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The Value of Expanding Asian Pacific Strategic Oil Stocks

Energy Division

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Introduction

The world oil market has undergone at least 18 significant oil supply shocks since 1951. The most memorable of these, the four largest world oil shocks between 1973 and 1991, are now recognized to have cost the Asian Pacific Economic Cooperation (APEC) economies hundreds of billions of dollars. These costs are manifested as lost GDP and higher payments for oil imports. Since oil is traded globally, a major oil price increase soon spreads throughout the world, with disruptive effects on most energy-intensive economies. Within each economy, the shock costs are spread economy wide. For this reason, oil-using firms and private consumers acting individually on their own behalf do not have sufficient motivation to adequately insure against the widespread costs of price shocks. Most of the economy-wide costs of disruptions are, understandably, "external" to the cost-benefit considerations of private agents.

Strategic oil stocks, by buffering supply losses and mitigating sudden major price shocks, are a direct and effective means for dealing with the risk to economies of persistent supply and price volatility. Private agents cannot justify holding large oil stocks for the long term as a contingency against potentially dramatic market upheavals or geopolitical struggles. The private storage costs are too high, the likelyhood of disruptions are too small, the planning time horizon is too long, and the direct benefits to the private agents are too low.[1]

Similarly, it may be more efficient for the APEC economies to take collective action and establish joint strategic oil reserves rather than act alone. Large scale shared storage can lower storage costs and garner enough benefits for a large economy or combined economies for the costs to be worthwhile.

This paper summarizes the estimated net benefits of expanding APEC strategic oil stocks, and analyzes the efficient size of those stocks. It recognizes that substantial strategic oil reserves already exist. The focus is on the *incremental* net benefits of expanded storage to all APEC economies, other than the U.S..[2] The estimates are based on the economic protection that additional storage would provide, *beyond* that protection already provided by the current Asian, U.S., and European strategic oil stocks. Thus we are considering the incremental net benefits to APEC of incremental changes in stockpile size.

The assessment of alternative APEC reserve sizes is done with a numerical simulation model. In Section 1 we begin by summarizing the analytical approach used, a probabilistic cost-benefit analysis. In Section 2 we characterize base oil market conditions used, and possible disrupted market conditions.

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[1]Unless the government provides incentives for added storage, private oil inventories are principally "working stocks" . They are held to ensure reliable plant operations and process flows in the face of routine logistical delays, normal demand fluctuations, and modest short-term price variations.

[2]The reasoning for excluding the U.S. from the analysis is twofold: 1) The U.S. government is conducting its own, independent reserve analysis, and 2) Given the relative size of the U.S. economy, including the U.S. would reduce the focus on the rest of APEC.

Other key assumptions used are presented and discussed in Sections 3 through 5. In establishing key conditions for this study, we draw on other background studies, including the engineering-estimates of storage facility costs developed by PB-KBB (1998), and the best available understanding of the macroeconomic cost of oil price shocks to APEC economies (Bachman and Ingram 1999). Section 6 describes the cases considered. Sections 7 and 8 show the results for what we characterize as the Base Case, where the focus is on storage in salt caverns, and disruptions of under 6 months in length. There we find that a substantial expansion of the APEC reserve (on the order of 600 million barrels) is justified on the basis of its expected net benefits to APEC economies. In Section 9 we explore the sensitivity of this conclusion to our treatment of oil market risk, possible program delay, estimated sensitivity of GDP to shocks, and the possible need to utilize higher-cost storage methods. In Section 10, we examine the economic benefits for different country groupings. The final section, Section 11, summarizes the implications of this study for efficient APEC reserve size.

1. Summary of the Cost-Benefit Analysis Used

The essential issues for APEC reserve planning may be summarized as follows:

- Assess the potential causes and likelihood of oil supply disruptions taking place.
- Account for existing APEC and IEA stocks and international cooperation on the use of stocks.
- Estimate the costs to APEC economies of oil disruptions, and the incremental ability of additional APEC strategic stocks to reduce those costs.
- Estimate the costs of buying and storing strategic crude oil stocks.[3]
- Determine the net benefit and efficient level of APEC strategic stocks.

The cost-benefit approach uses a simple model of the oil market and APEC economies to unify these factors. Because oil market disruptions are of highly uncertain frequency, magnitude, and duration, net benefits are estimated by solving the model over many possible market outcomes in a randomized or probabilistic fashion. Any additional APEC reserves are coordinated with existing APEC and IEA strategic stocks, which roughly total 1258 million barrels. New APEC reserves expand the combined pool and the maximum draw rate.[4] The benefits calculation takes into account recent empirical evidence on the macroeconomic cost of oil shocks, and uses shock-cost parameters estimated specifically for the APEC economies.

1.1. General Probabilistic Modeling Approach

The expected benefits and efficient level of APEC strategic oil stocks is determined using a Monte Carlo simulation of the world oil market, with and without additional APEC 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. 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 APEC reserve is used in coordination with the existing IEA reserves. For every random realization of the future oil market, we compare the benefits provided by the current world strategic stocks with the benefits that would be

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[3] This analysis considers a crude oil reserve, rather than petroleum product storage. While stored products can reach the end user more rapidly, stored crude also can enter the refinery stream in a timely fashion in the event of a crude supply loss. Furthermore, product storage is somewhat more expensive, given that steel tanks or specialized facilities may be required, and that products must be rotated periodically to assure that they do not degrade. Product storage is also less flexible in the sense that the mix of products yielded by the buffer stock is already predetermined. Thus, while product storage may be appealing or convenient in some contexts, its higher cost may make is less suited for strategic stocks. Furthermore, the principal advantage of product storage, rapid movement to market, is a short-run logistical convenience that is not easily captured in the modeling framework used here.

[4] The precise treatment of this stock coordination issue does not appear to be a critical assumption for the estimation of the benefits of incremental APEC storage. The key issue is the likelihood of situations where incremental storage is beneficial, after it is recognized that many circumstances are adequately covered by existing market buffers and strategic stocks.

offered by expanded stocks. Clearly, the world strategic stocks added by an APEC expansion will provide additional benefit only in the event of an especially large or long disruption, or in the case of a sequence of smaller disruptions in quick succession. While such events may be deemed unlikely, *if* they do occur, an expanded reserve could easily be worth $50 billion or more in avoided shock costs. The expected net benefit calculation weights the magnitude of these large avoided shock costs by their relative frequency of occurrence, and compares that expected benefit with the cost of the reserve.

1.2. Costs and Benefits Included

The costs included are the costs of the facility and of the oil. These costs are borne by the owners of the reserve. The benefits are the avoided disruption costs due to the reserve. These benefits are gained by all oil using and consuming economies. Consider first the net costs of the reserve itself. Viewed like any private venture, a strategic petroleum reserve has both a cost side and a revenue side. The costs include the capital expenditures necessary to build the reserve, the cost of oil purchases, and operation and maintenance (O&M) costs borne when filling, drawing down, or maintaining the reserve on standby.[5] The net revenue side includes the revenue from selling the oil. The costs and revenues are distributed over time, with most of the costs preceding the revenues. The payment streams are discounted to account for the opportunity cost or time value of funds. Ordinarily, for a private venture to occur, the discounted revenues must be expected to outweigh the discounted costs, and a profit is anticipated.[6] However, unlike profitable private ventures, a strategic petroleum reserve's net revenues are invariably negative due to long periods of discounting, the slow projected rate of oil price increase, and the comparatively low probability of ever selling the oil at a profit during a disruption. Thus, for a private firm to hold strategic or "emergency" stocks there must be more incentive.

Unlike private firms, governmental entities are concerned not only with net revenues or profit, but also with external benefits to the society as a whole. Such benefits are not internalized by private firms. One such benefit is the avoided GDP losses to the economy due to the existence of the reserve. A strategic reserve, properly used, has the effect of dampening or eliminating potential oil price increases due to a shock. Oil price increases reverberate through the economy in a costly way, as discussed at length in Jones, Bjornstad, and Leiby (1997). The costs of oil market disruptions has been studied extensively over the last two decades (Hamilton 1996; Mork 1989; Mork, Olsen and Mysen 1994). The magnitude of these losses can be roughly gauged through the use of the estimated GDP elasticity

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

[6]Because private agents are smaller and more risk averse than governments or entire economies, and because the private cost of funds (interest rate) typically exceeds the government cost of funds, the discount rate used by private investors is ordinarily much higher than that used in government planning. This raises another, significant, obstacle limiting the private long-term storage of strategic oil stocks.

with respect to oil price shocks.[7] Another public benefit is the terms of trade effect or avoided net import costs of oil. Net import costs can be simply defined as price times import quantity. When an oil price shock occurs, price rises and demand falls. Since oil demand is highly inelastic in the short run, the price rises more than demand falls and net import costs increase. The use of the emergency reserve in these circumstances reduces the price increase and the demand decrease. The combined effect is a reduction in net import costs.

In summary, the cost and benefits of a strategic reserve can be categorized into four components. Two concern the cash flows associated with the reserve itself and are borne by the owner-operators: the capital cost stream; and reserve net revenues. The other two components concern external and widespread benefits which are quite large, and which motivate collective storage by governments and economies: avoided GDP losses; and avoided net import costs. The net present value (NPV) of a strategic petroleum reserve is given by the discounted sum of these components. Writing the expected net benefit calculation in equation form, we have:

$$
\begin{aligned}
\text{Expected NPV(Net Benefits)} = {} & \text{Expected NPV(Avoided GDP Loss)} \\
& + \text{Expected NPV(Avoided Import Costs)} \\
& - \text{Expected NPV(Reserve Net Oil and O\&M Costs)} \\
& - \text{NPV(Facility Capital Costs)}
\end{aligned}
$$

Here “NPV” refers to the discounted Net Present Value over the time horizon of interest (1999-2030). “Expected” refers to the average or mean value over many thousands of possible realizations of the world oil market through 2030. These four cost and benefit components are estimated and totaled, and recorded using the probabilistic model, DIS-Risk, described in the next section.

1.3. Nature of the DIS-Risk Model Used

1.3.1. Brief Model Description

The DIS-Risk Model applies a risk analysis to assess the uncertain implications of oil stockpiling. It follows and extends the basic logic of the model previously used in the 1990 DOE/Interagency SPR Size Study (DOE 1990). For this study it has been adapted to the specific nature of the APEC economies.[8] DIS-Risk is a proven, easily understood, versatile model which allows for a variety of sensitivity analyses. We summarize qualitatively the model behavior here. See Leiby and Bowman, 1997 and Leiby and Jones, 1993 for complete model documentation.

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[7] 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 since the potential distortion in demand and the resulting deadweight surplus loss is small the given short-run demand inelasticity.

[8] This study was based on DIS-Risk version DR99M, January 1999.

In the DIS-Risk model, two strategic reserve sizes, one with an expanded APEC reserve and one without, are compared side-by-side. They are subjected to the same random disruptions. Each reserve is specified in terms of its costs, target size, normal fill rate, and maximum refill rate. Oil supply disruptions are simulated against reference paths for world oil prices, APEC oil demands, APEC oil supplies, and rest-of-world demands.

In each year, a disruption may occur. Disruptions have a random duration or length. The length is uniformly distributed over a predetermined range of months. The gross disruption size is a random outcome which, as a percentage of total world demand, follows a smooth, 2-parameter probability distribution called the weibull distribution. The gross disruption size is directly reduced by exogenously specified offsets from two sources: slack oil production capacity and short-run demand response (switching). The net disruption size is defined as the gross disruption size after these offsets are applied, but before any reserve draws.

If the net disruption size (after offsets) is positive, the reserve attempts to fully offset it. Drawdown rates are limited by the specified maximum draw rate for that year, and by the exhaustion rate. The "exhaustion rate" is given by the available oil in the reserve, divided by the anticipated disruption length (in days). Provided that no disruption has occurred, the reserve fills toward its target size at the specified normal fill rate. After a drawdown, the reserve fills at the exogenously specified refill rate until the planned fill-path is re-attained. Fill then reverts to the normal fill rate until the desired target size is attained.

Oil shortfalls are calculated as the remaining disruption after all offsets and reserve draws. After world excess oil production capacity has been utilized, non-OPEC supply is assumed to be essentially fixed during the disruption. World oil price increases sufficiently for world oil demand to contract and accommodate the remaining net oil supply shortfall. Demand is somewhat responsive to price in the short run, and becomes increasingly elastic as the disruption becomes more severe. Specifically, demand elasticities are a linear function of net disruption size.[9] To calculate monthly elasticities, adjustment factors are applied to annual values. These monthly adjustment factors ensure that the elasticity of demand also increases from month-to-month during a disruption. Thus demand becomes more responsive as the market remains longer and longer in a protracted disrupted condition. After a disruption ends, world oil price declines toward the base level according to a fixed monthly decline rate.

[9]The details of these variable elasticities are based on the treatment in EIA (1990), p. 4-5.

APEC oil demand is also increasingly elastic in price. APEC import demand equals APEC demand minus exogenously specified APEC supply, APEC reserve drawdown, and a fixed fraction of world short-run fuel switching. APEC GDP responds to oil price shocks with an annual GDP-elasticity. GDP losses occur only during disruptions, not during their after-effects.[10] Total disruption costs are GDP losses, plus incremental import costs. The NPV of the disruption costs, capital streams and reserve net revenue is calculated, and program differences (with and without an expanded APEC reserve) are reported. Thus for each randomized scenario sampled, the model tracks the incremental avoided disruption costs, less the incremental capital and operating costs of the reserve, for an expanded reserve compared to the existing reserve.

The DIS-Risk model compares oil market outcomes and APEC economic welfare over the next thirty-one years (2000-2030) for two distinct reserve programs. It uses the risk analysis methodology to simulate a large number of trajectories for oil prices and reserve activity over the time horizon, and gathers performance statistics. Both expected values and probability distribution information are gathered for the following variables: NPV benefits of one program versus the other; incremental reserve utilization; reserve net revenue; and the number and severity of net disruptions. An important feature is that in a given experiment both reserve programs are used to address the same randomly-generated sequence of oil supply shocks. This minimizes the random variation of (incremental) program results attributable to the disruption sampling process. In addition this same random sequence is applied to all prospective reserve sizes, and sensitivity cases.[11]

1.3.2. Assumptions in the Dis Risk Model

There are three categories of parameters in the DIS-Risk model: expectations about the ordinary operation of the oil market; characterizations of the riskiness of the oil market; and reserve program attributes.

The expectations about the oil economy are characterized by the reference (undisrupted) price and quantity paths for oil during the thirty-one year period over which the model evaluates the strategic reserve. These assumptions also include parameters determining the economic response to an oil price

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[10] While GDP losses are known to persist for at least a few quarters after the disruption, the treatment here merely requires that the GDP elasticities used be appropriately adjusted to reflect the discounted sum of contemporaneous and lagged losses.

[11] The number of random samples taken, 10,000 per run, was selected on the basis of two criteria: one automated and one by manual inspection. (1) the Monte Carlo engine was allowed to sample an internally monitor convergence criteria, including the combined stability of the mean values and certain percentiles from one sample iteration to the next. The software automatically declared convergence and stopped sampling at about the 7,500th sample. (2) We executed random samples of increasing size, with different random sequences, for a few important cases of interest. We plotted the time path of percentage change in sample mean values and found that stabilization occurred to within a few percent well in advance of 10,000 sample iterations.

rise: the "GDP elasticity," which signifies the responsiveness of aggregate production to changes in oil prices; and demand elasticities.

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.[12] The duration of interruptions is also random, and the model structure allows various degrees of knowledge by the reserve managers about the a shock's duration in advance of their draw-down response.[13] The principal market offset which may mitigate disruptions is the world's available excess oil production capacity (slack). The second major source of offsets to a gross oil supply disruption is the reserve.

The reserve program attributes include stockpile size, various physical operational characteristics, and several categories of cost. The current and target reserve sizes for the reserve can be varied in the model. The rates at which the reserve can be filled initially, drawn down in the event of a disruption, and refilled afterward, also are specified parametrically. Hand-in-hand with the maximum draw-down rate which the reserve may achieve in the event of a disruption are the implicit rules governing under what conditions draw will occur, and at what rate (i.e., at the maximum rate or some lower rate). The reserve program is further described by a time path of maximum reserve capacity for each year in the thirty-year evaluation period. The capital costs and operating costs other than filling costs also are specified for each year.

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[12] 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

$$F(x) = 1 - e^{-(x/\beta)^{\alpha}}$$

[13] They may have perfect knowledge about the duration, they may know the expected (average duration), or their drawdown rule may be invariant to disruption length.

