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Improving Energy Security Through an International Cooperative Approach to Emergency Oil Stockpiling

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March 29, 2002

Abstract

Recent world events have heightened concern about energy security and the possible risks of oil market disruptions. This paper examines the shared benefits of emergency oil stockpiling to the U.S., Asia and the IEA-Europe regions, in order to better understand the circumstances in which additional countries will find it in their interest to develop or increase their emergency oil stocks. The approach couples the results of a numerical simulation model of oil market disruptions and stockpile benefits with an analysis of the benefits of cooperation among stockpiling regions. To estimate the costs of oil market disruptions for individual countries and regions it utilizes aggregate estimates of the linkage between oil-price shocks and macroeconomic output.

Key words: oil stockpiling, energy security, strategic petroleum reserve, macroeconomic costs of oil market disruptions

Disclaimer:
The views and opinions expressed here are those of the authors and do not necessary represent the views of the Department of Energy, or ORNL. We are grateful for the support of the U.S. Department of Energy. We are particularly thankful for the ideas and comments of John Shages, Walter Chilman,and Inja Paik (of DOE) and Keiichi Yokobori (APERC).

Introduction

Oil stockpiling is an activity that provides benefits to the stockpiling economy (or group of economies), while also spilling over substantial benefits to other oil consuming economies who may have no direct stake in the stockpile. The principal benefit of stockpiling is to stabilize the world oil price, and oil price stabilization is a "public good" that benefits all oil-using economies. Accordingly, it is helpful to address the stockpiling issue as one of international interaction and cooperation. Cooperation is ultimately expected to be the dominant force, rather than "free riding," because in the long run economies should realize that their willingness to engage in stockpiling influences the decisions of other economies, both in matters of energy security and in other matters where these economies must cooperate.

We complement a conceptual discussion of the issues with numerical modeling and formal analyses. The modeling method used was initially developed to estimate the net benefits to the U.S. of expanding the Strategic Petroleum Reserve, and subsequently applied to assess the direct and shared benefits of stockpiling by Asian Pacific countries, for the Asia Pacific Energy Research Centre (APERC). A probabilistic model of world oil market (DIS-Risk) gathers together important quantifiable elements involved in making stockpile size investment decisions. Economic analysis is applied to estimate the net economic benefits of alternative U.S., APEC, and IEA Europe reserve sizes, drawdown rates and strategies.

The expected direct benefits of stockpiling for most smaller economies are shown to be less then the costs those economies would bear if they developed an oil stockpile on their own. At the same time, if they did stockpile, they would be assisting other oil consuming countries, just as the current stockpiling by other economies does and will benefit them. Countries included in the analysis are members of the Asia-Pacific Economic Cooperation (APEC) group, the United States and the IEA. The analysis also indicates that substantially larger stockpile sizes could be justified for certain regions and groups of economies, based on expected net economic benefit to the stockpiling region alone. We then assess the extent to which the stockpiling decisions for APEC and IEA economies (individually and in groups) interact with the stockpiling management and expansion decisions made by other economies which currently hold emergency stocks (IEA countries, particularly, the U.S., Japan, and IEA Europe). We consider the benefits of a range of cooperative strategies for groups of economies with the benefits of strategies where certain economies act independently and either build stocks on their own, or neglect to do so.

Assumption Regarding Drawdown Coordination

While we are interested in evaluating the potential incentives for cooperation among consuming nations when establishing stockpile *sizes*, we assume that stockpile *management* (that is, fill decisions during normal markets and draw decisions during disruptions) are essentially well-coordinated among regions. Thus, during the simulations of the benefits of alternative stockpile sizes, we treat the U.S., IEA-Europe, and other emergency stockpiles as well-coordinated at the time of a drawdown. One reason for doing this is the general observation that once a disruption has occurred, it is strongly to the benefit of a stockpile owner to draw down the reserve, regardless of the existence of public benefits to other regions. Conditional on the occurrence of a significant disruption, the hedging benefits of holding oil in the reserve are modest compared to the own-country benefits of drawing down the reserve. This is largely due to the common assumption that disruptions are rare, and that once a disruption occurs, the likelihood of a successive disruption in the near future that could require the use of oil held as a hedge is small.

