

Modeling Oil Price Fluctuations and International Stockpile Coordination

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Major interruptions in the supply of crude oil in the Middle East have caused significant economic damage in terms of lost output and increased inflation in the industrial countries. To the extent that the macroeconomic costs of shocks are a function of the magnitude of the oil price increases, domestic or internationally coordinated policies to restrain oil price increases during disruptions can be beneficial. One such policy initiative is the release of oil held in public stockpiles. We address the motivations for private and public stockpiling in an intertemporal optimizing model. As a special case of our general model, we develop and simulate a model of the world oil market to examine the benefits (in terms of lower world oil prices) of releasing oil from the U.S. Strategic Petroleum Reserve.

1. INTRODUCTION

The last 15 years have seen violent fluctuations in the international petroleum market. The substantial price increases of the early 1970s culminated in the oil embargo and quadrupling of oil prices in 1973–74. Oil prices rose sharply again during the Iranian Revolution of 1978–79 and with the outbreak of the Iran–Iraq war in 1980. Between these episodes, and at present, the oil market has been characterized by falling real prices and efforts by OPEC to restrain production. This paper examines these fluctuations and their effects on the industrialized economies, and models one policy designed to mitigate the macroeconomic effects.

The macroeconomic costs of oil supply shocks have been examined along several dimensions. Detailed analyses of the economic transmission of the first oil shock can be found in Gordon (1975) or in the

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We are grateful to F. Gerard Adams and Jaime Marquez for comments on a previous version of this paper. Financial support from the United States Department of Energy is acknowledged. The opinions expressed, however, are solely ours.

Received November 1983; accepted December 1984.

volume edited by Fried and Schultze (1975). Sachs (1979) has focused on the role of factor price responses (of the real wage rate and real interest rate) in determining the macroeconomic impact of a supply shock. Bruno (1982) and Bruno and Sachs (1982) have considered the role of the increase in the relative price of energy in explaining the slowdown in productivity experienced by most industrial nations in the middle and late 1970s. The extent to which oil price fluctuations may be responsible for current account movements has been discussed by Sachs (1981). Krugman (1983) looked at links between oil price fluctuations and appreciation or depreciation of the U.S. dollar. The Energy Modeling Forum at Stanford University has conducted a study of the economic effects of oil price increases and decreases using a set of macroeconomic models.¹

Two types of policy responses could be advanced to reduce the costs to the economy of a large oil price fluctuation, *income stabilization* policies and *oil market* policies. The former include tools for mitigating the short-run drain on aggregate demand for a given price increase—e.g., temporary tax rebate schemes, accommodating monetary policy, or investment incentives. Oil market policies encompass oil taxes and tariffs, price controls, and stockpile drawdown programs, interventions designed to affect oil prices directly. Clearly, the two categories are not mutually exclusive.

An analysis of the effectiveness of coordinating economic stabilization policy responses to deal with oil shocks is a topic of ongoing research and is beyond the scope of this paper. Our attention is focused here on “oil market” policies, particularly on the use of government stockpiles of oil (like the Strategic Petroleum Reserve in the United States), either by a single government in isolation or in the context of an agreement.

Section 2 of the paper reviews the institution of international cooperation in the oil market as embodied in the International Energy Agency (IEA) and addresses the basic policy issues of stockpile coordination. The third section develops intertemporal optimizing models of private and public inventory accumulation, comparing their motivations and implications. Of particular importance is the role of uncertainty over future oil prices in describing inventory behavior. Conditions under which public stockpile authorities are likely to release oil during a “crisis” are derived. The viability of existing cooperative agreements is discussed in that context. Public inventory accumulation is treated as an international game and noncooperative and cooperative

¹See Hickman and Huntington (1984).

solutions are contrasted to evaluate the benefits of cooperation and to evaluate the relative merits of various agreements.

Section 4 presents a simple case of the models of the previous section to illustrate the potential gains from stockpile policy coordination. We illustrate how a negative supply shock raises oil prices, with attendant macroeconomic damage. This damage in turn reduces oil demand, so that when the shock ends, oil prices are lower than if it had not occurred. This appears to capture what has happened in the 1980s. After developing a simple simulation model of the world oil market, the benefits of international stockpile coordination are quantified under a set of policy assumptions. Conclusions and directions for future research are given in Section 5.

2. INSTITUTIONAL BACKGROUND AND POLICY ISSUES

2A. The International Energy Agency

Before taking up policy questions, we review the relevant institutional background. Much has been written on this subject; our concern here is only with those aspects immediately relating to economic analysis of the problem.

Among the OECD countries cooperation on energy issues has been placed under the auspices of the International Energy Agency (IEA).² It is not our task here to provide a detailed critique of past IEA actions³; suffice to say that consumer cooperation has not always been a resounding success. Indeed, it has sometimes proved difficult to detect. It will, however, serve to summarize briefly the manner in which cooperation is to take place within the IEA. The salient points are three. First, member countries are required to hold stocks equal to 90 days of net imports. Second, the Agency's sharing mechanism is essentially dormant until such time as its members determine that a severe disruption has occurred. In order for the emergency program to be set in motion (referred to as "triggering"), the disruption must lead to a loss of at least 7 percent of IEA consumption (compared with a base period of the previous four quarters, with a one quarter lag for data collection).⁴

²The Agreement on an International Energy Program, which set up the IEA, was signed by 16 out of 24 OECD countries in November 1974. At this writing, 21 countries are members, including all of the major countries but France.

