration (FEA) was given control over the SPR.

Since 1977 oil has been stored at five underground salt domes and salt mine sites in Louisiana and Texas. Purchases of oil proceeded at a rate of 21 thousand barrels per day during 1977 and 162 thousand barrels per day during 1978 (see table 7.1).

In late 1978, however, as a consequence of tight oil market conditions associated with the Iranian crisis, the Carter administration postponed purchases of oil for the stockpile. At that time seven stockpiling nations agreed to curtail stockpiling acquisitions if such acquisition would "result in any pressure on the world oil market" (Glatt 1982, 22–23). Consequently, purchases fell to a daily rate of 67 thousand barrels in 1979 and 44 thousand barrels in 1980. In 1980, however, oil market conditions slackened and purchases resumed. In that year Congress passed the Energy Security Act which required that the president acquire reserves at a minimum rate of 100 thousand barrels per day (Glatt 1982, 11). In fact, during 1981 and 1982 the average acquisition rate has far exceeded that minimum. An issue for the management of the stockpile is whether acquisitions (or drawdowns) should respond to world oil market condi-

Table 7.1 **Average Crude Petroleum Production, Petroleum Consumption and End of Year Petroleum Stocks[a]**

	Thousands of Barrels per Day							Millions of Barrels (stocks)		
	Total World Production	World Minus USSR and China Production	OPEC Production	US Production	US Consumption	IEA[b] Consumption (inc. US)	SPR[c]	US (inc. SPR)	SPR	OECD[d] (inc. US)
1973	55748	46193	30989	8208	17308	34150	—	1008	—	NA
1974	55910	45595	30729	8774	16653	32960	—	1074	—	NA
1975	52552	41837	27155	8375	16322	31870	—	1133	—	NA
1976	57405	45592	30738	8132	17461	33770	—	1112	—	NA
1977	59795	47239	31278	8245	18431	34930	21	1312	7	3152
1978	60165	46898	29805	8707	18847	35880	162	1278	67	3089
1979	62698	49116	30928	8552	18513	35900	67	1341	91	3358
1980	59452	45568	26890	8597	17056	33000	44	1392	108	3566
1981	55710	41885	22665	8572	16058	31400	256	1484	230	3537
1982 (March)	51800	37980	18415	8597	15560	31600	182	1401	249	NA

SOURCE: U.S. Department of Energy, *Monthly Energy Review*, September 1982.

[a]Petroleum stocks include crude oil, unfinished oils, natural gas plant liquids, and refined products.

[b]The International Energy Agency includes twenty-one member nations (see details in the *Monthly Energy Review*).

[c]Strategic Petroleum Reserves.

[d]Organization for Economic Cooperation and Development.

tions (as the IEA agreement would suggest) or proceed independently of world market conditions (as implied to some extent by the Energy Security Act of 1980). Our analysis explores this issue.

As of March 1982 the reserves contained 250 million barrels of crude oil, while the current plan is to place 750 million barrels of oil in storage by the end of 1989. Since 1975 several studies have analyzed the ideal size of the SPR. They all try to determine the level of reserves that could maintain the rate of consumption in a period of disruption at the rate in "normal" years. The recommended size varies from 500 to 1000 million barrels (Glatt 1982, 41).

The storage facilities in the salt domes and mines have created several technical problems, including the possibility that the crude petroleum could not be pumped out of storage. It seems, however, that most of these technical issues are now resolved. Since only crude petroleum is stored in the SPR, several different types of crude oil must be stored to provide for different oil by-products.

An important and difficult question for the FEA to consider is the definition of supply interruption that triggers drawdowns from the SPR. An integral issue is the size of the drawdown and the distribution of the reserves in a case of supply interruption. These issues, as well as the decision to establish the SPR in the first place, require an understanding of the rationale and the objectives of the SPR.

The U.S. oil industry requires about 1 billion barrels of crude oil as minimum operating stocks, which equals about sixty days of petroleum consumption. The current goal of the SPR would almost double the days of consumption from the U.S. stock (table 7.1). The United States is a large consumer of oil; it consumes about 36–40 percent of world oil production (excluding the USSR and China). OPEC produces about 50–55 percent of the world production (excluding the USSR and China). As such, we suggest the view that the world oil market consists of one large producer (OPEC) and one large consumer (the United States) is a reasonable first approximation. However, the effect of other (small) producers and consumers as well as the large local production of oil in the United States (about 60 percent of current U.S. consumption) should be considered in extensions of this paper.

7.1.2 Outline and Summary

In section 7.2 we develop a simple two-period model of an oil importing country (the United States) and an oil exporter (OPEC). In section 7.3 we examine the competitive equilibrium of this model. We show that under certainty and in the presence of a full set of contingent commodity markets there is no role for inventories, not to mention government inventories, of any form since there are costs of holding inventories. Introducing a "convenience yield" on inventories, on the basis of their use in facilitating production, provides a justification for holdings of inventories on the part of the private sector. In the absence of production externalities, however, there is no reason for the government to hold inventories. Introducing uncertainty by itself does not provide an argument in favor of U.S. private inventories. Uncertainty combined with the absence of full contingent commodity markets or U.S. property rights in OPEC does imply a role for inventories as a form of portfolio diversification on the part of the United States. Private agents, however, have an incentive to hold inventories at the level that maximizes expected U.S. national welfare. In the absence of externalities, then, we can find no argument in favor of U.S. government inventories when all agents, including the government, behave competitively.

Eckstein and Eichenbaum (1982) show that when oil suppliers are competitive and U.S. imports have an effect on oil prices, an optimal, time consistent tariff policy exists for the United States. However, there is no role for government inventories. Eckstein and Eichenbaum conjectured that if there is a case for government inventories it should stem from strategic considerations arising from the fact that oil prices decrease as U.S. inventories rise.

In section 7.4 we turn to a strategic setting in which the U.S. government and OPEC both have the potential to exercise market power. Imposing the optimal tariff each period (the strategy considered by Eckstein and Eichenbaum 1982) provides the first-best means for the government to exploit its market power. However, unless the government sets its tariffs *before* OPEC establishes its price each period, the government has no incentive to set a tariff at the ex ante optimal level at the time it makes its tariff decision.

In the absence of equity investment by OPEC in the United States the ex post optimal tariff is in fact zero. If OPEC has invested in U.S. equity, however, the optimal ex post tariff is positive as long as oil and capital are complements in production. The tariff acts indirectly as a tax on OPEC's capital income. In anticipation of the tariff, OPEC sets a lower price in the second period. OPEC reduces its price so much that the U.S. price is actually lower despite the tariff. In addition, equity investment by OPEC acts *directly* to reduce OPEC's second period price. The reason is that OPEC takes into account the effect of its pricing decision on the rate of return on its investment in the United States. When capital and oil are substitutes, a higher oil price means a lower return. There are thus two channels whereby a high level of equity investment by OPEC in the United States acts to reduce the second period price of oil. Nevertheless, even when equity holdings are positive, the government would increase U.S. welfare if it could credibly impose the tariff that is optimal from an ex ante perspective.

In this context inventories can act as a second-best substitute for a tariff. The government can reduce the period 2 price by buying inventories in period 1 and selling them in period 2. In section 7.4 we show how, given the period 1 price, the government has an incentive to buy inventories in period 1 and to sell them in period 2 in order to lower the period 2 price. No atomistic private agent has an incentive to pursue this policy since he would take the second period price as given. Whether the government's ex post optimal inventory response actually raises U.S. welfare vis-à-vis the no inventory situation cannot be ascertained in general. In fact it could go either way.

Nichols and Zeckhauser (1977) show how, in the framework we consider here (in the absence of taxes or investment of any form), an inventory policy can raise U.S. welfare as well as OPEC's. An inventory policy reduces the distortion resulting from OPEC's monopoly power. The United States and OPEC share the gain. We present their example in section 7.5. We find, however, that their result is very sensitive to their specification of the problem. We show in another example that if OPEC's utility function is logarithmic rather than linear in each period's consumption, a U.S. inventory policy *lowers* U.S. welfare relative to a no inventory situation. A lower U.S. welfare is also obtained when OPEC and the government set price and inventory simultaneously rather than with OPEC acting as a Stackelberg leader. In each case the positive impact of the anticipation of a U.S. inventory on the first period price more than offsets its negative impact on second period price. When the government chooses inventories, the period 1 price is a bygone so that the government nevertheless has an incentive to set inventories at a positive level. In this case the government's capacity to acquire a stockpile actually reduces U.S. welfare.[3] These results imply that if a government inventory policy is to raise U.S. welfare, inventory purchases must respond to OPEC's prices, that is, OPEC must act as a Stackelberg leader in setting price each period. Another example shows that when the government acts as a Stackelberg leader in setting inventories, the optimal level is zero.

Section 7.6 contains a discussion of some other work that considers the desirability of government inventories. Here we discuss papers by Maskin and Newbery (1978), Wright and Williams (1982), and Tolley and Wilman (1977). Finally, section 7.7 contains some concluding remarks.

7.2 The Model

In this section we describe the main features of the model considered in this paper. Our focus is on bilateral trade in an exhaustible resource, oil, that together with capital enters into production of a single consumed good. There are two nations: the oil consuming country—USA; and the oil supplying country—OPEC. The extraction costs of oil are zero and there is no depreciation of capital. Furthermore, the consumption good is only produced in the USA.

There are two periods of consumption and production in the model. If the consumption good is stored in the first period it serves as capital in the second period. OPEC can invest some of its oil revenues in the first period in the USA and receive the interest payments in the second period.

The definitions of the variables in the model are as follows:

C_i = consumption in the USA in period $i = 1, 2$.

C_i^* = consumption in OPEC in period $i = 1, 2$.

K_i = capital stock in the USA in period $i = 1, 2$, (K_1 is given as an initial condition).

$\Delta K = K_2 - K_1$ = investment in capital in the USA in the first period.

O_i = consumption of oil in the USA in period $i = 1, 2$.

I = inventories of oil in the USA at the end of the first period.

