APPENDIX A1.
Detailed documentation of the model"DIS-Risk," APEC Version

A1.1 Modeling Approach

The general approach is summarized in the body of Chapter 7.

A1.2 Equations of the Model

Compact Statement of Model Equations

Our purpose in this section is to present the essential features of the DIS-Risk model, in the form of a compact statement of model equations . In this summary description, we gloss over certain fine points, such as the details of monthly model behavior, or what happens in the case of multiple disruptions.

In each period, reference levels of oil price, world demand, and APEC supply and demand are assumed: $\boldsymbol{P_r(t)}$, $\boldsymbol{D_{wr}(t)}$, $\boldsymbol{S_{ur}(t)}$, and $\boldsymbol{D_{ur}(t)}$. The market is subjected to a random gross disruption of size $\Delta_g(\boldsymbol{t})$, which follows a Weibull distribution:

$$\frac{\Delta_g(t)}{D_{wr}(t)} \cdot 100 \sim Weibull(\alpha,\beta) \qquad \textbf{(1)}$$

The exogenously assumed potential offsets $\boldsymbol{S_o(t)}$ (slack production capacity and demand switching) are applied to the gross disruption to yield the random net disruption size $\Delta_n(\boldsymbol{t})$:

$$\Delta_n(t) = \max\{\Delta_g(t) - S_o(t),\ 0\} \qquad \textbf{(2)}$$

The Emergency Reserve is applied to this net disruption, using the drawdown rule of full offset up to the maximum draw capability of the reserve, $\boldsymbol{S_{SPR}^{max}}$. The uncertain level of remaining supply loss is termed the net shortfall, $\Delta_n(\boldsymbol{t})$:

$$\begin{aligned} S_{SPR}(t) &= \min\{\Delta_n(t),\ S_{SPR}^{new}\} \\ \Delta_{sf}(t) &= \max\{\Delta_n(t) - S_{SPR}^{new},\ 0\} \end{aligned} \qquad \textbf{(3)}$$

The maximum draw from the reserve is a function of both the drawdown rate capability and the achieved size of the reserve, $Q_{SPR}(t)$. The achieved size of the reserve depends on the history of fills and draws:

$$Q_{SPR}(t) = Q_{SPR}(0) + \sum_{\tau=0}^{t} \left[D_{SPR}(\tau) - S_{SPR}(\tau)\right] \qquad \textbf{(4)}$$

The unaccommodated net shortfall determines the disruption price of oil $\boldsymbol{P(\Delta_{sf}, t)}$, as world demand contracts along a variable elasticity of demand curve by the amount of the shortfall:

$$P(\Delta_{sf}, t) = P_r \left(\frac{D_r - \Delta_{sf}}{D_r(t)} \right)^{1/\epsilon(\Delta_{sf}, t)} \qquad \textbf{(5)}$$

where

$$\epsilon(\Delta, t) = a(t) + b(t)\Delta$$

The costs of disruption are determined as a function of the disrupted oil price, with three components: increased imports costs, deadweight loss to consumers, and GDP adjustment costs.

$$C_d = \begin{cases} 0 \ \ if \ \ \Delta_{sf} = 0 \\ C_{imports}(P(\Delta_{sf})) + C_{cons-surplus}(P(\Delta_{sf})) + C_{GDPloss}(P(\Delta_{sf})) \end{cases}$$

where

$$C_{imports}(P(\Delta_{sf})) = (P(\Delta_{sf}) - P_r) \cdot (D_u(P(\Delta_{sf})) - S_{ur})$$

$$C_{cons-surplus}(P(\Delta_{sf})) = \left(\frac{\epsilon_{US}}{1 + \epsilon_{US}} \right) [P_r D_{ur} - P(\Delta_{sf}) D_{us}(P(\Delta_{sf}))] \qquad \textbf{(6)}$$

$$C_{GDPloss}(P(\Delta_{sf})) = GDP_r \left[1 - \left(\frac{P(\Delta_{sf})}{P_r} \right)^{\sigma} \right]$$