³This can be found in U.S.G.A.O. (1981).

⁴The agreement can also be triggered when one member country loses 7 percent of its base period consumption, but the IEA as a whole does not. Given the rigidities present in the oil market, this "specific trigger" situation is far more likely to occur than the "general trigger" described above, wherein countries are assumed to be affected equally. Given

Third, when the trigger is pulled, member countries are required to institute demand restraint to reduce consumption by 7 percent, reduce imports by more than 7 percent, and make up the difference by drawing down reserves.⁵ These measures are designed to restrict demand in the short run in an effort to prevent oil prices from skyrocketing.

Various technical problems with such a program have been pointed out in the literature; here, we take note of two broader difficulties. First, the 7 percent threshold corresponds to a severe disruption. Assuming Free World oil consumption of roughly 50 mmb/d (million barrels per day), and taking the IEA share of consumption as constant,⁶ a loss of 3.5 mmb/d (net of increased exports by other producers) is necessary to trigger the emergency mechanism. The Iranian crisis, during which oil prices more than doubled, was of considerably lesser magnitude. Second, demand restraint proved to be easier said than done—the March 1979 agreement to cut consumption by 5 percent had no provision for enforcement.

2B. Basic Questions

We view the IEA as an organization designed to foster collusion on the demand side of the oil market, and examine the economic effects of such behavior. Demand restraints can be effected through a short-term tariff, quota, or tax, or by regulation, be it mandatory (e.g., emergency conservation), or voluntary (e.g., exhortation, propaganda such as “the moral equivalent of war.”)

Unfortunately, raising the domestic oil price still further by means of a disruption tariff or tax can serve to exacerbate the adverse macroeconomic impacts described above. Demand regulations, in addition to well-known microeconomic inefficiencies (which are likely to be fairly small in this case, because of low short-run elasticities), are slow, cumbersome, and difficult to monitor, making them unsuitable as a response to a supply shock.

Use of strategic stockpiles is the alternative to demand restraint (response of production to higher prices in the short run is very limited). Stockpile release can address the oil price problem while avoiding the

however, that more is always available to those willing to pay, it is difficult to assign a meaningful interpretation to this case, and it will not be discussed further.

⁵A 12 percent shortfall requires members to cut consumption by 10 percent. In either case, stockpile draw is pro rata on the basis of imports; thus, more self-sufficient countries have smaller drawdown obligations.

⁶This will be strictly true only if the elasticities of IEA and free world demand are equal.

adverse macroeconomic consequences associated with demand restraint. **The remainder of this paper addresses international aspects of stockpiling.**

Stockpiling behavior on the part of public and private agents in the United States and other importing countries can play a large role in oil price outcomes during supply shocks. For example, the loss of oil production when the war between Iran and Iraq broke out in late 1980 did not cause nearly as great a price increase as the smaller disruption associated with the Iranian Revolution. General consensus in the oil industry credits the relatively high level of stocks at the outset of the Iran-Iraq War with facilitating the ensuing drawdown, thereby making up part of the loss and easing pressure on the spot markets. In contrast, world stock levels were below historical averages in the last quarter of 1978. The scramble to build up stocks which followed is widely credited with exacerbating the price effects of the relatively small Iranian disruption.

The various issues surrounding stocks policy can be distilled into four questions: the size of the reserve, the fill schedule, the draw schedule, and the institutional framework (e.g., ownership, finance, decision making). Clearly, the answer to any one of these questions is constrained by the answers given to the other three. Devising a comprehensive "cradle-to-grave" program for the reserve is prohibitively complicated, however. It may also be of limited value to policy makers, who seldom, if ever, have the luxury of creating the world anew.

In this paper, we take the questions of size, fill schedule, and institutional framework as answered, and concentrate on drawdown decisions. Our reasons for doing so are two. First, the drawdown issue has received considerably less analysis than the others.⁷ Second, while most economists tend to agree (or at least not to disagree too strenuously) about the size of the reserve and its institutional setup, considerable controversy exists about its use as an instrument of policy. It should be obvious that a reserve that is never intended to be used is no better than no reserve at all.

In analyzing drawdown alternatives, a firm grasp of the *objectives* of policy is paramount. The adverse economic effects (losses in GNP, increased unemployment and inflation) of a supply shock such as a rapid oil price increase are well known, we take the goal of stockpile release as

⁷The size question has been addressed by Balas (1980), Teisberg (1982), Hogen (1983), and Chao and Manne (1982). Institutional issues are treated by Krapels (1980, 1982) and Plummer (1982). Koenig, Blankenship, and McCully (1979) examine drawdown decisions.

mitigation of this damage through the above-described exertion of downward pressure on oil prices. We regard debates over whether reserves should be used for strategic or tactical purposes as without content (we assume that in the event of war, the armed forces will have priority access to oil as well as other goods). We take as given that government reserves are instruments of energy *emergency* policy, not a means for manipulating oil prices in the medium run.