This general insight is consistent with the results of Devarajan and Weiner (1989) who looked at the benefits of coordinating stockpile *use* (draw), compared to the non-cooperative equilibrium. In a 2- period model, dynamic game between 2 oil importers, they found that while free riding on size decisions may be likely, there are not many benefits to free riding on drawdown. Similarly, Murphy, Toman and Weiss (1985) used a dynamic programming approach to policy coordination, in stocks and (normal market) demand restraint. The decision was posed as a Nash dynamic game, and a key finding was that the gains from coordination of drawdown decisions are modest. With realistic inventory sizes, and with fairly low disruption probabilities, the "differences in the timing of [drawdown] decisions between cooperative and noncooperative outcomes may not be very significant." [p. 663]. An intuitive explanation is that cooperative/noncooperative differentials are in part due to the hedging value of holding stocks, and the differentials are small if the hedging value is small.

2. Description of Estimation Approach and Assumptions

The DIS-Risk Model applies risk analysis to assess the uncertain implications of oil stockpiling. The model has been used to assess the U.S. SPR size (Leiby and Bowman, 2000) for the U.S. Department of Energy and APEC strategic stocks (Yokobori/APERC, 1999). For this analysis it has been adapted and extended to estimate efficient stock sizes for the U.S. and the Asian Pacific regions plus the IEA Europe region.

In DIS-Risk, two SPR configurations are compared side-by-side. Those two configurations generally are the current reserve configuration and an alternative. An alternative program could consist of a higher combined draw rate capability or a higher combined reserve size or both. Each SPR configuration is specified in terms of its costs (capital, operations, and maintenance), draw rate capabilities, reserve sizes, and fill and refill rates. When compared, the two SPR configurations are subjected to the same set of random oil supply disruptions. Oil supply disruptions are simulated in the context of a market specified by a reference path for world oil prices, and reference oil demands and supplies for the major regions (the U.S., Asian Pacific region, and IEA Europe). Reference paths track low, base, and high oil price path cases from the Annual Energy Outlook and International Energy Outlook of the U.S. EIA.

Figure 1 below shows a simplified diagram of how the DIS-Risk model works. The expected benefits of expanding U.S., Asian Pacific, and IEA Europe emergency oil stocks is determined using a Monte Carlo simulation of the world oil market, with and without additional emergency stocks. Each simulation is composed of thousands of samples, each sample being a randomized projection of the world oil market through the year 2030. The thousands of iteratively sampled outcomes are then recorded and used to produce the expected (or mean) value of the reserves. The riskiness of the oil market is characterized by the frequency of supply disruptions, their duration and magnitude, and the availability of offsets to disruptions from various sources. The frequency and size of gross disruptions are governed by a Weibull probability distribution.[1] The duration of interruptions is also random. For a given random outcome of the world market, if a disruption occurs, any available offsets such as world excess oil production capacity are used to alleviate it. If a net disruption remains (after available offsets) then the existing strategic reserves are used, in a coordinated fashion. For every random realization of the future oil market, we compare the benefits provided by the current world emergency stocks with the benefits that would be offered by expanded stocks. The expected net benefit calculation weighs each shock outcome by the relative frequency of its occurrence, and compares the expected benefit with the cost of the reserve. The benefits are the avoided disruption costs due to the reserve. Most of these benefits are gained by all oil consuming economies, not just the owners of the reserves.

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[1] The Weibull distribution (also known as the extreme-value distribution) is commonly used to describe a random process where increasingly large values of a positive random variable are increasingly rare, such as the lifetime of a product, or the size of a disruption. For the Weibull distribution, the cumulative probability of observing a gross disruption of *x* percent or less of world demand is given by $F(x) = 1 - \exp\{-(x/\$)^{"}\}$. In this study, the Base disruption probabilities for different disruption sizes are drawn from the 1990 DOE/Interagency Study, as one of the two explicit and careful analyses currently available. The only other published study with sufficient detail and justification is based on work of the Energy Modeling Forum (EMF, 1997). A crucial aspect of the disruption probability distribution is the probability it assigns to large but unlikely disruptions, since those are the cases in which available slack production capacity and existing reserves might be inadequate, and additional emergency oil stocks would be beneficial. As a guideline, it is helpful to note that the DOE 1990 study assessed the annual likelihood of a disruption of 15% or more of world oil supply to be 1%.