The net costs of Reserve activity and oil disruptions are calculated for each period as the Reserve net revenue minus the costs of the disruption $\boldsymbol{C_d}$ minus any capital costs of oil expansion $\boldsymbol{C_k}$, discounted by the discount factor $\delta(\boldsymbol{t})$:

$$C(t) = \left\{ P(\Delta_{sf}, t)[S_{SPR}(t) - D_{SPR}(t)] - C_d(\Delta_{sf}, t) - C_k(t) \right\} \delta(t) \qquad \textbf{(7)}$$

These discounted net costs are cumulated across years for each of the two Reserve programs considered in a single model run. The expected difference between the two programs is reported as ΔNPV:

$$\Delta NPV = \sum_{\tau=0}^{\tau=T} \left[C(\tau, SPR_2) - C(\tau, SPR_1) \right] \qquad \textbf{(8)}$$

A1.3 Data Used in the Model

Oil Market Prices and Quantities

Seven time series projections are needed to complete the Oil Market Prices and Quantities portion of the APEC DIS-RISK model: World Oil Price, World Demand, OPEC Demand, Elastic Demand, APEC Demand, APEC Supply, and APEC GDP. For the purposes of the APEC oil reserve size study, the "domestic" region is interpreted as the collection of APEC economies for which we wish to track reserve costs and benefits. Data sources and assumptions for each of the seven inputs are given below.

World Oil Price

World oil price (WOP) is taken to be fixed (constant) in real terms, at the 1995 price level. This is consistent with the Asia Pacific Energy Research Centre (APERC) study *APEC Energy Demand and Supply Outlook* (APERC, 1998a and Paik 1998a)[1]. World oil price in 1995 (17.42 $96/bbl) is taken from the *Composite* Crude Oil Refiner Acquisition Cost for 1995 given in the Annual Energy Review 1996, Table 5.19 (EIA 1997a).

World Oil Demand

World oil demand for the years 1998 through 2020 is from the Annual Energy Outlook 1999, base case (EIA, 1998). The years 2021-2030 were extrapolated based upon the average growth rate for the years 2016 through 2020 (5 year average). In addition, for APERC's "Environmentally Friendly Scenario (EFS)" and "Protracted Crises Scenario (PCS)" sensitivity cases, world demand was changed according to the difference between the APERC base case (B98) and the sensitivity scenarios.

OPEC Oil Demand

OPEC oil demand for the years 1998 through 2020 is from the Annual Energy Outlook 1999, base case (EIA, 1998). The years 2021-2030 were extrapolated based upon the average growth rate for the years 2016 through 2020 (5 year average).

Elastic Oil Demand

Elastic oil demand is defined as the difference between World Oil Demand and OPEC Oil Demand assuming that OPEC Demand is price inelastic.

APEC Gross Domestic Product

Growth rates for APEC Gross Domestic Product (GDP) over the years 1998-2010 for the base case and EFS and PCS scenarios are derived from *APEC Energy Demand and Supply Outlook.* Reported in five year increments, intermitting years are "filled in" using linear interpolation. Starting levels for the years 1995-1997 are provided by Paik (1998b). The remaining years (2011-2030) are calculated assuming the same growth rate as the average of the five previous years (2006-2010)

APEC Oil Demand and Supply

APEC Oil Demand and Supply for the years 1995-2010 for the base case and EFS and PCS scenarios are derived from *APEC Energy Demand and Supply Outlook: Energy Balance Tables* (APERC, 1998b). Since APEC demands and supplies are reported in five year increments, intervening years are "filled in" using linear interpolation. For the years 2011-2030, APEC Oil demand and Supply are extrapolated using extrapolated oil prices and standard lagged-adjustment demand and supply formulations, such as those found in the EIA's Oil Market Simulation (OMS) model (EIA 1990:6):

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[1] Where possible oil market data and forecasts are drawn from APERC sources. We are grateful to Inja Paik and others for providing this information.

