

# The 'sub-trigger' crisis

## An economic analysis of flexible stock policies

R. Glenn Hubbard and Robert Weiner

*This paper investigates the value of international cooperation during an oil supply disruption. The International Energy Agency provides the aegis for energy cooperation among the industrialized countries, but only an enormous disruption would 'trigger' the Agency's emergency mechanism. Smaller ('sub-trigger') disruptions have occurred three times in the past decade, and twice, in 1973–74, and again in 1979, the result was havoc in the international oil markets and substantial economic damage. General consensus credits oil inventory accumulation with exacerbating these shocks and decumulation with averting similar problems during the 1980 disruption. The paper employs a small short-run econometric model of the oil market to examine inventory behaviour and to test coordinated government stockpile drawdowns (termed 'flexible stock policies') which have been proposed to address these issues. Impacts on GNP are obtained by solving the oil market model simultaneously with an econometric model of the US macro-economy.*

**Keywords:** Oil supply; Disruption; Inventories

[O]ne cannot help being struck by the following thought: how easy it is for people to agree that emergency oil stocks are necessary, and how difficult it is to get the same people to agree on when and how to use the stocks.

Edward Krapels<sup>1</sup>

### The issues

The two major disruptions in the supply of crude oil from the Middle East – in 1973–74, and again in

---

The authors are with the Energy and Environmental Policy Center, Kennedy School of Government, and the Department of Economics, Harvard University, Cambridge, MA 02138, USA.

This paper is based in part on a Harvard Energy Security Program Study funded by the US Department of Energy. Thanks are due to Alvin Alm, Harvey Brooks, Albert Danielsen, Shantayanan Devarajan, James Hamilton, William Hogan, and an anonymous referee for helpful comments. However, the views expressed herein, as well as any remaining errors, are solely the authors'. A previous version of the paper was presented at the IAEE/BIEE International Conference, Cambridge, UK, June 1982.

Final manuscript received 27 January 1983.

1979 – resulted in havoc in the international oil markets and substantial damage to the OECD economies. But the experience was not repeated when the Iran–Iraq war broke out in late 1980. General consensus attributes the relatively high level of stocks at the war's outset 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 ensuing scramble to build up stocks is widely credited with exacerbating the price effects of the relatively small Iranian disruption. In this paper, we undertake an economic analysis of stock behaviour, and, utilizing an econometric model which links the world oil market and the economy, investigate the effectiveness of so-called 'stock policies' in avoiding a repeat of 1979.

The Iranian crisis left in its wake numerous scholarly studies, many of which were variations on the theme 'What happened, and how can we avoid similar disasters in the future?' Among the conclusions reached were that cooperation among importing countries is highly desirable, but damnably difficult.

Several economists have constructed elegant optimizing models in order to quantify the potential benefits of cooperation. Such analyses have been carried out by Chao and Peck,<sup>2</sup> Hogan,<sup>3</sup> Manne,<sup>4</sup> and Rowen and Weyant.<sup>5</sup> The estimated value of cooperation varies due to the different modelling techniques employed as well as the diverse assumptions about OPEC behaviour, the structure of oil demand, the size and length of the disruption, the form the cooperation takes, and underlying economic factors. Although these benefits are measured along different dimensions (eg cost of protective policies, changes in GNP) and are thus difficult to compare across studies, a consensus exists on the value of joint action — it is substantial.

These studies are generally silent on the difficulties in designing and implementing a joint programme, although Hogan uses his model to demonstrate that the benefits to the USA of renegeing are small compared to the risk of having an agreement fall apart altogether. In actuality, the International Energy Agency (IEA), an organization within the OECD, has been charged with the development and refinement of such a programme.\*

It is not our task here to provide a detailed critique of past IEA actions;† suffice to say the 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 oil-sharing mechanism is essentially dormant until such time as its members determine that a severe disruption has occurred. In order for the emergency programme to be set in motion (referred to as 'triggering'), the disruption must lead to a loss of at least 7% of IEA consumption (compared to a base period of the previous four quarters with a one-quarter lag for data collection).‡ Third, when the trigger is pulled, member countries are required to institute demand restraint to reduce consumption by 7%, reduce imports by more than 7%, and make up the difference by drawing down reserves.§ 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 programme have been pointed out in the literature; here, we take

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

†For detailed description and analysis, see Keohane,<sup>6</sup> Krapels,<sup>7</sup> US GAO,<sup>8</sup> and Weiner.<sup>9</sup>

‡The agreement can also be triggered when one member country loses 7% 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, however, that more oil 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.

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

note of two broader difficulties. First, the 7% threshold corresponds to a severe disruption. Assuming free world oil consumption of roughly 50 million bbl/day, and taking the IEA share of consumption as constant,♦ a loss of 3.5 million bbl/day (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 reduce consumption by 5% was not accompanied by vigorous enforcement.

Among the lessons to come out of the 1979 and 1980 supply shocks was that while high stockpile levels are a *sine qua non* for the functioning of international sharing agreements, it is the *drawdown* (or build up) behaviour which is likely to spell the difference between containment and disaster. Another is that actions taken in a so-called 'sub-trigger disruption' (one falling beneath the threshold) may serve to avert a 1979-style catastrophic price run-up. Demand restraint having failed, the economic damage attending a sub-trigger disruption¶ has called forth proposals for coordinated drawdown programmes. These proposals, often termed 'flexible stock policies' have generated only moderate interest in the USA. The Reagan Administration officially supports IEA cooperation in the case of a large (trigger) disruption but prefers to rely on the market for anything smaller.\*\* We are unaware of any economic analysis of the effectiveness of these programmes in mitigating disruption damage; such is our task in this paper.

The Strategic Petroleum Reserve (SPR) figures prominently in the US government's energy emergency policy, and its fill has been expedited.†† How and when to use the Reserve is currently under study; it is by no means a foregone conclusion that the government considers a repeat of the 1979 debacle to be an acceptable outcome of market processes, or that SPR releases would be held off until mandated by international obligations.‡‡ Criticism of the IEA trigger often overlooks the fact that some type of threshold is necessary to any contingency

♦This will be strictly true only if the elasticities of IEA and Free World demand are equal.

¶For a discussion of the 'sub-trigger' crisis, and speculation on why demand restraint was inadequate in 1979, see Lantzke.<sup>10</sup>

\*\*For details, see US DOE,<sup>11</sup> wherein the door is left open: 'The Administration continues to support close consultation with IEA members and would not rule out future actions in the event of [a small] interruption, depending on circumstances' (p 29).