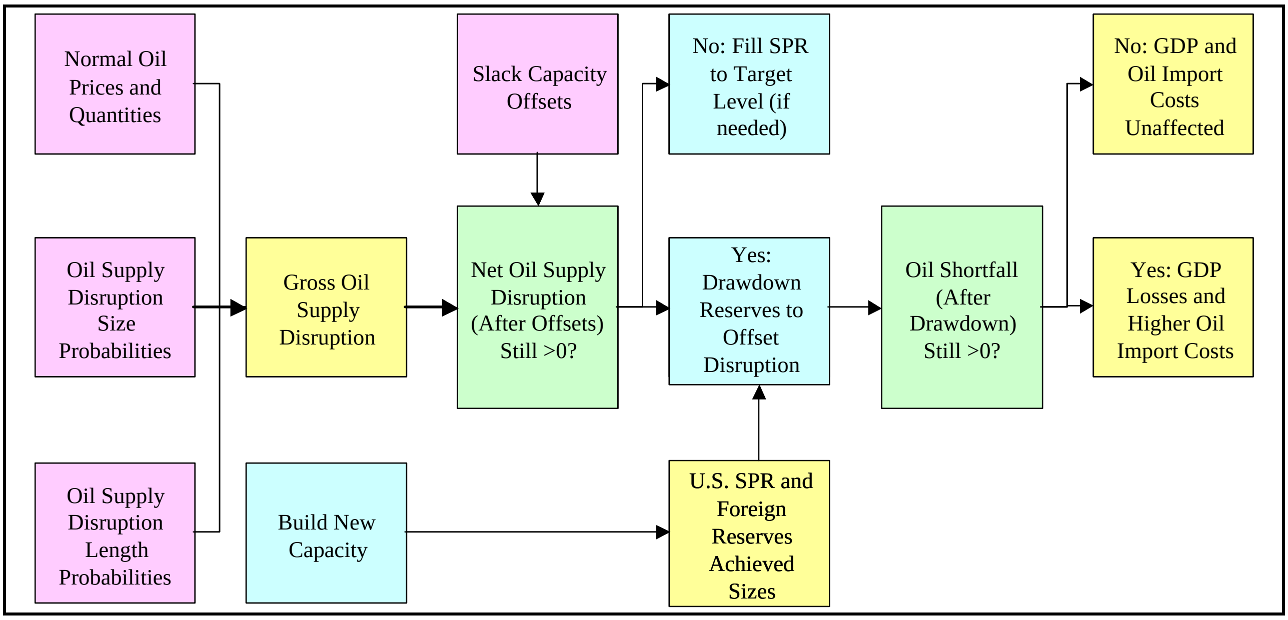

Figure 1: DIS-Risk Model Diagram

The costs included are the cost of the facilities and of the oil itself. These costs are borne by the owners of the reserve.[2] The costs include the net cost of oil purchases less oil sales revenue over the life of the reserves. Also included are the capital expenditures necessary to build the additional reserve facilities, the transaction costs of oil purchases, and the operation and maintenance (O&M) costs borne when filling, drawing down, or maintaining the reserves on standby.[3] The assumed storage method is solution-mined salt caverns which has a capital cost of about six dollars per barrel of storage (PB-KBB, 1998) to build. The costs and revenues are distributed over time, with most of the costs preceding the revenues.

Governmental entities are concerned not only with the costs of building and operating the reserves, but also with external benefits to the society as a whole. Included are avoided GDP losses to the economies due to ability of the reserves to dampen or eliminate potential oil price shocks. The magnitude of these avoided losses is roughly gauged through the use of the estimated GDP elasticities with respect to oil price shocks.[4] The other public benefit is the terms of trade effect or avoided net oil import costs. Net import costs can be simply defined as price times import quantity. When an oil price shock occurs, price rises and demand falls.

Larger and larger SPR sizes have the potential to alleviate more or all of future oil supply disruptions, thus dampening oil price spikes and providing more benefits. When these expected benefits exceed the costs of building, filling, and operating the additional capacity then the expected net benefits are positive. Optimal reserve sizes are achieved when either raising or lowering the size of the reserves cannot increase the expected net benefits. That is, the *marginal* expected benefits of the reserve just equal the marginal costs of expansion.

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[2]Who actually owns the reserve additions is not germane to the simulation and thus can be determined ex post. This ability provides sufficient flexibility to explore numerous combinations of ownership across different countries and country groupings.

[3]These O&M costs (during filling, drawing, and standby), are modest compared to the larger costs of capacity construction and oil purchase.

[4]For completeness, we also include the avoided deadweight loss of consumer surplus in the category of macroeconomic losses. This contribution, which is so small in magnitude as to be essentially negligible, is attributable to avoided reduction in oil demand when price is held lower (other than import savings). This component is small because the potential distortion in demand and the resulting deadweight surplus loss is small given short-run demand inelasticity.