$$D_t = D_{t,REF} \left(\frac{GDP_t}{GDP_{REF}} \right)^{IELAS} \left(\frac{P_t}{P_{t,REF}} \right)^{DELAS - FELAS * IELAS} \left(\frac{\left(\frac{D_{t-1}}{D_{t-1,REF}} \right)}{\left(\frac{GDP_{t-1}}{GDP_{REF}} \right)^{IELAS}} \right)^{DLAG} \left(\frac{P_{t-1}}{P_{t-1,REF}} \right)^{FELAS * IELAS * DLAG} \quad \textbf{(9)}$$

for demand, and

$$S_t = S_{t,REF} \left(\frac{S_{t-1}}{S_{t-1,REF}} \right)^{SLAG} \left(\frac{P_t}{P_{t,REF}} \right)^{SELAS} \quad \textbf{(10)}$$

for supply, where:

D_t	=	APEC Oil Demand in time t
$D_{t,REF}$	=	Reference APEC Oil Demand in time t
GDP_t	=	APEC GDP in time t
P_t	=	World Oil Price in time t
$P_{t,REF}$	=	Reference World Oil Price in time t
S_t	=	APEC Supply in time t
$S_{t,REF}$	=	Reference APEC Supply in time t
IELAS	=	Income Elasticity of Demand
DLAG	=	Demand Lag Coefficient
PELAS	=	Price Elasticity of Demand
FELAS	=	Feedback Elasticity of Demand
SLAG	=	Supply Lag Coefficient
SELAS	=	Supply Elasticity of Demand

Reference APEC Oil Demand and Supply for the years 1995-2010 are calculated by solving for $D_{t,REF}$ and $S_{t,REF}$ in the above equations (given that all else is known) and assuming $D_{1995,REF} = D_{1995}$ and $S_{1995,REF} = S_{1995}$. For the years 2011 to 2030, the reference levels are calculated using the average of the previous five years (2006-2010) growth rates.

Elasticities and lag coefficients are derived from the estimates used in AEO99 and NEMS99 (See OMSECON.dat and OMSREF.dat) for all countries except the U.S. which are from the 1995 version of OMS. Since the country and region listing between APEC and NEMS do not correspond exactly, some judgement groupings are made. The elasticities and lag coefficients are given in Table 1 below.

Table 1: Assumed Elasticities and Lag Coefficients							
APEC Regions	NEMS Regions	Income Elasticity	Feedback Elasticity of Demand	Price Elasticity of Demand	Price Elasticity of Supply	Demand Lag Coef-ficient	Supply Lag Coef-ficient
Australia	Australia/New Zealand	0.31	0.01	-0.03	0.02	0.79	0.80
Brunei Darussalam	Pacific Rim	0.41	0.01	-0.03	0.02	0.77	0.80
Canada	Canada	0.56	0.01	-0.08	0.01	0.80	0.85
Chile	Other South and Central America	0.40	0.01	-0.03	0.02	0.67	0.80
China	China	0.34	0.02	-0.06	0.02	0.72	0.80
Hong Kong, China	Pacific Rim	0.41	0.01	-0.03	0.02	0.77	0.80
Indonesia	Pacific Rim	0.41	0.01	-0.03	0.02	0.77	0.80
Japan	Japan	0.31	0.01	-0.06	0.05	0.92	0.95
Korea	Pacific Rim	0.41	0.01	-0.03	0.02	0.77	0.80
Malaysia	Pacific Rim	0.41	0.01	-0.03	0.02	0.77	0.80
Mexico	Mexico	0.47	0.01	-0.04	0.02	0.84	0.80
New Zealand	Australia/New Zealand	0.31	0.01	-0.03	0.02	0.79	0.80
Papua New Guinea	Pacific Rim	0.41	0.01	-0.03	0.02	0.77	0.80
Philippines	Pacific Rim	0.41	0.01	-0.03	0.02	0.77	0.80
Singapore	Pacific Rim	0.41	0.01	-0.03	0.02	0.77	0.80
Chinese Taipei	Pacific Rim	0.41	0.01	-0.03	0.02	0.77	0.80
Thailand	Pacific Rim	0.41	0.01	-0.03	0.02	0.77	0.80

Demand Elasticities used in the Model

The demand elasticities given above assume *Business As Usual* (BAU). In actuality demand elasticities may be a function of the price level, or equivalently an (increasing) function of net oil disruption sizes. The increasing elasticities reflect the growing opportunity for substitution or behavior changes as the oil price gets very high, even in the short run. For this analysis we use the variable-elasticity relationship developed by the U.S. EIA for oil market disruption analysis.

