Working Paper

A Review of the New Undiscovered Conventional Crude Oil Resource Estimates and their Economic and Environmental Implications

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ABSTRACT

Three new probalistic assessments of oil resources by the United States Geological Survey and the United States Minerals Management Service result in an expansion of global remaining conventional world oil resource estimates. The new value used here is 3.3 trillion barrels; the comparable earlier 1991 assessment was 2.1 trillion barrels. Using optimal control depletion theory, a global monopoly has theoretical net present value economic rent of $22 trillion, with supply-demand quantity equilibria peaking in about 85 years, then declining to exhaustion in 25-30 years. However, actual global markets (as distinct from theoretical markets) operate in a game theoretic-framework. The Persian Gulf-OPEC team of exporters (accompanied by Norway and Mexico) faces the United States- Organization for Economic Co-operation and Development team of importers. The acceptable price range before September 11 was $23 - $30 per barrel. The Persian Gulf continues to be the major locus of world oil resources, and has production costs (including return on capital and a risk allowance) at $5 per barrel or less

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I. The Data on Remaining Resources

The U.S. Geological Survey recently published its estimates of global oil resources outside the United States (USGS 2000). The U.S. Minerals Management Service also released its estimates of Federal outer continental shelf resources (USMMS 2000). Taken together, and combined with the earlier analysis of on-shore U.S. petroleum resources (USGS 1995b), the three assessments provide a global snapshot for the mid-1990's. Table 1 shows one possible summary of these data. (The concepts are explained in Table 2.)

These estimates have grown significantly beyond earlier world assessments. In Figure 1, each curve is identified by the year of publication. They are based upon the original endowment concept; this partially neutralizes the impact of cumulative production on comparability in the 17 years spanned by the estimates. For the latest assessment, the graph suggests a 95% probability that original endowment was at least 2.3 trillion barrels. There is, apparently, a small probability of 5% that the endowment was as high as 3.9 trillion barrels. The 5% estimates are generally used here, because they approximate the increased recovery associated with higher future oil prices.

Table 1. Probability 5% Estimates of Remaining World Oil Resources (billion barrels)

Category	Amount
Proved Reserves	883
Potential Reserve Expansion	1,101
Undiscovered Resources	<u>1,290</u>
Total Remaining Resources	3,274

Note: The 2000 Assessment data have been organized on a benchmark
date of January 1, 1995. Production in the 6 years 1995-2000
was 144 billion barrels. Remaining resources as of January 1,
2001, would be 3.13 trillion barrels (3,274 billion less 144 billion,
rounded to 3.13 trillion). World cumulative production 1859
through 2000 was 883 billion barrels, resulting in an original
endowment figure of 4.01 trillion barrels. See text.

Sources: USGS 2000, USMMS 2000, USGS 1995b.

Table 2. Concepts in Resource Definition

A. *Proved Reserves* –   Economically recoverable conventional crude oil at known fields and reservoirs, estimated directly by engineering as well as geological data. Similar to an inventory concept.

B. *Potential Reserve Expansion* –   Identified reserves expected to be developed in existing fields through improved recovery, extensions, revisions, and the addition of new reservoirs and pools.

C. *Undiscovered Resources* –   Geological extrapolation of potential crude oil based upon knowledge of geological formations outside existing fields. A probabilistic concept.

D. *Total Remaining Resources* –   An estimate of total conventional crude oil available for recovery; the sum of the preceding categories.

E. *Original Endowment* –   The amount of oil existing before production began in 1859. It combines the amount of cumulative production to date with the remaining resources estimate.

Sources: USGS 1995b, Chapman 1993.