The fact that coordination is beneficial and that the price reduction achievable is an increasing function of coordination still begs the questions of the likelihood of such coordination in a "market" (non-interventionist) outcome and of the types of institutional mechanisms that could facilitate the coordination. To examine these questions, we must focus more closely on the motivations for holding strategic oil inventories.

3. OPTIMAL PUBLIC STOCKPILING AND THE BENEFITS OF STOCKPILE COORDINATION

Understanding the motives behind public stockpiling is important not only for a realistic analysis of the response of public reserves to price movements in the world oil market, but also for evaluating the viability of particular international agreements. Agreements whose provisions run in opposition to the optimizing behavior of the various nations involved are unlikely to prove workable and successful in a crisis.

Stockpile policy is inherently more complex to analyze than are tariffs and quotas, since it requires an explicitly intertemporal model; in a one-period framework, it is always optimal to liquidate the entire stockpile. This section utilizes the dynamic methods recently popularized in macroeconomics (Sargent 1979). Similar techniques should be of interest to commodity modelers examining buffer-stock price stabilization schemes.

The public stockpile is to be used in accord with each country j 's assumed general economic policy of maximizing the present discounted value of real income (output less imported intermediate goods).⁸ In each country j , output (y_j) of a single final good is produced from oil (Q_j) and other inputs (\bar{X}_j) according to the production function

$$y_{jt} = f_j(Q_{jt}, \bar{X}_j), f_{j1}, f_{j2} > 0, \text{ and } f_{j11}, f_{j22} < 0. \quad (1)$$

Each nation imports all of its oil, which is the only imported intermediate

⁸This assumption is not so restrictive as it seems. Having as an objective the minimization of squared deviation of real income about a trend or including a "fear of inflation" in the objective function would produce qualitatively similar results.

input. Nonoil factor supplies are fixed, so that f is separable. Oil use depends negatively on its relative price, p/\bar{p} , where p and \bar{p} are the prices of (imported) oil and output. For simplicity, we make the produced good the numeraire, so that \bar{p} equals unity. Hence,

$$Q_j = Q_j(p), \quad Q_j' < 0. \quad (2)$$

The price of oil, p , is determined according to

$$p = p\left(\sum_m Q_m - \sum_m S_m\right) + \eta_t, \quad p' > 0, \quad (3)$$

where $S_m = I_m - I_{m-1}$ represents the net release of stockpiled oil from the public inventory by country m , and η is an additive disturbance.

The stockpile authority's objective is to maximize the discounted present value of real income (by minimizing oil price increases)⁹ less the costs of carrying out the stockpile program and of adjusting stockpile levels, subject to the constraint that stockpile releases not exceed the amount of oil held in the reserve. The problem for each country j is to choose the stockpile level I_j (or, equivalently, the net stockpile release S_j) in each period t so as to

$$\begin{aligned} \max_{I_{j,t+i}} \sum_t E_t \{ & (1 + \delta_j)^{-t} \{ y_{j,t+i} - p_{t+i} Q_{j,t+i} + (1 + \delta_j)^{-1} p_{t+i+1} I_{j,t+i} \\ & - p_{t+i} I_{j,t+i} - c_j I_{j,t+i} - \frac{h_j}{2} (I_{j,t+i} - I_{j,t+i-1})^2 \} \}, \end{aligned} \quad (4)$$

subject to the constraint that

$$I_{j,t+i} = I_{j,t+i-1} - S_{j,t+i}, \quad (5)$$

where δ_j and c_j are, respectively, the discount rate and unit carrying cost in the j th country. The quadratic term is a proxy for the cost of adjusting stock levels.

There are clear distinctions between the optimization problem for the public stockpile authority and the problem for the private firm. Most obvious is the attention paid by the public authority to aggregate output. Private firms do not consider the macroeconomic effects of their stockpiling behavior; that is, they do not consider the impact of their transactions on the world oil price. Second, the behavior of other countries becomes important. Because the stockpile release decisions of

⁹Note that countries do not increase only their own oil supplies by releasing stored oil. The oil market is a world market; the effect of a stockpile release will be on the world price.

other countries (also) affect the oil price, they may affect the optimal release strategy of the domestic authority.

Because the market for oil is a world market, price outcomes from one country's stockpile movement depend on the actions of other countries. The problem is inherently game-theoretic. As a base case, we can consider the noncooperative solution. In the Cournot-Nash solution, players do not consider the beneficial impact of their own actions on the others. Each country takes the stockpiling decisions of the others as given, then selects its own stockpile level. As a result, this solution does not fully exploit the positive externalities associated with stockpile policy; all parties might be better off by agreeing to release more oil at the onset of a disruption.