M_i = imports of oil in the USA in period $i = 1, 2$.

θ_i = one plus the import tax rate on oil in the USA in period $i = 1, 2$.

θ_k = one plus the tax rate on foreign investment in the USA in period 2.

P_i = international price of oil in terms of the single consumption good in period $i = 1, 2$.

r = interest payments on capital investment in the USA in the second period.

R^* = stock of oil in OPEC at the beginning of the first period.

$Q_i = F(K_i, O_i)$ = output of the consumption good in the USA in period $i = 1, 2$. $F(\cdot, \cdot)$ is strictly concave in both arguments.

H = OPEC investment in the USA in period one.

$D(I)$ = Units of oil available in the second period given an inventory of I units of oil in the first period. For all $I > 0$, $0 \leq D(I) \leq I$, $D'(I) > 0$. $I - D(I)$ equals the carrying costs of oil inventories.

Preferences of the representative consumer/producer in the USA and OPEC are given, respectively, by

$$U(C_1, C_2) = U(C_1) + \beta U(C_2), \quad U^*(C_1^*, C_2^*) = U^*(C_1^*) + \beta^* U^*(C_2^*),$$

where $U(\cdot)$ and $U^*(\cdot)$ are strictly concave, and β and β^* are between zero and one. Obviously, one may consider a much more complicated model in which, for example, the total reserves of oil in OPEC, R^*, are uncertain, the USA also has an exhaustible stock of oil, extraction of oil is costly, there are third countries, and the like. We later consider some extensions along these lines, but prefer first to present out model in its simplest form.

While this framework *is* very simple, we believe that it captures the essential relationships between the United States and the oil producing countries. First, it recognizes, although in a simple way, that the supply of oil depends fundamentally on the *intertemporal* allocation of resources. Second, OPEC countries do receive a large share of their consumption goods from the OECD countries. Third, many OPEC countries have substantial investments in OECD countries. Our model allows their oil pricing decisions to affect their return on these investments.

We shall use the model first to consider the competitive allocation of resources in the absence of government intervention. In particular, we wish to determine if there is a case for the government to hold inventories of oil in a competitive, perfect foresight world. The "second-best" arguments in favor of the SPR are not considered, since we do not want here to justify one policy instrument because of the misuse of another policy instrument.

7.3 The Competitive Case

The perfect foresight, optimal allocation can be characterized by solving the "social planning" problem of the above economy. It is straightforward to show that this allocation is identical to the world competitive, perfect foresight equilibrium.[4]

The social planning problem is to maximize

$$\delta_1[U(C_1) + \beta U(C_2)] + \delta_2[U^*(C_1^*) + \beta^* U^*(C_2^*)], \tag{1}$$

subject to

$$C_1 + C_1^* + \Delta K \leq F(K_1, O_1), \tag{2}$$

$$C_2 + C_2^* \leq F(K_1 + \Delta K, O_2), \tag{3}$$

$$O_1 + O_2 + I - D(I) \leq R^*, \ \delta_1 \geq 0, \ \delta_2 \geq 0; \tag{4}$$

by choice of C_1, C_2, C_1^*, C_2^*, ΔK, O_1, O_2, and I. Let λ_1, λ_2, and μ be the Lagrangian multipliers of equations (2), (3), and (4), respectively. Equations (2) and (3) are the world budget constraints each period. Equation (4) states that world oil consumption across the two periods cannot exceed the total supply, $\bar{R}$. Then, the first-order condition with respect to inventories is

$$-\mu[1 - D'(I)] \leq 0 \qquad (= 0 \text{ if } I > 0). \tag{5}$$

Given that $\mu > 0$, since we assume an economy in which oil is consumed each period, equation (5) implies that $I = 0$ if $0 < D'(I) < 1$. Given our assumption that oil does not appreciate in storage, we conclude that in a perfect foresight equilibrium there will be *no* storage of oil. The reason is that the economy is better off holding the oil in the ground with zero inventory costs than above the ground incurring the cost $I - D(I)$. It is also obvious that the inclusion of linear extraction costs does not affect the above result.

It is of interest to see the characterization of the competitive equilibrium resulting from the above planning solution. Given that P_i is the real price of oil in period $i = 1, 2$, we get that $P_i \equiv (\mu/\lambda_i) = F_2(K_i, O_i), i = 1, 2$, from the first-order conditions with respect to O_i. Then, the equilibrium is characterized by the conditions

$$\frac{U'(C_1)}{\beta U'(C_2)} = \frac{U^{*\prime}(C_1^*)}{\beta^* U^{*\prime}(C_2^*)} = \frac{P_2}{P_1}, \tag{6}$$

and

$$\frac{P_2}{P_1} = F_1(K_2, O_2) \equiv r. \tag{7}$$

Equation (6) establishes that the marginal rate of substitution is equal to the marginal rate of transformation in both the USA and OPEC, and equation (7) is simply the Hotelling rule for extraction of an exhaustible resource.[5]

7.3.1 Convenience Yield

We next consider the private storage of oil. Private stocks of crude petroleum in the United States are in fact as large as the level of monthly sales (about 300–350 million barrels) and their existence should be explained. These inventories, termed "operating stocks" by the industry, facilitate the process of getting oil to consumers. In economic terms the argument for operating stocks is called the "convenience yield" (see Brennan 1958). It can be modeled analytically using ad hoc functional forms of the costs of holding inventories. These typically yield an inventory rule that is a function of oil consumption or output production (see, e.g., Eckstein and Eichenbaum 1982). Usually it is assumed that for an inventory below some given level, say I^*, there are *negative* marginal costs of inventories where the level I^* is given exogenously. We could introduce a convenience yield into our example by considering a storage technology, $D(I)$, that has the properties $D(I) > I$, $D''(I) < 0$ over some range $I < \bar{I}$. The competitive solution would then establish

$$P_2 D'(I) = P_1 r, \tag{8}$$

as the first-order condition for a maximum. Equation (6) and (7) would continue to characterize the optimum. Thus the competitive solution would be fully characterized by the conditions

(9)
$$\frac{U'(C_1)}{\beta U'(C_2)} = \frac{U^{*\prime}(C_1^*)}{\beta^* U^{*\prime}(C_2^*)} = F_1(K_2, O_2) = \frac{r}{D'(I)} = \frac{P_2}{P_1}$$

The first three of these conditions would also characterize the planner's solution. If $D(I)$ is increasing and differentiable, the solution establishes $D'(I^*) = 1$ both for the social planner and for the competitive equilibrium. The "convenience yield" argument thus justifies private operating stocks but not any government SPR.

7.3.2 Uncertainty

Another popular reason for private and possibly public inventories is given by the existence of uncertainty about the oil supply or proven oil reserves. The argument is based on precautionary savings to smooth final consumption. In the presence of a full set of contingent commodity markets, this argument seems without merit. Private agents could optimally insure by trading contingent claims. If storage is costly (i.e., if $D(I) < I$), then an allocation (supportable by a competitive equilibrium) without storage exists which is Pareto superior to any allocation with storage. This result would not extend to a situation in which extraction costs are nonlinear, however.

It is possible that a full set of contingent claim markets does not exist. However, a more fundamental problem might be the nonexistence of property rights in an international context. Private agents in the USA cannot obtain property rights over oil that is in the ground in OPEC. Americans may be prohibited from acquiring these rights or else they may not trust OPEC governments' willingness to enforce these rights. In this context an additional argument for storing oil emerges: as a form of insurance.

We illustrate this result in the competitive model by assuming that the total stock of OPEC reserves, R^*, is not known until period 2.[6] We assume there *are* no contingent commodity markets or futures markets. (In fact, there are no formal contingent markets, and futures markets are limited, none covering a period greater than one year.) All oil is sold on spot markets. The second period price, then, is established by equating second period supply, $[R^*(s) - O_1 - I + D(I)]$, where $R^*(s)$ denotes the oil supply in state of nature, s, to second period demand, O_2, determined by the condition

(10)
$$F_2(K_1 + \Delta K, O_2) = P_2.$$

This condition implicitly defines a demand function

(11)
$$O_2 = E(K_1 + \Delta K, P_2),$$

which is increasing in $K_1 + \Delta K$ and decreasing in P_2. Equilibrium price in state s is then established by the condition

$$R^*(s) - O_1 - I + D(I) = E[K_1 + \Delta K, P_2(s)]. \tag{12}$$

The interest payment on investment is given by

$$F_1[K_1 + \Delta K, O_2(s)] = r(s). \tag{13}$$

Consider now the inventory decision of a USA agent in period 1. He chooses ΔK, I, and O_1, taking P_1, H, and $r(s)$ as given, to maximize:

$$\begin{aligned} &U[F(K_1, O_1) - \Delta K + H - P_1(O_1 + \mathrm{I})] \\ &+ \beta \sum_s \Pi\,(s)\ U\{F[K_1 + \Delta K, E(K_1 + \Delta K, P_2(s))] - r(s)\,H \\ &- P_2(s)[E(K_1 + \Delta K, P_2(s)) - D(I)]\}. \end{aligned} \tag{14}$$

Here $\Pi(s)$ denotes the probability with which $R^* = R(s)$. The first-order conditions for ΔK and I are

$$U'(C_1) \geq \beta \sum_s \Pi\,(s)\ U'(C_2)\,r(s) \qquad (= 0 \text{ if } \Delta K > 0). \tag{15a}$$

$$P_1\ U'(C_1) \leq \beta \sum_s \Pi\,(s)\ U'(C_2)\ P_2(s)\ D'(I) \qquad (= 0 \text{ if } I > 0). \tag{15b}$$

If ΔK and I are strictly positive, these conditions imply

$$\sum_s \Pi(s)\ U'(C_2) r(s) = \sum_s \Pi(s)\ U'(C_2) \frac{P_2(s)}{P_1} D'(I). \tag{16}$$

The OPEC first-order conditions with respect to H and M_1 yield that

$$\sum_s \Pi(s)\ U^{*\prime}(C_2^*)\ r(s) = \sum_s \Pi(s)\ U^{*\prime}(C_2^*) \frac{P_2(s)}{P_1}, \tag{17}$$

if H and M_2 are positive. Under certainty, equation (16) is inconsistent with (17), which yields the Hotelling rule, $(P_2/P_1) = r$, since $D'(I) < 1$ (see [9]; and the left-hand side of [16] is greater than the right-hand side). Hence, under certainty, $I = 0$. Under uncertainty, when $U(C_i)$ is concave, then both (16) and (17) can hold as equalities. Hence, there are equilibria in which I is positive. The reason is that under uncertainty $U'(C_2)$ and $P_2(s)$ are positively correlated when $D(I) = 0$. Via Shephard's lemma

$$\frac{dU'(C_2)}{dP_2} = -\ U''(C_2)\ [O_2 - D(I)]. \tag{18}$$

The diminishing marginal utility of consumption implies that this expression is positive (assuming that some oil is imported in period 2). Thus when $P_2(s)$ is high, $U'(C_2)$ will also be high: for oil importers, a high price of oil lowers consumption, raising the marginal utility of consumption.