Figure 1. Change in Probability Distribution of Original Resources Estimates

Original World Crude Oil Endowment
(Billion Barrels)
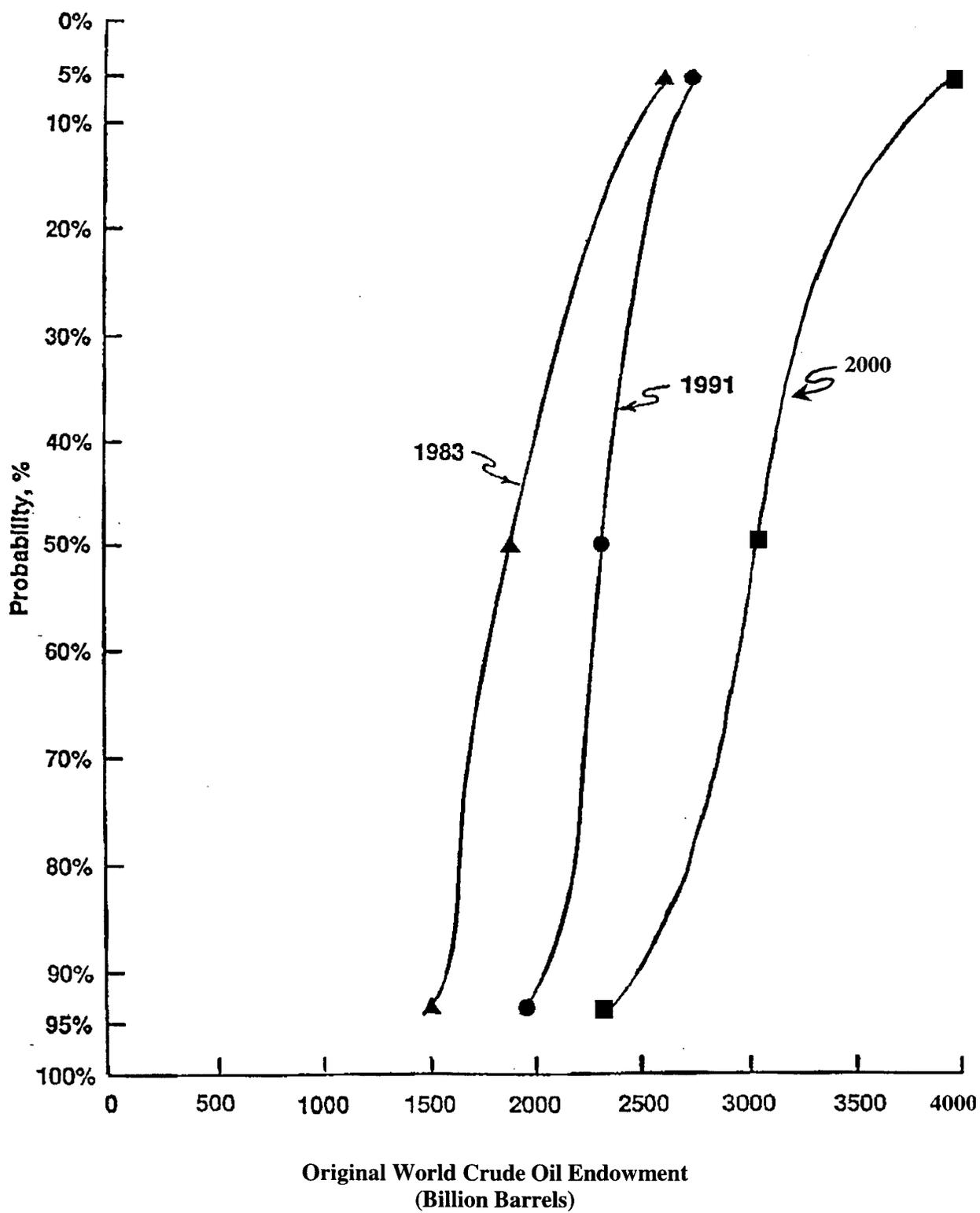
There are two major differences in the latest analysis. First, potential reserve expansion now plays a significant role in reserve analysis; it constitutes one-third of the remaining resource estimate. In contrast, there has essentially been no change in the undiscovered resource estimates. For example, the 1991 value at the 5% probability level was 1.0 trillion barrels; the estimate nine years later was 1.3 trillion barrels. Proved reserves at 883 billion barrels in 2000 were actually 170 billion barrels lower than the earlier and more broadly defined identified reserves.

In other words: the estimates of proved reserves and undiscovered resources combined are only slightly different for 2000 than for 1991. The growth is in the delineation of potential expansion in existing fields. Table 3 compares the two assessments.