††US DOE<sup>12</sup> sets out the official emergency policy of primary reliance on the market, and substitution of SPR releases for government intervention to allocate supplies.

‡‡ Authority to draw down the SPR stems from the Energy Policy and Conservation Act (1975). The President must make a finding that 'a severe energy supply interruption or obligations of the United States under the International Energy Program necessitates SPR release, where 'severe' is defined as 'of significant scope and duration, and of an emergency nature' and causing 'major adverse impact on national safety or the national economy'. This information is taken from Allen.<sup>13</sup> The definitions of 'significant scope and duration' and 'major adverse impact' are left open.

plan. The threshold value is a more difficult question, and constitutes part of the debate.

In evaluating SPR drawdown strategies, international coordination considerations must be kept in mind. How effective would SPR draw be in relieving pressure in the world oil market if other IEA members do not do likewise? Or, even worse, what if some countries fill while others draw? The existence of this problem is well known, but notwithstanding a few relatively superficial observations, analysis of the magnitudes involved is lacking. It is to this task that we now turn.

### The world oil market

Be it explicit or implicit, a model of the world oil market is crucial to any discussion of stocks policy. Essential to our analysis is a rigorous notion of market 'tightness'; we abstract from much of the rich institutional detail of the oil trade in order to focus on this aspect. We employ two prices as proxies for the many prevailing in the market at any given time. Crude oil is sold under term contracts at the *contract price*. The *spot price* (labeled  $P^{SPOT}$  below) is paid for oil purchased on a single-cargo basis. §§

The contract price is set by OPEC in accord with its production decisions and demand estimates. ♦♦ Given the difficulty in forecasting demand and the numerous minor shocks inherent in any market, the contract price will not in general equate supply and demand. The spot market serves to satisfy the excess, and thus acts as a signal of market disequilibrium to OPEC, which adjusts the contract price. The process is then repeated.

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. In order to capture both effects, we employ a form of price reaction function, following Nordhaus,<sup>15</sup> Plummer,<sup>16</sup> and Hubbard and Fry (see Figure 1).<sup>17</sup>

When a disruption occurs, capacity is removed from the market, and the output-to-capacity ratio of the non-disrupted producers rises. At higher prices, these producers are willing to accelerate output, thereby bumping up against their own capacity constraints. When excess capacity no longer exists (output/capacity = 1), even large increases in the spot price can elicit little further supply response, hence the non-linearity of the curve. In equation form (Table 1 collects the variable names for convenience):

$$P_t^{SPOT} = \psi P_{t-1}^{SPOT} + \beta f(OUTPUT/CAP)_t \quad (1)$$

§§ We use data on Mideast Light, since it makes up the largest fraction of crude oil traded internationally. Our results will thus be biased to the extent that the behaviour of spot-contract price differentials differs systematically across grades of crude oil. For further discussion, see Verleger.<sup>14</sup>

♦♦ This description of the short run is consistent with several views of medium-to long-term behaviour, and we are thus agnostic on the question of OPEC internal structure, whether it be a cartel, a dominant-country oligopoly, or something else.

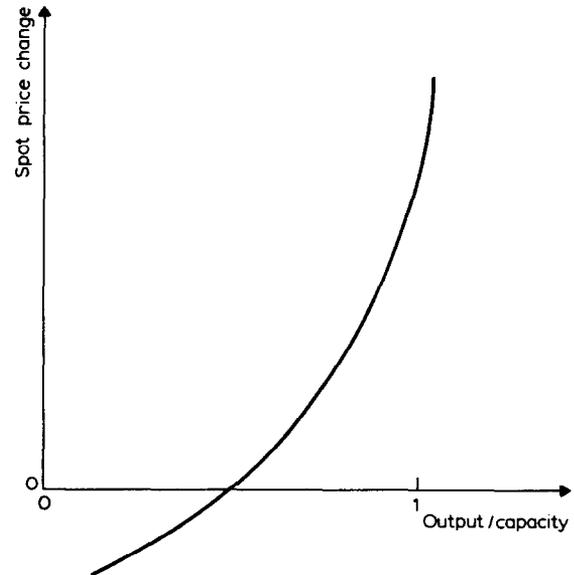


Figure 1. OPEC price reaction function.

Table 1. Variables employed in the exposition.

Variable	Determination	Definition
<b>Oil supply</b>		
<i>CAP</i>	Exogenous	Available capacity of 'non-disrupted' OPEC members
<i>OUTPUT</i>	Endogenous	OPEC production from 'non-disrupted' members
<i>DISRUP</i>	Exogenous	Production from 'disrupted' countries
<i>NONOPEC</i>	Exogenous	Non-OPEC production
<b>Oil demand</b>		
<i>USCON</i>	Endogenous	US oil consumption
<i>FCON</i>	Endogenous	Free world oil consumption outside the USA
<i>USSPR</i>	Exogenous	US Strategic Petroleum Reserve demand
<i>USSTCH</i>	Endogenous	US private sector oil inventory demand
<i>FSTCH</i>	Exogenous	Free world oil inventory demand outside the USA
<b>Prices</b>		
<i>PSPOT</i>	Endogenous	Spot price of Mideast light crude oil
<i>PUS</i>	Endogenous	US refiner acquisition cost
<i>PF</i>	Endogenous	Foreign refiner acquisition cost
<b>Other</b>		
<i>Y</i>	Endogenous	Gross national product
<i>X</i>	Endogenous	Vector of structural variables used in calculating consumption demand

where  $t$  indexes the time period,  $f$  is the function graphed above ( $f' > 0$ ),  $\psi$  and  $\beta$  are parameters to be estimated,  $CAP$  denotes capacity, and  $OUTPUT$  and  $CAP$  refer to OPEC.

Capacity decisions are assumed to be determined by longer-term considerations outside the scope of the model, and are taken as exogenous.  $OUTPUT$  is obtained

from the conditions that supply and demand be equal:

$$(USCON + FCON) + (USSPR + USSTCH + FSTCH) = OUTPUT + DISRUP + NONOPEC \quad (2)$$

where *US* stands for United States, *F* for foreign, *CON* for consumption, *STCH* for (non-SPR) stock change, *SPR* for Strategic Petroleum Reserve fill or draw, *OUTPUT* for the production of non-disrupted OPEC producers, *DISRUP* for the (reduced) output from the disrupted country, and *NONOPEC* for non-OPEC production.