2. Projected Undisrupted (Normal) Oil Market Conditions

The Asia Pacific Energy Research Centre (APERC) and EIA projections of the normal, undisrupted oil market are used in determining net benefits. World oil price is used in buying oil to fill the reserve, selling of remaining reserve oil in 2030 (provided the market is undisrupted) and as a starting point for the disrupted price. The assumed world oil price path for the analysis Base Case is constant (in real terms at $17.4/BBL), and is derived from the underlying assumptions in the APERC market projections. As a sensitivity case, we use the U.S. EIA's Mid Case oil price projection from their 1999 Annual Energy Outlook (1998). As seen in Figure 1, the EIA AEO99 projection rises rapidly over the next 9 years, and then rises slowly (at about 2% per year) through 2020. This alternative price path suggest a valuable near-term opportunity for accumulating low cost strategic stocks.

Elastic world oil demand (world demand less OPEC demand) is used in determining the quantity of world oil shortfall given that a disruption occurs. Elastic domestic demand and is used to determine consumer surpluses and combined with inelastic domestic supply is the basis of net imports. The projected APEC GDP path indicates the magnitude of the GDP at risk to shocks each year, for the target region of interest. The magnitude of the avoided GDP losses, should a disruption occur and be mitigated by the reserve, increases in proportion to the level of GDP in the shock year.

The target region for analysis is all of the APEC economies, other than the U.S.. This group of economies can be denoted as "APEC-U.S." (APEC minus U.S.). By "target region," we mean that we track the net benefits of an expanded reserve for APEC-U.S. economies, and assess whether expansion yield a net benefit from their perspective.

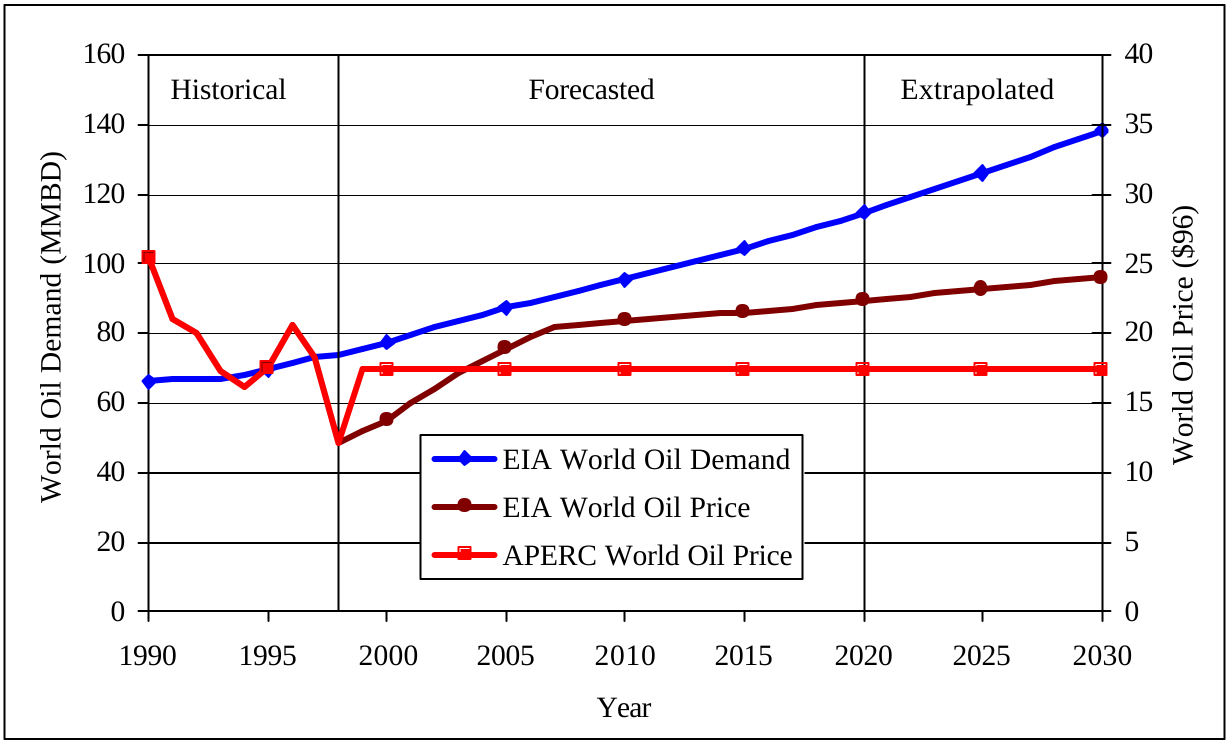

Figure 1: Normal Market Oil Price Projections, APERC (1998b) and EIA (1998).

Since GDP levels and oil import levels are important determinants of a region's exposure to oil market shock costs (through GDP adjustment costs and higher oil import costs), it is helpful to review the magnitude of these items. The current GDP for the APEC-U.S. target region is quite large, and projected to grow robustly after a few years of recovery (APERC 1998a). A shown in Figure 2, the APEC-U.S. GDP is currently comparable to the U.S. GDP, and is expected to grow even more rapidly. While some of the APEC economies are net oil exporters, collectively the APEC-U.S. region is a major oil importer. As seen in Figure 3 the APEC-U.S. group of economies has net imports that are currently about 75% of the U.S. level, and rise to about 95% of the projected U.S. level in 2010.

In summary, the target region of APEC-U.S. economies has GDP levels and oil import levels that suggest levels of exposure to oil market disruptions that are comparable to those of the U.S.. In addition another key factor is the GDP's responsiveness to oil price shocks, as measured by the GDP elasticity with respect to oil price. In Section 5 we show that the estimated GDP elasticity for the aggregate group of economies denoted by APEC-U.S. is substantial (about -0.065), and also quite comparable to recent estimates of the GDP elasticity for the U.S.. These general observations suggest that our ultimate findings that show that a substantial expansion of the APEC-U.S. reserve beyond its current level of 370 million barrels would be justified is not surprising, in light of the current and planned levels of U.S. strategic oil stocks.

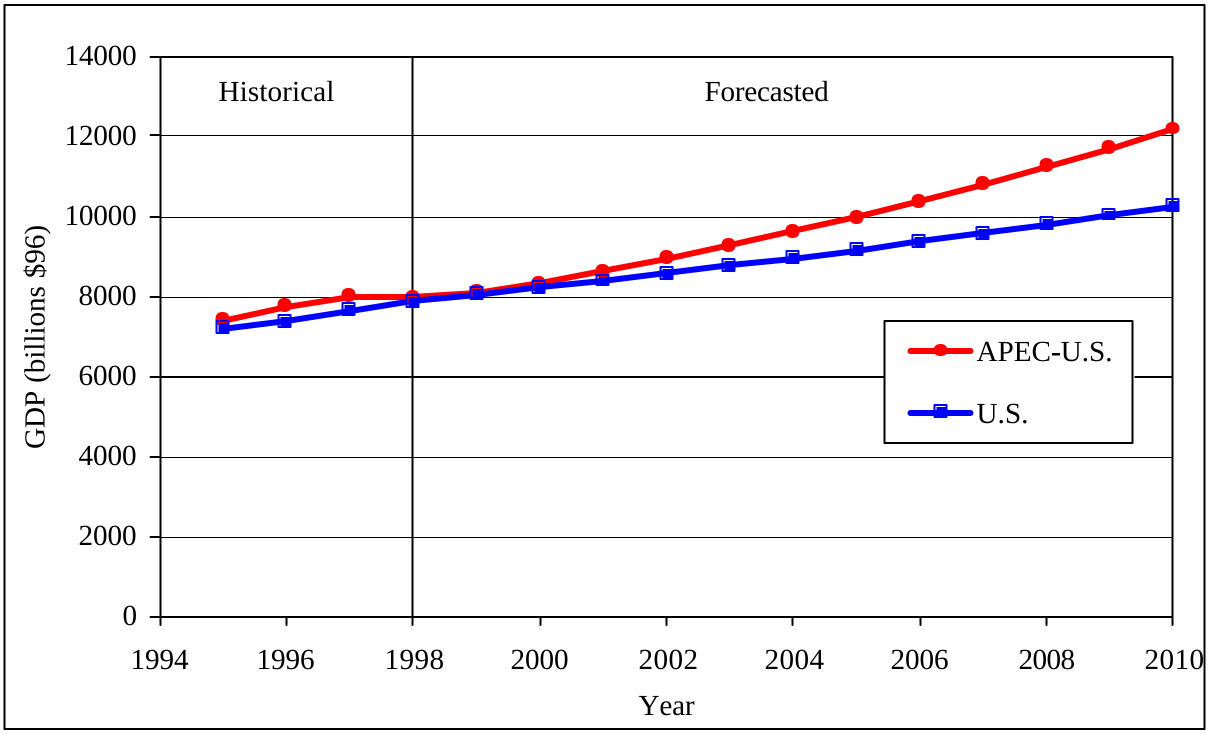

Figure 2: Projected Gross Domestic Product for the Study Target Region (APEC-U.S.).

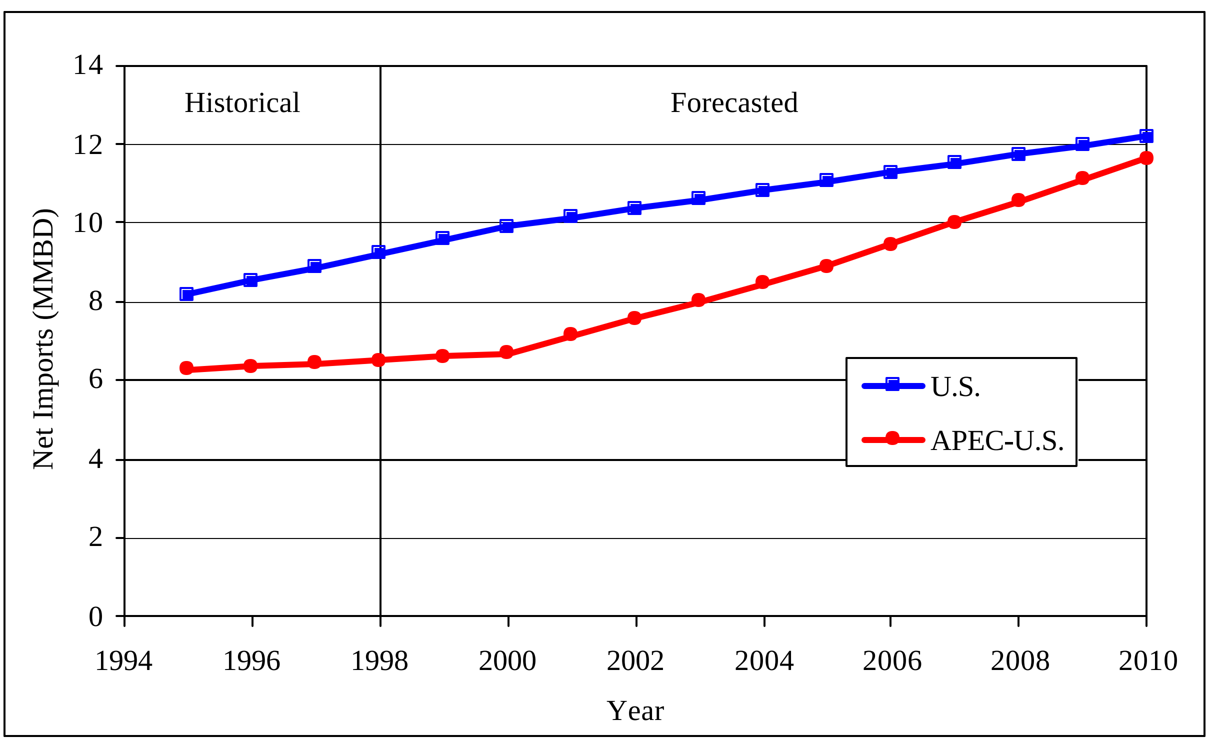

Figure 3: Projected Net Oil Imports for the Target Region (APEC-U.S.).

3. Key Determinants of Stockpile Size Analysis: Oil Market Factors

3.1. Estimated Oil Market Risk

It is very difficult, or perhaps not even possible, to reliably establish the likelihood and nature of future oil market disruptions. However, there are organized ways to cope with this uncertainty. There are three promising approaches to assess the risk of oil market disruptions.

! Look to the historical pattern and frequency of events
This approach relies on the limited historical record with the understanding that there are valuable lessons to be gained from history. It also is founded on the expectation that, given little information to the contrary, the past is a reasonable indicator of the future. As one good example of this approach, the 1990 DOE/Interagency study estimated disruption probability distributions based on the historical frequency of disruptions of various sizes from 1951 to 1989.

! Think about the problem carefully and apply Expert Judgement.
This approach yields "subjective" probabilities, but goes beyond the historical data to consider what might have happened, and the important disruption events that could happen under changing conditions in the future. Expert judgement was also applied in the DOE 1990 analysis, in benchmarking the probability of an extremely large event. The best published example of this expert judgement was produced by the Energy Modeling Forum (1997), which gathered a group of experts in three successive workshops to assess disruption probabilities with a subjective event-tree analysis.[14]

! Explicitly model and analyze the sources of prospective disruptions.
This approach is ambitious but problematic, and has not yielded much fruit as of yet. It entails such methods as numerical model of OPEC power, estimates of political and economic incentives for cooperation or opportunistic supplier behavior, and the stability of cartel supply. Such an analysis may seek to account for expectations of growing regional imports and the growing OPEC share in the world oil market.

Of these three approaches, we rely on a combination of the historical and judgmental methods, as embodied in the disruption probability estimates used in the 1990 DOE/Interagency Size Study. These probabilities refer to possible global supply losses as a percentage of world demand.

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[14]From 1994 to 1996 an Energy Modeling Forum (EMF) working group held three Workshops to estimate oil disruption probabilities using a process of expert judgment elicitation, akin to the Delphi method. The EMF expert panel considered specific event sequences and causes of disruptions. It focused on potential losses of supply from Saudi Arabia. It also explicitly consider the issue of disruption duration and the availability of excess production capacity as an offset.

Since 1951 there have been 18 significant crude oil supply disruption events (Figure 4). The causes of these disruptions are varied, but can be generally classified as war (3-5 events), internal political struggles (5 events), economic disputes and embargos (3-5 events), and accidents (5 events). The effects of an oil shock, if they are felt, are usually global in nature. As the historical record on supply shocks and price movements in Figure 5 shows, oil supply disruptions did not always translate into sharp oil price increases. Some events had little price effect due to the ability and willingness of suppliers to offset the shortfall, or due to the existence (mostly prior to 1973) of long-term pricing and supply contracts. On the other hand, some disruptions of lesser size led to enormous and long-lasting price increases (e.g. the 1973 and 1979-80 events). This history supports the important conclusion that not all supply disruptions are alike. Not only do they differ in cause and duration, but they can differ in terms of price effect. As mentioned before, a key issue is the availability of excess production capacity and the willingness of undisrupted suppliers to use it.

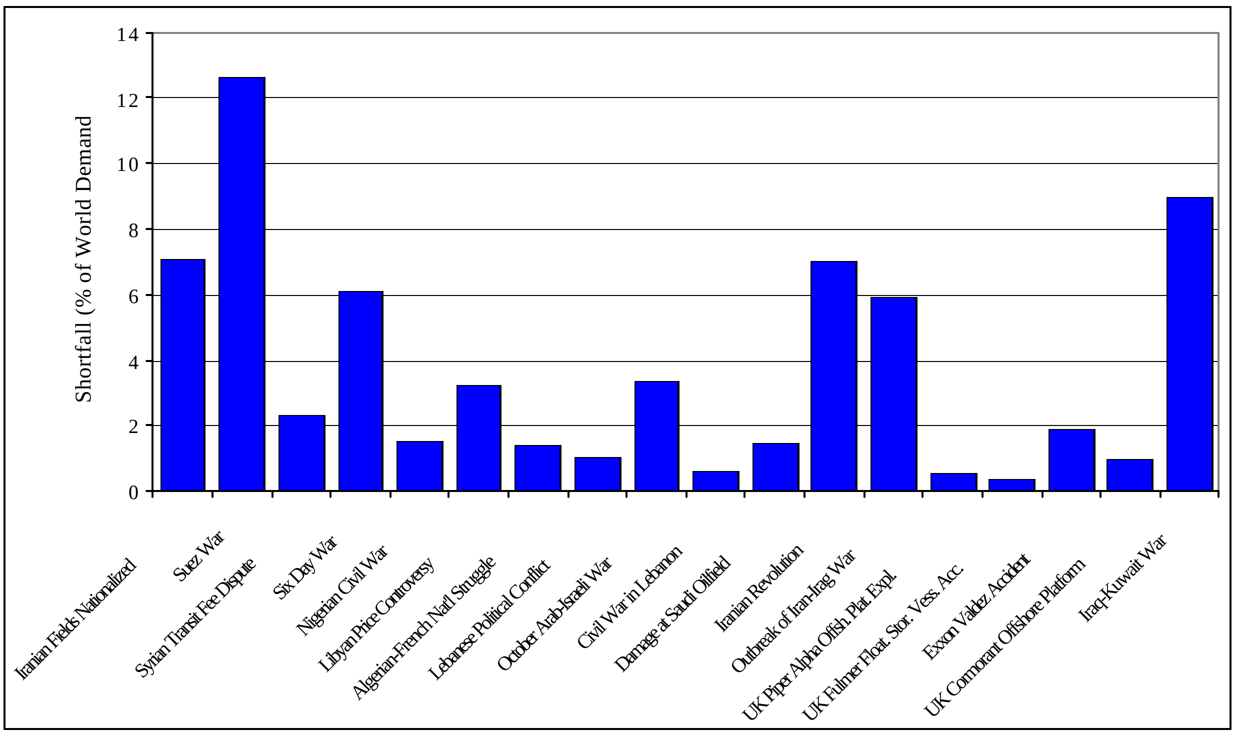

Figure 4: 18 significant Crude Supply Shock Events since 1951.