3. Result from the Stockpiling Benefits Simulation for Various Country Groupings

This short paper describes some recent findings from a simulation analysis of emergency oil stockpiling benefits, using different groups of countries as the basis for computing expected benefits. The results of this analysis (shown in Figures 2 and 3 and Tables 1 and 2) correspond to the base case assumptions given in Leiby and Bowman (2000,2000a,b,c) and Paik *et al.* (1999). Some of the results given here are based on calculations made "ex post" to the simulation process, and are therefore only an approximation. However, the estimates have been benchmarked to several simulations of key groupings and therefore are considered very accurate. Also since the results are calculated ex post to the simulation process, any number of country groups can be examined. For this short note we have chosen three principal country groupings:

(1) The U.S.
(2) An "Asian Pacific" region, comprised of all APEC economies except the U.S.[5]
(3) IEA Europe.

We offer a few insights based upon the analysis below.

The crucial factor driving the results presented here is that, since the price-mitigation benefits of oil stockpiling are shared globally in a non-rivalrous (public good) fashion, adding more and larger economies to the benefits calculation uniformly increases the measured benefits, with no effect on the stockpiling costs. The benefits to each country are composed of two terms, one roughly proportional to its GDP and the other proportional to its level of imports. Smaller countries (with smaller GDPs and lesser imports), or even groups of smaller countries, may not accrue sufficient benefits on their own to justify the substantial cost of oil acquisition and storage facilities.

Table 1: Net Economic Benefits of Expansion for Various Country Groupings (Billions $99)

Incremental SPR Size (MMB)	0	100	200	300	400	500	600	700	800	900	1000
Asian Pacific (APEC excluding the U.S.)	0.00	1.00	1.75	2.29	2.63	2.80	2.81	2.69	2.45	2.09	1.63
Asian 7	0.00	0.52	0.84	0.99	0.99	0.84	0.58	0.20	-0.27	-0.83	-1.46
Asian 7 excluding Japan	0.00	-0.28	-0.67	-1.16	-1.75	-2.41	-3.14	-3.92	-4.77	-5.66	-6.59
Japan	0.00	-0.47	-1.03	-1.67	-2.39	-3.17	-4.01	-4.89	-5.82	-6.79	-7.79
U.S.	0.00	0.71	0.93	0.80	0.55	0.18	-0.28	-0.83	-1.46	-2.16	-2.92
IEA Europe	0.00	0.60	0.99	1.21	1.26	1.17	0.95	0.62	0.19	-0.33	-0.93

[5] APEC, or the Asian Pacific Economic Cooperation group, includes Australia, Bruni Durussalam, Hong Kong China, Indonesia, Malaysia, New Zealand, Papua New Guinea, China, Chinese Taipei, Philippines, Japan, Singapore, South Korea, Thailand Canada, Mexico, Chile, and the U.S. Of these, seven major Asian economies of interest are China, Chinese Taipei, Philippines, Japan, Singapore, South Korea, Thailand. For lack of a better name, we refer to these as the "Asian 7."