US consumption is assumed to depend on the domestic refiner's acquisition cost ( $P^{US}$ ), income ( $Y^{US}$ ), and a vector of structural variables, including past prices ( $X^{US}$ ). Foreign consumption is defined similarly:

$$USCON = h^{US}(P^{US}, Y^{US}(P^{US}), X^{US}) \quad (3)$$

$$FCON = h^F(P^F, Y^F(P^F), X^F) \quad (4)$$

The US refiner's acquisition cost is taken to be an average of spot and contract prices (plus transport costs), and to adjust to the spot price. The domestic price abroad is defined similarly:

$$P_t^{US} = a_0 + a_1 P_{t-1}^{US} + a_2 (P_t^{SPOT} - P_{t-1}^{US}) \quad (5)$$

$$P_t^F = b_0 + b_1 P_{t-1}^F + b_2 (P_t^{SPOT} - P_{t-1}^F) \quad (6)$$

In general, the *a*'s and *b*'s will be different for institutional as well as tax reasons. For the moment, we take the other variables as exogenous.

To obtain *OUTPUT* in terms of consumption, stock change, and production by other countries, rearrange Equation (2):

$$OUTPUT = (USCON + FCON) + (USSPR + USSTCH + FSTCH) - (DISRUP + NONOPEC) \quad (7)$$

The objective of stocks policy should be clear — to lower the second of the three terms in order to reduce demand for OPEC output, thus moderating increases in the output-to-capacity ratio, and reducing pressure on the spot price. Stock policy yields 'more bang for the buck' as a disruption worsens due to the non-linearity of the price-reaction function.

We are interested in the effect of SPR releases on the spot price. In this model, such effects are three. The *direct effect* is to ease pressure as the SPR release reduces demand for OPEC output. The *feedback effect* occurs because holding down the spot price serves to hold down domestic prices at home and abroad as well, thus reducing the cutbacks in US and foreign consumption. The feedback effect clearly works against the direct effect. Together, these two comprise what we shall call the *domestic effect*. The *international interaction effect* depends on the reaction of foreign stocks to SPR releases. *Cooperation* implies that the SPR and foreign stockpiles are drawn down simultaneously. Under *competition*, foreign stocks may be built up as the US government draws down the SPR. In equation

form:

$$\begin{aligned} \frac{dP^{SPOT}}{dUSSPR} &= \frac{\beta f'}{CAP} \frac{dOUTPUT}{dUSSPR} \\ &= \frac{\beta f'}{CAP} [(dUSCON/dP^{US})(dP^{US}/dP^{SPOT}) \\ &\quad \times (dP^{SPOT}/dUSSPR) + (dFCON/dP^F) \\ &\quad \times (dP^F/dP^{SPOT})(dP^{SPOT}/dUSSPR) \\ &\quad + (1 + dFSTCH/dUSSPR)] \quad (8) \end{aligned}$$

Substituting Equations (5) and (6) into Equation (8) and labelling the international interaction effect,  $dFSTCH/dUSSPR$ , as  $\gamma$  yields:

$$\begin{aligned} \frac{dP^{SPOT}}{dUSSPR} &= \frac{\beta f'}{CAP} \left[ 1 - \frac{\beta f'}{CAP} \left( a_2 \frac{dUSCON}{dP^{US}} + b_2 \frac{dFCON}{dP^F} \right) \right]^{-1} \\ &\quad \times (1 + \gamma) \end{aligned}$$

direct effect
feedback effect
interaction effect

domestic effect
interaction effect

(9)

The sign of the direct effect is positive. The term in brackets is larger than one, so inverting it yields a number less than one — the feedback effect partially offsets the direct effect. The effect of international interaction depends on the sign of  $\gamma$ . Cooperation ( $\gamma > 0$ ) serves to magnify the benefits of the SPR release, while competition ( $\gamma < 0$ ) serves to mitigate them. In the extreme case, when foreign stocks are built barrel-for-barrel as the SPR is released ( $\gamma = -1$ ), the net effect on the oil market is nil. It is important to realize that the *magnification (or mitigation) effect is more than proportional*, due to the non-linearity of the price reaction function. Thus for a given SPR draw-down, a higher value of  $\gamma$  not only hits the spot price proportionally through the interaction effect, but also works through the direct effect (by lowering the argument of  $f'$ ) to exert additional downward pressure. ¶¶ Thus, as in the analyses referenced above, cooperation provides more than proportional benefits.

Finally, we should note that the benefits of stock draw are likely to be underestimated by the above analysis, which covers only 'within-drawdown-period' effects. Insofar as future spot prices are determined by an autoregressive process such as Equation (1), an SPR draw-down will be felt in future periods as well.

### The role of private stocks

For the sake of exposition, attention thus far has focused on strategic interaction between the SPR and foreign

stocks. The SPR, however, constitutes but a small fraction of US inventories. The bulk of the rest is controlled by the petroleum industry, which is free to build or draw as it sees fit. Indeed, folklore has it that private companies were largely responsible for destabilizing the oil market in 1979 through stock building.

Some have suggested that this stocking up represented a 'panic reaction' by those seeking supplies 'regardless of price'. A related, more sophisticated line of reasoning holds that firms build stocks as prices rise, only to draw them down when the market slackens. The view of stock change as pro-cyclical implies that inventory behaviour necessarily serves to exacerbate the problems associated with disrupted markets (see Frankel<sup>18</sup> and Danielsen and Selby<sup>19</sup>). Drawing down the SPR makes little sense in this type of world.

Verleger<sup>20</sup> has advanced an alternative theory, which centres on the relationship between stock changes and potential profits, predicting stock build when the difference between expected future prices and current prices exceeds the cost of storage. As long as prices are *expected* to rise sufficiently, the two theories' predictions are identical. These expectations cannot continue indefinitely. Eventually, stocks act as a stabilizing force. As Verleger points out (p 120): '[i]t is difficult to model the behavior of oil industry inventories'. His examination

¶¶ To calculate the effect of a change in cooperation, we need to differentiate Equation (9) with respect to  $\gamma$ .

$$\frac{d}{d\gamma} \frac{dPSPOT}{dUSSPR} = \frac{d(dPSPOT/dUSSPR)}{d(dFSTCH/dUSSPR)} = \frac{d^2PSPOT}{dFSTCH^2}$$

$dPSPOT/dFSTCH$  is just Equation (9) with  $1/\gamma$  substituted for  $\gamma$ . Thus

$$\frac{d^2PSPOT}{dFSTCH^2} = \frac{d(\text{domestic effect})}{dFSTCH} \quad (\text{interaction effect}) \\ + \frac{d(\text{interaction effect})}{dFSTCH} \quad (\text{domestic effect})$$