A second important difference between the 1991 and 2000 analyses is that the United States sees an actual increase in the remaining resource estimate, and a higher percentage of global remaining resources. The current estimate at the 5% probability level, including both Artic National Wildlife Refuge (ANWR) and OCS data, is 277 billion barrels for the U.S. This gain from the 1991 U.S. assessment to the 2000 analysis is primarily due to two factors: the potential reserve expansion estimate of 60 billion barrels, and the increased delineation of OCS (approximately outer-continental shelf) resources, now at 102 billion barrels.

One important conclusion is unchanged in the new assessment: the Persian Gulf and the Organization of Petroleum Exporting Countries (OPEC) continue to dominate the resource picture. OPEC had 50% of the world's original endowment, but has produced only 10% of that initial amount. In contrast, the Organization for Economic Cooperation

Table 3. Differences in 2000 and 1991 Estimates
(5% probability level, billion barrels)

Year of Assessment Publication:	2000	1991
Identified/Proved Reserves	883	1,050
Undiscovered Resources	1,290	1,000
Sum of Identified/Proved and Undiscovered Resources	2,173	2,050
Potential Reserve Expansion	1,101	nc
Total Remaining Resources	3,274	2,050

Note: "nc" means not calculated for the 1991 assessment; see text.

Source: Table 1, USGS 1991.

and Development (OECD) countries as a group and the U.S. individually have each produced more than 50% of their original endowment. Production has been declining in the U.S. since 1970, and has reached a peak in the North Sea.

Consider the long history of development of the methodology of resource estimation and its reflection in Figure 1: It would seem premature to conclude that the latest estimates will not themselves be superceded in the future by higher values.
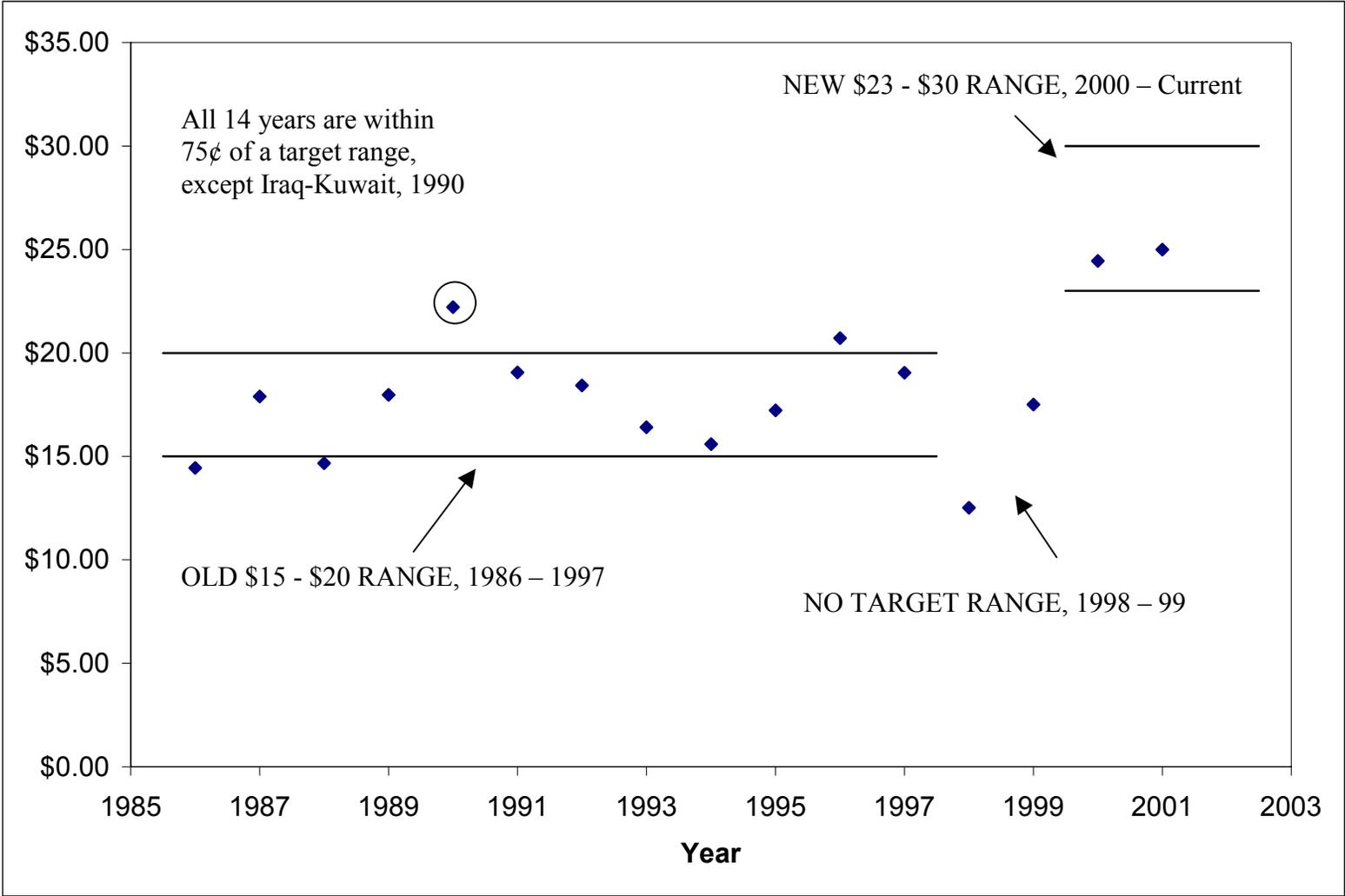
II. Impact on Crude Oil Prices