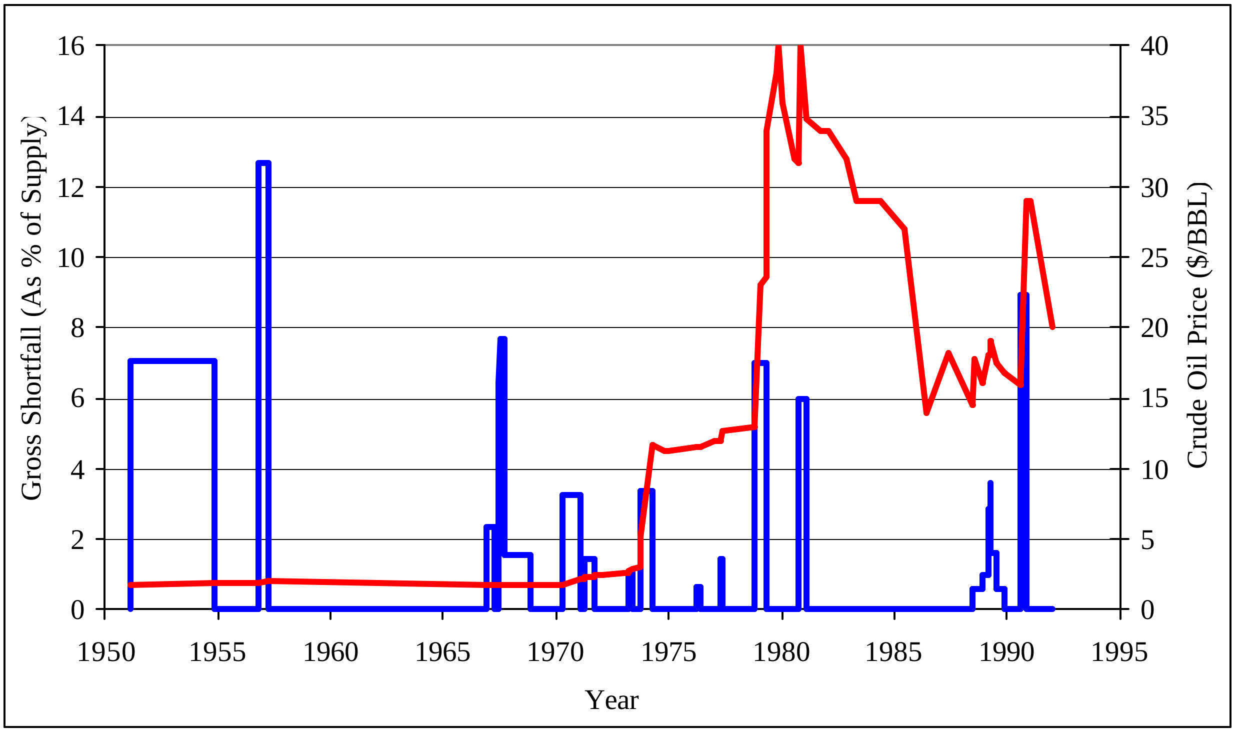

Figure 5: Historical Disruptions. Not all Oil Supply Shocks Translate into Oil Price Shocks.

3.1.1 Disruption Probabilities

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.

The resulting cumulative distribution function for the low, high and base case disruption probabilities of the 1990 analysis is given in Figure 6 below. It is contrasted with the cumulative subjective probabilities from the EMF expert assessment. The combined results of expert judgement from this group indicate larger disruption probabilities and greater sizes than the DOE 1990 study. However, given the lack of public review of the EMF results, and some ambiguities about their interpretation, the 1990 study results are used here instead.

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 strategic 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%. See the Table 1 below.

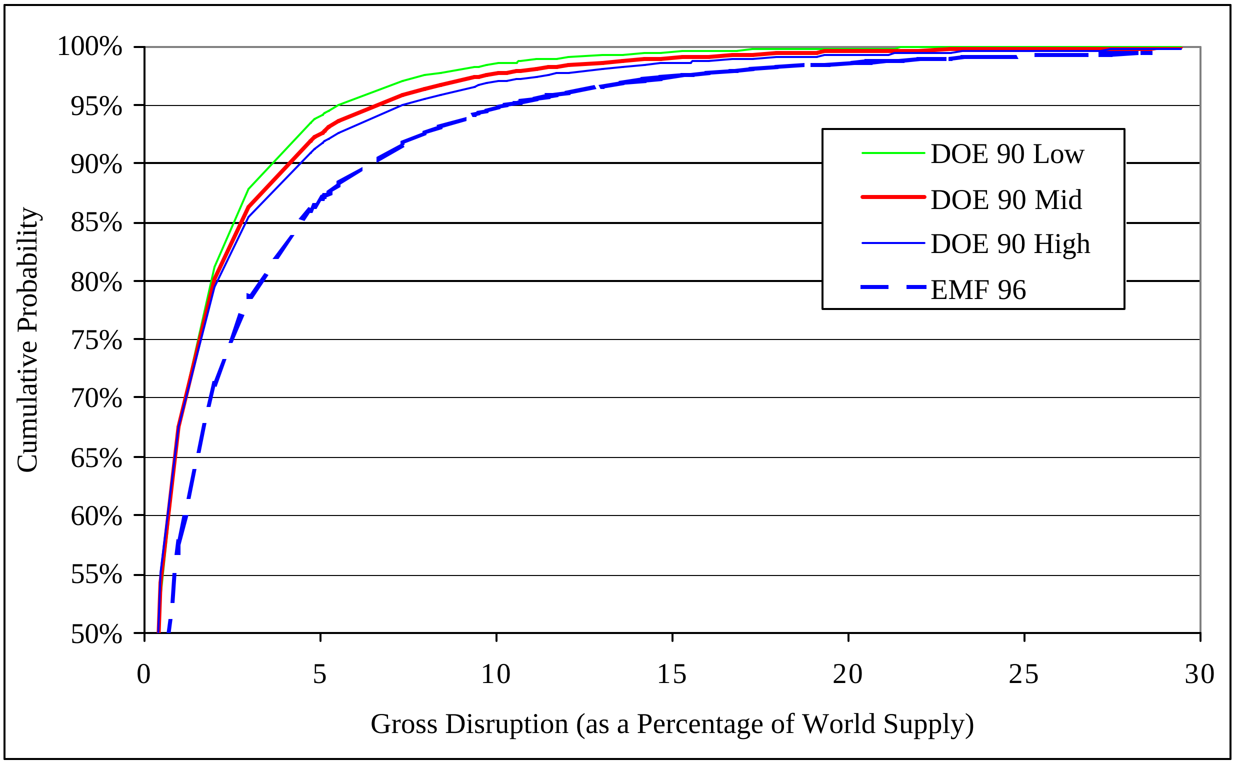

Figure 6: Comparing Disruption Probabilities: Cumulative Probability Distributions (Probability of Disruption with Size # Given Percentage of Demand) from DOE 1990 Study and EMF 1996 Assessment.

Table 1: DOE/Interagency Study Disruption Probabilities: Annual Probability of Gross Disruption, Given as Percentage of World Supply

Case	10% or More Supply Disruption	15% or More Supply Disruption
Lower Risk	1.5%	0.5%
Midcase	2.4%	1.0%
Higher Risk	3.1%	1.5%

3.1.2. Disruption Lengths

A less studied issue is the length of the disruptions given a disruption occurs. No clear evidence points to a relationship between disruption size and disruption length (Figure 7), however the median historic disruption length appears to be about five months (Figure 8). Given this uncertainty, disruption lengths are assigned a random, uniformly distributed probability. In keeping with the low historical correlation between disruption size and duration, we treat the random size and duration outcomes as independent. Sensitivity analyses using disruption lengths of 1-6; 3 and 6; 3,6 and 9; and 3,6,9 and 12 months are performed.

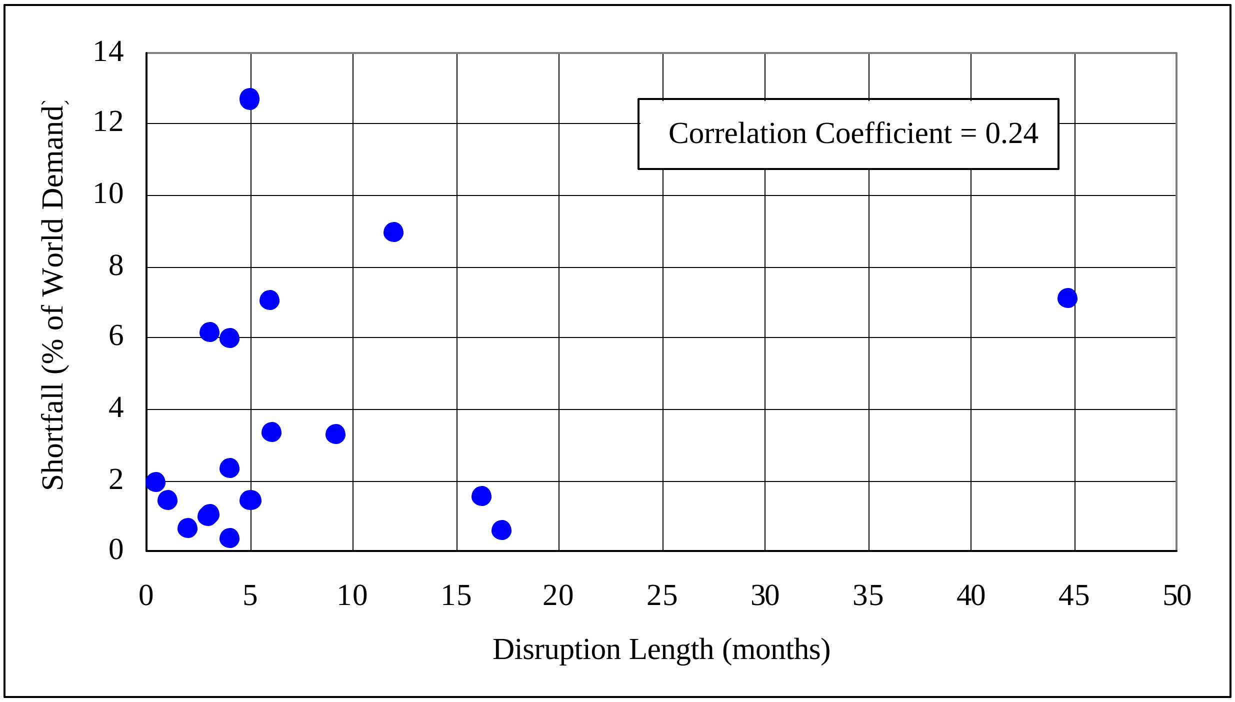

Figure 7: Correlation of Disruption Sizes and Lengths. Historically, Disruption Size and Duration Only Loosely Correlated.

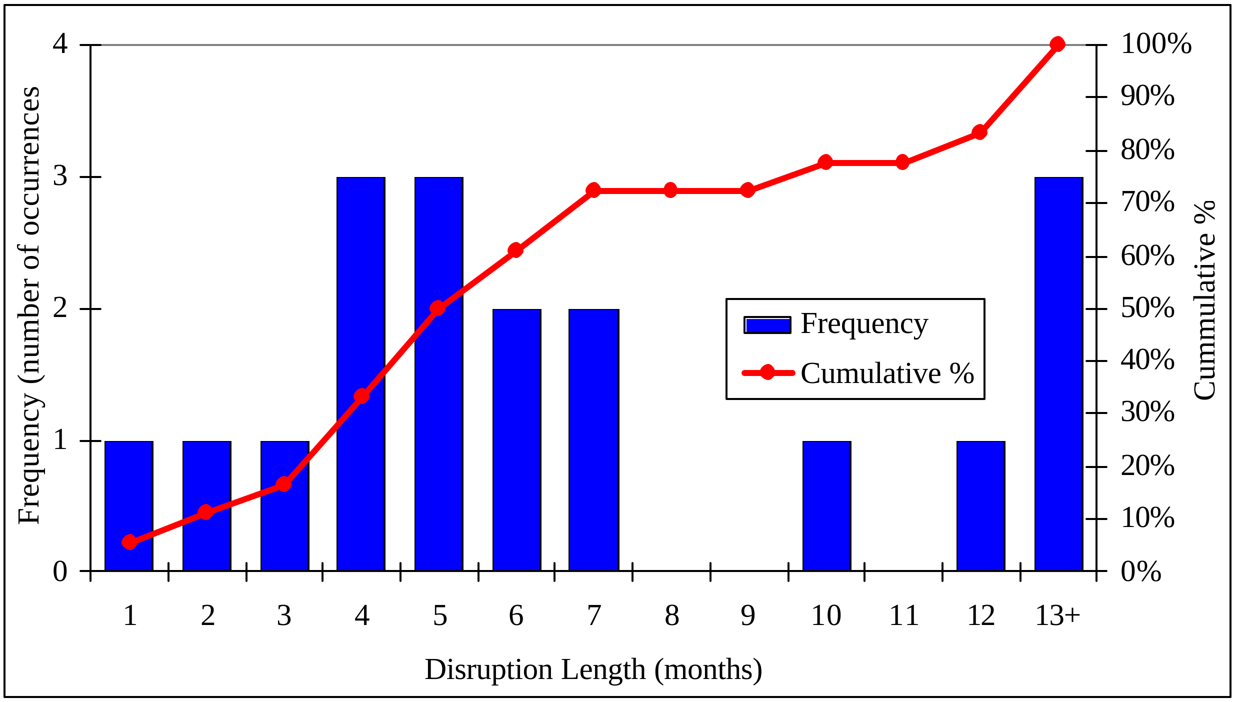

Figure 8: Distribution of Historical Disruption Lengths (Median = 5 Months).

3.2. Treatment of Offsets Available to Mitigate Disruptions

3.2.1. Excess Oil Production Capacity Available

Disruption probabilities determine the gross disruption level but not the net disruption level. That is gross disruptions after offsets and prior to an APEC strategic petroleum reserve drawdown. Offsets which attempt to accommodate a gross disruption include excess oil production capacity or slack, demand switching, and current world strategic stocks. Slack is the excess capacity which can go online immediately (within a month) to address a gross disruption. Slack offset estimates are drawn from the U.S. EIA (Kendell, 1998) and extrapolated to 2030. The Base Case slack oil production capacity estimate hovers near 3 million barrels per day (MMBD) for most of the forecast period. High and low slack sensitivities are estimated assuming a +/- 5% change in OPEC capacity utilization. The resulting excess capacity in the high slack case is quite high, above 5 MMBD for most of the forecast horizon, and reaching 6 MMBD in the later years (see Figure 9). Given that the vast majority of excess capacity exists among OPEC members and uncertainty surrounding its availability during a disruption, these slack estimates should be considered an upper bound.