If we assume that the discount rates, holding costs, and stock adjustment parameters are the same across countries, so that $\delta_j = \delta, \forall_j$, $c_j = c, \forall_j$, and $h_j = h, \forall_j$, and the nonnegativity constraint does not bind, then the solution to (4) can be written as

$$I_{j,t+i} = \lambda_{1j} I_{j,t+i-1} + h^{-1}(1 + \delta)\lambda_{2j}^{-1} \sum_{k=0}^{\infty} \lambda_{2j}^{-k} E_t[(1 + \delta)^{-1} p_{t+i+k+1} - p_{t+i+k} - c] - h^{-1}(1 + \delta)\lambda_{2j}^{-1} \sum_{k=0}^{\infty} \lambda_{2j}^{-k} \left(\frac{dp}{dI} \Big| I_j \right) Q_{j,t+i+k}, \quad (6)$$

where λ_{1j} and λ_{2j} are the roots of the Euler equation.

Examining (6), we can consider the impacts of changes in expected future prices on public inventory accumulation in each country. In this model, the expectation of higher oil prices in the future represents the anticipation of an interruption in the supply of imported oil or worsening conditions attendant to an existing supply disruption. The uncertainty over future oil prices plays an important role here. The first two terms in (6) resemble the result for a profit-maximizing firm, namely, that higher expected future prices, *ceteris paribus*, lead to larger stockpiles (smaller releases) today. That impact is smaller in the "public" case than in the "firm" case because the former takes into account the fact that stockpile releases affect current-period oil prices. dp/dI is written with respect to the conjecture about the reaction of other countries; $dp/dI|I_j$ denotes evaluation for changes in I_j alone.

The third term in (6) represents the principal difference between the two problems, stemming from the macroeconomic concern of the public stockpile authority. An oil price increase large enough to generate an output reduction leads to a stockpile release. Because oil price increases

affect output in a nonlinear manner, the expectation of an oil price next period much higher than the current price (i.e., the expectation of low oil consumption, and hence output, relative to trend) will also work through the "income stabilization" motive to reduce releases today.

To see this, note that the third piece of (6) represents the inframarginal benefits of a stockpile release in terms of payment for oil consumed. Rewriting (6) in terms of stocks relative to current consumption yields

$$\frac{I_{jt}}{Q_{jt}} = \dots - p'[\lambda_2^{-1} + \lambda_2^{-2}Q_{j,t+1}/Q_{jt} + \lambda_2^{-3}Q_{j,t+2}/Q_{jt} + \dots] \quad (7)$$

If an initial "oil shock" at time t is expected to worsen at time $t + 1$, then oil consumption at time $t + 1$ falls relative to oil consumption at time t , raising the ratio of stocks to consumption at time t . This effect is scaled by the extent to which movements in public inventory accumulation affect the world price.

To put the problem in perspective, think of the OECD as being composed of "large" countries (the United States and Japan) and "small" countries (the European nations, Australia, and New Zealand). Because of their size, small countries are unlikely to have much of an effect on world oil prices through their stockpiling behavior. In the limit, they may behave like the firms, taking p' as zero. If they ignore or do not perceive the impact of their stockpiling behavior on the world oil price, their income stabilization motive for releasing stocks vanishes; no matter how great the impact of oil price fluctuations on output, the fact that stockpile releases are not perceived to affect the world oil price vitiates their purpose. In that case, equation (6) can be rewritten as

$$I_{j,t+1} = \lambda_1 I_{j,t+1-t} + \lambda_2^{-1} \sum_{k=0}^{\infty} \lambda_2^{-k} E_t[(1 + \delta)^{-1} p_{t+i+k+1} - p_{t+i+k} - c] \quad (8)$$

To evaluate the benefits of cooperation, we analyze the case of perfect collusion, where a single stockpile authority maximizes the joint benefits of reserve management. Such a case is not designed to be realistic, but rather to provide a measure against which agreements can be judged. Using the assumptions that generated (6), and denoting total stocks in period t by $I_t = \sum_{j=1}^m I_{jt}$, the central authority's problem is to

$$\max_t \left\{ \sum_{i=0}^{\infty} E_t[(1 + \delta)^{-i} (p_{t+i+1} - p_{t+i})Q_{t+i} + ((1 + \delta)^{-1} p_{t+i+1} - p_{t+i} - c)I_{t+i} - \frac{h}{2} (I_{t+i} - I_{t+i-1})^2] \right\}, \quad (9)$$

subject to the constraint that

$$I_{t+1} - I_t = \Delta I_{t+1} \quad (10)$$

where

$$y_t = \sum_{j=1}^m y_{jt}, \quad Q_t = \sum_{j=1}^m Q_{jt}, \quad \text{and} \quad S_t = \sum_{j=1}^m S_{jt}$$

denote total output, oil consumption, and stock change in period t , respectively.

Using a superscript C to denote the cooperative inventory level, the solution to (9) may be expressed as

$$I_{t+i}^C = \lambda_1^* I_{t+i-1}^C + mh^{-1}(1 + \delta)\lambda_2^{*-1} \sum_{k=0}^{\infty} \lambda_2^{*-k} E_t[(1 + \delta)^{-1} F_{t+i+k+1} - p_{t+i+k} - c] - h^{-1}(1 + \delta)\lambda_2^{*-1} \sum_{k=0}^{\infty} \lambda_2^{*-k} \left(\frac{dp}{dI} \Big|_{\sum_j I_j} \right) Q_{t+i+k} \tag{11}$$

Note that $\lambda_1^* < \lambda_1$; and $\lambda_2^* > \lambda_2 \forall_j$. Because dp/dI in the cooperative case is evaluated considering all stock changes, $dp/dI|_{\Sigma I_j} > dp/dI|_{I_j}$.