Slack Production Capacity

In the 1990 DOE/Interagency Size Study, non-OPEC slack oil production capacity was assumed to be 0.2 MMBD for 1995 forward. Midcase OPEC slack capacity was based on projected OPEC production and assumed capacity utilization rates. High and low slack capacity was based on OPEC capacity utilization rates which were 5% lower and higher, respectively, than the midcase. This study uses OPEC production from EIA's AEO 98 base case, and OPEC Capacity estimates from a separate EIA study (EIA/Kimball 1998). The High and low cases excess capacity cases are again developed to be consistent with OPEC production capacity utilization levels plus-and-minus 5% from the base level. The table below shows the midcase old estimates from DOE 1990 study and the new (based upon Kimball, 1998) slack capacity offsets. Also, we extrapolate excess capacity beyond 2020.

Table 2: World Slack Production Capacity (MMBD)				
Year	EIA/Kimball 1998	DOE 90 Low	DOE 90 Mid	DOE 90 High
1995	3.6	3.0	6.0	6.0
1996	3.6	2.8	5.8	5.8
1997	3.4	2.6	5.6	5.6
1998	3.4	2.4	5.4	5.4
1999	3.2	2.2	5.2	5.2
2000	3.1	2.0	5.0	5.0
2001	3.0	1.9	4.8	4.9
2002	3.0	1.8	4.6	4.8
2003	2.9	1.7	4.4	4.7
2004	2.8	1.6	4.2	4.6
2005	2.6	1.5	4.0	4.5
2006	2.7	1.3	3.8	4.4
2007	2.6	1.1	3.6	4.3
2008	2.6	0.9	3.4	4.2
2009	2.6	0.7	3.2	4.1
2010	2.5	0.5	3.0	4.0
2011	2.5	0.5	2.8	3.9
2012	2.5	0.5	2.6	3.8
2013	2.4	0.5	2.4	3.7
2014	2.5	0.5	2.2	3.6
2015	2.6	0.5	2.0	3.5
2016	2.7	0.4	1.9	3.5
2017	2.7	0.3	1.8	3.5
2018	2.9	0.2	1.7	3.5
2019	3.1	0.1	1.6	3.5
2020	3.3	0.0	1.5	3.5