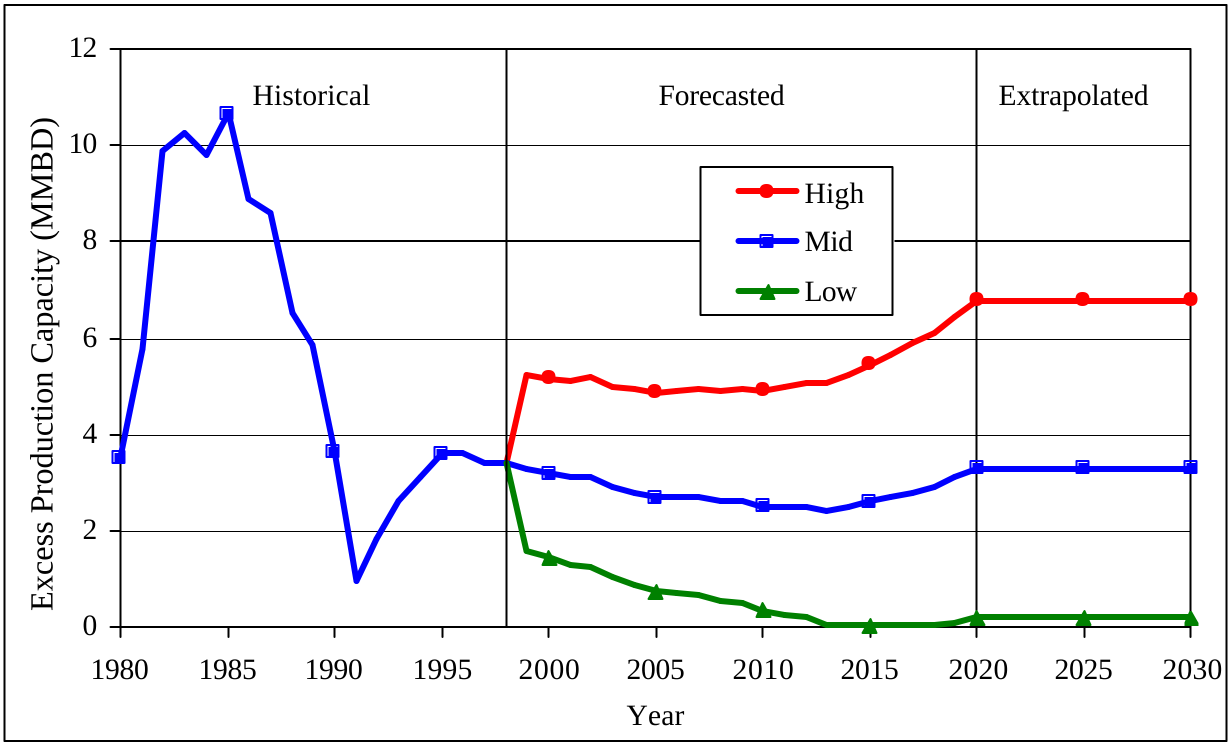

Figure 9: High, Mid, and Low Projected Excess Oil Production Capacity.
Source: James M. Kendall, "Measures of Oil Import Dependence," in EIA, Issues in Midterm Analysis and Forecasting 1998, Figure 4.

3.2.2. Fuel Switching

Fuel switching relates to capability of firms (primarily utilities) to switch from crude oil to other sources such as natural gas in the short run, at virtually no cost and in response to very small price changes. Fuel switching comprises small fraction of the total offsets.[15] The final offset which can be used to address a gross disruption is other strategic oil reserves. These include those reserves held in the U.S., Europe, Japan, Korea, and Chinese Taipei.

3.2.3. Existing APEC and Non-APEC Strategic Oil Stocks

Existing strategic stocks, including those currently held in Japan, Korea, Chinese Taipei [16], Europe and

[15]Not all of the world's demand that employs switchable fuel inputs can necessarily switch fast enough or at low enough cost to be included in this category. Furthermore, excess supply and distribution capacity for the substitute fuel must also be readily available.

[16]Unlike the other countries Chinese Taipei has no official governmental reserve, rather a sizable private stockpiling mandate. Also unlike other countries whose private reserves could be considered working stocks, the Chinese Taipei reserves are sufficiently large (60 days of domestic consumption) that a portion (20 days or 1/3) is

the U.S. provide an important cushion between a net oil supply shock (after supply offsets) and an oil price shock. Used in coordination with any additional APEC stocks, they are the final line of defense after all other alternatives are exhausted. In identifying the level of strategic oil stocks, the following definition was used: strategic stocks are defined as government owned stocks *plus* government-mandated commercial stocks in excess of normal working stocks.[17] Current strategic stocks total approximately 1258 MMB, as itemized in Table 2. Current strategic stocks, in coordination with any incremental APEC reserve being evaluated, are drawn down collectively to offset net supply shortfalls. Each stock is drawn in equal proportions, with the maximum drawdown rate equal to the six-month exhaustion rate. The benefits of existing strategic stocks are accounted for, but not reported in the net present value calculations here. This is because all costs and benefits are computed based on the *incremental* contribution of additional APEC stocks, and the incremental net benefits are then reported. The contribution of existing stocks nets out of these incremental benefit calculations. This is an appropriate approach, in order to evaluate the incremental costs and benefits of an incremental size expansion beyond current reserves.

Table 2: Total Existing Strategic Stocks*

Region	**Size**
U.S.	563
Japan	315
Republic of Korea	43
Chinese Taipei	12
Europe**	325
Total	1258

*Strategic stocks as defined here are government stocks plus government-mandated commercial stocks in excess of normal working stocks (40 days).
**OECD Europe government controlled stocks of which 63 MMB are government owned. Sources: *International Petroleum Statistics Report*, DOE/EIA-0520(98/09), September 1998, Table 1.6. International Energy Agency, *Monthly Oil Market Report*, Table 5.

considered as strategic stocks available for drawdown.

[17]This definition of strategic stocks was applied to the data in the stockpile survey in APERC 1998b, to produce the Table 2. Based on the discussion in that document, our operating definition of normal working stocks is 40 days of production or imports, whichever is larger.

4. Key Determinants of Stockpile Size Analysis: Stockpile Cost and Performance Factors

4.1. Oil Stockpile Costs

Table 3 below summarizes the cost and performance characteristics of the three storage technologies given in the PB-KBB (1998) report: in-ground trench, hard rock mine, and salt caverns. The major cost categories are facility capital costs, and Operations and Maintenance (O&M) costs. O&M costs are given for standby operations (in $/BBL-yr) and fill and draw operations (in $/barrel).[18]

Table 3: Summary of Facility Cost Information from PB-KBB

Technology	**In-Ground Trench**	**Hard Rock Mine**	**Salt Caverns**
Suitable Countries	U.S., China, Australia, South Korea, Thailand	U.S., China, Australia, South Korea, Thailand	U.S., China, Australia, Thailand
Capital Cost, U.S., $/BBL-Capacity	$15.68	$15.44	$5.51
O&M Cost, U.S., $/BBL-Year	$0.16	$0.09	$0.17
Fill/Refill Cost, $/BBL	$0.05	$0.05	$0.09
Drawdown Cost, $/BBL	$0.07	$0.07	$0.10
Facility Size, MMB	100	100	100
Maximum Drawdown Rate, MMBD	1.17	1.17	1.17
Maximum Fill Rate, MMBD	0.27	0.27	0.27
Development Time, Years	11	13	8

This table also provides some of the important operating characteristics of these reserves which used in the analysis. The most important difference is in the development time (8 to 13 years). The technical maximum fill rate and draw rate are far faster than would likely ever be needed. Looking across technologies, although there are some differences in operating, filling, and drawing costs of the three technologies, the capital costs dominate by far. Figure 10 shows the discounted time stream of capital costs for program development. For all technologies, there is an initial 3-4 year period of modest costs, and then the bulk of capital costs occur around the middle of the development period. The Figure also shows that the discounted capital cost stream for salt caverns lies well below those of the other two technologies. Salt Cavern storage is available sooner and at lower cost. An even clearer contrast is in Figure 11, which shows discounted sum of capital costs for each technology, on a per-barrel basis. These NPV capital costs per barrel are reported for different completion years. Since the rock and

[18]These costs are expected to vary slightly with the location of the site, based on host-economy costs. However, such regional variations are modest, and can be accommodated by *ex-post* adjustment of any simulation results. For simplicity, U.S. costs (in $/BBL) were used. Since the U.S. costs were generally higher than for other countries, this can be taken as an upper bound on the cast of constructing, operating, filling and drawing down.

trench technologies have longer development times, expressing costs in terms of equivalent completion years accounts for the fact that rock and trench expenditures are not only larger, but would have to begin sooner. In present value costs per barrel, both the rock and trench technologies are almost exactly 3 times as expensive as salt caverns completed in the same year. This ratio holds true for *any* year of facility completion. The NPV cost of salt caverns completed by 2008 is $4.03/BBL. Based on costs and operating characteristics alone, there is never a case in which trench or hard rock storage would be preferable, regardless of when it is built. For these reasons this analysis focuses attention on salt cavern storage. A quick rule of thumb, however, is that if one of the other two technologies is used, capital costs are approximately three times higher. Recognizing that there may be non-cost reasons for choosing another storage site and technology than salt, we show some sensitivity analyses with respect to capital costs in Section 9.

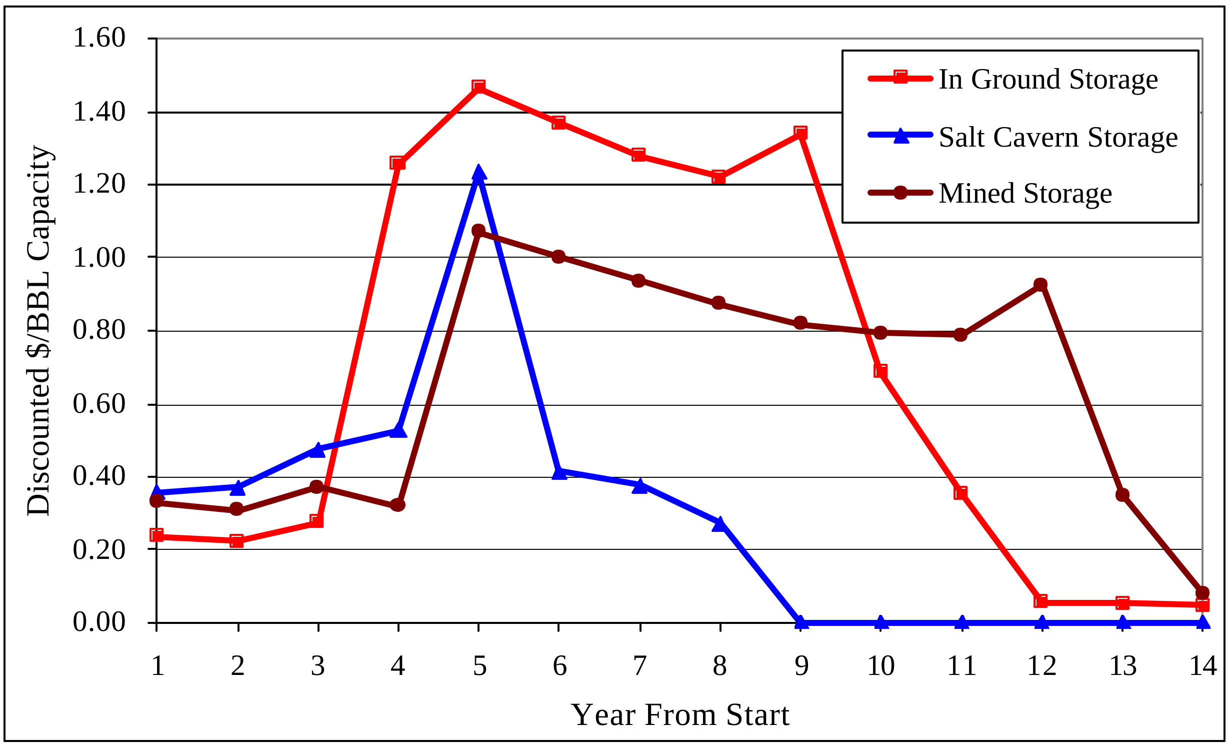

Figure 10: Time Stream of Discounted Storage Facility Construction Costs.

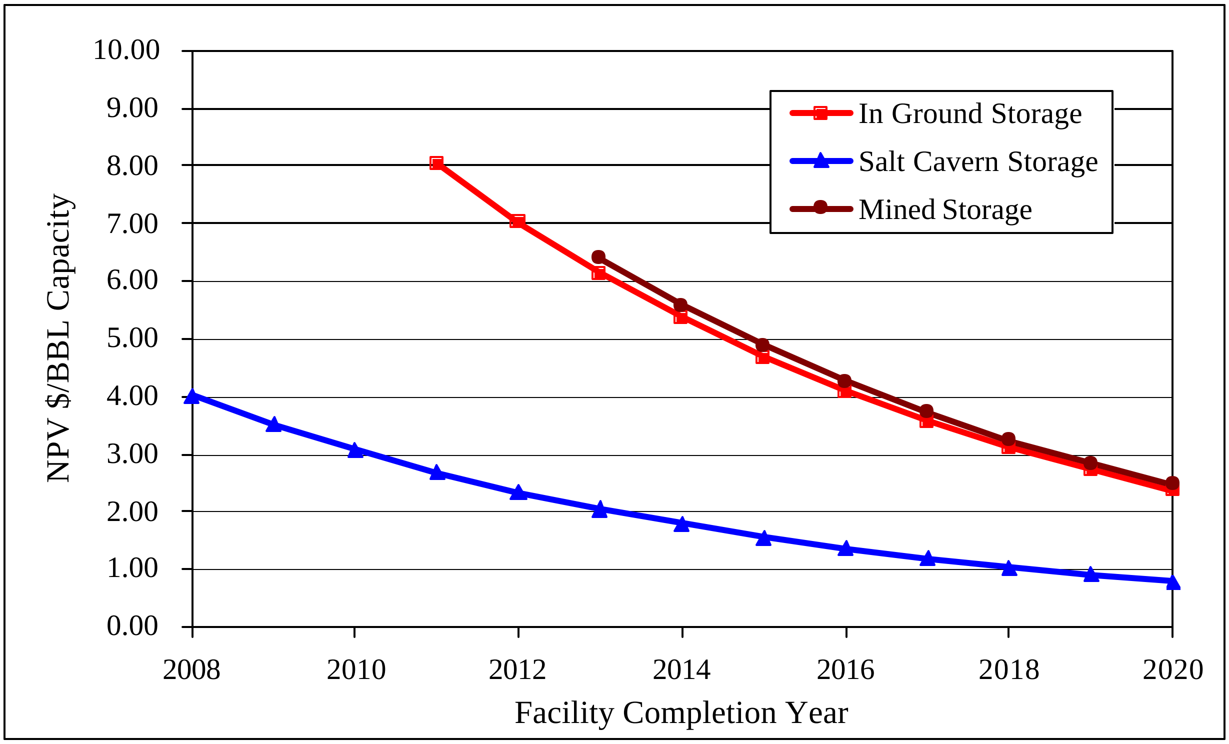

Figure 11: NPV of Facility Capital Cost vs Completion Year ($/BBL).

4.2. Oil Stockpile Configuration

When considering alternative reserve expansion sizes, the costs and operating characteristics of any size reserve are presumed to scale up for the PB-KBB data for 100 million barrels, in direct proportion to the reserve's size. One interpretation is that each reserve is modular: if 200 MMB storage is desired, two separate reserves are built, for 300 MMB, three reserves are built and so on. More generally, the scaling assumption implies that 1) there are no economies of scale, and 2) performance characteristics are additive.

Because the technical maximum fill and draw rate capabilities are so large, they were deemed unlikely to be used. As an alternative, we have set the maximum drawdown rate to a six month exhaustion rate. This is roughly consistent with the IEA goals and drawdown capabilities of the U.S. SPR. Similarly, the fill rate is set such that the incremental reserve would be filled in 5 years, regardless of size. These rates will likely be based more on political or budgetary concerns than on technical design constraints. The maximum drawdown rate and the refill rate grow with program size, meaning that a larger reserve can both address a larger short disruption and a longer moderate disruption.