The question is thus the following. Given an oil shock, how will the sizes of the stockpiles (stockpile releases) under the noncooperative and cooperative solutions diverge? Comparing (6) and (11) reveals that the cooperative solution leads to larger stockpile releases at the onset of a supply disruption than the noncooperative (Cournot-Nash) solution. Moreover, the difference arises because of the oligopsony power of the importing countries in the world oil market.¹⁰

That substantial benefits to cooperation exist still begs the question of how such cooperation might be effected. The difference between the noncooperative and cooperative solutions suggests the possibility that a “miniagreement” among the countries with the largest stockpiles may achieve a substantial portion of the benefits of complete cooperation. With respect to the OECD and the IEA agreement, it may be that a bilateral U.S.–Japan accord would achieve much of the benefits (in terms of lower oil prices) attainable by the group as a whole.

¹⁰The difference between the cooperative and noncooperative solutions arises in similar problems of coordination across sovereign nations given economic integration, as pointed out by Cooper (1968). Cooper noted three significant consequences of interdependence for national economic policy, namely, (i) an increase in the number of disturbances with which national economic policy must cope, (ii) a reduction in the speed with which the impacts of stabilization policy are felt, and (iii) the notion that competition in the use of national policies can leave the community of nations worse off.

4. EMPIRICAL IMPLEMENTATION: QUANTIFYING THE BENEFITS OF COOPERATION

Several approaches are possible in empirical work. One strategy is to calculate the optimal draw-cum-fill schedule for the SPR under the various assumptions about the stock behavior of other OECD members. Such a procedure entails a dynamic programming solution and requires a Markov state-transition matrix specifying the probability of disruption of size D_t in period t given the existence of a disruption of size D_{t-1} in period $t-1$. Teisberg (1981) took this approach. Hogan (1983) extended it to incorporate international interaction. Neither considered private inventory behavior. In a recent paper, Wright and Williams (1982) incorporated private stocks, but their assumptions result in inventory draw in a disruption; the behavior examined here is excluded.

Another possibility is to assume away most of the uncertainties associated with the disruption, then optimize by linear programming methods. Such an approach was taken by Kuenne, Blankenship, and McCoy (1979).

Despite their attractive features, we do not employ control models here; they are not well designed for modeling short-run fluctuations. Instead, we utilize stimulation models with econometrically estimated equations in an attempt to mimic actual market behavior.

4A. Modeling the World Oil Market

A short-run model of the oil market is crucial to our discussion. The presence of (explicit and implicit) contract rigidities requires that (3) be modified for empirical work. Essential to our analysis is a quantitative notion of market "tightness"; we thus abstract from the rich institutional detail of the oil trade in order to focus on this aspect, employing two prices to proxy for the several prevailing in the market at any given time. These are termed "spot" and "contract" prices.¹¹

The contract price is set in accordance with production decisions and demand forecasts. Given the difficulty in accurately estimating demand and the numerous minor shocks inherent in any market, this price will not in general equate supply and demand. The spot (single cargo)

¹¹In empirical work, we use data on Mideast light crude oil, since it makes up the largest fraction of crude oil traded internationally. Our results will thus be biased to the extent that the behavior of spot-contract price differentials differs systematically across grades of crude oil.

market satisfies the excess, thus acting as a signal of short-run disequilibrium. The contract price is then adjusted, and so on.¹²

The spot price increases when the market "tightens." Two forms of "tightening" are possible: demand can increase due to changes in consumption or stock buildup, and supply can decrease due to disruption in a producing country, or deliberate production cuts. To capture these effects, we parameterize supply by production capacity, following Nordhaus (1980).

When a disruption occurs, capacity is removed from the market, and the output-to-capacity ratio of the nondisrupted OPEC producers rises. At higher prices, these producers are willing to accelerate output, thereby bumping against their own capacity restraints. When excess capacity no longer exists (output/capacity = 1), even larger increases in the spot price can elicit little further supply response, hence the nonlinearity of the curve. In equation form, we have

$$P_t = \psi P_{t-1} + \beta g(X_t/X_t^*), \quad (12)$$

where t indexes the time period, ψ and β are parameters to be estimated, and X_t and X_t^* refer to OPEC production and capacity production, respectively. Capacity decisions are assumed to be determined by longer-term considerations outside the scope of the model, and are taken as exogenous.

This description of the short run can be associated with various views of medium-to-long-term behavior, and we are thus agnostic on the question of OPEC internal structure, be it a cartel, a dominant firm oligopoly, or something else. Non-OPEC producers and disrupted countries are assumed to produce at capacity (an alternative would be to treat them as price takers).

We model demand as a function of price and income (which itself depends on oil prices). Since adjustment is limited in the short run, we include the previous quarter's demand as an explanatory variable. The price employed in the demand equation is actually the refiners' acquisition cost, and is taken as an average of spot and contract prices, plus transport costs. We thus implicitly assume that the refining industry is competitive.