Figure 1: EIA/Kimball 1998 and 1990 Study Excess (slack) Production Capacity

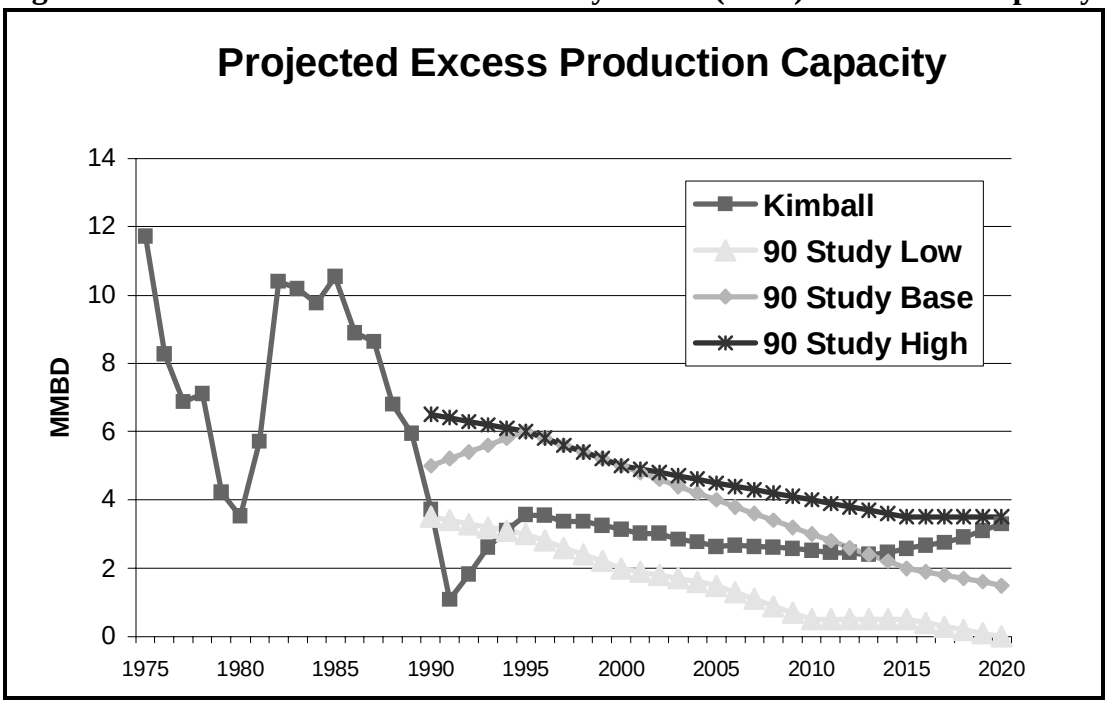


Figure 2: Historic, Forecasted, and Extrapolated Excess Oil Production Capacity (Source: EIA/Kimball 1998)

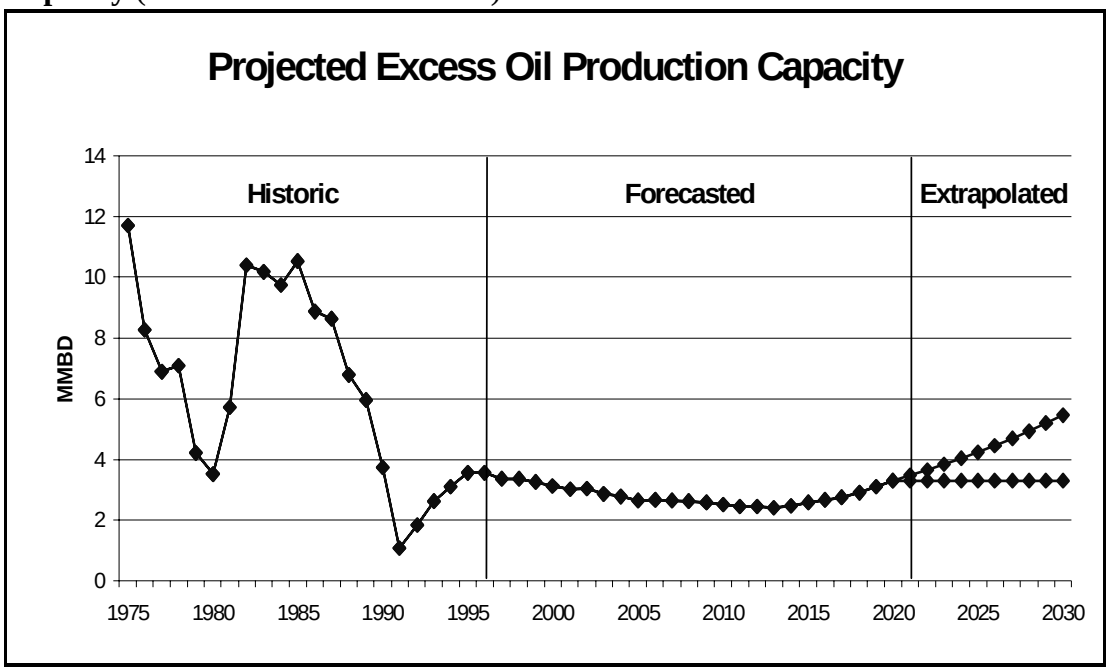
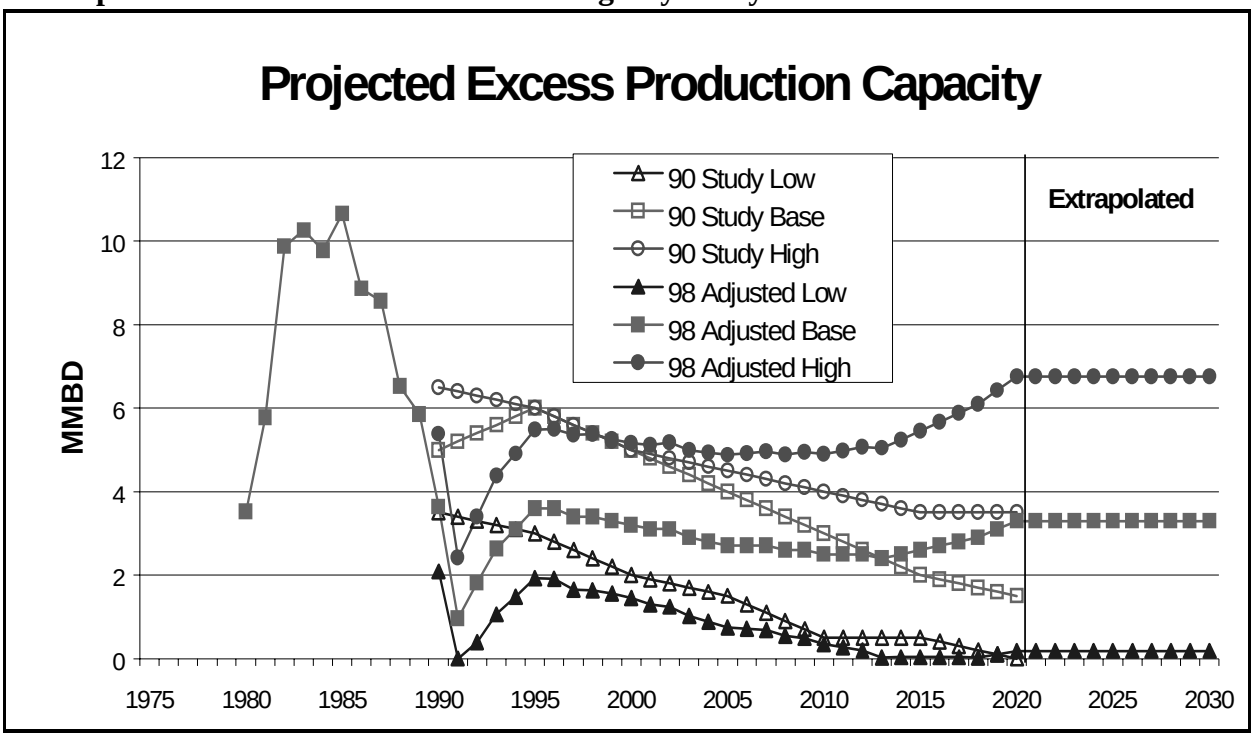