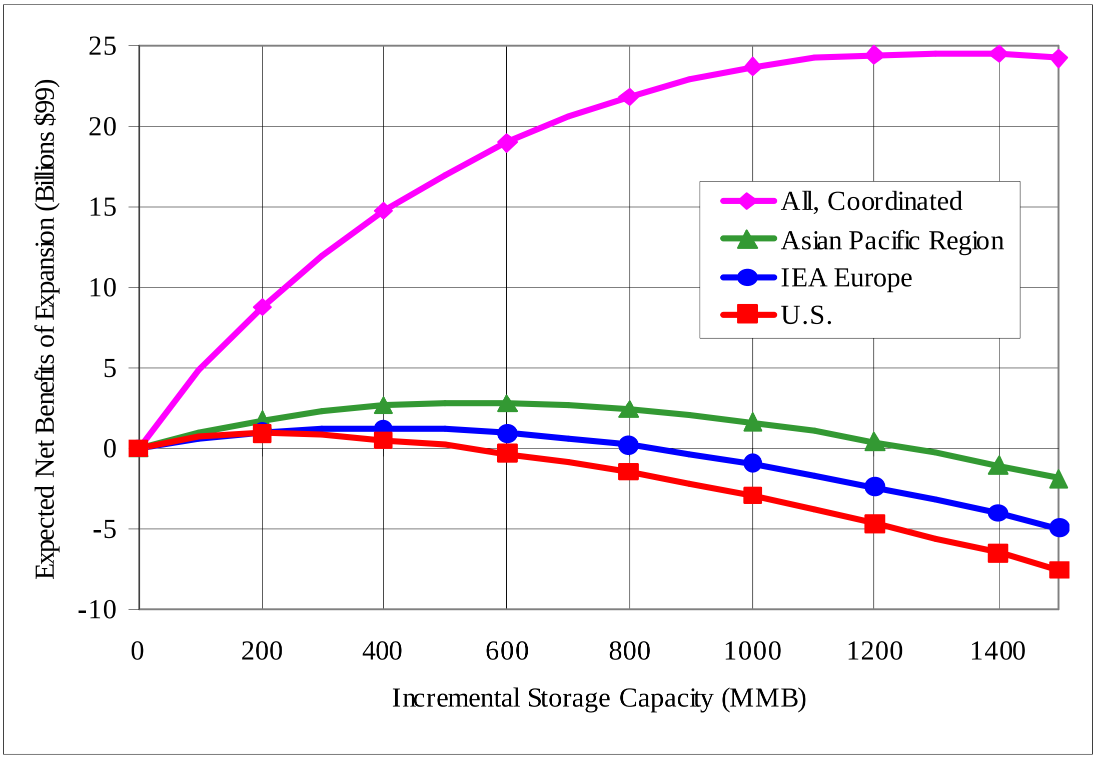

Figure 2. Net Benefits of Stockpile Expansion for the three main regions, each acting independently. Also shows the shared net benefits to all regions of a jointly owned stockpile.

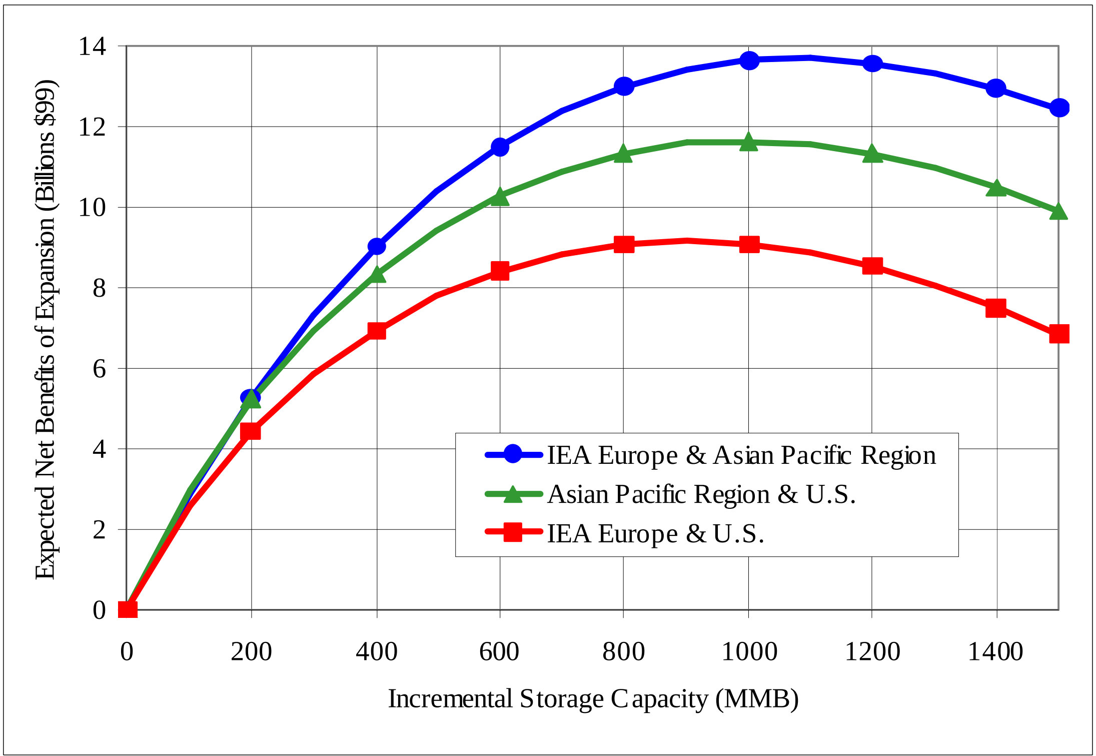

Figure 3. The shared net benefits to owners of a stockpile jointly owned by two of the three main regions (three possible pairings). Optimal expansions range from to 800 to 1100 MMB.

Table 2: Benefits from Stockpile Expansion to the U.S. and IEA-Europe

KEY: Each cell corresponds to an IEA-Europe expansion level and a U.S. expansion level.
For each cell, the lower-left value is IEA-Europe benefit, upper-right value is U.S. benefit,
and the lower-right number is the combined net benefit number.
Benefits are discounted expected values in billions $99.