Additionally, we account for inventory demand by private firms, based on (8); see the description in Hubbard and Weiner (1983).

¹²The reasons for conducting the bulk of the oil trade through term contracts are not entirely clear. It is probable that the oil exporting countries are highly risk averse and have imperfect access to world capital markets. Historically, transactions costs associated with operating in the spot market are likely to have been high due to lack of marketing expertise in these countries, and to the inability of the oil tanker market to clear instantaneously.

4B. Macroeconomic Modeling

The macroeconomic costs of oil shocks arise in part from "rigidities" in the economies of oil-importing countries. An increase in the relative price of oil, an important input, reduces firms' profit-maximizing level of output. This reduction in output reduces the demand for other inputs (at least in the short run), such as labor, lowering the real wage at which the prevailing quantities of labor supplied and demanded are equalized. Short-run declines in aggregate demand may occur because of domestic income redistribution and because of the transfer of resources to the oil-producing countries. These direct aggregate supply and demand effects are magnified to the extent that economic systems are not perfectly flexible. Because of rigidities in the economy—particularly sticky real wages—unemployment results, and the economy will fail to attain its already diminished consumption and production possibilities. The failure of wages and nonoil prices to adjust downward aggravates the rise in the price level caused by the oil price increase. The ultimate consequences for inflation and real income will depend on the size and timing of the disruption (and oil price increase), on the effect of the consequent price level increase on wage settlements, and on the fiscal, monetary, and regulatory responses of governments.

These macroeconomic rigidities cannot easily be captured in an equation such as (1). For the sake of realism, we determine output from an econometrically estimated income-expenditure model, rather than hypothesizing a production function and parameter values.

The transmission of an oil shock is modeled through a set of structural linkages. A sudden increase in the price of oil lowers the economy's potential output, reducing aggregate supply. Aggregate demand effects come through several channels. Personal consumption spending depends on permanent income and consumer wealth; an oil shock would lower consumption both by reducing the value of the existing capital stock (wealth effect) and by reducing current output (income effect). Business fixed investment depends on expected output and on the cost of capital services, which includes the cost of borrowed and equity funds as well as considerations of depreciation, investment tax credits, and the corporate income tax. Oil price increases influence capital spending through their impact on those channels. Housing and inventory investment decisions are also modeled. Oil shocks also affect the economy through the current account, though this impact is much larger in the short run than in the long run in the model because of the difference in short-run and long-run price elasticities of the demand for oil, the propensity to import of oil-producing countries, and exchange rate movements. Shocks affect

unemployment through their impact on real output in conjunction with their impact on real unit labor costs.

The model also emphasizes the determination of wages and prices as an important transmission mechanism. A common problem in many macroeconomic models is the simultaneity of the determination of wages and prices. Increases in unit labor costs are certainly a factor in inflation, but workers presumably consider inflation when making nominal wage demands. The growth of (nominal) wages in the model depends on inflationary expectations and on the unemployment rate. Labor compensation depends on wages, fringe benefits, and the employers' contribution to payroll tax programs (such as Social Security and unemployment insurance).

Inflationary expectations depend on lagged inflation and on money growth. Hence, while oil price shocks may ultimately affect wage demands through their inflationary impact, the stance of monetary policy (i.e., whether or not to accommodate the shock) is important for the path of nominal and real wages after the shock. The implicit price deflator for the gross national product is determined from information about unit labor costs, the cost of capital services, and the aggregate price of energy (determined from the world oil market model and from assumptions about the prices of coal and natural gas).

The macroeconomic model also contains a model of the domestic money market, focusing on the supply of and demand for money. Short-term interest rates from that model in conjunction with a term structure equation (influenced by the financing of government debt) yield long-term interest rates (which influence business fixed investment) and mortgage rates (affecting housing demand). Central bank decisions on the growth of the monetary base also affect inflationary expectations, with resulting impacts on wage rate and exchange rate determination.

The government can also affect the outcomes of the variables in the model through changes in fiscal policy (taxes and spending). Changes in payroll taxes affect labor compensation and the price of output; changes in corporate income taxes, the investment tax credit, or allowable depreciation rates affect investment. In analyzing the impact of fiscal policy, the model focuses on (a) the timing of the revenue and expenditures changes, (b) the components of aggregate demand affected (and their feedbacks to the rest of the model), (c) the inflationary consequences of the changes, and (d) the way in which the change is financed.

The oil market and macroeconomic models are solved simultaneously by iteration in order to obtain consistent values of oil prices and output.

4C. Simulation Results

Our simulations cover the four-year period 1983–86 (i.e., the version of the model used here is initialized in the fourth quarter of 1982). We first present a “control scenario,” wherein no further disruption takes place. Combined Iranian and Iraqi production recovers throughout the interval. U.S. oil production is projected to drop slowly throughout the interval, although it is more than offset by increases outside OPEC. In this setting we model a relatively “loose” market (i.e., low output-to-capacity ratio) in the absence of further deliberate restrictive actions by OPEC, with oil prices first falling, then rising as the OECD economies recover from the recession (see Table 1). In the control scenario, the U.S. fills the SPR at 200 mb/d.