Notwithstanding the large proportional growth in the U.S. resource estimates, it is unlikely that crude oil prices globally or in the U.S. will decline in the future. In fact, the potential development of the Arctic National Wildlife Refuge (ANWR) is a factor supporting crude oil prices in the upper end of the current $23 - $30 price range. (This is discussed in a later section.)

In Hammoudeh's recent work (2001), he analyzes the interactions of target price and the OPEC quantity ceiling with actual prices and quantities for the years 1988-2000 with monthly data. He uses a reference price of $21 per barrel for his 13 year data set, and believes that OPEC replaced the reference price with a price band centered on $21. He finds that his model does well in fitting the data. In a related paper, Tang and Hammoudeh (2001) propose a price band of $15 - $25 for the 1988-1999 period. They find this model fits their data well, although it is in only partial agreement with Figure 2.

Figure 2 represents the price range system as it has existed from 1986 to mid-2001. The old price range was $15-$20; the new range is $23-$30. This price structure

Figure 2. Target Price Ranges: Old and New

All 14 years are within 75¢ of a target range, except Iraq-Kuwait, 1990

NEW $23 - $30 RANGE, 2000 – Current

OLD $15 - $20 RANGE, 1986 – 1997

NO TARGET RANGE, 1998 – 99

Year

was introduced previously in *Contemporary Economic Policy (CEP)*, in Chapman and Khanna 2000, 2001, and also in Chapman 2000. It is essentially a game-theoretic explanation as summarized in Table 4. The OECD countries, led by the United States, constitute the oil import team. The OPEC-Persian Gulf countries, led by Saudi Arabia, constitute the oil export team. Each side, as shown in Table 4, prefers the price range structure because of the consequences of the anticipated response of the other side if crude oil prices move outside the range.

Production cost is the full cost to the producer of bringing crude oil to the surface, gathering it, and making it accessible to buyers. It includes a return on investment and a risk premium. Scarcity or depletion rent is not included in production cost. On a global basis, production costs range from below $5 per barrel in the Persian Gulf to $15 per barrel in the North Sea and Alaska. Anticipated ANWR production costs are on the order of $25 per barrel (Chapman 2000, Chapman and Khanna 2000).

Economic theory shows us that low cost resources will be fully exploited before higher cost locations are brought into production. This is clearly not the case in world oil markets, where the political and security considerations in Table 4 assume equal importance with economic factors. (Please see the earlier *CEP* articles for a fuller explanation of production costs, price range, and issues in military security.)

There is no basis to believe that the new resource assessments will change the existing price structure and its political, military, and economic framework.