The positive correlation between $U'(C_2)$ and $P_2(s)$ raises the term on the right-hand side of equation (16). The *expected return* on inventories is greater because inventories serve as a hedge. This provides a justification for holding inventories.

Two comments about this result are in order. First, if USA agents could buy oil in the futures market or obtain property rights over oil in the ground in OPEC, inventories would not be desirable as long as $D(I) < I$. Second, this result by itself does not justify the establishment of a *government* reserve unless the government has a superior storage technology (i.e., for the government $D(I)$ is larger).

The simplest competitive case thus yields no justification for inventories at all. A convenience yield, however, or uncertainty with an incomplete set of contingent commodity markets and imperfect cross-national property rights are reasons why oil stocks may benefit the USA. In these cases the private sector holds a level of inventories that maximizes social welfare as well. Therefore, one may still wonder what scope there is for *government* holdings of inventories. Next, we find that once strategic considerations in the relationship between OPEC and the USA are introduced, an argument for a *government* SPR emerges. An argument can also emerge, however, in favor of divesting the government of its capacity to store oil.

7.4 The Bilateral Monopoly Case: A Possible Justification for the SPR

The presence of national market power frequently yields situations in which government intervention can improve national welfare if not world welfare. The nationally optimal tariff is an example.

In fact, in 1978 OPEC provided 65 percent of production in noncommunist countries while the United States accounted for 55 percent of consumption in main consuming countries.[7] There is certainly a presumption of market power on the part of OPEC to the extent that it can maintain its cohesiveness as a cartel. We assume here that it can. There seems to be a presumption of market power on the USA's part as well, although this is less strong. If we were to consider a potential oil-*importing* country cartel consisting of the OECD or the International Energy Agency (IEA), the assumption of a bilateral monopoly situation between sellers and buyers would certainly fit the facts closely. Even in the absence of a cartel arrangement among importers, the assumption of bilateral monopoly seems to capture much of the relationship between OPEC and the USA.

In this section we consider how the presence of a bilateral monopoly situation can create an incentive on the part of the government to establish an SPR. To focus clearly on strategic considerations, we ignore the convenience yield and uncertainty considerations raised earlier. In the next section we show, via example, that by pursuing an inventory policy the government can raise USA welfare. But it can also lower it. Because results are, in general, sensitive to the specification of behavior, we find it useful to discuss alternative "rules of the game" that we can choose among.

7.4.1 Rules of the Game

We now consider alternative rules of behavior in relationships between the USA and OPEC. We identify as OPEC's strategy variables the oil prices (P_1, P_2) and OPEC's level of investment in the USA (H). The USA's strategy variables are the tariff rates on oil in periods 1 and 2 ($\theta_1 - 1$ and $\theta_2 - 1$), the tax rate on OPEC's investments ($\theta_k - 1$), and the level of government inventory holdings (I^g). USA private agents, behaving atomistically, choose oil consumption in periods 1 and 2, (O_1, O_2), investment (ΔK), and private inventories (I^p) to maximize discounted utility. We assume that USA private agents correctly anticipate the policies that are actually pursued both by OPEC and by the USA but then take them parametrically.

Open Loop Policies

An open loop policy is one in which values of the strategy variables are set for the current and future periods as of the initial period. Within the class of open loop policies we can identify strategic variables that are chosen by one player prior to the choice of some other strategic variable by the other player (in which case the first player acts as a *Stackelberg leader* with respect to those variables, the first player taking into account the effect of his choice on the response of the second player), or the decisions are made simultaneously by the two players (in which case they act as *noncooperative Nash players* with respect to those variables, each taking the level set by the other player as given in making his choice).

When the game is specified as open loop, the issue of time consistency does not arise. The levels of the strategic variables set in the first period (whether in a Nash or Stackelberg fashion) are the ones actually implemented. A difficulty with this formulation is that the players may not have an incentive, in the second period, to follow the open loop solution. Because of this inconsistency, the open loop policy will not be credible. Open loop solutions therefore may not be able to explain the behavior that we observe. Nevertheless, the open loop solution provides an interesting benchmark against which to compare time-consistent solutions.

Feedback Solutions and Perfect Equilibria

An alternative policy is one that maximizes the objectives of each player as of the period the policy is implemented, taking previous policy as given. The two players thus play a separate game each period. The policies that are pursued each period are the outcome of *that period's* game. Hence, the players' decisions are based on feedback from the previous period. When players correctly take into account the effect of each period's decision on the outcome of subsequent games, then the solution to the set of games is described as "perfect." (See Selten 1975 for a discussion of perfection and Kydland 1977 for a discussion of the distinction between open loop and feedback solutions.) The advantage of a specification of this type is that the emerging solution is based on behavior that is in each player's interest at the time he acts.

Within the class of feedback solutions, we can also distinguish between variables that are chosen in a Nash or Stackelberg fashion. This choice should be dictated by the underlying technology of the problem.

We do not consider all possibilities for structuring the game. We assume the following rules:

R1(a): OPEC acts as a Stackelberg leader each period with respect to price (i.e., OPEC chooses P_1 before USA chooses O_1 and I^g; OPEC chooses P_2 before USA chooses θ_2 and θ_k).

R1(b): OPEC and USA act as Nash players with respect to P_1, θ_1, and I^g in period 1, and with respect to P_2, θ_2, and θ_k in period 2.

R1(c): USA acts as a Stackelberg leader each period (i.e., USA chooses θ_1 and I^g before OPEC chooses P_1, USA chooses θ_2 and θ_k before OPEC chooses P_2).

R2: USA private agents take the values of USA and OPEC strategic variables as parametric. Subject to these parameters they maximize utility.

R3: Both OPEC and USA correctly anticipate the effect of their policy on USA private agents' behavior.

R4: All agents have perfect foresight.

Rule 1(a) best captures the strategy implicit in the IEA's stockpiling procedures: purchases are made contingent upon the oil price that OPEC sets. Rules 1(b) and 1(c) reflect more accurately the stockpiling procedure embodied in the Energy Security Act: purchases proceed independently of OPEC's price.

7.4.2 The Solution

We now attempt to characterize the solution to the game. Since first period decisions affect outcomes in both periods while, in the second period, first period decisions and outcomes are a bygone, it is simplest to consider the second period first.

The Second Period

Profit-maximizing firms in the USA private sector choose O_2 to maximize profits. Given the USA domestic price, $\theta_2 P_2$, this behavior implies the first-order condition

(19) $F_2(K_1 + \Delta K, O_2) \leq \theta_2 P_2 \quad (= 0 \text{ if } O_2 > 0)$,

which implicitly defines the second period oil demand function

(20) $O_2 = E(\theta_2 P_2, K_1 + \Delta K)$,

where $E_1 < 0$, $E_2 \lesseqgtr 0$, as oil and capital are substitutes or complements. In the case of constant returns to scale (CRS) in capital and oil this function takes the form:

(20′) $O_2 = e(\theta_2 P_2)(K_1 + \Delta K)$.

Substituting (20) into (19) gives second period output as a function of the capital stock and the second period oil price:

(21) $G(K_1 + \Delta K, \theta_2 P_2), \quad G_1 > 0, G_2 < 0$.

In the case of CRS, this function takes the form:[8]

(21′) $g(\theta_2 P_2)(K_1 + \Delta K)$.

OPEC's investment in the USA pays an interest rate r equal, before tax, to the marginal product of capital

$$G_1(K_1 + \Delta K, \theta_2 P_2)[= g\ (\theta_2 P_2) \text{ under CRS}].$$

We assume that USA's objective is to maximize the utility of USA private agents. In period 2, first period consumption is, of course, a bygone, and the policy in period 2 can only affect period 2 consumption. The USA therefore maximizes $U(C_2)$ where

(22) $C_2 = G(K_1 + \Delta K, \theta_2 P_2) - \theta_k G_1 H$
$\quad - P_2[E(\theta_2 P_2, K_1 + \Delta K) - D(I^g) - D(I^P)]$.

Under rules R1(a) and R1(b), government policy involves choices of θ_2 and θ_k that maximize C_2 taking P_2, as well as ΔK, I^g, and O_1, as given. C_2 is strictly decreasing in θ_k, and a maximum, therefore, involves establishing θ_k at its minimum level (zero), effectively confiscating OPEC investments. When $\theta_k = 0$, the first-order condition for a maximum with respect to θ_2 is given by

(23) $F_2 - P_2 = 0$,

which is satisfied at $\theta_2 = 1$, the zero tariff condition. Since the USA acts taking P_2 as given, the optimal tariff is zero.

An interesting case emerges when USA is constrained to set $\theta_k > 0$, that is, not to confiscate fully OPEC investment. In this case the first-order condition for θ_2 is

(24) $F_2 = P_2 + \theta_k F_{12} H$.