Figure 3 Current Study High, Mid and Low Excess Oil Production Capacity vs. Assumptions Used in 1990 U.S. DOE/Interagency Study



Foreign Offsets

Foreign stocks which can also offset disruptions are given in Table 3. Existing APEC reserves other than those in the U.S. SPR are included in the starting size of the APEC reserve. The U.S. SPR and other OECD stocks (other than Japan) are treated as "foreign," but cooperative, emergency stocks.

Table 3: 1999 APEC Study "Foreign" Emergency Stocks Offsets

Note: Reduced Emergency Stock Size Compared to 1990 assumptions, due to loss of OECD Eur govt stocks.

Source: www.eia.doe.gov/emeu/security.
See also Int'l Petrol. Stat Report,DOE/EIA-0520(98/09) Sept 1998, Table 1.6.

Emergency (Government) Stocks (MMB)

Year	U.S.	Japan	OECD Europe	Other APEC (Republic of Korea and Chinese Taipei	Total
1990	580	190	230	NA	1000
1991	596	230	230	NA	1056
1992	589	247	197	NA	1033
1993	583	264	163	NA	1010
1994	576	281	130	NA	987
1995	570	298	96	NA	964
1996	563	315	63	NA	941
1997	563	315	63	NA	941
1998	563	315	63	55	996
1999	563	315	63	55	996
2000	563	315	63	55	996
2001-2030	563	315	63	55	996

Discount Rate

An important input to the Reserve size analysis (or any multiperiod net benefit analysis) is the discount rate. In recent US studies we have centralized around a 7% discount rate, in accordance with the applicable guidelines from the U.S. Office and Management and Budget (OMB). [2] This rate is used as the base value for the APEC reserve analysis. It is a "real" discount rate, to be applied to cash flows in constant (uninflated) dollars. OMB guidelines differentiate between the real discount rates to be used for cost-benefit and cost effectiveness analyses. The OMB Circular A-94 says:

> "8.b.1.Base-Case Analysis. Constant-dollar benefit-cost analyses of proposed investments and regulations should report net present value and other outcomes determined using a real discount rate of 7 percent. This rate approximates the marginal pretax rate of return on an average investment in the private sector in recent years."