		U.S.							
	Incremental SPR Sizes (MMB)	0	100	200	300	400	500	600	700
IEA Europe	0	0.0 0.0 0.0	0.7 1.9 2.6	**1.0** **3.5** **4.5**	0.8 5.0 5.8	0.6 6.3 6.9	0.2 7.5 7.8	-0.2 8.6 8.4	-0.7 9.6 8.8
	100	1.4 0.6 2.0	2.0 2.3 4.3	2.1 3.8 5.8	1.8 5.1 6.9	1.5 6.3 7.8	1.0 7.3 8.4	0.5 8.3 8.8	-0.1 9.2 9.1
	200	2.7 1.0 3.7	3.1 2.5 5.6	3.1 3.8 6.9	2.7 5.0 7.8	2.3 6.1 8.4	1.8 7.0 8.8	1.2 7.9 9.1	0.5 8.7 9.1
	300	3.8 1.3 5.1	4.1 2.6 6.7	4.0 3.8 7.8	3.6 4.8 8.4	3.0 5.8 8.8	2.4 6.6 9.1	1.7 7.4 9.1	1.0 8.1 9.1
	400	**4.9** **1.3** **6.2**	5.0 2.5 7.6	4.8 3.6 8.4	4.3 4.5 8.8	3.7 5.4 9.1	3.0 6.1 9.1	2.2 6.8 9.1	1.4 7.4 8.8
	500	5.8 1.3 7.0	5.9 2.3 8.2	5.5 3.3 8.8	4.9 4.1 9.1	4.2 4.9 9.1	3.5 5.6 9.1	2.7 6.2 8.8	1.8 6.7 8.5
	600	6.6 1.1 7.7	6.6 2.0 8.6	6.2 2.9 9.1	5.5 3.6 9.1	4.8 4.3 9.1	3.9 4.9 8.8	3.1 5.4 8.5	2.2 5.9 8.0
	700	7.3 0.8 8.1	7.2 1.6 8.9	6.8 2.4 9.1	6.0 3.1 9.1	5.2 3.6 8.8	4.3 4.2 8.5	3.4 4.6 8.0	2.5 5.0 7.5
	800	8.0 0.4 8.3	7.8 1.1 8.9	7.3 1.8 9.1	6.5 2.4 8.8	5.6 2.9 8.5	4.7 3.4 8.0	3.7 3.8 7.5	2.7 4.1 6.8
	900	8.5 -0.1 8.4	8.3 0.5 8.9	7.7 1.1 8.8	6.8 1.7 8.5	5.9 2.1 8.0	5.0 2.5 7.5	4.0 2.9 6.8	
	1000	9.1 -0.7 8.3	8.8 -0.1 8.7	8.1 0.4 8.5	7.2 0.9 8.0	6.2 1.3 7.5	5.2 1.6 6.8		
	1100	9.5 -1.4 8.1	9.2 -0.9 8.3	8.4 -0.4 8.0	7.5 0.0 7.5	6.5 0.3 6.8			
	1200	9.9 -2.1 7.8	9.5 -1.7 7.9	8.7 -1.3 7.5	7.7 -0.9 6.8				
	1300	10.2 -2.9 7.3	9.8 -2.5 7.3	9.0 -2.2 6.8					
	1400	10.5 -3.8 6.8	10.1 -3.4 6.6						
	1500	10.8 -4.7 6.1							

Insight 1: **Outside the U.S., No Single APEC or IEA-Europe Country Can Well-Afford To Go It Alone**

No single country other than the U.S. has sufficient expected net benefits from stockpiling to merit expanding its reserve on its own, on the basis of economic benefits alone. There may be other national security considerations motivating national stockpiling. But the cost of building, filling, and operating expanded reserves, in most circumstances, far exceeds the benefits to the individual countries. As Table 1 shows, even Japan, the largest of the non-U.S. APEC economies, is unlikely to gain expected net economic benefits from acting alone and increasing its reserves.[6] The U.S. economy is sufficiently large (and reliant on oil) to warrant some expansion. Only through cost sharing arrangements with other countries can any one country other than the U.S. expect to come out ahead, since measured economic benefits are largely proportional to the GNP of the owning group,[7] while costs of developing and managing a reserve are largely independent of ownership.