THE DISRUPTION. We simulate a disruption of moderate size. Available capacity is reduced by 7 mmb/d for one year, starting in 1983(1). Much

Table 1: Comparison of Control and “Base Case” Disruptions

Quarter	Spot price (U.S. dollars/barrel)		Refiner's acquisition cost (U.S. dollars/barrel)		U.S. private stock change (mb/d)	
	C ^a	D ^a	C	D	C	D
1982(4)	32.10	32.10	32.00	32.00	1780	1780
1983(1)	28.40	39.00	31.70	34.90	-1780	-1510
1983(2)	25.50	45.00	30.70	38.80	150	370
1983(3)	22.60	48.00	29.00	42.40	60	260
1983(4)	23.90	59.70	28.30	48.60	-200	66
1984(1)	24.90	53.40	28.10	51.10	-740	-800
1984(2)	26.30	48.20	28.30	51.40	230	290
1984(3)	28.20	43.60	29.10	50.20	430	460
1984(4)	30.80	39.40	30.40	48.00	-280	-380
1985(1)	31.20	34.30	31.50	45.00	-890	-1040
1985(2)	31.90	30.40	32.50	41.60	300	100
1985(3)	33.00	27.50	33.50	38.30	470	340
1985(4)	35.20	25.60	34.90	35.50	-230	-400
1986(1)	35.20	23.20	36.00	32.70	-860	1030
1986(2)	35.60	22.10	36.80	30.40	300	170
1986(3)	36.60	22.20	37.70	28.80	460	350
1986(4)	38.80	24.00	39.00	28.20	-210	-300

^aC, control; D, disruption.

of the loss is made up (albeit at higher prices) because of the substantial excess capacity at that time. (In the absence of disruption, capacity would be utilized at about 75 percent.) With no policy intervention, OPEC production, which is endogenous, falls relative to the base case roughly by 100 mb/d in 1983(1), 400 mb/d in 1983(2), 800 mb/d in 1983(3), 1.4 mmb/d in 1983(4), 2.2 mmb/d in 1984(1), 2.4 mmb/d in 1984(2), 2.9 mmb/d in 1984(3), and 3.6 mmb/d in 1984(4).

Table 1 presents quarterly spot and U.S. refiner's acquisition cost data and changes in private inventories. Although capacity is restored by 1984(1), the spot price does not descend to its predisruption level until 1985(1). U.S. private inventories are built relative to the control, rapidly at first (roughly 90 mmb/d in 1983), more slowly thereafter. Starting in 1984(4), private inventories are decumulated relative to the control. Experimentation with other simulations revealed that the results are not highly sensitive to changes in initial conditions.

POLICY. The proper policy exercise is to calculate optimal stock releases by the United States and the rest of the OECD. At present, however, models of the OECD economies are not available to us. Instead, we utilize the result of another study, done by the Commission of the European Communities, which suggested a figure of five days' worth of consumption ($I/Q = 5$). We provide illustrative simulations of three cases.

1. Noncooperative Case. This is the disruption described above. Following our earlier discussion, we assume other OECD countries act like private firms, while the United States continues its predisruption policy.
2. Cooperation. All countries follow EC Commission proposal.
3. "Miniagreement." The United States, Japan, and Germany act "cooperatively" as in 2, other countries "noncooperatively" as in 1.

The economic effects to be considered are two. First, we seek to quantify the above-described effects to stock adjustments on the world oil market. Second, we examine the resulting macroeconomic impact, which is presumably the *raison d'être* of stock policy. Our assumptions about domestic fiscal and monetary policy are taken from the recent Energy Modeling Forum study, "Macroeconomic Impacts of Energy Shocks" (Hickman and Huntington 1984).

The proposed policy of releasing five days' worth of consumption translates into 80 million barrels for the United States and 100 million barrels for the rest of the OECD, given consumption figures of roughly

Table 2: Effects of Stock Policies on Spot Prices and Refiner Acquisition Costs (in U.S. Dollars/Barrel)

Quarter	Spot Price			Refiner's Acquisition Cost		
	Base case (noncooperative)	Cooperative case	Miniagreement	Base case (noncooperative)	Cooperative case	Miniagreement
1983(1)	39.00	37.80	37.60	34.90	34.50	34.50
1983(2)	45.00	40.00	40.40	38.80	37.00	37.10
1983(3)	48.00	40.40	41.00	42.40	39.00	39.20
1983(4)	59.70	52.90	53.40	48.60	44.00	44.40
1984(1)	53.40	48.00	48.40	51.10	46.30	46.60
1984(2)	48.20	44.60	44.70	51.40	46.80	47.10
1984(3)	43.60	41.80	41.60	50.20	46.40	46.50
1984(4)	39.40	38.70	38.50	48.00	45.10	45.20
1985(1)	34.70	34.50	34.30	45.00	43.00	43.00
1985(2)	30.40	31.10	31.10	41.60	40.50	40.40
1985(3)	27.50	29.00	28.80	38.30	38.00	37.90
1985(4)	25.60	27.90	27.70	35.50	35.90	35.80
1986(1)	23.20	25.90	25.70	32.70	33.80	33.70
1986(2)	22.10	25.00	24.80	30.40	32.10	31.90
1986(3)	22.20	25.20	25.00	28.80	30.90	30.70
1986(4)	24.00	27.00	26.90	28.20	30.60	30.40

16 mmb/d and 20 mmb/d, respectively. We assume these releases are initiated in the second quarter of the disruption [1983(2)] and are repeated in the third quarter, amounting to 450 mb/d SPR draw and a 550 mb/d draw of foreign stocks. Obviously, other configurations are possible. Table 2 presents the effects on spot prices.