Thus, if capital and oil are complements ($F_{12} > 0$) then the tariff on oil should be positive (raising F_2 above P_2), and conversely if they are substitutes ($F_{12} < 0$). Intuitively, the tariff acts as an indirect tax on OPEC investments.[9] If the USA is constrained not to tax these investments fully, then a tariff redistributes income away from OPEC to the USA. In the CRS case, the formula for the optimal tariff is given by

(25) $$t^* = \frac{\theta_k H}{K + \Delta K - \theta_k H},$$

in which case the tariff is independent of P_2. When there is no OPEC investment in equity or when $\theta_k = 0$ (confiscation of OPEC equity) the optimal tariff is zero.

Consider, now, OPEC's problem. In period 2 OPEC sets P_2 to maximize the utility of OPEC's period 2 consumption. As with the USA, period 1 consumption is at this point a bygone. OPEC therefore sets P_2 to maximize period 2 utility, $U^*(C_2^*)$, where

(26) $$C_2^* = P_2[O_2 - D(I^g) - D(I^P)] + \theta_k G_1 H.$$

Under rule R1(a), OPEC considers the effect of P_2 on θ_2. The first-order condition with respect to P_2 is given by:

(27) $$O_2 - D(I^g) - D(I^P) + (P_2 + \theta_k G_{12} H) \frac{dO_2}{d(\theta_2 P_2)}(\theta_2 + \frac{d\theta_2}{dP_2} P_2) = 0,$$

subject to the constraint

$$O_2 - D(I^g) - D(I^P) \leq R^* - M_1.$$

Dividing (27) by O_2 yields

(27′) $$1 - \frac{D(I^g) + D(I^P)}{O_2} - \lambda(\theta_2 P_2)(1 + \zeta) \left(1 + \frac{\theta_k F_{12} H}{P_2}\right) = 0,$$

where

$$\lambda(\theta_2 P_2) \equiv \frac{dO_2}{d(\theta_2 P_2)} \frac{(\theta_2 P_2)}{O_2},$$

the elasticity of USA oil demand with respect to the USA price ($\theta_2 P_2$), and

$$\zeta = \frac{d\theta_2}{dP_2} \frac{P_2}{\theta_2},$$

the elasticity of the USA tariff with respect to P_2. Note that under CRS, $\zeta = 0$; the USA tariff is independent of P_2.

Condition (27′) implicitly defines P_2 as a function of I^g, I^P, θ_2, θ_k, and H. The most important point to note is that the P_2 solving (27′) falls as I^g and I^P rise as a share of O_2. In addition, when $H = 0$, P_2 falls as θ_2 rises to maintain a constant domestic price. If $H > 0$ and $G_{12} > 0$ (oil and capital are complements), an increase in θ_2 causes P_2 to fall in greater proportion, lowering not only the world price but the domestic price as well.[10]

This completes the characterization of second-period equilibrium under rule R1(a), with OPEC acting as a Stackelberg leader in setting P_2. When the level of θ_2 implied by equation (24) is independent of P_2, as in the case under CRS, then the solution under rule R1(b), with OPEC and USA acting as Nash players, is exactly the same as under rule R1(a). Under rule R1(c), with the USA acting as a Stackelberg leader in setting θ_2, the USA can impose the traditional optimal tariff. From equation (27′), $\theta_2 P_2$ stays constant or falls as θ_2 rises, if $G_{12}H \geq 0$. In this case the optimal tariff rate is infinite. Introducing extraction costs or other buyers would modify this result, but the point is that the USA can exert its monopsony power via tariffs only if it is able to commit itself to a tariff rate before OPEC sets P_2.

The First Period

Taking the solutions to the second period choice variables, θ_2 and P_2, as given depending on I^P, I^g, $K_1 + \Delta K$, H, and $R^* - M_2$, we now consider how these magnitudes are determined in period 1. Here we assume $\theta_k = 1$ (no taxation of OPEC investment income). The USA private sector takes OPEC and USA government policy variables (P_1, H, θ_1, I_g) as given to maximize

(28) $$U(C_1) + \beta U(C_2),$$

with respect to O_1, ΔK, and I^P, where

(29a) $$C_1 = F(K_1, O_1) - \theta_1 P_1(O_1 + I^P) - \Delta K + H - T_1;$$

(29b) $$C_2 = G(K_1 + \Delta K, \theta_2 P_2) - \theta_2 P_2(O_2 - I^P) - G_1 H - T_2.$$

Here T_1 and T_2 denote taxes each period. We assume that they are imposed in a lump-sum fashion. The government constraint implies,

(30a) $$T_1 = (1 - \theta_1)\, P_1\, (O_1 + I^P) + P_1 I^g;$$

(30b) $$T_2 = (1 - \theta_2)\, P_2\, [O_2 - D(I^P)] - [P_2 D(I^g)].$$

First-order conditions for a maximum are:

(31a) $$F_2(K_1, O_1) - \theta_1 P_1 \leq 0 \qquad (= 0 \text{ if } O_1 > 0).$$

(31b) $$-U'(C_1) + \beta U'(C_2) F_1\, (K_1 + \Delta K, O_2) \leq 0 \qquad (= 0 \text{ if } \Delta K > 0).$$

(31c) $$-U'(C_1)\,O_1P_1+\beta U'(C_2)\,\theta_2P_2D'(I^P) \le 0 \qquad (=0 \text{ if } I^P>0).$$

These equations implicitly define functions for first period oil demand, investment demand, and private inventory demand.

Consider now the problem facing the USA under rules R1(a) and R1(b). Taking P_1 parametrically, the USA chooses θ_1 and I^g to maximize social welfare, given, as before, by expression (28). The USA correctly anticipates the effect of its decisions this period on this period's private sector behavior (as determined by equations [31]) and on the second period outcome.

Consider the first-order equation for a maximum with respect to I^g:

(32) $$-U'(C_1)P_1+\beta U'(C_2)\left\{P_2D'(I^g)+\frac{dP_2}{dI^g}[O_2-D(I^g)]-D(I^P)\right\} \le 0 \qquad (=0 \text{ if } I^g>0).$$

From equation (27) (dP_2/dI^g) is positive. Comparing (32) with (31c), observe that the USA has an incentive to invest in inventories beyond that facing the private sector. The reason is that individuals in the USA private sector, taking both θ_1P_1 and θ_2P_2 as given, do not take into account the effect of their own inventory decision on lowering the second period price. The USA internalizes the effect of its own inventory decision on the second period price. The USA then, facing a given *first* period price, has an incentive to accumulate inventories even when the private sector does not.

Subsidizing first period imports, via setting $\theta_1 > 1$, provides an alternative method of lowering P_2 by raising *private* inventories. This approach subsidizes first period oil consumption as well as inventory accumulation, however. A direct government investment in inventories does not suffer this difficulty. The private sector continues to establish $F_2 = P_1$ whether or not I^g is positive. If the government has available a storage technology that is not, at the margin, inferior to that provided by the private sector, then the optimal first period tariff is zero.

Consider now OPEC's decision. OPEC chooses P_1 and H to maximize

$$U^*(C_1^*)+\beta^*(C_2^*),$$

where

$$C_1^*=P_1M_1-H;$$
$$C_2^*=P_2M_2+F_1H.$$

Under rule R1(a), OPEC acts anticipating the effect of its choice on I^g and θ_1, as well as on the second period equilibrium. Under rules R1(b) and R1(c), it treats I^g and θ_1 as given. USA inventories augment first period demand. Under rules R1(b) and R1(c), P_1 is necessarily greater when $I^g > 0$. This result does not necessarily emerge when OPEC is a leader. If I^g is very price elastic, it is conceivable that a government inventory purchase could lower P_1. In any event, OPEC will set P_1 at a higher level under rules R1(b) and R1(c), given any level of I^g.

Finally, under rule R1(c), the USA chooses θ_1 and I^g anticipating OPEC's response. Because an increase in I^g now raises P_1, the USA has less incentive to implement a reserve policy. While releasing the inventory lowers the price in period 2, acquiring it raises P_1. Under rules R1(a) and R1(b), USA policy takes the second into account but not the first, P_1 is a bygone when I^g is established. Nevertheless, OPEC, in anticipating (under R1[a]) or observing (under R1[b]) a USA inventory, is likely to establish a higher P_1 as a consequence.

Calculating the overall welfare effects of optimal inventory policy under alternative rules of the game is difficult in a general setting. In the next section we use a simple quadratic case to consider these issues further.

7.5 An Uneasy Case for Government Inventories: A Quadratic Example

We now consider a special case of the game discussed in section 7.4, making specific assumptions about the functional forms that describe technology and preferences. Our first and fourth examples assume that the behavior of the USA and OPEC is described by rule R1(a), OPEC acts as a Stackelberg leader each period. In the second example they act as Nash players, (rule R1[b]). Our third example is one in which the USA acts first (rule R1[c]).

We consider the following production function for Q_i:

$$Q_i = F(K_i, O_i) = a_0 K_i - \frac{a_1}{2} K_i^2 + a_2 K_i O_i \tag{33}$$

$$+ a_3 O_i - \frac{a_4}{2} O_i^2,\ a_i \geq 0,\ i = 1, 2.$$

Note that this function exhibits *decreasing* returns to scale in capital and oil.

7.5.1 The Second Period

We assume that the return on investment in USA capital is the same for USA citizens and OPEC members and is equal to the marginal product of capital, that is,

(34) $$F_1(K_2, O_2) = a_0 - a_1 K_2 + a_2 O_2 .$$

That is, USA sets $\theta_k = 0$. The private sector sets the demand for imports of oil in the second period by equating the marginal product of oil to the market price, that is,

$$F_2(K_2, O_2) = \theta_2 P_2 \text{ and } O_2 = M_2 + D(I),$$

where $I = I^p + I^g$ = private inventories + public inventories. Then we get that

(35) $$M_2 + D(I) = \frac{a_3}{a_4} + \frac{a_2}{a_4}(K_1 + \Delta K) - \frac{\theta_2}{a_4} P_2 .$$

We consider only a limited set of instruments for USA intervention. In the second period the only instrument available is the tariff on oil. The objective of the USA is to maximize second period utility by maximizing C_2, that is,

$$\underset{\theta_2}{\text{maximize}} \; F(K_2, O_2) - F_1 H - P_2 M_2 ,$$

subject to equations (33)–(35). The first-order condition is:

$$(F_2 - F_{12} H - P_2) \frac{\partial M_2}{\partial \theta_2} = 0 ,$$

and the optimal tax on imports is

(36) $$\theta_2^* = \frac{a_2 H}{P_2} + 1 .$$

Thus the optimal tariff rate is zero in two cases: (i) OPEC does not invest in the first period in the USA ($H = 0$), or (ii) oil and capital are separable in the production of the consumption good ($a_2 = 0$).