Discount Year

All costs and benefits are discounted back the starting year 1999.

[2] U.S. Office of Management and Budget, Circular No. A-94, Revised (Transmittal Memo No. 64), October 29, 1992 "MEMORANDUM FOR HEADS OF EXECUTIVE DEPARTMENTS AND ESTABLISHMENTS, SUBJECT: Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs." This circular is currently available at OMB website: http//www1.whitehouse.gov/WH/EOP/OMB/html/circulars/a094/a094.html).

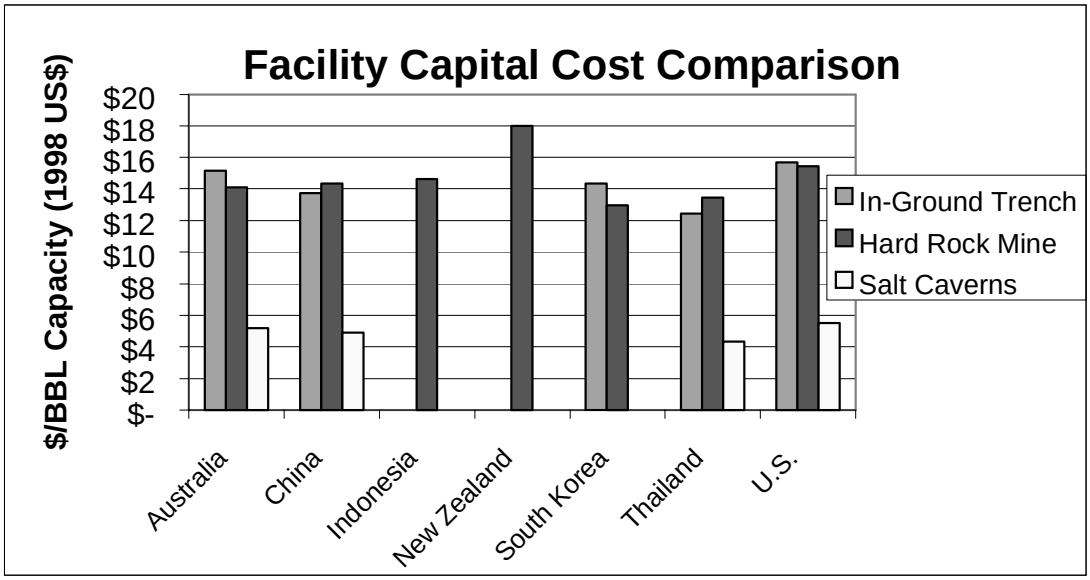
Exogenous Demand Switching
This is a small item. For simplicity we assume a limited ability of consumers to switch away from oil at virtually no costs (due to dual-fired boilers): 0.350 MMBD.

Additional Storage Capacity Characteristics
The characteristics, costs, and capabilities of new APEC storage are based on the study by PBKBB (1988). We assume that construction of new storage begins in the year 2000. Fill of the reserve begins when construction is complete (8 to 13 years, depending on storage type). Fill is expected to occur over 5 years.

Table 4: Results of PB-KBB Study

Technology	**In-Ground Trench**	**Hard Rock Mine**	**Salt Caverns**
Suitable Countries	US,Ch,Au, SK,Th	US,Ch,Au, SK,Th	US,Ch,Au,Th
Dev Cost, US ($/BBL)	$ 15.68	$ 15.44	$ 5.51
O&M Standby Cost, US ($/BBL-yr)	$ 0.16	$ 0.09	$ 0.17
Fill Cost ($/BBL)	$ 0.05	$ 0.05	$ 0.09
Draw Cost ($/BBL)	$ 0.07	$ 0.07	$ 0.10
Facility Size, MMB	100	100	100
Max Draw Rate (MMBD)	1.17	1.17	1.17
Max Fill Rate (MMBD)	0.27	0.27	0.27
Development Time (years)*	11	13	8
Source: PB-KBB 1998: p. 7-3 (Table 16), PBKBBFacilityCosts0.xls			

The capital cost of facility construction is also expected to vary somewhat by the country in which is it located. The following bar graph shows these regional cost adjustments.