5. Key Determinants of Stockpile Size Analysis: Disruption Cost Factors

In calculating the effect of disruptions, the elasticity of world demand determines the world oil price change, ? *P*, for any given net oil supply shortfall (after supply offsets and the use of the reserve). The two principal costs to APEC economies due to disruptions, increased cost of oil imports and macroeconomic (GDP) adjustment costs, are then easily calculated. The APEC-U.S. region's net import demand elasticity determines import levels *I* for the given price change ? *P* during the shock, and shock import costs ? C_I are the product of the import level and the price change:

$$? C_I = I ? P$$

The macroeconomic losses during the shock are summarize by a parameter s , called the "GDP-elasticity" with respect to oil price shocks. The GDP elasticity specifies the percent GDP change for each percent change in the oil price:

$$\%? \mathrm{GDP} \; . \; s \; \%? P$$ [19]

Recent research commissioned by the U.S. Department of Energy (Jones, Bjornstad, and Leiby 1997) shed considerable light on the nature of the macroeconomic costs of oil price shocks. By improving our understanding it also increased our confidence in the macroeconomic significance of oil price shocks, and in econometric estimates of the magnitude of shock effects. For the purposes of this APEC reserve study, independent econometric estimates were made for the individual APEC economies. The methods used followed the general body of oil shock research and relied on available aggregate macroeconomic data. These estimates are discussed in Chapter 6 and are summarize in Figure 12 below. Figure 12 shows the GDP elasticity estimates for each APEC economy, along with 90% confidence intervals around those estimates. It also show the aggregate GDP elasticity for the combined economies of all APEC excluding the U.S. This elasticity is -0.065, with an estimated standard error of 0.019.[20]

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[19]This is a very close approximation. The actual calculation is done with the elasticity formulation:

$$(1 \; \% \; \frac{? \, GDP}{GDP}) \; ' \; (1 \; \% \; \frac{? \, P}{P})^{s}$$

[20]The aggregate elasticity for the combined APEC-U.S. region is based on a GDP-weighted average of the GDP elasticities for individual economies. As a rough approximation, the standard error for the combined GDP elasticity is also a GDP-weighted average. This approximation is accurate if the errors for the individual elasticity estimates are independent, or if they are correlated with a mix of positive and negative correlations that roughly offset one another.

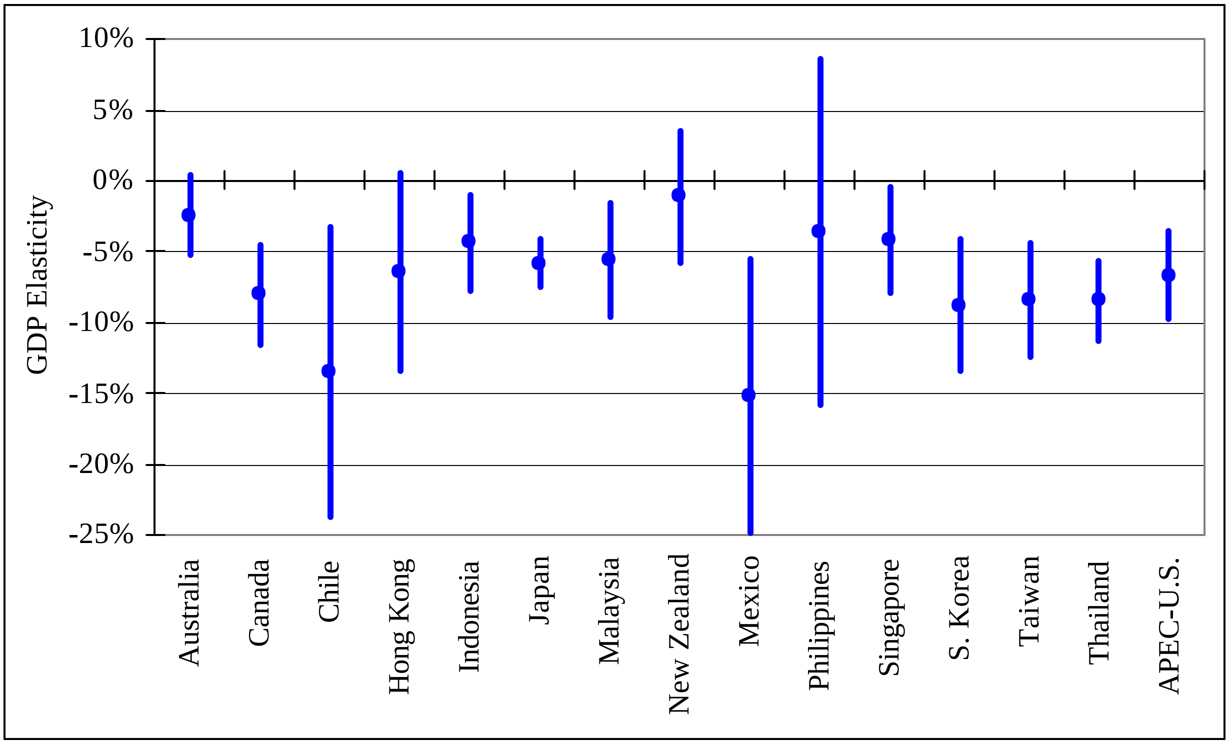

Figure 12: Oil Price Up Coefficients and 90% Confidence Intervals.

Note: Estimated with money supply control, annual data except for Philippines, which used quarterly data. Based on Bachman and Ingram (1999).

6. Cases Considered

Past studies of the United States SPR have provided valuable insight into which factors most strongly influence the value of strategic oil stockpiling. The list in the Table 4 below reports the parameters that have been shown to be most influential, in approximate order of importance. Those parameters that are followed by "plus" signs (+) lead to higher benefits when they are increased in magnitude, and lower benefits when they are decreased. The converse holds true for parameters followed by a "minus" sign (-). The number of pluses or minuses is a rough indicator of the strength of the effect.

Table 4: Key Parameters for Strategic Reserve Size

Factor	Strength of Influence on Benefits
Disruption Size Probability	(+++)
Disruption Offsets	(+++)
GDP Elasticity	(+++)
Disruption Length Probabilities	(++)
Import Demand Elasticities	(++)
Reserve Fill Rate	(++)
Import Levels	(++)
Discount Rate	(--)
GDP Growth Rate	(+)
Max Reserve Draw Rate	(+)
Oil Price Path	(+?)
Reserve Refill Rate/Policy	(-)
Short-run Fuel Switching	(-)
Foreign Draw Coordination	(-)

Recognizing these principal uncertain inputs which influence the reserve size evaluation, we structured a small set of important sensitivity-analysis cases. Their inputs are shown schematically in Figure 13. Each of the cases considered a combination of the key factors including disruption probability, disruption duration, and slack production capacity. The third of the most important factors, the GDP elasticity with respect to oil price shocks, was considered through sensitivity analysis applied to the results of the basic set of cases. Because the results of the analyses showed strong support for APEC reserve expansion, the principal focus of sensitivity analysis was on assumptions which might diminish reserve benefits. We also considered different start years for the APEC reserve expansion (2000, 2005, and 2010), and two oil price paths (APERC's reference case, and DOE/EIA's 1999 base case projection).

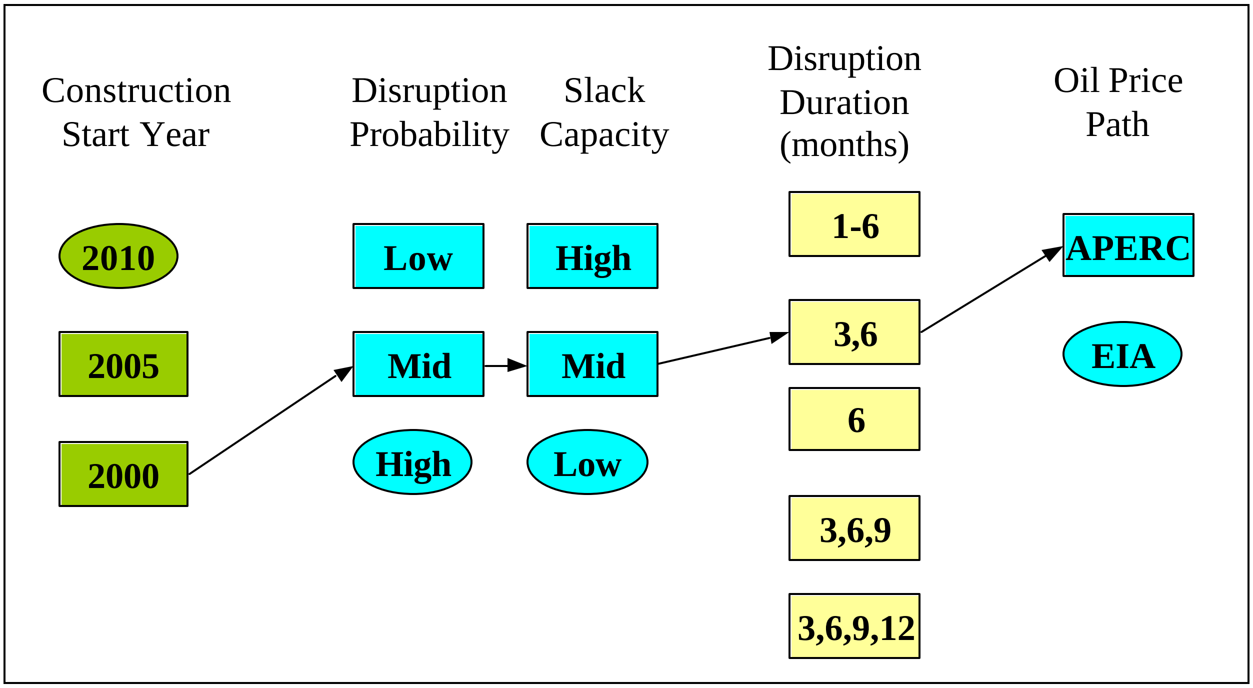

Figure 13: Schematic diagram of the main sensitivity cases considered.

Key: A case consists of one selection from each column. The arrows connect the selected elements in the "Base" case. All combinations of the conditions in boxes were examined, and a limited number of cases were run with the conditions in ovals.

7. Base Case Results of Incremental Storage Capacity

7.1. Summary of Base Case Assumptions

As a Base Case, or point of departure, we examine the results of setting all assumptions at their middle or reference levels, and assume that should a disruption occur, its duration would be random, and uniformly distributed over 3 and 6 months. To recapitulate, the essential Base Case assumptions are listed below.

Table 5: APEC Reserve Size Analysis Base Case Assumptions	
Disruption Probability	DOE/Interagency 1990 base case (a weibull distribution over disruption sizes, with a 1% annual probability of a disruption equal to 15% or more of world demand.)
Slack Production Capacity	EIA 1999 base path, corresponding to 3.4 MMBD in 1998, declining to 2.5 MMBD by 2015, and then recovering to 3.3 by 2020. Assumed OPEC production capacity utilization rises from current 90% to 95% by 2020 and beyond.
GDP Elasticity	Mid value, -0.065. Roughly, a sudden oil price doubling causes a 6.5% reduction in GDP.
Disruption Lengths	Random, uniformly distributed over 3 or 6 months in duration (average duration is 4.5 months).
Oil Storage Technology	Salt caverns. NPV capital cost is $4.03/BBL.
Program Start Year	2000. Beginning with site design studies and architectural engineering, followed by facility construction. Fill begins 8 years after program start, for the Salt Cavern storage technology.
Undisrupted Oil Price Path	Base oil market conditions follow APERC "Baseline" (B98) path (flat in real terms at $17.42/BBL, 1996 US$)
Foreign Draw Coordination	APEC, U.S., and IEA strategic reserves of approximately 1258 million barrels are coordinated with incremental APEC reserves to mitigate disruptions. All reserves drawn in proportion to their sizes.
Import Demand Elasticities	Following the DOE/Interagency 1990 analysis, APEC and World net import demand elasticities for 1999 are approximately -0.125 in the short run (first month of a disruption). Elasticities rise over the duration of the disruption, increasing by 50% after 12 months. First-month elasticities also increase over time, rising to -0.15 by 2020.
Discount Rate	7%
Fill and Refill Rates	Initial fill and refill rates are sufficient to fill reserve in 5 years.

7.2. Reserve Size Maximizing Expected Net Economic Benefits

The Base Case (Figure 14) results indicate that a substantial incremental reserve could provide about $2.7 billion in discounted expected benefits, net of all costs. The peak benefits occur around a size of 600 million barrels, but benefits are roughly equivalent within ±100 million barrels of that size. While is a large incremental reserve, it may be viewed best as simply a 50% expansion of the current world strategic oil reserves of 1258 million barrels. The size is justified on the basis of collective net benefits to *all* APEC countries excluding the U.S., a group with enormous projected GDP and substantial net oil imports. The size conclusion is also predicated on the use of the least expensive storage alternative (salt caverns), and the best available estimates of the sensitivity of APEC economy GDP to oil prices shocks.

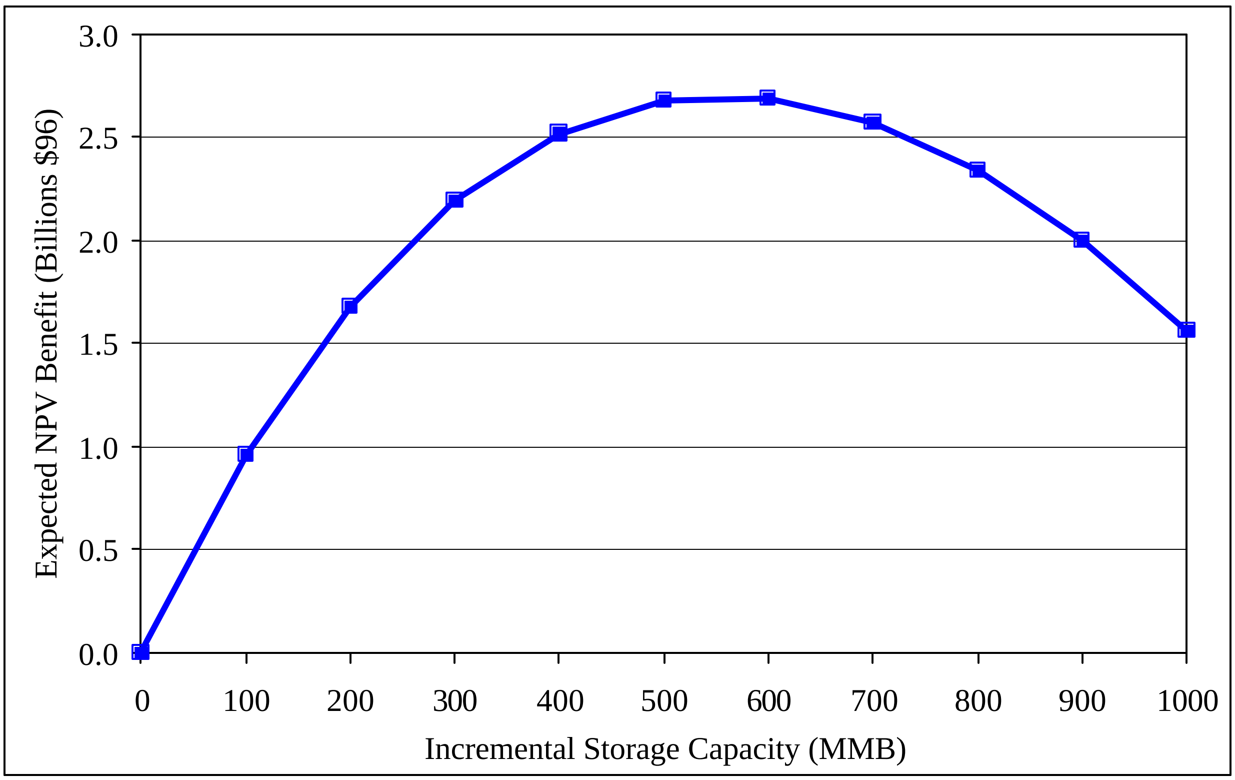

Figure 14: Base Case Results for the Benefits of Incremental Storage Capacity (Mid Case inputs, disruption lengths evenly distributed over 3 and 6 months in length).
Note: See DR99M1_out15.xls, case OA0.

8. The Net Benefit Components of Stockpile Expansion

It is instructive to separate the total Net Benefits of alternative reserve sizes out into the various cost and benefit components. As discussed above, the principal components are

GDP Savings	- Avoided GDP losses due to disruptions
Import Cost Savings	- Avoided import costs due to disruptions
Reserve Net Revenue	- Reserve oil sales revenue minus oil purchase costs and transaction (fill/draw) costs
Capital Stream	- A negative financial flow corresponding to facility capital costs and O&M costs.

Figure 15 shows how each of these components change as a function of increasing reserve size. The benefit terms for GDP Savings and Import Cost Savings are positive contributions, and are shown that way. The Capital Stream, representing capital and O&M costs, is shown as a negative term. The reserve Net Revenue, or net oil costs for the reserve, is negative, indicating that on average the reserve oil is sold for less than its purchase cost (in real terms).