The second term provides the proportional impact on the spot price noted above. The first term gives the extra kick. Differentiating the domestic effect is rather involved and the results are uninformative. We make the simplifying assumption that the effect on the weighted-average slope of the demand curves,

$$a_2 dUSCON/dPUS + b_2 dFCON/dPF,$$

of changes in  $FSTCH$  is of second order, and can be neglected. We call this average  $Z$  in the calculation below. Further, we approximate

$$dPSPOT/dFSTCH$$

by a second order Taylor Series:

$$\frac{d^2PSPOT}{dFSTCH^2} \approx \text{proportional effect} \\ + (1 + 1/\gamma) \frac{\beta f''}{CAP} \left[ 1 + \frac{2Z\beta f'}{CAP} \right] \left[ \left( 1 + \frac{1}{\gamma} \right) \right] \\ + Z \left( \frac{\beta f'}{CAP} + \frac{Z\beta^2}{CAP^2} [f']^2 \right)$$

It then follows that:

$$\frac{dPSPOT}{dFSTCH} \approx \left[ \frac{\beta f'}{CAP} + \frac{Z\beta^2}{CAP^2} [f']^2 \right] \underbrace{(1 + 1/\gamma)}_{\text{interaction effect}}$$

If we assume  $f$  to be convex and approximable by a polynomial, then  $f'$  and  $f''$  are positive and the bracketed terms are positive. The effect of changing  $\gamma$  is thus more than proportional.

of the profit motive produced weak (ie correctly signed, but largely statistically insignificant) results, implying that the 'panic' theory could not be rejected. In this paper, we draw on work currently being performed under the aegis of the Harvard Energy Security Program.<sup>21</sup> The specification estimated here contains a profit motive, but differs from the one employed by Verleger in that:

- the stock and consumption data have been seasonally adjusted (to account for the normal pattern of alternating build in the second and third quarters, and draw in the fourth and first quarters);
- effects of unanticipated changes in demand ('surprises') are incorporated;
- we allow for the effects of price controls on stock behaviour; and
- we do not lump the disparate countries of the OECD together.

We take the inventory-to-sales ratio, rather than the raw inventory level, as the variable to be explained. Although not strictly defensible on the grounds of economic theory alone, the use of this ratio is consistent with trade and industry characterization of stocks in terms of 'days of consumption'.

Our explanatory variables are three. The first attempts to capture the profit motive by comparing expected future prices with today's prices and carrying costs. We expect stock build when the difference is positive. The second reflects the fact that stock adjustment is not costless by comparing the inventory-to-sales ratio last quarter with a four-quarter moving average. If last quarter's value is high relative to trend, we expect a gradual movement back. Finally, the 'demand surprise' term captures the simple fact that higher-than-expected demand last quarter (due to say, unexpected climatic or economic conditions) will result in stock depletion, since contract renegotiation is gradual. We seek to capture this 'surprise' term by comparing the previous quarter's demand with a four-quarter moving average.

The results here summarize a larger effort.<sup>22</sup> In the absence of any *a priori* wisdom concerning the correct structure for the regression, we use logarithms, so that the effect of changes can be readily compared across variables, and the results interpreted as elasticities. The regression was estimated using two-stage least squares over the period 1974:4 to 1981:2 (the final digit refers to the quarter) with all variables seasonally adjusted (the adjustment is based on quarterly data extending back to 1960) and in logarithmic form. The results were as follows (absolute values of  $t$ -statistics in parentheses):

$$(I/S)_t - (I/S)_{t-1} = 0.16 \times [eP_{t+1}^{US} - (1 + r_t)P_t^{US}] \quad (2.0)$$

$$-0.54 [(I/S)_{t-1} - \overline{(I/S)}_{t-1}] \quad (4.0)$$

$$-1.44 [S_t - \bar{S}_t] \quad (5.5)$$

$$\bar{R}^2 = 0.54, \quad DW = 1.24$$

where  $t$  indexes time,  $I$  is inventories,  $S$  is sales (both

seasonally adjusted, and in logarithmic form),  $P^{US}$  is the US domestic price,  $r$  is the three-month Treasury Bill rate divided by four, a bar over a variable indicates a four-quarter moving average, and  $\epsilon$  denotes expectation. Equations (5) and (6) characterize the domestic price as a weighted average of the spot price and its own lagged value. Thus the expected domestic price *next period* is a weighted average of the future spot price and the domestic price *today*. From Equation (1), the output-to-capacity ratio and today's spot price can be used as instruments for next period's spot price in the estimation of Equations (5) and (6).

The results imply that companies build stocks in terms of days of consumption:

- when they expect prices to increase by more than the cost of holding them;
- when their inventory-to-sales ratios are below historical levels; and
- when consumption is unexpectedly low.

The coefficients, which are significant at the 95% level, can be interpreted as elasticities. A 1% increase in expected profit leads to a 0.16% increase in the inventory-to-sales ratio, or roughly 20 000 bbl/day (inventory-to-sales ratio of 80 days  $\times$  0.16%  $\times$  15.5 million bbl/day sales  $\approx$  2 million bbl/quarter  $\approx$  20 000 bbl/day). *It is too simplistic to characterize inventory accumulation as 'pro-cyclical' or 'anti-cyclical' per se. Stock build or stock draw (or both) can accompany the various stages of an oil supply disruption.*

### Policy issues

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 (eg ownership, finance, decisionmaking). 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' programme for the reserve is prohibitively complicated, however (the answer to each of the questions being far from trivial). It is also of limited value to policymakers, 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.\*\*\* Second, while most economists tend to agree (or at least not disagree too strenuously) about the size of the reserve and its institutional set-up, considerable controversy exists about its use as an instrument of policy, as noted in the opening quotation.††† It should be obvious that

\*\*\* The size question has been addressed by Balas,<sup>23</sup> Teisberg,<sup>24</sup> Hogan<sup>25</sup> and Chao and Manne.<sup>26</sup> Institutional issues are treated by Krapels<sup>27,28</sup> and Plummer.<sup>29</sup> Kuenne, Blankenship, and McCoy<sup>30</sup> examine drawdown decisions.

††† Neither do we address the questions of how the SPR oil should be sold, or to whom. For a discussion of these issues, see Allen.<sup>31</sup> For a specific proposal to sell SPR oil through a futures market, see Devarajan and Hubbard.<sup>32</sup>

a reserve which is never intended to be used is no better than no reserve at all.