Now we turn to OPEC's determination of the second period price by maximizing its second period consumption, that is, it maximizes $P_2 M_2 + F_1 H$ subject to (33)–(36) by choice of P_2. The optimal P_2 turns out to be:

(37) $$P_2 = \frac{a_3}{2} + \frac{a_2}{2}[(K_1 + \Delta K)] - a_2 H - \frac{a_4}{2} D(I) .$$

Again we observe that if oil and capital are separable in production ($a_2 = 0$), the capital stock does not affect the determination of oil prices in the second period. Furthermore, P_2 is a linear function of capital, but OPEC has an incentive to decrease oil prices as *its* investment in the USA is larger. This result suggests why different members of OPEC would have different incentives in setting oil prices conditional on their portfolio decisions. Finally, it is important to observe that P_2 decreases as USA inventories go up. This result establishes a possible role for public inventories if the USA in the first period takes into account OPEC supply behavior in the second period, while USA private agents take P_2 parametrically. That P_2 falls as I rises does not depend on the assumption that the USA takes P_2 parametrically in period 2 while OPEC is assumed to act upon (36), that is, OPEC is a Stackelberg leader in setting P_2. Under rule R1(b), in which OPEC takes θ_2^* parametrically so that θ_2 and P_2 are set simultaneously in a noncooperative Nash game, then the optimal P_2 turns out to be:

$$P_2 = \frac{a_3}{2\theta_2^*} + \frac{a_2}{2\theta_2^*}(K_1 + \Delta K) - \frac{a_2}{2}H - \frac{a_4}{2\theta_2^*}D(I). \tag{38}$$

Note that if $H = 0$ the Nash solution and the solution with OPEC as the Stackelberg leader yield the same price. Otherwise, P_2 may move either way with θ_2. P_2 moves negatively with $D(I)$ as long as θ_2^* is positive. Whichever game is played in the second period, the oil price is not affected by total capital $(K_1 + \Delta K)$ and by H in the same degree. The results in the second period are independent of the utility function since the maximization of welfare is equivalent to the maximization of consumption.

The third logical possibility, of course, obtains when the USA acts as a Stackelberg leader (Rule R1[c]). As we described in section 7.4, in this case the USA can impose the optimal tariff, driving the world price to zero (the marginal extraction cost for oil that we have assumed here).

7.5.2 The First Period and the Complete Solution

Example 1 (Nichols and Zeckhauser)

To solve the first period problem we have to postulate a utility function for both the USA and OPEC. We first assume that utility is linear and that $\beta = \beta^* = 1$. In this case inventories benefit the USA. We then compare the government inventory policy with a tax/subsidy scheme. To do so, we make the following assumptions

A1: $H = \Delta K = 0$, that is, no investment.

A2: $D(I) = I$, that is, no inventory carrying costs for oil.

A1 implies that $\theta_2 = 1$, and as a result we get the following equations for the second period problem:

$$M_2 = \frac{\tilde{a}_3}{a_4} - \frac{P_2}{a_4} - I. \tag{39}$$

$$P_2 = \frac{\tilde{a}_3}{2} - \frac{a_4}{2}I, \tag{40}$$

where $\tilde{a}_3 \equiv a_2K_1 + a_3$. Note that these solutions obtain *either* when the USA and OPEC establish θ_2 and P_2 as the outcome of a noncooperative

Nash game *or* when OPEC acts as a Stackelberg leader. Together (39) and (40) yield

(41) $$M_2 = \frac{\tilde{a}_3}{2a_4} - \frac{1}{2}I.$$

Since capital is constant, we can write the production of the single good at time i as:

(42) $$Q_i = F(K_i, O_i) = a + \tilde{a}_3 O_i - \frac{a_4}{2} O_i^2, \qquad i = 1, 2,$$

where $$a \equiv a_0 - \frac{a_1}{2} K_i^2.$$

We consider the economy under alternative USA government policies. *Case (i)*. The USA chooses both M_1 and I in the USA in the first period taking the structure of the period 2 problem as given. Given the linear utility functions, the USA's problem is to maximize

$$F(K_1, M_1 - I) - P_1 M_1 + F(K_1, M_2 + I) - P_2 M_2,$$

subject to (40), (41), and (42) by choice of M_1 and I. The first-order conditions with respect to I and M_1, respectively, are:

(43) $$\frac{\tilde{a}_3}{2} - a_4\left(\frac{\tilde{a}_3}{2a_4} + \frac{I}{2}\right)\frac{1}{2} + \frac{a_4}{2}\left(\frac{\tilde{a}_3}{2a_4} - \frac{1}{2}I\right) + \frac{1}{2}\left(\frac{\tilde{a}_3}{2} - \frac{a_4}{2}I\right) - \tilde{a}_3 + a_4(M_1 - I) = 0.$$

(44) $$\tilde{a}_3 - a_4(M_1 - I) - P_1 = 0.$$

Solving for I and M_1 as functions of P_1 we get,

(45) $$I = \frac{\tilde{a}_3}{a_4} - \frac{4}{3}\frac{P_1}{a_4}.$$

(46) $$M_1 = 2\frac{\tilde{a}_3}{a_4} - \frac{7}{3}\frac{P_1}{a_4}.$$

Given the above result with respect to USA decision rules, OPEC's problem is to maximize $P_1 M_1 + P_2 M_2$ subject to (40), (41), (42), (45), and (46) by choosing P_1. The result is

(47) $$P_1 = \frac{9}{17}\tilde{a}_3.$$

Hence, we have the following allocation of resources in the two periods:[11]

(48)
$$\begin{cases} O_1 = \frac{8}{17}\frac{\tilde{a}_3}{a_4}, & O_2 = \frac{11}{17}\frac{\tilde{a}_3}{a_4}, \\ P_2 = \frac{6}{17}\tilde{a}_3, & I = \frac{5}{17}\frac{\tilde{a}_3}{a_4}, \end{cases}$$

Utility levels in the USA and OPEC are, respectively,

(49a)
$$U = C_1 + C_2 = 2a_0K_1 - a_1K_1^2 + \frac{155}{578}\frac{(\tilde{a}_3)^2}{a_4}.$$

(49b)
$$U^* = C_1^* + C_2^* = \frac{9}{17}\frac{(\tilde{a}_3)^2}{a_4}.$$

Hence, the price of oil falls from period one to period two and inventories are 5/11 of oil consumption at the second period. We now turn to the case where there is no USA government intervention.

Case (ii). USA private agents choose both oil consumption and oil inventories. There is no government intervention. USA private agents maximize profits by setting O_1 such that $F_2(K_1, O_1) = P_1$, and they set $I^P > 0$ if $P_1 < P_2$, otherwise $I^P = 0$. The first-order conditions with respect to O_1 imply that

(50)
$$O_1 = M_1 - I^P = \frac{\tilde{a}_3 - P_1}{a_4}.$$

As a result, we can solve OPEC's problem assuming that $I^P = 0$ then see whether the condition for zero inventories is satisfied. OPEC's problem is to maximize $P_1M_1 + P_2M_2$ subject to (40), (41), (49), and $I^P = 0$. Hence, we get $P_1 = P_2 = (1/2)\tilde{a}_3$, and the condition for zero inventories is satisfied. Furthermore, we get $M_1 = M_2 = (1/2)(\tilde{a}_3/2)/a_4) = O_1 = O_2$. Hence, the two periods are completely symmetric, and the model is equivalent to the case in which OPEC is a simple monopoly in both periods separately.

Utility levels in the USA and OPEC are, respectively,

(51a)
$$U = C_1 + C_2 = 2a_0K_1 - a_1K_1^2 + \frac{\tilde{a}_3^2}{4a_4};$$

(51b)
$$U^* = C_1^* + C_2^* = \frac{\tilde{a}_3^2}{2a_4}.$$

Case (iii). USA private agents choose O_1 while USA government chooses inventories. The allocation of O_1 is determined by (49) which is identical to (44), the first-order condition with respect to M_1 in case (i). Hence, the solution for USA optimal inventories turns out to be identical to that of case (i): (45), and the final allocation of case (iii) and (i) are identical and given by (37) and (48).

Result. In the above example a monopolistic OPEC behaves as a Stackelberg leader in a time-consistent game, and optimal private inventories are zero. This is equivalent to the result of zero private (optimal) inventories in the case of competition (section 7.3). However, given the fact that the government can exploit the effect of inventories on oil prices in the second period, we find that the optimal USA allocation is to have a positive level of inventories that raises the first period oil price and lowers the second period price.[12] Hence, the USA has a real cost of holding inventories, $(P_1 - P_2)I$, but it creates a welfare gain from changing the terms of trade and reducing the monopoly power of OPEC in the second period.

We present the result in figure 7.1. Moving from no intervention in the USA to a government inventory policy, the demand and marginal revenue curves that OPEC faces are moving from the solid lines to the broken lines. The USA loses the area $P_1^* P\ B\ A$ of consumer surplus in the first period, while it gains the area $P\ P_2^* C\ B$ of consumer surplus in the second period and here the difference is positive.