By far the largest benefit of the reserve is the Avoided GDP losses. For the combined APEC economies excluding the U.S., the avoided GDP losses are about three times as large as the avoided import costs. This is an important insight: while APEC economies are rightly concerned about their growing levels of oil imports, the vulnerability of their economies to transitional losses during sudden price movements due to allocative dislocations appears to be an even larger concern. The curves in Figure 15 Also show the slow marginal decline of avoided import costs and avoided GDP losses as the reserve size expands. This is because as the reserve increases in size, we would anticipate fewer and fewer situations in which the added size is needed. The first 100 million barrels provides an expected marginal GDP savings of about $1.75 billion, or $17.50/barrel. By 500 million barrels that marginal savings has declined to about $10/barrel, and it declines more rapidly thereafter.

Capital costs and net SPR revenue are comparable in magnitude. The capital cost stream increases proportionally with the size of the reserve. This is true because we treat all storage as of the same type (salt caverns), with the understanding that capacity can be expanded in 100 million barrel increments at a fixed unit cost. The net cost of reserve oil is not its purchase price, but rather its purchase price plus transaction costs *minus* the expected, discounted sales price (either in a subsequent disruption or in the reserve "salvage" calculation for the end year 2030). We see that typically the expected NPV oil cost per barrel of stored is slightly larger than the capital cost of the salt cavern facility: about $6.90 per barrel.

The ability to decompose expected reserve net benefits in this way offers a powerful opportunity for sensitivity analyses. Knowing the magnitude of expected GDP losses allows us to examine the sensitivity of reserve net benefits to GDP levels, and to the GDP-elasticity with respect to oil shocks. Knowing the magnitude of expected import cost savings allows sensitivity analysis with respect to oil import levels. And knowing capital costs allows an exploration of how our results on reserve net benefits (and efficient reserve sizes) would change if a different (and higher cost) mix of storage technologies were chosen.

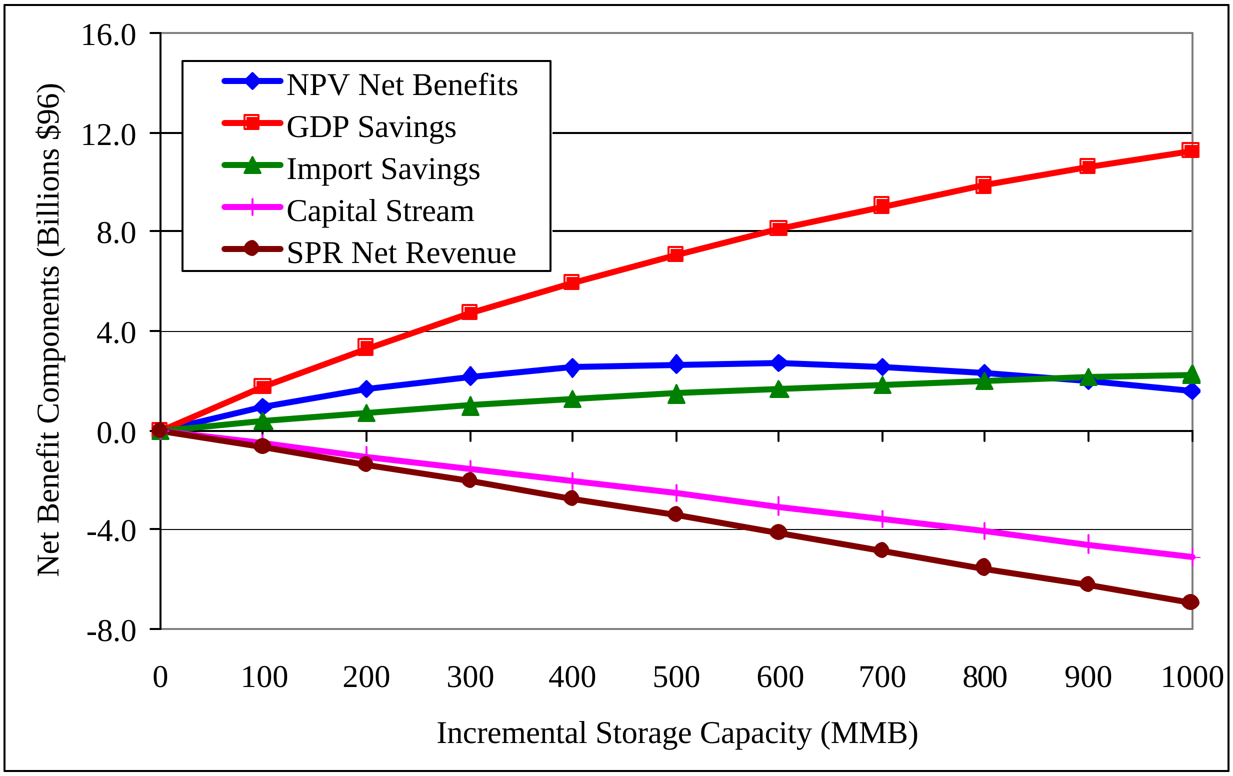

Figure 15: Decomposition of Base Case Net Benefits Components.
Note: See DR99M1_out15.xls, case OA0.

9. Sensitivity of Results to Changes in Key Assumptions

In this section we report the effect on benefits and efficient reserve sizes if the expected duration of disruptions is longer (or a bit shorter) than the Base Case average of 4.5 months. We also consider the variation of benefits under cases of lower shock risk, higher and lower GDP elasticity, and higher capital costs.

9.1. Effect of Increasing Market Risk: Longer Disruption Lengths

This corresponds to an increase in oil market risk. It is reasonable to consider longer disruptions than the Base Case average of 4 ½ months, since the historical median disruption length is 5 months. The arithmetic average or mean historical disruption length is even longer, since the observed length distribution is skewed to the right, with some very long duration events. There is however, the question of whether the reserve ever can or should be sized to protect against very long events (12 months or longer). In those cases the "shock" begins to look more like a change in market regime, and there is value to allowing the price to (slowly) rise and induce the needed investment changes. Even in those cases of very long disruptions, however, the strategic oil reserve can help to buffer and slow the price increase in the early months.

The sensitivity cases over disruption length shown below (Figure 16) indicate that the benefits of strategic stocks and the efficient stock size grow markedly as the average disruption duration increases. If disruptions stay somewhat shorter on average than in the Base Case (i.e., if they are uniformly distributed over 1 to 6 months in length, averaging 3 ½ months long) then the efficient expansion of strategic stocks is closer to 300 million barrels.

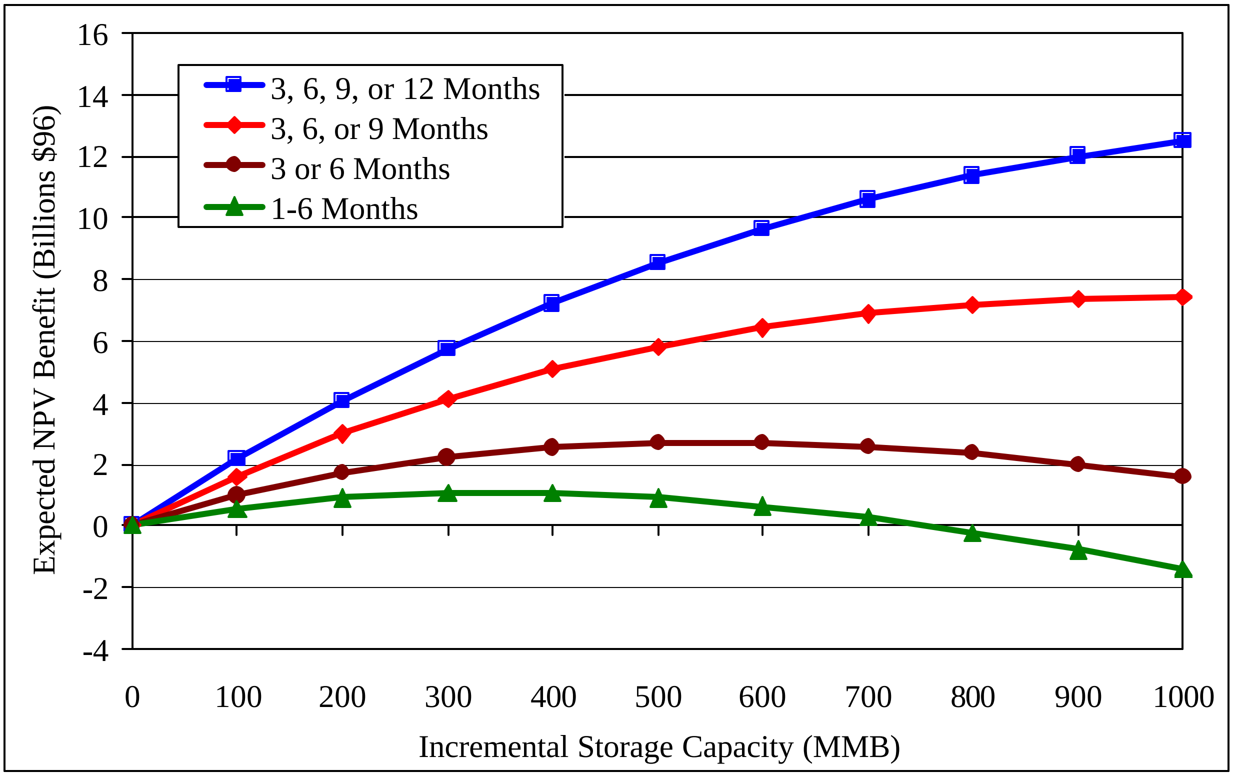

Figure 16: Sensitivity of Net Benefits to Disruption Length. If disruptions averaging longer than 6 months are expected, and if the reserve is intended to address them, then substantially larger reserves than 600 million barrels are efficient.

9.2. Effect of Decreasing Market Risk: Decreasing Risk of Shocks, Increasing Slack Capacity

Since the Base Case, and the variations around it considered so far, indicate such clear support for a substantial expansion of the APEC reserve, it is informative to consider the degree to which alternative assumptions which are *more optimistic* about the future world oil market may diminish that support. The following four diagrams each show how the efficient size of the APEC expansion would be smaller if we expect *lower* market risk than the Base Case. Collectively, they indicate that an expansion is worthwhile in all but the most optimistic assumption about the world oil market. Those optimistic assumptions assume High Offsets. In the High Offsets Case there is a substantial quantity of excess oil production capacity available in the world oil market (5 to 6 million barrels) that persists across the forecast time horizon, and it is used in the event of a disruption. They also assume that the lower disruption probability distribution is used, meaning that the likelihood of a very large disruption is half as great as in the Base Case (i.e., a 0.5% annual probability of 15% loss of world supply compared to a 1% probability in the Base Case). Finally this most optimistic case assumes that oil market disruptions are no longer than 6 months in duration, and average at most 4 ½ months in duration.

On the other hand, without all of these optimistic assumptions *combined*, there is generally a significant benefit to be gained by expanding the APEC reserve. If only two of these optimistic assumptions (regarding offsets, disruption probability, and disruption length) hold true, then an expansion of at least 200 million barrels is worthwhile, and it could be very valuable.

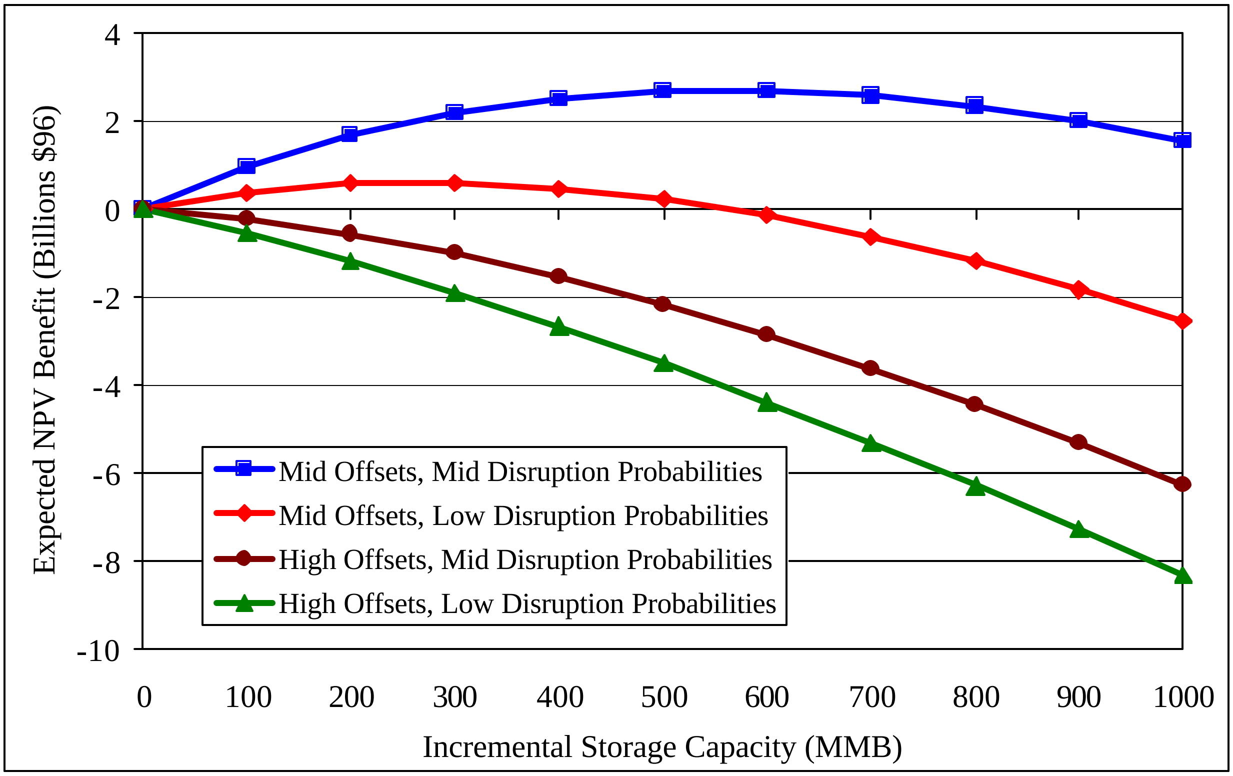

Figure 17: Sensitivity of Benefits and Efficient Size to Lower Levels of Oil Market Risk I. In this variation on the Base Case (disruptions still average 4 ½ months in length, but are less probable and smaller), expansion of at least 300 million barrels is beneficial unless "High Offsets" can be assured. High Offsets correspond to substantial excess oil production capacity (6.0 MMBD) persisting and being readily available in any disruption that may occur through year 2030.

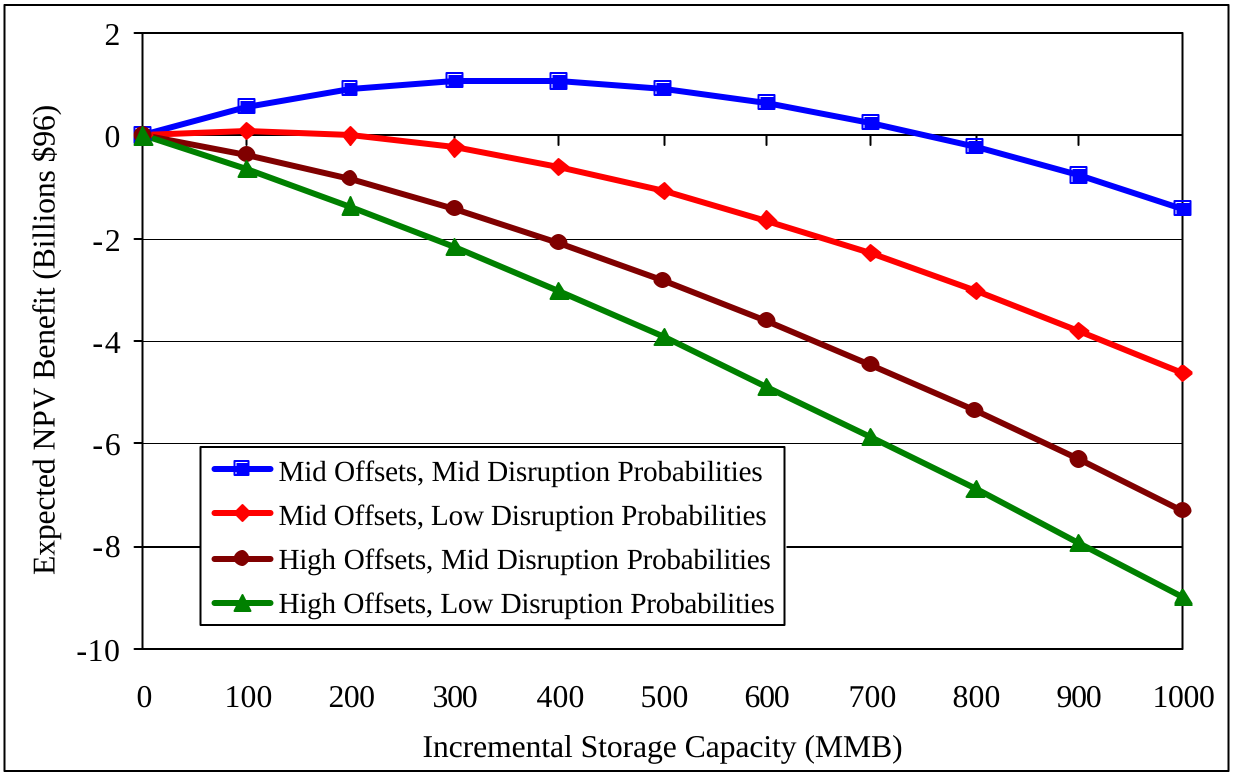

Figure 18: Sensitivity of Benefits and Efficient Size to Lower Levels of Oil Market Risk II. These cases involve smaller, less likely, and slightly shorter disruptions (averaging 3 ½ months in length). Here, an expansion of 100-200 MMB is still beneficial, or at least a breakeven proposition, under the optimistic assumptions of lower shock probabilities and shorter disruptions. However, if much higher slack production capacity (5-6 MMB/day) is always available, then expansion is not needed to cover short (1-6 month) disruptions.