The effects of using the SPR are two. First, the decreased demand for OPEC output exerts downward pressure on spot prices. Second, SPR drawn substitutes for imported oil almost entirely. This import reduction improves the U.S. trade balance and hence the U.S. GNP.

Finally, we compare the "cooperative" (all draw) case with a "miniagreement," in which countries other than the United States, Japan, and Germany are free to "cheat." The tables indicate that the "miniagreement" does almost as well as complete cooperation; the other countries are not large enough to upset the applecart.

"OIL SHORTAGES" AND "OIL GLUTS." Tables 1 and 3 illustrate how "shortages" and "gluts" are related. The supply disruption is harmful to the economy (e.g., for 1984 alone the cost is about \$17 billion in 1972 dollars to the U.S.), which reduces the demand for oil. As a result, spot prices after a disruption eventually fall substantially below their value in the base case—more than \$10 per barrel by 1986. The refiner's acquisition cost exhibits a similar pattern.

Stock policies thus can play a significant role in moderating oil fluctuations in both directions, through two channels. First, rebuilding stocks drawn down during a disruption serves to keep prices from falling during "glut times," and second, averting disruption-induced losses in real income raises oil demand. Cooperation provides measurable benefits in addition to its well-known spiritual ones.

5. CONCLUSIONS

Major interruptions in the supply of crude oil in the Middle East have caused significant economic damage in terms of lost output and increased inflation in the industrial countries of the OECD. To the extent that the macroeconomic costs of shocks are a function of the magnitude of the oil price increases, domestic policies or internationally coordinated efforts to restrain oil price increases during disruptions can be beneficial. One such policy initiative is the release of oil held in public stockpiles.

In the third section of the paper, we address the motivations for private and public stockpiling behavior in an intertemporal optimizing model. The benefits to one country from public stockpile releases during

Table 3: U.S. Real GNP (in Billions of 1972 Dollars/Year) Under Various States of Nature^a

Quarter	Control	Base case disruption	Cooperation	Miniscrement
1983(1)	1489.7	1485.9	1486.2	1486.2
1983(2)	1510.7	1504.6	1509.4	1509.3
1983(3)	1533.5	1524.0	1530.3	1530.1
1983(4)	1540.9	1524.8	1528.0	1527.8
1984(1)	1555.0	1538.3	1540.9	1540.7
1984(2)	1579.9	1562.6	1564.9	1564.8
1984(3)	1596.7	1578.6	1580.7	1580.7
1984(4)	1607.0	1589.4	1591.0	1591.0
1985(1)	1626.3	1609.8	1610.9	1610.9
1985(2)	1648.7	1632.3	1633.3	1633.4
1985(3)	1664.7	1648.7	1649.7	1649.8
1985(4)	1678.6	1664.5	1665.3	1665.3
1986(1)	1691.6	1679.2	1679.8	1679.9
1986(2)	1710.7	1699.0	1699.5	1699.6
1986(3)	1726.9	1717.2	1717.4	1717.5
1986(4)	1737.9	1731.6	1731.2	1731.2

^aNote: One 1972 dollar equals two 1982(1) dollars.

an oil shock depend on the stockpiling behavior of other countries. By contrasting noncooperative and cooperative solutions to the optimization problem, we ascertain the mutual benefits of cooperation and develop conditions under which public stockpile authorities are likely to release oil during a crisis.

As a special case of our general model, we develop and simulate a model of the world oil market to examine the benefits of releasing oil from the U.S. Strategic Petroleum Reserve (in terms of lower oil prices). Those results were heavily influenced by the behavior of private oil inventories in the United States and by the (assumed) extent of international cooperation. Cooperation in drawing down oil produced a much greater oil price reduction than that achievable by the United States acting alone. That analysis did not, though, address how or why such cooperation might occur.

The benefits of stockpile coordination in reducing oil prices are nontrivial. Further research is needed on public and private oil inventory behavior in OECD countries. We believe that the results presented here are illustrative. To capture the benefits of coordination, a viable

agreement (one in the interests of the individual signers) must be fashioned. A clear direction for future work is to analyze the role of coordination of macroeconomic policy in reducing the costs of large oil price increases. (Even within the context of examining stockpiling policies, the exchange rate is obviously a factor in determining the "price of oil" outside the U.S.) The benefits of coordinated fiscal and monetary policies probably greatly exceed those generated from stockpile cooperation, though achieving the former is even more difficult than achieving the latter.

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