Existing APEC Economy Emergency Stocks

The size of existing APEC emergency oil stocks was determined from the information in APERC (1999b). This document describes the existing government and private stocks in most APERC economies. In cases where an economy is said to hold no government stocks and impose no obligation on its private companies to hold stocks, we conclude that the economy hold no emergency oil stocks. In cases where an economy requires its importers, refiners, or marketers to hold stocks, we consider as emergency stocks only that amount of oil which is held in addition "normal operating stocks." For most economies, privately held stock are recognized as working stocks. Chinese Taipei is the only clear exception. Chinese Taipei imposes a stockpiling obligation on its state-run oil corporation (CPC) and electric utility (Taiwan Power Companies). The quantity of stocks held (60 days of storage), are estimated to be about 20 days in excess of working storage. So we interpret 1/3 or privately held oil inventories in Chinese Taipei (12.5 million barrels) to be emergency stocks.

This leads to the following breakdown of existing APEC Stocks

Table: Current APEC Emergency Oil Stocks	
Region	**Stock Level (Million BBL)**
Chinese Taipei	12.5
Japan	315.0
Republic of Korea	43.0
U.S.	563.0
Total Non-U.S. APEC	370.5
Total APEC	933.5
Europe	63.0
Total World	996.5

Appendix A2
Using empirical estimates of the oil price-GDP elasticity in SPR benefit projections

Ultimately, the only basis for assigning a numerical value to the oil price-GNP elasticity parameter in a projection of benefits from strategic petroleum stocks is the empirical evidence on that relationship. The difficulty, of course, is that, in view of the differences in the empirical estimates available, just which estimate to use or which estimates to use as brackets, requires judicious assessment.

The problem of assigning a numerical value for this parameter can be divided into two parts: determining what value to use for a base, and determining the upper and lower limits to call "high" and "low" possibilities. The base value of an aggregate, APEC oil price-gdp elasticity is best constructed as a weighted average of the individual APEC economies' individual elasticities, weighted according to their relative GDP sizes. This will give the dominant weight to Japan (some 60 percent of the total), followed distantly by South Korea. The Japanese elasticity has small confidence intervals—i.e., it has a large t-statistic—so the 95% confidence intervals on either side of the estimate would not be especially wide. So does the South Korean elasticity. Wider confidence intervals on the estimates of some of the smaller economies will not matter materially to the aggregate confidence interval, just as the large (e.g., Chile with -0.13) and small (e.g., New Zealand with -0.01) elasticities of the smaller countries will not pull the aggregate elasticity that far from the combined, weighted value dominated by the Japanese and South Korean elasticities.

There are several alternatives for determining upper and lower limits. One option is to base the upper and lower limits on some multiple of the standard deviation of the composite estimate. Not having a joint confidence-interval estimate for the weighted average of the estimates (allowing for covariances among the estimated elasticities of the different countries), it would be reasonable to use the Japanese estimate's confidence interval. The choice then becomes "What multiple?" One standard deviation, two, or a fraction of one? Another option is to choose an arbitrary percentage of the level of the weighted-average estimate to add and subtract to obtain upper and lower values. While the first rationale may appear to have a sounder probabilistic basis, in practice, the two methods have an equal measure of arbitrariness. A third option is not available for the APEC economies—to use alternative estimates, derived from different models of the oil price-GDP relationship, as high, medium, and low estimates. That option has its own difficulties, however, since the different elasticity estimates obtained, say, for the United States, generally derive from different concepts of the underlying oil price-GDP relationship. The estimates derived from similar regression specifications tend to yield similar elasticity values (even if they are statistically different), even over somewhat different sample periods.

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