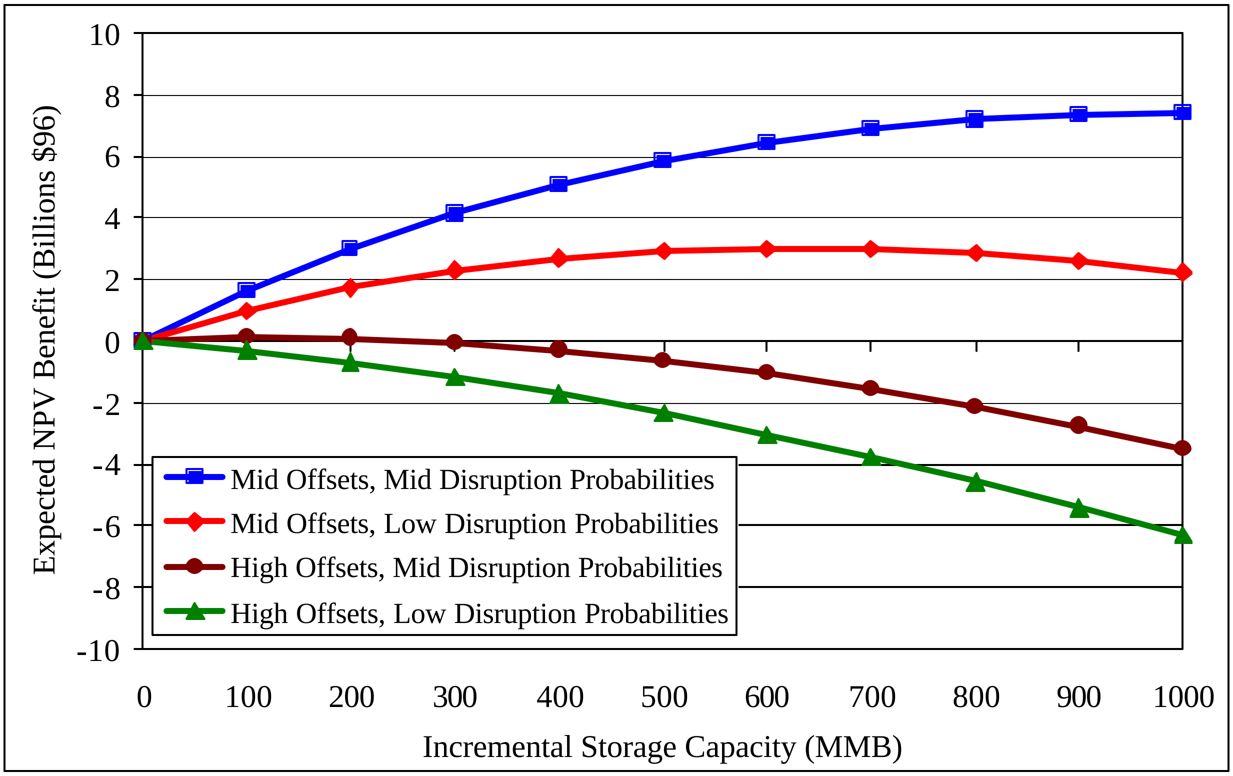

Figure 19: Sensitivity of Benefits and Efficient Size to Lower Levels of Oil Market Risk III: In these cases disruptions are expected to typically last 6 months (uniformly distributed lengths over 3, 6 and 9 months). In these cases, expansions are beneficial under all but the most optimistic expectations regarding oil market risk. That most optimistic case assumes low disruption probability and the persistent availability of large (5-6 MMBD) excess oil production capacity.

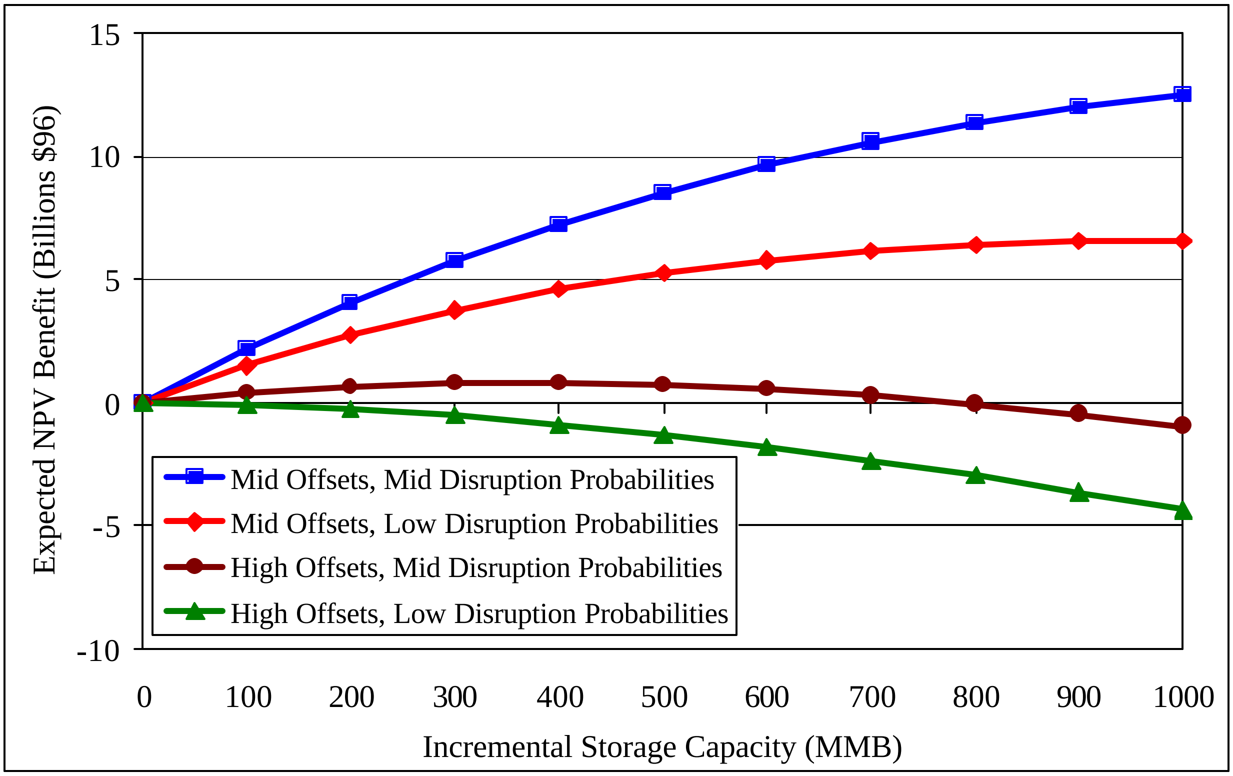

Figure 20: Sensitivity of Benefits and Efficient Size to Lower Levels of Oil Market Risk IV: Here we consider lower disruptions risks in the context of longer disruptions, lasting 3,6,9 and 12 months. In the extreme case where disruptions are expected to be quite long on average, and APEC economies wish to size the reserve to protect against that risk, then an expansion of 200 million barrels is worthwhile under all but the most optimistic assumptions. Even in that case, a 100-200 million barrel expansion would break-even on average, and could provide large insurance benefits in some extreme oil market events.

9.3. Effects of Program Delay

The Base Case analysis assumes that the new reserve development begins in the year 2000. This does not mean that APEC economies would be expected to commit to large expenditures that soon. As the time stream of capital costs provided in Figure 10 shows, the first three years of expenses are modest for all three storage technologies. The early years require site investigation and engineering studies. Then, construction begins in earnest. The most rapid expenditures, the oil procurement costs, follow when the storage facility is complete after 8 to 13 years. Assuming that the reserve will be filled over the space of five years means that it will not be complete until 13 to 18 years after the program starts.[21] Despite this considerable lag, and the relatively modest initial financial commitment required by the reserve program, APEC economies may wish to consider delaying the program.

Delaying the reserve program moves capital costs, fill costs, and draw benefit streams back to more distant times. For program sizes which yield a positive net benefit, the additional years of discounting will reduce the present value of net gains. This discounting is partially exacerbated by the fact that a delayed program offers fewer years of use, at least within the 31 year time horizon under consideration (2000-2030). The benefit reductions due to discounting and reduced availability are partially offset by the projected changing (worsening) oil market conditions. That is, while disruption probabilities are not assumed to change over the forecast horizon, world oil demand and oil trade is growing. Furthermore, world excess production capacity, an important shock buffer, is projected to be a declining share of production. Since disruptions are expressed as a percentage of world demand, later-year disruptions are potentially larger, and may have more-than-proportionally larger costs, since projected APEC imports are growing, and the GDP's at risk are growing.

On balance, delaying the reserve program has a moderate effect on reserve benefits. As the net-benefit curves in Figure 21 show, reserve programs delayed to 2005 or 2010 yield slightly lower discounted benefits, and indicate slightly larger optimal sizes.

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[21] A more rapid APEC reserve could be developed by purchasing oil over the next few years and storing it in existing space leased from the U.S. SPR. Later, the APEC oil could be exchanged or swapped out of the U.S. reserve, and deposited in a new APEC facility elsewhere. This approach has the advantage of making the reserve available quickly, and is also beneficial if the current low oil prices represent an unusual buying opportunity.

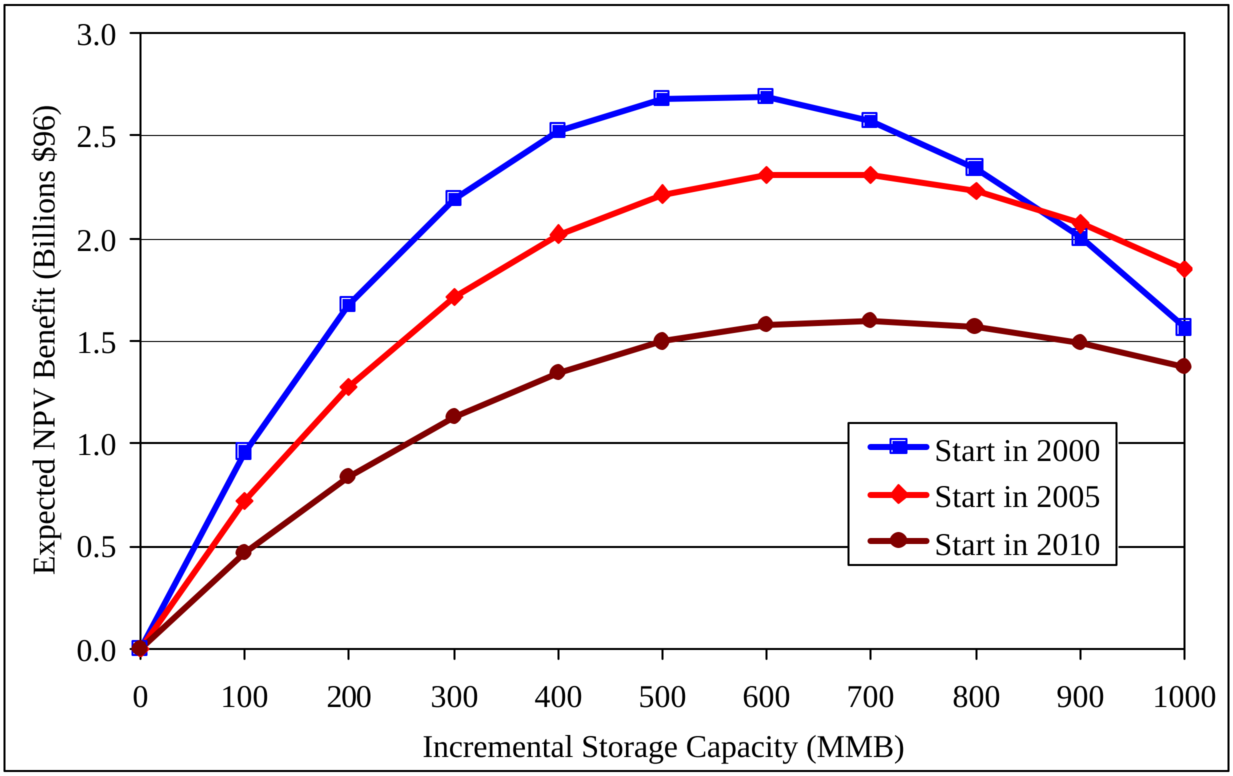

Figure 21: Effect of Changing the Program Start Year. Delaying the start of construction lowers optimal net benefits and increases efficient size.

Note: See DR99M1_out15.xls, case PA0, PA2, PA8.

9.4. Robustness Over Range of GDP-loss Elasticity

The GDP elasticity parameter is very important to the analysis. The Figure 22 below shows how the efficient reserve size, and the net benefits gained at that size, vary as the GDP elasticity is varied up or down by 30%, or within one standard error of the central estimate. The Figure confirms that our essential results on efficient size are robust for variations in GDP elasticity. For Base Case conditions on oil market risk and disruptions of 3 or 6 months in length, the optimal size ranges from 300 to 750 million barrels. The resulting expected NPV benefits range from $0.9 billion to $6 billion.

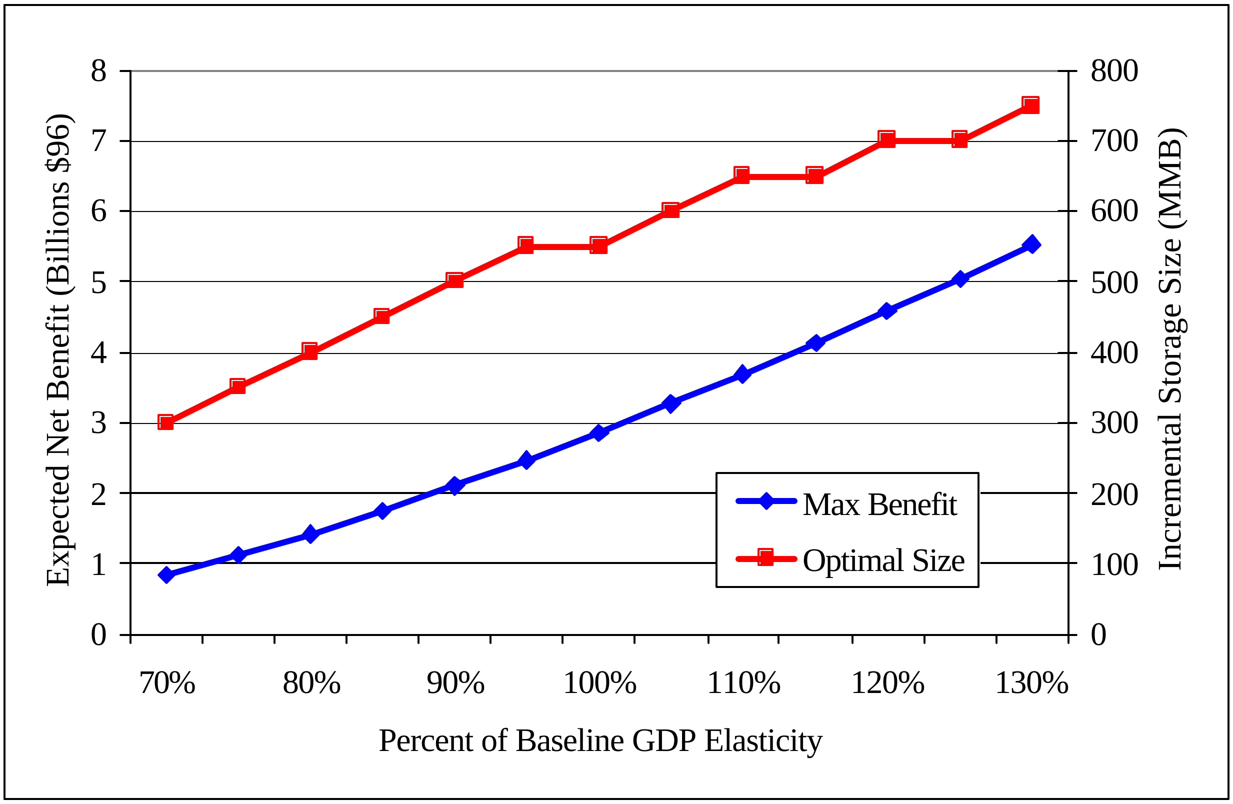

Figure 22: Sensitivity of Maximum Benefits and Optimal Size to GDP Elasticity. Lower GDP Elasticity Reduces Net Economic Benefit (NEB), but Optimal Sizes and Net Benefits are Still Substantial.