Given the sequence of decisions that we assume here, in case (i) we characterize the optimal allocation for the USA. We show in case (ii) that

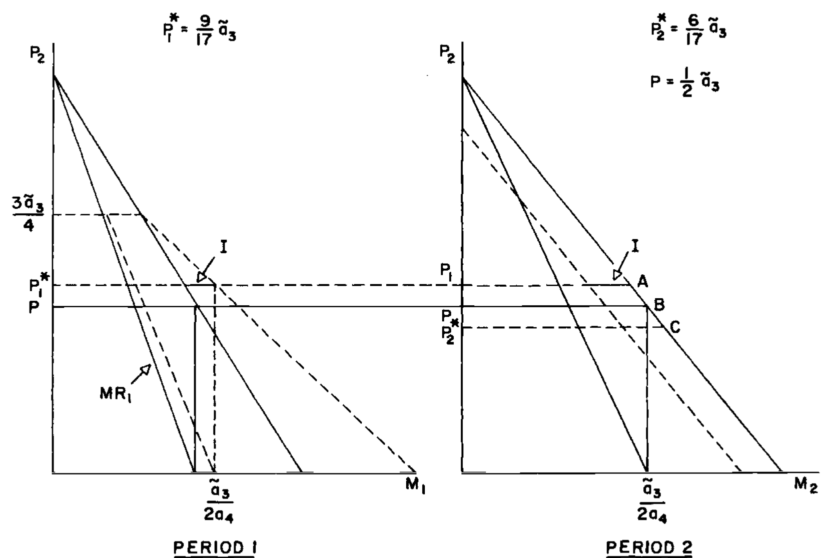

Fig. 7.1 U.S. oil demand with OPEC as a Stackelburg leader.

the private sector does not achieve the same allocation since it cannot exploit the negative effect of inventories on the period 2 oil price. If the only government instrument is a public inventory (case iii), the allocation is the same as in the first case.

Comparing (49) with (51) note that USA welfare is in fact greater when the USA chooses inventories optimally. In addition, OPEC welfare is greater as well. USA inventory policy is reducing a monopoly distortion in a way that benefits both OPEC and the USA. Note that under the inventory policy imports over the two periods together are greater than when the USA does not use inventories.

Could an optimal level of inventories be sustained by other policies? The answer is yes, if the government can impose lump-sum and firm-specific taxes or subsidies to make holding the optimal level of inventories consistent with the firm's profit-maximizing problem. This set of incentives must be specified in the first period. However, once P_2 is determined in the second period there will be no incentive for the government to fulfill its obligations. The previous time-consistency argument applies to the tax incentive program for private inventories. Only by buying the inventories in period 1 itself can the government credibly commit itself to a policy of lowering the second period price through increased inventories.

Example 2

Now assume that rule R1(b) applies, USA and OPEC set I^g and P_1 simultaneously as noncooperative Nash players rather than sequentially, that is, the USA chooses I^g taking P_1 as given, as before, and OPEC sets P_1 taking I^g as given. In the consequent equilibrium we get:

(52)
$$O_1 = \frac{2\tilde{a}_3}{5}, \qquad O_2 = \frac{3\tilde{a}_3}{5},$$
$$P_1^* = \frac{3\tilde{a}_3}{5}, \qquad P_2^* = \frac{2\tilde{a}_3}{5},$$

(53)
$$I^g = \frac{\tilde{a}_3}{5a_4},$$

while

(54a)
$$U = C_1 + C_2 = 2a_0K_1 - a_1K_1^2 + \frac{11\tilde{a}_3}{50a_4};$$

(54b)
$$U^* = C_1^* + C_2^* = \frac{13}{25}\frac{\tilde{a}_3}{a_4}.$$

Compared with a situation in which $I^g = 0$, the USA is now worse off while OPEC is again better off.

Moving from a situation in which the USA acts entirely as a Stackelberg follower to one in which the USA and OPEC act as Nash players reduces USA welfare. The reason is that USA inventory demand is price elastic. Given the structure of the problem in period 2, the USA's demand for inventories is given by

$$I^g = \frac{\tilde{a}_3}{a_4} - \frac{4P_1}{3a_4}. \tag{55}$$

When OPEC incorporates (55) into its decision making, it sets, ceteris paribus, a lower price. Taking I^g as given, it perceives total demand as more inelastic and consequently sets a higher P_1.

This result is illustrated in figure 7.2. While the USA inventory demand shifts OPEC's demand curve rightward in a Nash game, the slope of OPEC's perceived marginal revenue curve is unaffected by a USA inventory policy. When OPEC acts as a leader, the optimal USA inventory policy makes the perceived MR curve flatter. OPEC consequently charges a lower price each period.

Example 3

Consider now the problem posed in example 1 for the case in which the USA acts as a Stackelberg leader, that is, rule R1(c) applies in period 1. We continue to assume that rules R1(a) or R1(b) apply in period 2, so that the structure of the second period game is unchanged. We assume zero tariffs.

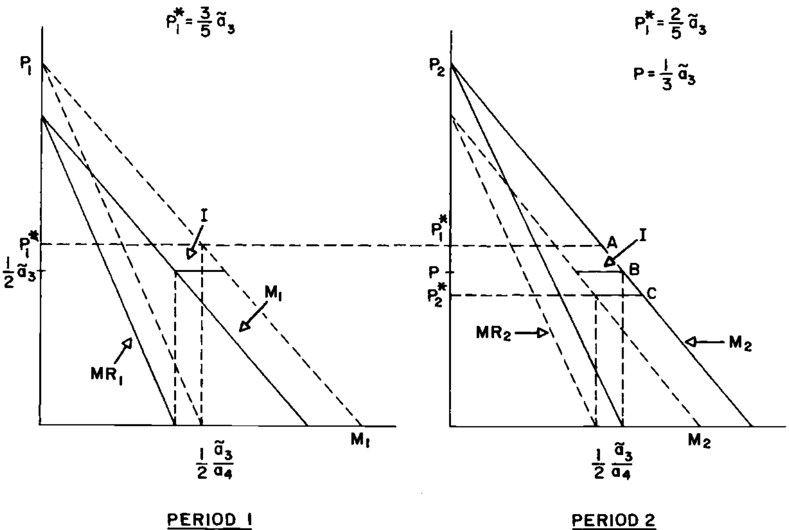

Fig. 7.2 U.S. oil demand with OPEC and the USA as Nash players.

The USA now sets I^g taking the price response of OPEC,

$$P_1 = \frac{\tilde{a}_3}{2} + \frac{a_4 I^g}{2}, \tag{56}$$

as given. It is straightforward to show that in this case the optimal USA policy is to set $I^g = 0$. The same solution as that for example 1, case (ii), that is, the competitive solution without government intervention, obtains here. When the USA must precommit itself to some level of inventories, it chooses a zero level. This result obtains when OPEC has a Bernoulli utility function as well as when OPEC's utility is linear.

Example 4

We now show that a USA inventory policy is not necessarily in the USA's interest even when OPEC acts as a Stackelberg leader. We make the following small modification to example 1. Assume that instead of being linear in consumption (as in equations [49b] and [51b]), OPEC's utility function is Bernoulli:

$$U^* = \log C_1^* + \log C_2^*. \tag{57}$$

In this case the solution in the presence of a government inventory (cases [i] and [iii]) involves

$$O_1 = \frac{5\tilde{a}_3}{14a_4}, \qquad O_2 = \frac{4\tilde{a}_3}{7a_4}, \tag{58}$$

$$P_1 = \frac{9\tilde{a}_3}{14a_4}, \qquad P_2 = \frac{3\tilde{a}_3}{7a_4},$$

In addition,

$$U = C_1 + C_2 = 2a_0K_1 - a_1K_1^2 + \frac{11}{56}\frac{\tilde{a}_3^2}{a_4}. \tag{59a}$$

$$U^* = \log C_1^* + \log C_2^* = \log\frac{9}{28} + 2\log\frac{3}{7} + 2\log\frac{\tilde{a}_3}{a_4}. \tag{59b}$$

When there is no government inventory (case [ii]), the solution is exactly as that for example 1. The reason is that, in this case, the choice of P_1 has no implications for intertemporal substitution in OPEC. Thus OPEC's utility is given by

$$U^* = 2\log\frac{1}{4} + 2\log\frac{\tilde{a}_3^2}{a_4}, \tag{60}$$

while the USA's welfare continues to be given by (51a).

Again, comparing (59b) and (60), note that OPEC has benefited because the USA has pursued an inventory policy. The USA, however, has lost; (59a) is less than (51a). The reason is that when OPEC has diminishing marginal utility of consumption in period 2, it is less willing to transfer consumption from period 2 to period 1 in response to a USA inventory policy. It sets higher prices in both periods to maintain a higher consumption level in period 2. The USA is consequently worse off. In terms of figure 7.1, when OPEC has a Bernoulli objective function P_1^* and P_2^* are displaced upward relative to P. The loss in period 1 from having an inventory is consequently greater while the gain in period 2 is less. Note also that here total imports over the two periods have *fallen* because of the inventory policy.

Given that the USA is better off without a government inventory, will it in fact set $I^g = 0$? If the USA does set I^g taking P_1 as given it will set $I^g > 0$ for all $P_1 < (3\tilde{a}_3/4)$, given the structure of the remaining problem. As in example 2, once P_1 is set it is too late for the USA to affect P_1 via its inventory policy.

Consider a situation in which the USA announced that it would establish $I^g = 0$. If OPEC believed this announcement it would establish $P_1 = (\tilde{a}_3/2)$. The USA would then have an incentive to establish $I = (\tilde{a}_3/3a_4)$ and drive $P_2 = (\tilde{a}_3/3)$. Anticipating this behavior, OPEC will in fact set P_1 higher. In example 1 the USA nevertheless benefited from having a government inventory when OPEC adjusted P_1 in anticipation of period 1 inventory purchases. An implication of this example and example 2 is that the USA can actually lower USA welfare by developing the capacity to maintain inventories. The absence of such a capacity constitutes a credible commitment not to store oil before OPEC establishes P_1.

7.5.3 Conclusion

These examples suggest that, in a strategic setting, the ability of the USA to pursue an inventory policy can have both desirable and undesirable consequences, depending on both the nature of OPEC's preferences and on the structure of the process whereby OPEC sets prices and the USA sets inventories.