**Table 4: General Economic Impact of Crude Oil Price Decision–Making
in a Game Theory Price Range Framework**

2000-01 Price per barrel	OECD Countries	Persian Gulf Oil Producers
$15 or less	- higher GNP growth - shut some domestic production - greatly increased oil consumption - much more imports - more pollution, climate change - end Persian Gulf political support by OECD oil industry	- loss of political support from OECD oil industry - lower revenue, greater volume - internal economic problems - faster depletion - higher market share
$23 - $30	- stable GNP growth - stable OECD oil production - slow growth in oil consumption - slow growth in import share - stable prices - ANWR production feasible - continued Persian Gulf support	- continued OECD political, military support - stable revenue, rent - higher revenue, rent - cooperation with OECD oil industry
$40	- decline in GNP growth - rapid near-term growth domestic production - stable or declining consumption - ANWR production profitable - OECD Persian Gulf support opposed by oil consumers	- loss of OECD political, military support - increased incentives for Central Asia, other non-OPEC production - less market share - less production, more profit, rent - greater payoff to successful Iraq-type action

III. The New Resource Estimates and the Magnitude of Economic Rent

If the global oil market were to be wholly competitive, crude oil price would be determined by the marginal cost of Persian Gulf producers. A competitive price would be on the order of $5 per barrel. In contrast, a truly monopolistic structure would result in a price on the order of $40 per barrel.

Depletion theory, extended to incorporate market structure and dynamic upward-shifting demand functions, can provide the tools to estimate quantities of production and consumption, economic rent, and optimal years to depletion. The basic goal, for a monopoly, is to maximize

$$\underset{\{q_t, T\}}{\text{Max}} \ \Pi = \int_0^T \int_0^{q_t} \frac{(P_t(q_t, N_t, Y_t) - C_t)}{e^{rt}} \ dq_t dt \qquad (1)$$

subject to $\dot{X}_t = q_t$, $X_T \leq S$.

Here, q_t is the path of market-equilibrium quantities that maximize the present value of economic rent for a monopoly. The optimal number of years to depletion is T. P is the inverse demand function, which shifts in response to growing world population (N) and per capita income (Y). C is cost, r is the discount rate, X is cumulative production, and S is the estimate of remaining resources at the beginning of the initial period. (The methodology is described previously at length in *CEP*, in Chapman and Khanna 2000, 2001, and also Chapman 2000 and Khanna and Chapman 2001.)

A quantitative solution to the maximum net present value of rent is shown as the higher curve in Figure 3. Optimal T is 111.78 years. Optimal q starts at 17 billion barrels annually, peaks in 77 years at an annual output level of 38 billion barrels, and then declines to depletion. This analysis assumes that S is 3.13 trillion barrels, as explained in Table 1.

The earlier value for remaining resources S is reflected in the lower curve in the Figure. The geometric area under each q_t trajectory is equal to the appropriate S. The numerical results are summarized in Table 5. They are initially counter-intuitive. The remaining resource assessment has increased 48%, to 3.13 trillion barrels. However, the present value of economic rent grows only 8%, and T is increased only 18 years, or 20%. The explanation, of course, is discounting at high values of T.

Notwithstanding the two-decimal values in Table 5, these results should be seen as rough approximations, indicating the considerable magnitude of economic rent associated with the world's remaining oil resources. With $20 trillion as the order-of-magnitude value for economic rent, it is comparable to the global gross economic product, itself $29 trillion in 1998 (World Bank 2000).

However, as discussed with the Table 4 concepts, this high level of economic rent is only one of many important financial, political, and military factors that define the game-theoretic framework for the target price range.