9.5. Effect of Higher Storage Cost Technologies

Sensitivity analysis on storage costs allows us to infer the effects of using alternate storage technologies. According to the PB-KBB study, the salt cavern technology dominates the others in terms of cost, schedule, and environmental merits. However, given the lower availability of salt cavern sites, there may be institutional or other reasons to consider storage in rock mines or trenches. Figure 23 below shows that the net benefits of reserve expansion erode substantially if the stocks are held in higher cost facilities than salt caverns. Storing instead in rock or trenches essentially triples the cost per barrel. Thus, the sensitivity case for capital costs at 300% of the Base Case level corresponds storing all the additional oil in rock mines or trenches. Even then, an expansion of 150 million barrels remains efficient in the Base Case, providing about $0.3 billion in benefits. If a mix of salt caverns and rock or trenches is used, then intermediate sizes and benefits are appropriate (a storage mix which is half salt caverns and half other technologies yields benefits of $1.2 billion and an efficient size of 300 million barrels).

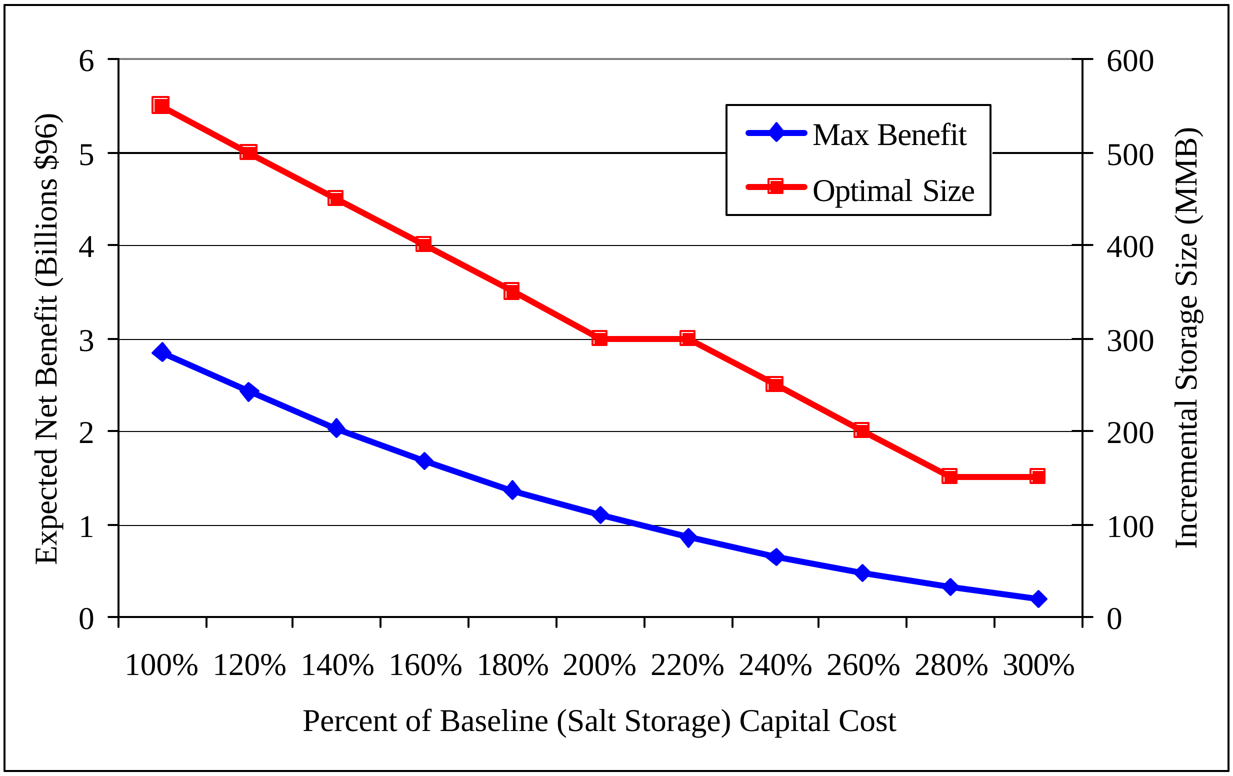

Figure 23: Sensitivity of Maximum Benefits and Optimal Size to Capital Cost. Efficient size, and the net benefits obtained at the efficient size, both decline but remain positive if higher cost storage options must be used.

10. Estimation of Benefits for Different APEC Economy Groupings

The results given above are for the economic group APEC less the U.S. (APEC-U.S.). It would be interesting, however, to consider what optimal size (including zero) would develop for different groupings. This section describes the findings from the simulation analysis of APEC strategic oil stockpiling using different groups of countries as the basis for computing expected benefits. The results of this analysis (shown in Figure 24 and Table 6) correspond to the base case assumptions given in Section 7.3 above.

1. All APEC;
2. APEC-U.S.;
3. China, Chinese Taipei, Philippines, Japan, Singapore, South Korea, Thailand, (Asian Seven);
4. Asian Seven less Japan, adding Hong Kong;
5. Japan alone; and
6. Asian Seven less Japan and China, adding Hong Kong.

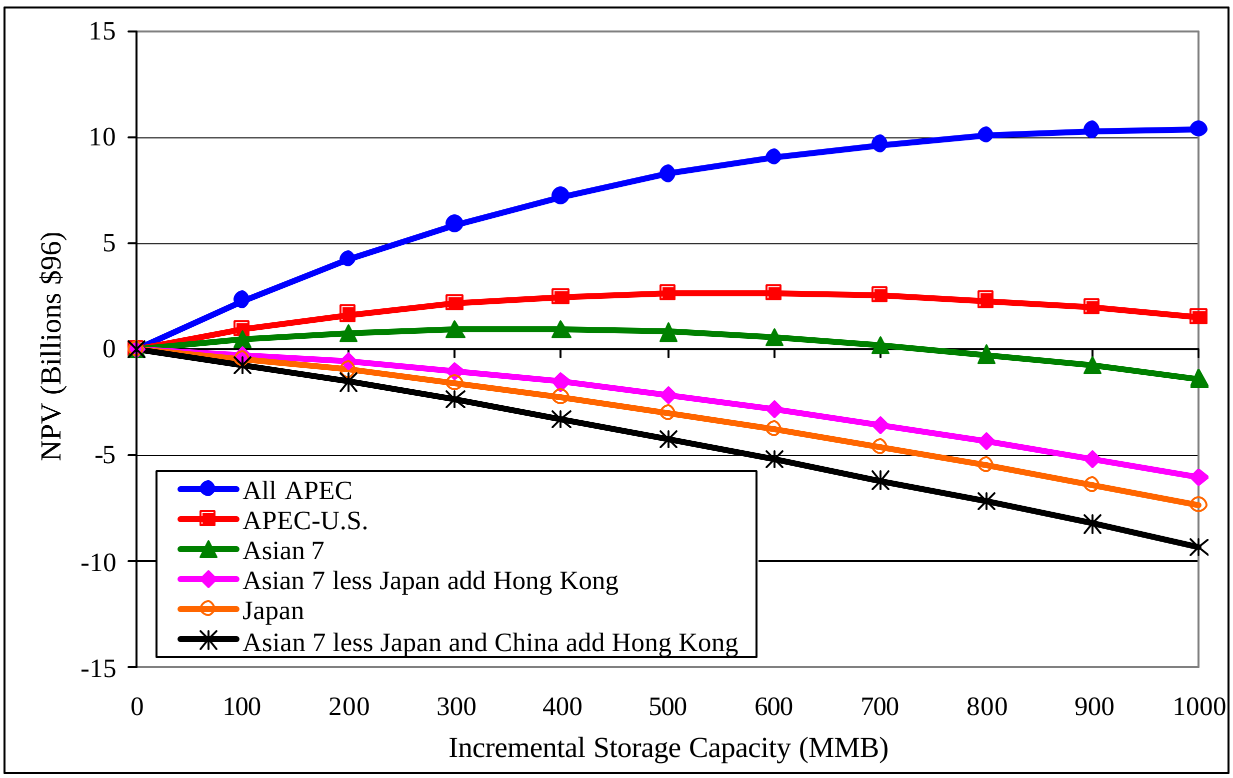

Figure 24: Net Economic Benefit for different economic groupings. Base Case Assumptions.

Table 6: Net Economic Benefits of Expansion for Various Country Groupings

Incremental SPR Size (MMB)	0	100	200	300	400	500	600	700	800	900	1000
APEC	0.00	2.34	4.29	5.92	7.23	8.28	9.09	9.69	10.10	10.33	10.40
APEC-U.S.	0.00	0.96	1.67	2.19	2.52	2.68	2.69	2.57	2.34	2.00	1.56
Asian 7	0.00	0.51	0.82	0.97	0.97	0.84	0.59	0.23	-0.21	-0.75	-1.35
Asian 7 less Japan add Hong Kong	0.00	-0.23	-0.57	-1.00	-1.53	-2.14	-2.81	-3.54	-4.33	-5.17	-6.04
Japan	0.00	-0.43	-0.95	-1.55	-2.22	-2.96	-3.75	-4.58	-5.46	-6.38	-7.33
Asian 7 less Japan and China add Hong Kong	0.00	-0.73	-1.53	-2.37	-3.26	-4.20	-5.16	-6.16	-7.18	-8.23	-9.30

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 GDP's 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. From the results given in Figure 24 and Table 6, four insights can be drawn.

1. All-APEC Achieves Greater Benefits and Larger Optimal Size than APEC-U.S. This result is not surprising, although the magnitude of effect may appear large. The results for U.S. alone (not shown) point towards a 200 MMB reserve expansion, for APEC-U.S. a 600 MMB reserve, and for all APEC including the U.S. a 1000 MMB reserve. The reason for this is that while benefits are additive, the optimal size is not strictly additive.

2. Outside the U.S., No Single APEC Country Can Afford To Go It Alone. As Figure 1 and Table 1 shows, even Japan, the largest of the non-U.S. APEC economies, can not justify increasing its reserves when acting alone.[22] Only through cost sharing arrangements with other countries can any one country expect to come out ahead.

3. Asian-Pacific APEC Could Justify Increased Reserves. Based upon the results for the "Asian Seven" shown in Figure 1 and Table 1, a group of the larger economies in the Asian-Pacific region could justify increased reserves, albeit slightly smaller

[22] 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.

reserves than the APEC-U.S. region (400 MMB in the base case, compared to 600 MMB). For the Asian Pacific APEC region as a whole, the optimal size will be larger.

4. Japan and Possible 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.

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 APEC countries may also attribute value to stockpiling for additional reasons, such as risk avoidance, political or foreign policy considerations, and the recognition that if enough countries individually engage in stockholding, they all collectively will come out ahead.

11. Overall Conclusions Regarding APEC Reserve Size

The analysis presented here strongly supports the conclusion that expanding the APEC reserves by at least 200 Million barrels is justified on the basis of its expected net benefits to APEC economies. Our evaluation considered the combined net benefit of expanded reserve sizes to all APEC economies other than the U.S.. It included the reserve's ability to reduce GDP losses and oil import costs during oil shocks, and subtracting the costs of building, filling, and operating the reserve. The conclusion that a substantial reserve expansion is justified holds true over a range of conditions, including more optimistic oil market assumptions which entail lower disruption risk over the next few decades. It also holds true for a range of variation in other key parameters such as the GDP elasticity with respect to oil price shocks, and for substantially higher storage costs than those of the least expensive alternative, underground salt caverns.

When it comes to analyzing the oil market, and its effect on world economies, there are unavoidably many uncertainties. Nonetheless, while our state of knowledge is imperfect, we still have a foundation on which to proceed, and proceed we must, making the best use of historical experience and expert judgement. Our estimates of the magnitude of macroeconomic loss that APEC economies could suffer during a future oil shock are based on the well-established empirical literature for OECD economies. That established methodology was extended to all APEC economies using the available data on historical macroeconomic performance and policies for each economy. The input conditions for oil market risk (including disruption probabilities, disruption lengths, and available slack production capacity during a disruption) are among the most difficult of all factors to establish. For this analysis, we relied on "Midcase" disruption probabilities constructed for the 1990 U.S. SPR size study, by U.S. DOE/Interagency team. As described above and in U.S. DOE (1990) these probabilities, while deemed the best available, are still far from certain.

For the Base Case presented here, the efficient incremental reserve size is about 600 million barrels, yielding an expected net benefit of about $2.7 billion (U.S. $). While this may seem like a large size, particularly for the Asian APEC countries alone to develop, it should be viewed in the context of the existing global strategic oil stocks of roughly 1.26 billion barrels, growing oil imports, and the enormous combined GDP of APEC countries which is at risk. In many cases, even a much larger reserve is efficient. Specifically, the value of strategic oil stockpiling and the efficient reserve size grow markedly if we anticipate that future disruptions may be, on average, a few months longer than the somewhat optimistic "base" assumption of 4 ½ months average duration applied here. The history of 18 oil market shocks since 1951 indicates a median length of close to 6 months.

The determination of efficient Size is based on a general understanding of reserve benefits over a range of sizes and conditions. It is not a "precise estimate." The modeling and estimation approach taken here is consistent with the wise advice of UCLA Professor Arthur Geoffrion (1974), an expert in modeling: "The purpose of mathematical programming is insight, not numbers." The insight provided by these modeling experiments is that a substantial addition to APEC reserves is worthwhile under a wide range of conditions, including a number of conditions ordinarily unfavorable to strategic storage. The results may even underestimate the efficient expansion size, since they presume that all of the existing global "strategic stocks" (both government-owned and government-controlled commercial stocks) will be promptly used and well coordinated in the event of a disruption.

The sensitivity analyses in Section 9 clearly show that the net benefits and efficient size of the reserve is much larger if average disruptions are longer than in the Base Case (i.e, durations of 6-9 months vs 4 ½ months). The sensitivity analyses also show that expansion can provide net economic benefits under all but the most optimistic assumptions regarding the likelihood of disruptions and the availability of excess oil production capacity. Even under these most optimistic assumptions, if disruptions are expected to be an average of over six months in duration, expansion is beneficial.

By looking at the individual *components* of net benefits, further sensitivity analysis is made easy. For example, we can easily infer the effects of using alternate storage technologies and the resulting higher capital costs. Sensitivity analyses with respect to facility costs show that the net benefits of reserve expansion erode substantially if the stocks are held in higher cost facilities than salt caverns. Storing instead in rock or trenches essentially triples the cost per barrel. Even then, an expansion of 150 million barrels would be efficient in the Base Case, providing about 0.3 billion ($96) in benefits. If a mix of salt caverns and rock or trenches is used, then intermediate sizes and benefits are appropriate.

Sensitivity analysis with respect to the very important parameter GDP elasticity is similarly straightforward. That analysis confirms that our results on efficient size are robust for variations in GDP elasticity up or down by 30%, or within one standard error of the estimate.

Finally, we can estimate the benefits of additional strategic storage for individual APEC member economies. We find that essentially all member could benefit, even those that are net oil exporters, from the greater oil price stability afforded by a larger reserve.

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