In analysing 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 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. As David Stockman<sup>33</sup> described it: 'That would be a little like a mouse taking on an elephant; our [proposed OECD reserves of] two billion barrels in salt domes is no match for their 500 billion barrels in the ground'.

An inherent problem in any contingency programme is determining when the 'emergency' has occurred. We devote some attention to this critical question of timing, which lies at the heart of the sub-trigger controversy.

### Options

What alternatives (short of pulling the trigger) are available to OECD members when confronted with the spectre of a disruption? First, they can do nothing. *Laissez-faire* has been a popular option in the past, and can serve as a 'control' against which to compare 'do something' alternatives.

In the 'do something' sphere, recent stress appears to be on informality, flexibility, and consultations among governments and between governments and oil companies (see Becker,<sup>34</sup> Keohane,<sup>35</sup> and Lantze<sup>36</sup>). Such measures, while admirable as *modi operandi*, are of little value in the absence of ideas to talk about. Otherwise, they will very likely wind up serving as a fig leaf for a 'do nothing' policy.

Second, governments can exhort companies to refrain from making spot market purchases, or at least from doing so at 'abnormal' prices. We regard spot prices as being determined by supply and demand. (See Equations (1) and (7).) Thus, insofar as spot market abstinence follows from stock draw or demand restraint, price pressure will be eased. Otherwise, such exhortations are *per se* foolish. The spot price represents not the illness, but the thermometer, and disabling the latter can do little for the former.

Third, correction of 'imbalances' – due to rigidities in the oil market, a supply shock is likely to affect countries unequally. Informal reallocation can serve to correct these 'imbalances', and hence to limit recourse to the spot market. This option is thus a version of the last; reallocation can be effective if accompanied by demand restraint or stock draw.

Fourth, demand restraint is effective, but terribly difficult to implement.

Fifth are so-called 'flexible stock policies', our focus for analysis in this paper. Several approaches are possible.

One plan of attack is to calculate the optimal draw-cum-fill schedule for the SPR under the various assumptions about the stock behaviour of other OECD members. Such a procedure entails a dynamic programming solution and requires a Markov state-transition matrix specifying the probability of a disruption of size  $D_t$  in period  $t$  given the existence of a disruption of size  $D_{t-1}$  in period  $t-1$ . Teisberg<sup>37</sup> took this approach. Hogan<sup>38</sup> extended it to incorporate international interaction. Neither considered private inventory behaviour. In a recent paper, Wright and Williams<sup>39</sup> incorporate private stocks, but their assumptions result in inventory draw in a disruption; the behaviour 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.<sup>40</sup>

Despite its attractive features, we do not employ an optimizing model in this paper. The data and simplifying assumptions required to do so limit its value in short-term policy applications. Instead, we adopt the less intellectually satisfying but simpler approach of comparing a few proposed strategies designed to be illustrative of a broad range of alternatives.

We examine five stock policies:

- 1 *Laissez-faire*. In this 'base case', countries rely on the market to allocate supplies. The IEA mechanism is not triggered, even in a severe disruption.
- 2 The USA relies on the market, other countries release five days of stocks (ie  $(I/S)_{t+1} - (I/S)_t = -5$ ) held compulsorily. A plan of this type has been advanced by the Commission of the European Communities.<sup>41</sup>
- 3 As in (2) but other countries increase stockpiles by five days (ie  $(I/S)_{t+1} - (I/S)_t = 5$ ).
- 4 Unilateral US SPR drawdown of five days of consumption (other countries rely on the market).
- 5 All countries participate in an agreement to release five days of consumption from stocks.

The players involved are three – the US SPR authorities, the US oil industry (whose behaviour is described above), and the foreign authorities. Diverse forms of regulation make separation of public and private stock behaviour abroad a formidable task, and prevent our treating foreign stock behaviour endogenously. This is equivalent to assuming either that foreign governments are able to dictate stock behaviour to their domestic oil companies or that foreign stock changes reflect decisions taken in both the public and private sectors. Neither is particularly palatable, but modelling foreign stock behaviour must await future work.

#### *Economic analysis of stock policy alternatives*

The economic effects to be considered are two. First, we seek to quantify the above-described effects of stock adjustments on the world oil market. Second, we examine the resulting macroeconomic impact, which is presumably the *raison d'être* of stocks policy. The effects of unilateral American action (eg the infamous 1979

middle distillate entitlement) on other buyers in the world oil market are well appreciated. *In this paper, we turn the question around by investigating the impacts of OECD policies on the US economy*, utilizing a short-run macroeconomic model linked to a model of the world oil market. Unlike most large macroeconomic models (where the oil price is a datum), the linkage here runs in both directions. The world oil market model and the macroeconomic model are solved simultaneously; income effects of oil price changes feed back into oil demand, which affects the price of oil, etc. A brief description of the macroeconomic model can be found in the Appendix; see Hubbard and Fry<sup>42</sup> for more detail and documentation.

How can policies designed to influence oil prices affect the economy? Through which channels do oil shocks have economic impacts? First, the increased oil price diverts spending from home-produced goods to imports, increasing the transfer of resources to oil-producing countries and reducing aggregate demand for US output (net exports fall since oil exporters don't spend all their increased wealth immediately). Second, the rise in the relative price of oil, an important input, reduces the profit-maximizing level of output for firms which use oil, necessitating a fall in real GNP from the supply side. This reduction in output reduces the demand for other inputs (at least in the short run), such as labour, thus lowering the real wage at which the supply of and demand for labour would be equalized.

These direct aggregate demand and supply effects are magnified because the economic system is not perfectly flexible. Because of rigidities in the economy, particularly rigid real wages, unemployment results and the economy will fail to attain its (already diminished) consumption and production possibilities. The failure of wages and prices to adjust downward aggravates the rise in the price level caused by an oil price increase. The ultimate consequences for inflation and real income will depend on the size and timing of the disruption (and oil price increases), on the effect of the consequent price level increase on wage settlements, and on the fiscal, monetary, and regulatory responses of the government.

In principle, two types of policy responses could be advanced to reduce the costs to the economy of a large oil price increase attendant to a supply disruption – *income stabilization* policies and *oil market* policies. The former includes such devices as temporary tax rebate schemes, accommodating monetary policy, or investment incentives – tools for mitigating the short-run drain on aggregate demand for a given oil price increase. Oil market policies encompass oil taxes and tariffs, price controls, and stockpile drawdown programmes – interventions designed specifically to alter oil prices directly. Clearly, the two categories are not mutually exclusive.