Our results can be interpreted in light of Samuelson's (1972) analysis of the desirability of destabilizing speculation. Like Samuelson, we are considering a situation in which given demand and supply conditions persist for two periods. Samuelson showed that in a competitive setting, that is, one in which buyers and sellers behave as price-takers, a destabilizing speculator would raise the welfare of both buyers and sellers. His own losses would exceed the gain of the other two groups combined, however. Hence, in our example, if the USA faced a competitive OPEC there would be no positive role for a government inventory policy. The government would be acting as a destabilizing speculator. The gain to the rest of the world, not just to USA consumers, would fall short of the capital loss the government would sustain in buying in period 1 to sell in period 2.

In facing a monopolistic seller, however, our examples indicate, first of all, that a government inventory policy can raise not only USA but world welfare. The reason is that the optimal USA inventory rule makes USA demand, on net, more elastic over the two periods. As a consequence the distortion due to monopoly is diminished and both sides can benefit. More oil is consumed overall, so the world is moved closer to the competitive equilibrium.

This result requires that OPEC set prices incorporating the USA's response into its decision. An implication is that to succeed at raising USA welfare the government inventory purchases should respond very closely to actual oil prices; that is, the government should, according to our model, establish purchasing rules that are price contingent.

A second implication of our examples is that, unless the USA acts as a leader in setting I^g before OPEC sets P_1, it may have an incentive to establish a positive inventory even when USA welfare is higher when there is a precommitment to no inventories. The reason is that the loss to the USA from having an inventory is incorporated in the first period price. Once OPEC has established this price it is too late for the USA to avoid the undesirable consequences of having an inventory. From that point on the benefits exceed the costs.

7.6 Other Arguments for Government Inventories

Our analysis has focused on convenience yields, uncertainty, and strategic interactions to explain the existence of petroleum reserves. Only in the third case did we find an argument for government intervention. Other economists have analyzed the case for a strategic reserve and we discuss their results here. Closest in spirit to our own analysis is the paper by Maskin and Newbery (1978) which examines the possible effect of U.S. monopsony power on the optimal tariff response. Wright and Williams (1982) have argued that reserves may be justified as a second-best response to other (suboptimal) government policies, in particular, price controls. Finally, the stockpile has been justified as a means of reducing U.S. vulnerability to the threat of an embargo. Tolley and Wilman (1977) discuss this issue.

7.6.1 U.S. Monopsony Power and Government Inventories

Maskin and Newbery (1978) develop a two-period model in which a monopsonistic United States faces a competitive set of oil producers and other buyers. The optimal open loop policy is for the United States to establish a monopsony price (via an optimal tariff, for instance) that must be equal (in discounted terms) across the two periods to extract positive supplies in the two periods. The two prices must be equal because of Hotelling's formula. In the second period, however, the United States has an incentive to deviate from the period 2 price that is optimal from the open loop perspective. The reason is that the effect of the period 2 price on oil producers' willingness to hold oil in the ground in period 1 is at this point a bygone. The price that is optimal from period 2's perspective can be higher or lower than that which was optimal ex ante. If oil producers and other buyers believe the announced open loop rule in making their period 1 decisions about extraction, the United States can benefit from reneging on the contract. If, however, the rest of the world anticipates the reneging, the United States can lose from its monopsony position. If, say, the government has an incentive to revise the price downward in period 2 and individuals correctly anticipate this revision, the period 1 price will be driven down as well (again via the Hotelling rule). The consequent equilibrium can be worse from the U.S. perspective than one in which the United States has no monopsony power at all. The United States would be best off if it could precommit itself to its optimal open loop policy. If this is not possible it could benefit by somehow divesting itself of its monopsony power in the second period. Otherwise the anticipation that the United States will exercise monopsony power in the second period leads to behavior by other agents in the first period that is detrimental to the United States.

In this context, Maskin and Newbery show that the United States can benefit from government storage in period 1 as a means of precommitting itself to a course of action. By buying stocks of oil the government can establish that it has an interest in maintaining the announced price of oil in the second period when, in the absence of storage, it would want to revise the second period price downward. Maskin and Newbery find that in a rational expectations equilibrium the United States cannot be hurt by a government stockpile while in some circumstances the United States will strictly benefit. The argument here is again in favor of a *government* inventory. Private agents do not have an incentive to invest in inventories as a means of making the government's optimal tariff commitment credible.

7.6.2 Price Controls and Government Inventories

Wright and Williams (1982) develop a model in which agents anticipate that in some periods (e.g., when the price is high) the government will impose price controls on oil. The private rate of return on storing oil into these periods is consequently lower than the social rate of return. The private sector consequently stores too little. There is scope for additional government reserves. Government storage here is a second-best response to other distortionary government policies. The government does not actually have to impose price controls for a justification for inventories to emerge. Private agents simply need to anticipate that controls will be applied with some probability. Wright and Williams do not attempt to model why the government would impose controls and, hence, why it cannot credibly commit itself never to impose controls.

7.6.3 Vulnerability and Government Inventories

The threat of a future embargo by OPEC can provide an additional justification for an inventory. In a competitive setting, of course, this issue does not arise. In the face of a monopolistic exporter, however, the supplier could decide to curtail supplies at some moment. A complete modeling of the embargo issue would require a specification of the supplier's motives in imposing an embargo. A real possibility is that a government inventory is a means of preventing an embargo.

Tolley and Wilman (1977) show that if a country is faced with an exogenous threat of an embargo that a justification for inventories emerges. There is scope for government intervention, however, *only* when the embargo generates external effects. Otherwise, individuals would have an incentive to maintain the socially optimal level of inventories themselves in the face of an embargo threat, as we discussed in section 7.3. They derive the optimal level of the government inventory as a function of the externalities generated by the embargo and the exogenous likelihood and length of a potential embargo.

A more complete analysis would specify (1) the nature of the externalities and (2) the effect of the inventory policy itself on the likelihood and duration of an embargo. An analysis of this sort could be provided in a multiperiod game theoretic framework. It remains an important topic for future research. Aiyagari and Riesman (1982) consider the desirability of the embargo policy to the sellers. They find that only in a very special case can this policy improve the seller's position from a purely *economic* perspective.

The oil price shocks of the last decade have spawned a large literature on policies toward oil. A number of other articles have considered aspects of policies toward oil or optimal stockpile behavior. Examples include Nordhaus (1974), Calvo and Findlay (1978), Gilbert (1978), Wright (1980), Teisberg (1981), Ulph and Folie (1981), Newbery (1981), Ulph and Ulph (1981), and Epple, Hansen, and Roberds (1982).

7.7 Conclusion

This paper investigates the desirability of U.S. government oil inventories in a two-period, two-country model in which the world stock of oil is exhaustible. We show that in competitive markets under certainty or uncertainty there is no welfare improving role for public inventories and, leaving aside operating stocks, a precautionary demand for stocks of oil is the result of the exclusion of international insurance markets or property rights.

We show that only under a limited set of strategic games between the United States and OPEC can one justify public Strategic Petroleum Reserves. Even then their desirability depends on the structure of preferences.

An inventory policy is inferior to imposing optimal tariffs in the two periods. But implementing the optimal tariff may not constitute a *time-consistent* policy (see Kydland and Prescott 1977): while the United States could bring U.S. welfare to a higher level by imposing optimal tariffs in the two periods, the United States may not have an incentive actually to impose the tariff in the period in which it acts. A threat to impose the tariff at the time OPEC sets price may therefore not be credible. An SPR, while not raising U.S. welfare to a level equal to that when optimal tariffs are imposed, may nevertheless raise welfare above that attainable by any other time-consistent policy. An inventory constitutes a second-best, but *credible*, alternative to an optimal tariff policy.

In all our examples the government inventory makes a loss. Consequently, private, atomistic agents, acting as price-takers, have no incentive to hold any inventories at all. Inventories serve the purpose of driving down the price in the second period. The price is driven down for *all* second-period users. Any nonaltruistic individual considering investing in an inventory will not take into account the effect of his own inventory holding on lowering the price for other individuals. The case is one of a classic externality. A government that maximizes welfare will internalize this effect. Hence, in moving to a strategic setting, a justification for a *government* SPR can be made. As its name implies, strategic considerations seem to have motivated the establishment of the U.S. SPR (see Senator Jackson's statement quoted in the introduction.)

Whether or not an inventory enhances welfare depends very much on the structure of decision making in the United States and OPEC, and on the parameters of the system. We find three examples in which the presence of an SPR *reduces* U.S. welfare relative to a situation of zero inventories. Nevertheless, once OPEC has acted, the United States may find it in its interest to pursue an inventory policy. Holding inventories may then constitute a *time-consistent* policy that is inferior to a credible precommitment to hold zero inventories. Merely by developing the capacity to hold inventories the SPR can reduce U.S. welfare.

Another aspect of our analysis is to show that if OPEC invests some of its first-period income in U.S. equities, a credible, welfare-enhancing tariff policy on the part of the United States can emerge. We have not considered the interaction between OPEC investment and government inventories here. We consider this avenue as a promising one for further research on the SPR. One possibility is, since U.S. inventories raise OPEC's first-period income relative to its second-period income, that an inventory policy will increase OPEC's equity investment in the United States. For the reasons we discussed in section 7.3 and 7.4, this investment acts to reduce the second-period price further. There is a second channel, then, whereby a government purchase of inventories in period one can reduce the price of oil in period two.