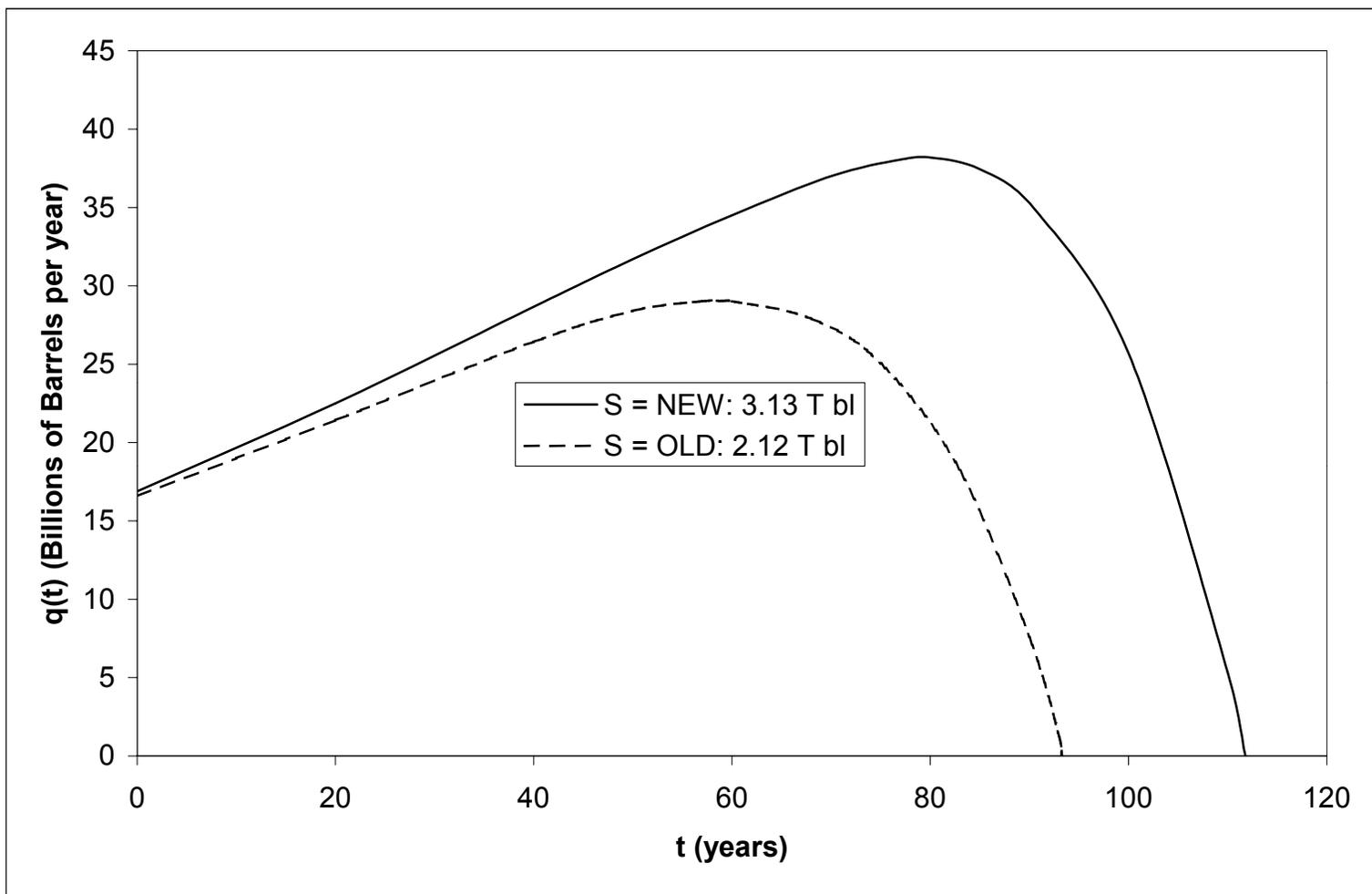**Figure 3. Supply-Demand Equilibria with Old & New Resource Estimates**

Table 5. The Impact of Higher Remaining Resource Estimates

	1991 Resource Assessment	2000 Resource Assessment
S, Remaining world resources	2.12 T bl	3.13 T bl
T, optimal years to depletion	93.51 years	111.78 years
Π, net present value rent	$20.7 T	$22.4 T
Consumers surplus	$8.0 T	$9.3 T
Social welfare	$28.7 T	$31.7 T
r, interest rate	5%	5%

Notes: "T bl" represents trillion barrels, and "$T" is trillion dollars. Social welfare is simply the sum of rent and consumers' surplus. On a future value basis, the 2000 assessment rent has a value of slightly more than $7 quadrillion.