Insight 2: Collective Groups of Countries Sharing a Reserve Achieve Greater Benefits and Larger Optimal Size than the Sum of Individual Countries Acting Alone

This result is not surprising, although the magnitude of the effect may be larger than one might imagine. The results for U.S. alone (in Figure 2) point towards a 200 MMB reserve expansion, for the Asian-Pacific region jointly a 600 MMB reserve, and for all APEC including the U.S. a 1000 MMB reserve (see Figure 3). Similarly, the results for IEA Europe alone indicate that an expansion of 400 MMB would be optimal for them, while the U.S. and IEA Europe collectively could jointly maximize benefits with a 900 MMB expansion. The reason for this is that while *benefits* are additive, as more countries are included in the joint region, costs are unchanged and therefor the optimal *size* is not strictly additive.

Insight 3: The Asian-Pacific Region Could Justify Increased Reserves, as Could IEA-Europe

Based upon the results for the “Asian Seven” shown in Figure 2 and Table 1, a group of the larger economies in the Asian-Pacific region could justify increased reserves, albeit slightly smaller reserves than the entire Asian Pacific region (400 MMB in the base case, compared to 600 MMB). The IEA-Europe region also collectively has a large enough GNP at risk to justify a moderate unilateral expansion of reserves as well, on the order of 300 to 400 million barrels.

Insight 4: For an Asian-Pacific reserve, Japan and China Must be Involved

For an Asian-Pacific reserve to be justified on an economic cost-benefit basis, Japan and China must be involved. The combined GDP exposure (GDP and GDP elasticity) and net imports for the Asian-Pacific APEC economies outside of Japan and China are simply not enough to outweigh the stockpiling costs. This of course does not mean that these countries would not benefit from maintaining stocks. Rather, their benefits are too small relative to the costs. Only by including Japan and possible China would the aggregate economic benefits be greater than the costs.

Caveat: All of these Conclusions Are Based Only on Expected Net Economic Benefits, Not Risk Reduction or Other National Security Considerations:

These observations all rely solely on expected values of the measured economic net benefits, under base case assumptions. Oil stocks can have markedly larger economic benefit under more risky oil market conditions than those considered in the Base Case, for example if disruptions are somewhat longer on average than 4.5 months, or if the amount of spare oil production capacity available during disruptions is less than what is anticipated here. Furthermore, certain countries may also attribute value to stockpiling for additional reasons, such as risk avoidance, political or foreign policy considerations, and “leadership” (the recognition that if enough countries individually engage in stockholding, they all collectively will come out ahead).

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[6] Based upon cost benefit analysis. There may be other non-quantifiable reasons for increasing Japan’s emergency oil stocks but these are outside the scope of this study.

[7] The constant of proportionality is essentially equal to the estimated GDP loss parameter, the “elasticity of GDP with respect to oil price shock increase.”

Insight 5: World Consuming Regions Could Benefit from Much More Stockpiling
The optimal expansion of strategic reserves for all major consuming regions in the world (U.S., APEC, and the IEA Europe) is large, on the order of 1300 million barrels (see the Figure 2 curve for "All, Coordinated"). This is the joint maximum, accounting for the expected economic costs and benefits to all major regions.

4. Overall Conclusions Regarding Stockpile Size Cooperation

The motivations for using the reserve during a disruption are sufficiently great, compared to the modest value of holding oil as hedge against future disruptions, that all countries have an incentive to utilize the reserve in much the same pattern. During a disruption there is a strong incentive to use the reserve to the maximum extent possible to offset the price shock. For these reasons, based on economic considerations alone, we can characterize all strategic reserve *drawdown* behavior as essentially well coordinated. We model the combined reserves of the world as managed jointly in this fashion, without regard to ownership of the reserves.

Free-riding is a potential problem with strategic oil stocks, particularly for stockpile sizing decisions by small individual economies. Since the primary effect of drawing down a reserve is a reduction in the world oil price from disrupted levels, most oil consuming nations benefit. Strategic stockpiling is a public good: the bulk of the benefits are shared by all oil consuming regions and economies, regardless of who owns and pays for the reserve.

When sufficiently large regions or groups of economies coordinate their efforts, and recognize joint benefits, the jointly optimal reserve is often substantially larger than the sum of the individually optimal reserves. For example, the Asian Pacific region or the IEA-European region acting collectively should recognize a net benefit to expansion, while the individual member countries of those regions acting alone would not.