There are two basic difficulties with relying solely on stabilization policies to address the problems of oil shocks. First, precisely to the extent to which they are successful (in maintaining real income), oil demand

remains high, keeping upward pressure on prices. ‡‡‡ Second, the imprecision with which stabilization policies achieve their goals is well known. The lags inherent in implementing policy, and phasing it out (not to mention correctly diagnosing the problem) may well nullify the intended result. Temporary tax changes may be ineffective. An accommodating monetary policy runs the risk of raising inflationary expectations.

Analyses of oil market policies have produced similarly ambiguous conclusions. Oil taxes and tariffs put downward pressure on world oil prices, but in the process, they may exacerbate the price shock at home and generate a substantial fiscal drag problem. Oil price controls reduce the domestic price, but may reduce incentives for domestic production and increase the demand for imported oil, thereby raising world oil prices. In contrast, stockpile releases can serve to reduce world oil prices without the unpleasant economic side effects.

### Simulation results

Our simulations cover the five-year period 1982–86 (results for 1986 are omitted for brevity). We first present a 'control scenario', where no further disruption takes place. Combined Iranian and Iraqi production recovers throughout the interval. US oil production is projected to drop slowly throughout the interval, although it is more than offset by increases outside OPEC. We expect a relatively 'loose' market (ie 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. In the control scenario, the USA fills the SPR at 200 000 bbl/day.

### The disruption

We simulate a disruption of moderate size. Available capacity is reduced by 7 million bbl/day for one year, starting in 1983:1. Much 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%.) With no policy intervention, (we actually assume that the US government 'intervenes' to the extent of halting SPR fill during 1983), OPEC production, which is endogenous, falls relative to the base case roughly by 100 000 bbl/day in 1983:1, 400 000 bbl/day in 1983:2, 800 000 bbl/day in 1983:3, 1.4 million bbl/day in 1983:4, 2.2 million bbl/day in 1984:1, 2.4 million bbl/day in 1984:2, 2.9 million bbl/day in 1984:3 and 3.6 million bbl/day in 1984:4.

Table 2 and Figure 2 present quarterly spot and US 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. US private inventories are built

‡‡‡ As mentioned above, there are certain 'necessary' costs of an oil supply shock. If stabilization policies attempt to completely insulate the economy, inflation will be higher than it need be in the short run, and the economy's long-run growth path may be adversely affected.

relative to the control, rapidly at first (roughly 90 million bbl in 1983), more slowly thereafter. Starting in 1984:4, private inventories are decumulated relative to the control.

### Policy

Borrowing from the EC proposal, we examine a policy of releasing from inventory five days of consumption. The USA and rest-OECD consumption are taken as roughly 16 million bbl/day and 20 million bbl/day respectively, which translates into releases of 80 and 100 million bbl. § § § We assume these releases are initiated in the second quarter of the disruption (1983:2) and are repeated in the third quarter, amounting to a 900 000 bbl/day SPR draw and a 1.1 million bbl/day draw of foreign stocks. The 160 million bbl released from the SPR represent about half of its current contents. Obviously, other configurations are possible. Table 3 presents the effects on spot prices. Table 4 presents the effects on the US real GNP.

The tables reveal that given a US *laissez-faire* policy (no SPR draw or fill) during the disruption, it makes a noticeable (although not enormous) difference whether the rest of the OECD follows a 'cooperative' (draw) or 'noncooperative' (build) path. Even under the moderate assumptions employed (the 200 million bbl stock increase or decrease is smaller than the rest-OECD build of about

§ § § These consumption figures are for stock release illustration only. In the model, consumption (*USCON* and *FCON*) is endogenous.

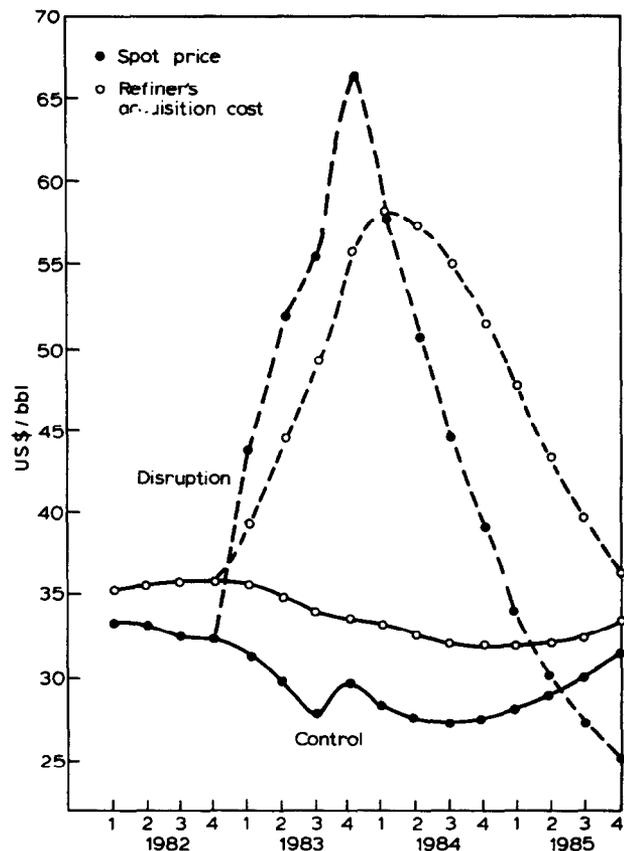


Figure 2. Oil prices: control v disruption.

Table 2. Comparison of control and 'base case' disruption.

Quarter	Spot price (US \$/bbl)		Refiner's acquisition cost (US \$/bbl)		US private stock change (10 <sup>3</sup> bbl/day)	
	C	D	C	D	C	D
1982:1	33.15		35.20		-840	
1982:2	33.05		35.70		620	
1982:3	32.30		35.85		550	
1982:4	32.25		35.90		-410	
1983:1	31.05	43.90	35.65	39.55	-1050	-750
1983:2	29.70	51.85	35.00	44.60	370	580
1983:3	27.80	55.70	34.00	49.40	500	730
1983:4	29.80	66.50	33.90	56.10	-290	-40
1984:1	28.20	57.95	33.40	58.25	-1110	-1110
1984:2	27.45	50.80	32.80	57.60	230	350
1984:3	27.30	44.65	32.30	55.23	450	520
1984:4	27.80	39.20	32.15	51.85	-330	-410
1985:1	28.20	34.15	32.15	47.90	-1030	-1210
1985:2	29.00	30.30	32.40	43.90	250	150
1985:3	30.10	27.35	32.90	40.20	480	370
1985:4	31.90	25.25	33.85	36.90	-240	-420

Key: C = control; D = disruption.