IV. Economics, Resources, and ANWR

Economics plays a growing role in the geological estimates of petroleum resources. In the early 1990's, conventional crude oil resource assessment had $50 per barrel as the ceiling for feasible production. For example, if new oil in Western New York could be produced at a cost of $75 per barrel, this would not have been included in the estimates.

In the U.S., the cost analysis for undiscovered conventional crude oil estimates that 9 billion barrels would be producible at $18 per barrel, and 22 billion barrels at $50 per barrel (USGS 1995b).

Similar analysis for Alaska's Artic National Wildlife Refuge is more complex (USEIA 2000). Using USGS assessments for conventional crude oil in ANWR, the Energy Information Administration analyzed, the interaction between probabilistic resource estimates of undiscovered oil with incremental cost. Their complex findings can be approximated in a simplified form as

$$CDQ = [.0342 * (P - \$18) + .614] * [4.2 + 8.444 * (.95 - F)] \tag{2}$$

$$\$18 \leq P \leq \$24, \qquad 5\% \leq F \leq 95\%.$$

Here CDQ is the commercially developable crude oil in ANWR in billions of barrels, P is assumed U.S. imports refiner acquisition price, dollars per barrel (in constant year 2000

dollars). F is assumed probability. For example, with assumptions for price at $22 and probability at 0.50, the result is an estimate of 6 billion barrels from ANWR.

When these data are examined in the context of the game-theoretic price range, an important question arises. Would ANWR production be feasible at the old price range of $15 to $20? Probably not. In fact, prices in the upper end of the current price range ($23 to $30) are probably necessary to insure a high probability of profit from ANWR development.

A corollary question follows: are high gasoline prices necessary for ANWR petroleum production?

V. Summary

The new USGS assessments of remaining resources have some limited implications for current policy. Because of the explicit inclusion of potential reserve expansion, the probability distribution has shifted considerably. Roughly one trillion barrels have been added to the estimate of remaining global resources.

Although there is a U.S. increase, OPEC and the Persian Gulf continue to have one-half of world resources, and the lowest production costs. (Persian Gulf production costs are on the order of $5 per barrel, including return on investment and a risk allowance.)

Globally, cumulative production is 20% to 25% of the original endowment, although the U.S. has used more than half of its original amount.

Since 1986, the world oil market has been characterized by a target price range structure. It is based upon a system resembling basic game theory: OECD importers and

OPEC exporters (with Norway and Mexico) balance their economic, political, and military interests with a stable price. The new range is $23 - $30 per barrel; the old range was $15 - $20. The target price range is too high to be purely competitive and too low to be purely monopolistic; it represents a pragmatic policy.

If the world oil industry were to be a pure monopoly, the net present value of economic rent above production cost would be on the order of $20 trillion. This estimate is derived from an optimal control depletion theory analysis which incorporates upwardly shifting demand functions that rise in response to growing world population and income. In this analysis, with the new remaining resource estimate of 3 trillion barrels, optimal use peaks in 77 years. According to the analysis, depletion is 112 years in the future. Of course this is heuristic rather than precise prediction.

With respect to ANWR, its potential development is dependent upon crude oil price. If the old target price range ($15 - $20 per barrel) still prevailed, development probably would not be feasible. With the new target price range ($23 - $30 per barrel), ANWR development is profitable, especially at the higher end of the range. It seems that the new, higher target price range is essential if ANWR is to be developed. Put simply, ANWR development in the United States requires high international crude prices.

Given these facts: (1) U.S. production exAlaska peaked in 1970, and has declined 50% to 1.8 billion barrels annually, and (2) Alaskan production peaked in 1988, and has also declined 50%, to 350 million barrels annually, it seems improbable that even the most aggressive policy for increased production on public land could reverse the decline in total U.S. production for a significant period.

U.S. remaining resources (277 billion barrels at the 5% probability level) are high cost and often in environmentally sensitive areas. The new USGS resource assessments expand both U.S. and global estimates, and the estimates for low-cost areas in the Persian Gulf.

Given the degree of stabilization in international pricing and production that has existed since 1985, I think serious consideration should be given to deferral of decisions for major current production increases in environmentally important areas.

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