There appears to be a benefit-payoff structure that supports collaborative initiatives between large regions, such as the U.S. and IEA-Europe. Referring to the payoffs tabulated in Table 2, we see that with independent size choices, the U.S. would choose a 200 MMB expansion and the IEA-Europe 400 MMB. These are the individual optima for the two regions, each assuming that the other region will do nothing (not expand). The associated cells are shown in Table 2 in bold font and highlighted in grey. If each region follows its independently optimal strategy, the total expansion will be 600 MMB, and joint benefits will total $8.4 billion. This outcome, however, is off the diagonal of "jointly maximum" cells, which are highlighted in grey and give $9.1B total benefits. The joint maximum benefits are obtained for a variety of expansion combinations that total roughly 900 MMB to 1000 MMB. There seems to be substantial scope for negotiation and agreement on cost allocation so that one of these jointly-preferred outcomes could be achieved.

As the decision-making regions get sufficiently large, the public good aspect of the stockpiling problem becomes less pronounced compared to the individual benefits involved, and the need for explicit coordination declines. This can be seen by contrasting the U.S. individual optimization with the stockpile optimization for the rest of the world (where the Rest of World or ROW is defined as the Asian Pacific region plus IEA-Europe). In the absence of any ROW incremental reserves, the U.S. would choose to expand by 200 MMB. In the absence of any U.S. incremental reserves, *if* the ROW could act collectively it would choose to expand by 1100 MMB. At the same time, the combined expansion of 1300 MMB (U.S. = 200 MMB, ROW=1100 MMB) turns out to be on the "world maximum ridge," yielding some $24.8 billion in combined benefits. For these two very large regions, the individually optimal expansions, assuming the other party does nothing, sum to a combined stockpile that is nearly jointly optimal for the regions together. Thus it seems that for sufficiently large parties, little or no coordination is actually necessary to get to a world maximum-benefit level of reserves: each country would move to a nearly-optimal size on its own, and in the absence of coordination. Of course, this hypothetical outcome relies on the fiction that all consuming countries outside of the U.S. can act as a unified agent. In actuality, most decision making regions are insufficiently large, and the public good problem of oil stockpile sizing remains relevant.

Selected References

Devarajan, Shantayanan and Robert J. Weiner 1989. "Dynamic Policy Coordination: Stockpiling for Energy Security," Journal of Environmental Economics and Management, 16(1):9-22, January.

Hogan, William W. 1982. "Oil Stockpiling: Help Thy Neighbor," Harvard Energy Security Program Discussion Paper Series, No. H-82-02, March.

Hubbard, R. Glenn and Robert J. Weiner 1983. Chapter 11, "Government Stockpiles in a Multi-Country World: Coordination vs. Competition," in A. Alm and Robert Weiner, eds., *Managing Oil Shocks*, 1983.

Energy Modeling Forum 1997. *Quantifying Oil Disruption Risks Through Expert Judgement*, EMF-SR 7, Hillard Huntington, Antje Kann, and John Weyant, EMF, Phil Beccue, Applied Decision Analysis, April.

Leiby, Paul and David C. Bowman, 2000. *The Value of Expanding the U.S. Strategic Petroleum Reserve*, Oak Ridge National Laboratory, ORNL/TM-2000/179, November 30.

Leiby, Paul N. and David C. Bowman, 2000a. *The Value of Expanded SPR Drawdown Capability*, Final Report, Draft 2, Paul Leiby and David Bowman, Oak Ridge National Laboratory October 18.

Leiby, Paul N. and David C. Bowman, 2000b. Chapter 6, "Economic and Size Analysis of APEC Emergency Oil Stocks," in *Emergency Oil Stocks and Energy Security in the APEC Region*, Asia Pacific Energy Research Centre.

Leiby, Paul N. and David C. Bowman, 2000c. *The Value of Expanding Asian Pacific Strategic Oil Stocks*, Energy Division, Oak Ridge National Laboratory, ORNL-1999/39, January 23.

Murphy, F.H., Toman, M.A. and H.J. Weiss 1985. "International Cooperation in Stockpiles and Tariffs for Coping with Oil Supply Disruptions," Journal of Policy Modeling, 7(4), 649-672.

Paik, Inja, Paul Leiby, Donald Jones, Keiichi Yokobori, and David Bowman, 1999. "A Strategic Oil Stocks in the APEC Region," *Proceedings of the 22nd IAEE Annual International Conference*, International Association for Energy Economists, Rome, Italy, 9-12 June.

PB-KBB, 1999. *Conceptual Design for 300 MMB SPR Site Expansion*, Final Draft Report, Prepared for the U.S. Department of Energy, April 19.

Yokobori, K *et al.* (APERC) 2000. *Emergency Oil Stocks and Energy Security in the APEC Region*, Asia Pacific Energy Research Centre,., Tokyo, March.