Table 3. Effects of stock policies on spot prices (US \$/bbl).

Quarter	Spot price: base case disruption	Difference in spot price relative to base case			
		US market rest-build	US market rest-draw	US draw rest-market	All draw
1983:1	43.90	0	0	0	0
1983:2	51.85	3.70	-3.25	-2.55	-5.45
1983:3	55.70	6.25	-5.50	-4.25	-9.20
1983:4	66.50	4.60	-4.00	-2.95	-6.55
1984:1	57.95	3.80	-3.30	-2.40	-5.30
1984:2	50.80	3.00	-2.60	-1.85	-4.15
1984:3	44.65	2.30	-1.95	-1.40	-3.15
1984:4	39.20	1.65	-1.35	-0.95	-2.15
1985:1	34.15	1.05	-0.85	-0.70	-1.25
1985:2	30.30	0.50	-0.35	-0.20	-0.50
1985:3	27.35	0.05	0.05	0.10	0.20
1985:4	25.25	-0.40	0.45	0.35	0.85

Table 4. Losses in US real GNP (in billions of 1982:1 \$/year relative to control) under various stock policies.

Quarter	Base case disruption	US market rest-build	US market rest-draw	US draw rest-market	All draw
1983:1	1.6				
1983:2	5.6	6.6	4.8	-5.0 <sup>a</sup>	-5.6
1983:3	11.8	13.6	10.2	-1.4	-2.8
1983:4	20.0	21.8	18.2	17.0	15.4
1984:1	24.2	26.0	22.4	22.4	20.6
1984:2	30.4	32.2	28.4	28.0	26.2
1984:3	34.6	36.4	32.8	32.2	30.4
1984:4	36.4	38.0	34.8	34.2	32.8
1985:1	36.6	37.6	35.2	35.2	34.0
1985:2	39.0	40.8	37.2	37.8	35.8
1985:3	40.8	43.0	38.6	39.2	37.2
1985:4	38.8	41.2	36.6	37.2	35.0

<sup>a</sup> Negative numbers indicate GNP is higher than in the control.

220 million bbl in 1979),<sup>43</sup> the difference in the spot price is substantial: about \$7/bbl in the first 'policy' quarter (1983:2), \$11.75 in the second (recall that the policy lasts only two quarters), \$8.60 in the third, and about \$7 in the fourth. By 1985, the effect on the spot price is insignificant, but US domestic prices (not shown) remain higher (by about \$4/bbl in 1984:4). The loss in US GNP is of the order of 30–40% greater in the 'noncooperative' case in the first two quarters, 15–20% greater in the next two quarters.

The effects of using the SPR are two. First, the decreased demand for OPEC output exerts downward pressure on spot prices. It can be seen from Table 3 that this beneficial effect is only about three-fourths as large as in the case where foreign stocks are decumulated, due to the smaller size of the SPR draw (900 000 bbl/day v 1.1 million bbl/day). Second, SPR draw substitutes for imported oil almost entirely; US oil imports fall by 900 000 bbl/day in 1983:2 and 850 000 bbl/day in 1983:3. This import reduction improves the US trade balance and hence the US GNP. Given that market policies are followed by the other OECD members, SPR drawdown in 1983:2 and 1983:3 reduces the loss in real GNP by \$7.2 billion (all GNP figures are in 1982:1 dollars) over the year starting in 1983:2. Since the disruption costs the economy \$21.5 billion during this period, use of the SPR recoups about one-third of the loss. A rough estimate of the value of SPR oil can be obtained by dividing the \$7.2 billion by the 160 million bbl released, yielding \$45/bbl. This figure measures economic benefits over and above the revenues accrued from SPR sales. In an intertemporal optimization calculation, these revenues must be compared with the costs (which we also ignore) of buying and storing the oil for the Reserve.

Finally, we compare the 'cooperative' (all draw) case with *laissez-faire*. The 2 million bbl/day decumulation shaves about \$5.50 off the spot price in 1983:2, just over \$9 in 1983:3. In the following two quarters, spot prices are \$6.55 and \$5.30 lower respectively. The US GNP is increased over the year starting in 1983:2 by \$8.5 billion, about 20% more than in the unilateral drawdown case.

## Conclusion

Flexible stock policies (including 'don't build') can play a significant role in moderating spot price fluctuations and reducing disruption-induced losses in real income, even in a moderate ('sub-trigger') disruption, where the US refiner's acquisition cost rises by about 60% (50% in real terms). Inflation and unemployment (not shown) are also reduced. Cooperation provides noticeable tangible benefits in addition to the widely claimed spiritual advantages. Benefits are understated insofar as GNP is an imperfect measure of economic welfare because it ignores wealth transfers abroad. The 'terms-of-trade adjusted' figure would be larger. We should note that while the gains from stockpile coordination are significant, they are hardly overwhelming. Whereas macroeconomic policy responses are partly

responsible for damage associated with past oil shocks, we have held them constant throughout. In this respect, international coordination of stabilization policies can play a role.

We find the claim that government stock drawdown is impotent due to countervailing actions taken in the private sector to be without foundation. Government releases dampen spot price increases, serving to reduce private inventory accumulation, not increase it. Unless the structural forces behind company decisions are different from in the past, private stockpiling will tend to exacerbate the disruption effects in the early stages, and mitigate them thereafter.

Our simulations are designed to be illustrative, and clearly depend on our policy assumptions. We are also constrained by the well known limitations of economic models, but we nevertheless believe that until such time as policy is truly conducted on an optimizing basis, this type of analysis will continue to be a useful input to policy discussions.