Notes

1. For a detailed description of the SPR, see Glatt (1982). For a discussion of the quota system that prevailed during 1954–71, see Dam (1971). Dam suggests that in 1969 the tariff equivalent of the quota averaged about $1.25 per barrel.
2. CBS Television Network, *Face The Nation*, Sunday, 18 July 1982.
3. Nichols and Zeckhauser (1977) show that a stockpile can reduce U.S. welfare when the resource constraint is binding. In this context, however, OPEC is not exercising monopoly power by restricting total supply. In fact, even when the resource constraint is *not* binding the inventory can reduce U.S. welfare, as we show.
4. See Varian (1978).
5. Here we assume that capital cannot be consumed and therefore that the interest rate is equal to the marginal product of capital.
6. This uncertainty could arise either from imperfect information about the physical quantity of OPEC's oil or from uncertainty about OPEC's desire to sell oil to the USA. The possibility of an embargo, for example, creates uncertainty about OPEC's supply of oil to the USA. To be consistent with the analysis here, the embargo must be considered as a possibility that is *exogenous* to the USA's behavior. We discuss the issue of an *endogenous* embargo in section 7.6.
7. U.S. imports that year equalled more than one-third of OPEC's production. See table 7.1.
8. Observe that $G_1 = F_1$ and so $G_{12} = F_{12}$.
9. See Marion and Svensson (1981) for a competitive model dealing with the relationship between the oil price and OPEC's investments.
10. This result is reminiscent of the well-known Metzler paradox. Here it arises because of the interaction between the price of oil and the return on capital.
11. Note that it is assumed here that $R^* > (19\tilde{a}_3/17a_4)$.
12. This allocation (case [i]) is optimal, subject to the particular rules of the game that we assumed for USA and OPEC.

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Comment John Whalley

This is an extremely well-written and clearly argued paper which presents analytical justifications for the existence of the U.S. Strategic Petroleum Reserve (SPR), primarily on potential terms of trade grounds. What I especially liked about the paper was the helpful introduction which succinctly lists the main points raised in the paper.

The main results presented have strong intuitive appeal to them and I have no basic disagreement with them. It is nonetheless helpful just to briefly summarize them:

(a) In a two period international trade model in which a country is a small open price-taking economy and where there is no foreign ownership of capital, the authors demonstrate that there is no role to be played by a government inventory policy for oil. There is no particular reason for the government to be in the business of accumulating inventories of oil since private markets can meet whatever inventory demands occur. Even in the presence of uncertainty, this result still prevails since with a complete set of Arrow/Debreu contingent commodity markets the free market economy can achieve a Pareto optimal allocation.

(b) If oil prices are affected by import volumes so that we relax the small open price-taking economy assumption, there does exist an optimal tariff for the United States. The authors show that this is a little more complex than the traditional optimal tariff argument which involves a static model. In an intertemporal framework the prices in the two periods have to be taken into account in setting the optimal tariff, but the same basic optimal tariff argument familiar to trade theorists applies.

(c) It is possible to complicate the strategic setting slightly: the authors show that if OPEC owns some U.S. capital, and if capital and energy are complements, then a tariff on energy will reduce the return on OPEC-owned capital, providing a further argument for the use of a tariff on oil.

(d) The authors then go on to argue that an inventory policy such as used in the SPR can provide a second-best substitute for a tariff. The inventories are used to change the time profile of deliveries from OPEC

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and, in effect, change the structure of demands which OPEC faces in the United States in the two periods. It is worth highlighting that to operate in this way, the inventory policy should ideally be price contingent so that the elasticity of demand for oil in the United States is changed through the operation of the SPR.

(e) The authors dispute an earlier finding of Nichols and Zeckhauser (1977) that it is possible through inventory policy to make both players better off in the implicit two-person game characterizing U.S. and OPEC oil trade. The Nichols/Zeckhauser argument is that OPEC monopoly power leads to a distortion in world energy markets and SPR can offset this distortion in such a way that the United States and OPEC can share the gain. The authors show that this result depends, rather critically, on the utility function specification; if the logarithmic rather than linear utility functions are used, they show that the United States can lose through the SPR.

My main points concerning the paper do not involve the analytics of these results which, as I say, seem to be fairly intuitive and are both clearly and persuasively argued in the paper. I will concern myself with the broader context of their applicability to policy discussion of the SPR.

As the authors hint in much of their discussion, they approach the SPR primarily in terms of attempting to find its rationale as a trading policy rather than as an analysis of its impact as a policy in place. When one goes back to the events surrounding its introduction, however, as the authors state, the SPR is best seen as an outgrowth of the events of 1973. It is thus perhaps better seen primarily as a form of insurance against further embargos and supply disruptions. As such, the insurance approach rather than a deliberate approach to manipulate the terms of trade which the United States faces in oil would seem to be both the rationale for the SPR and the main viewpoint from which to evaluate its impact.

In approaching the SPR from this direction, one immediately begins to think of the potential welfare costs or welfare gains to the United States which might be involved. A very simpleminded approach is to say that the main threat of supply disruptions now appears to have passed, and that if one discounts the insurance significance of the SPR, then the welfare cost to the United States would be dominated by the associated inventory carrying costs. Assuming that oil pumped into SPR remained there to perpetuity, with the SPR accumulating to 750 million barrels by 1989, each priced at approximately $30 a barrel, would yield a welfare cost to the United States in the region of $20 billion. The cost to the United States is simply the foregone resources invested in SPR and left in the ground. This simpleminded approach, while leaving many features remaining to be analyzed, nonetheless provides a ballpark figure from which to evaluate the net benefits by calculating what insurance gains the United States might expect to offset this cost.

A further crucial issue, however, is the possible behavior of firms in response to the existence of SPR. One approach would be to argue that firm behavior totally offsets the existence of the SPR. Firms hold inventories and form their own expectations both of future prices and the probability of supply disruptions, and knowing the existence of the SPR they appropriately modify their own inventory decisions. Under this approach, there is no welfare cost to the United States from the SPR and no terms of trade effect. The only welfare costs are the resource costs of trucking and pumping the oil into the SPR and any administrative costs exceeding the private cost to firms carrying inventory.

An alternative approach would be to make the assumption that firms do not offset the existence of the SPR through their own inventory policies. This could be justified by the assumption that firms face uncertainty about the precise allocations from the SPR they might receive from SPR if there is a supply disruption. Since there are no firm-specific contingent claims on oil in the SPR, firms may well view the government as unable to satisfactorily allocate and organize oil supplies in the event of a supply disruption. In this case the SPR is simply an addition to oil already being held by firms in the United States to cover both normal inventory needs and additional inventory motivated by the probability of a supply disruption. The welfare cost to the United States from SPR is dominated by the inventory carrying costs, and SPR would clearly worsen the terms of trade for the United States, since the SPR constitutes a once and for all addition to the oil demand function for the United States. Oil prices must rise unless the world supply function of oil to the United States is perfectly elastic. These two different approaches of firm offset and no firm offset thus make a substantial difference to the perception of the impacts of the SPR.

In approaching the SPR it would seem that at an intuitive level the probable terms of trade effects are quite small. With current OPEC proven reserves of perhaps 300 billion barrels plus an additional 200 billion barrels non-OPEC reserves, if one accepts optimistic Mexican claims, an SPR of less than 1 billion barrels would seem likely to produce only small terms of trade effects. In addition, it is important to note that the United States is not the only importer of oil, and the terms of trade gains which the authors focus on so heavily in their paper will accrue also to the EEC and Japan. This free-rider aspect of U.S. oil policy is an important complication which should be noted both in evaluating this alternative approach to the SPR and the approach used in the paper.

Two further issues regarding the SPR and an alternative approach to evaluating its effects are also worth raising. First, as soon as one approaches SPR from the insurance viewpoint it would seem important to estimate the potential adjustment costs involved with supply disruptions: how large these are likely to be; which sectors they are concentrated in; and how much labor reallocation costs may be. Indeed the events of 1973 suggest that not only the adjustment costs are at issue, but also the other possible policy regimes associated in the United States with the oil supply disruption. Since the supply disruption by OPEC was accompanied by price controls on oil, this further complicates an evaluation of possible adjustment costs. Some people would argue that the price controls prevented the necessary adjustments taking place as smoothly as perhaps they would have otherwise occurred. Thus, in evaluating the insurance value to the United States of the SPR, one needs to know both the probability of a supply disruption and the potential loss to the United States should that supply disruption occur.

A further point concerns a question raised by the authors in the paper, namely, the possible use of inventories as a second-best policy for tariffs. Little comment is made on the relative efficiency of inventories and tariffs. As the authors state, there is a potential for inventories to act as a second-best substitute for a tariff, but the relative efficiency of the two policies is not fully discussed. At an intuitive level it would seem that an inventory policy is a significantly inferior policy than a tariff since the costs involve unused resources. Resources employed in the inventory policy are idle whereas with a tariff the resource misallocation is the distortion of resources to less desirable uses. While this intuition may not fully apply in this case, given that with a tariff a distortion occurs between domestic and foreign prices, it is nonetheless an important issue to be evaluated in deciding on policy toward the SPR.

Finally, I have some further comments on the paper of a more analytical nature. One point concerns the exclusive use of a two period model rather than an infinite period model. In some areas if finite rather than infinite period models are used, analytical results that apply in the finite case tend to be nonrobust when infinite period models are used. Recent work has analyzed these questions for overlapping generations and infinitely lived consumer models and comes to that conclusion, and it is of some interest whether such nonrobustness might apply in this case.

A further point applies to the introduction of OPEC ownership of capital into the models. The analysis in the paper assumes that OPEC investments in the United States are given, but in a more complete analysis one would perhaps expect to see OPEC investments in the United States as endogenous. Given the endogeneity of these investments, the externality feature associated with a tariff on energy in reducing the return on OPEC-owned capital and providing gains to the United States would seem to disappear since OPEC investments would take that into account. Also in this area there is a substantial amount of recent literature, notably that by Bhagwati and Breacher which the authors might rerfer to.

A further point concerns the third country issue. Most of the analysis is in terms of two countries but, as has already been mentioned, there is a free-rider issue with the terms of trade effects. Europe and Japan in particular free ride on any terms of trade gain from U.S. oil policy.

A final point concerns the convenience yield on oil mentioned in the paper. This is the inventories' yield from their availability to cover potential shocks to the economy either in meeting increased oil demands or covering supply disruptions. What is not made clear in the paper is the extent to which the convenience yield of oil in the SPR is any different than the convenience yield of oil in conventional fields. Some discussion of the technical aspects of this issue in the paper would be helpful.

References

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