## References

- 1 E. Krapels, ed, *International Oil Supplies and Stockpiling: Conference Proceedings*, Economist Intelligence Unit, London, 1982.
- 2 H. Chao and S. Peck, 'Coordination of OECD oil import policies: a gaming approach', mimeo, Electric Power Research Institute, September 1980.
- 3 W. Hogan, 'Oil stockpiling: help thy neighbor', Harvard Energy Security Program Discussion-Paper Series, H-82-02, March 1982.
- 4 A. Manne, 'The potential gains from joint action by oil importing nations', in J. Plummer, ed, *Energy Vulnerability*, Ballinger, Cambridge, 1982.
- 5 H. Rowen and J. Weyant, 'Reducing the economic impacts of oil supply interruptions: an international perspective', *Energy Journal*, January 1982, pp 1–34.
- 6 R. Keohane, 'International agencies and the art of the possible: the case of the IEA', *Journal of Policy Analysis and Management*, Summer 1982, pp 469–481.
- 7 E. Krapels, *Oil Crisis Management*, Johns Hopkins University Press, Baltimore, 1980.
- 8 USGAO, 'Unresolved issues remain concerning US participation in the International Energy Agency', ID-81-38, September 1981.
- 9 R. Weiner, 'The oil import question in an international context: institutional and economic aspects of consumer cooperation', Energy and Environmental Policy Center Discussion Paper Series, E-81-06, Kennedy School of Government, Harvard University, June 1981.
- 10 U. Lantzke, 'The use of oil stockpiles: the view from the International Energy Agency', in E. Krapels, *op cit*, Ref 1.
- 11 US Department of Energy, 'International energy emergency preparedness', July 1981.
- 12 US Department of Energy, 'Securing America's energy future: the national energy policy plan', July 1981.
- 13 M. Allen, 'Strategic petroleum reserve drawdown and distribution decisions', paper presented at IGT Symposium: Planning for Energy Disruptions, May 1982.
- 14 P. Verleger, *Oil Markets in Turmoil*, Ballinger, Cambridge, 1982.
- 15 W. Nordhaus, 'Oil and economic performance in industrial countries', *Brookings Papers on Economic Activity*, No 2, 1980, pp 341–388.

- 16 J. Plummer, 'Methods for measuring the oil import reduction premium and the oil stockpile premium', *Energy Journal*, January 1981, pp 1-18.
- 17 R. G. Hubbard and R. Fry, 'The macroeconomic impacts of oil supply disruptions', Energy and Environmental Policy Center Discussion Paper Series, E-81-07, Kennedy School of Government, Harvard University, revised June 1982.
- 18 P. Frankel, 'Motivations of governments and companies', in E. Krapels, *op cit*, Ref 1.
- 19 A. Danielsen and E. Selby, 'World oil price increases: sources and solutions', *Energy Journal*, October 1980, pp 59-74.
- 20 Verleger, *op cit*, Ref 14.
- 21 R. G. Hubbard and R. Weiner, 'Oil inventory behaviour: an empirical analysis of public-private interaction', paper presented to the IAEE North American Conference, November 1982.
- 22 *Ibid*.
- 23 E. Balas, 'Choosing the overall size of the strategic petroleum reserve', in W. Ziemba *et al*, eds, *Energy Policy Modeling: US and Canadian Experiences*, Nijhoff Publishing, The Hague, 1980.
- 24 T. Teisberg, 'A Dynamic Programming Model of the US Strategic Petroleum Reserve', *Bell Journal of Economics*, Autumn 1981, pp 526-546.
- 25 W. Hogan, *op cit*, Ref 3.
- 26 H. Chao and A. Manne, 'An integrated analysis of US oil stockpiling policies', in J. Plummer, ed, *Energy Vulnerability*, Ballinger, Cambridge, 1982.
- 27 E. Krapels, *op cit*, Ref 1.
- 28 E. Krapels, *op cit*, Ref 7.
- 29 J. Plummer, 'US stockpiling policy', in J. Plummer, ed, *Energy Vulnerability*, Ballinger, Cambridge, 1982.
- 30 R. Kuenne, J. Blankenship and P. McCoy, 'Optimal drawdown patterns for strategic petroleum reserves', *Energy Economics*, Vol 1, No 1, January 1979, pp 3-13.
- 31 M. Allen, *op cit*, Ref 13.
- 32 S. Devarajan and R. G. Hubbard, 'Drawing down the strategic petroleum reserve: the case for selling futures contracts', BIEE/IAEE Paper, June 1982.
- 33 D. Stockman, 'Needed: a dual resurrection?', *Journal of Energy and Development*, Spring 1980.
- 34 E. Becker, 'The use of oil stockpiles: the view from Bonn', in E. Krapels, *op cit*, Ref 1.
- 35 R. Keohane, *op cit*, Ref 6.
- 36 U. Lantzke, *op cit*, Ref 10.
- 37 T. Teisberg, *op cit*, Ref 24.
- 38 W. Hogan, *op cit*, Ref 3.
- 39 B. Wright and J. Williams, 'The roles of public and private storage in managing oil import disruptions', *Bell Journal of Economics*, Autumn 1982, pp 341-353.
- 40 R. Kuenne *et al*, *op cit*, Ref 30.
- 41 Commission of the European Communities, 'Measures to limit the effects of a limited shortfall in oil supply', COM (81) 533, September 1981.
- 42 R. G. Hubbard and R. Fry, *op cit*, Ref 17.
- 43 US Department of Energy, *Monthly Energy Review*.

## Appendix

This appendix provides a brief description of the Hubbard-Fry econometric model; detailed documentation is in a paper available from the authors upon request. The model is designed to quantify the short-term economic costs of oil supply disruptions and to pinpoint the general equilibrium impacts of policy responses. Domestic economic aggregates are linked to a model of the world oil market by a core macroeconomic model

with real and financial sectors. Solution of the models is fully simultaneous and is accomplished through iteration. The government has at its disposal a set of fiscal and monetary policy instruments, with which it can influence aggregate demand and supply. The basic output of the model consists of a set of relevant oil prices accompanied by endogenous OPEC output projections and a set of macroeconomic variables dealing primarily with inflation, unemployment, financial variables, and income.

### Macroeconomic model

The transmission of an oil shock is modelled 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 these channels. Housing and inventory investment decisions are also modelled. 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 labour 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 labour 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. Labour compensation depends on wages, fringe benefits, and the employers' contribution to payroll tax programmes (like 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 (ie 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 labour 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 labour compensation and the price of output; changes in corporate income taxes, the investment tax credit, or allowable depreciation rates affect investment. In analysing the impact of fiscal policy, the model focuses on:

- the timing of the revenue and expenditures changes;
- the components of aggregate demand affected (and their feedbacks to the rest of the model);
- the inflationary consequences of the changes; and
- the way in which the change is financed.

#### *Oil market model*

As described in the text, supply and demand are calculated simultaneously, and determine the spot price. OPEC output is given by the price reaction function; other supplies are exogenous. Demand is as follows: US oil consumption depends on real income, real domestic price, its own lagged value, and seasonal adjustments. Foreign oil consumption depends on its own lagged values, US oil consumption, exchange rates, and seasonal adjustments. Foreign stock change is exogenous. US stock change is as described in the text.