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# World Crude Oil Resources

## Evidence from Estimating Supply Functions for 41 Countries

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A gloomy outlook for non-OPEC oil supply is unwarranted. Several countries are still expanding, others show no sign of declining supply, and even those contracting will continue to add to reserves.

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## Summary findings

Evidence to support or deny expectations of future scarcity or abundance of crude oil must show whether crude oil supply functions are shifting and, if so, in what direction. Watkins and Streifel estimate oil supply functions for 41 countries for which suitable data are available. Because of the poor quality of data, especially for reserves, the model specification is simple.

Their model relates reserve additions to the imputed *in situ* price of discovered but undeveloped reserves and to the passage of time. The passage of time is a surrogate for measuring the net impact on supply conditions of the chance of finding oil, resource depletion, cost efficiency, and technology. Time's impact could be expansionary or contractionary.

They test two main versions of the model, one a straightforward linear function, the other nonlinear, assuming decreasing returns. Both models yield similar results.

In most cases the models fit the data reasonably closely, after adjustment for outliers. The complete

model results show 26 countries with statistically significant shifts in supply functions — in almost equal parts expansionary and contractionary.

The shift is often contractionary in countries with a long production history (including Burma, Tobago, Trinidad, and the United States). Some are OPEC countries, to which a model specification involving market price response does not properly apply.

Tests on a small sample of countries for differences between earlier and later periods reveal limited evidence of an expansionary shift from 1980 onward.

There is partial evidence that lower oil prices stimulate productivity.

Watkins and Streifel suggest that a gloomy outlook for non-OPEC supply is unwarranted. Several countries are still in an expansionary phase. Others show no evidence of entering a period of decline. And countries in a contractionary phase will continue to add to reserves.

Further research requires improving the database rather than employing more elaborate models.

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This paper — a product of the Commodity Policy and Analysis Unit, International Economics Department — is part of a larger effort in the department to analyze commodity markets and their impact on developing countries. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Jean Jacobson, room N5-032, telephone 202-473-3710, fax 202-522-3564, Internet address [jjacobson@worldbank.org](mailto:jjacobson@worldbank.org). April 1997. (55 pages)

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**World Crude Oil Resources:  
Evidence from Estimating Supply Functions for 41 Countries\***

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## SUMMARY

The economics of oil supply are at the crux of the outlook for the world oil industry. Expectations of limited supplies outside of OPEC countries often lie behind the view of those who foresee a return to OPEC dominance and strong oil price increases. The major premise here is that supplies cannot keep pace with consumption growth. This premise must be examined, not presumed.

**Objectives.** The main objective is to estimate oil supply functions for all countries for which suitable data were available. The intention is to provide evidence to support or deny expectations of future oil scarcity or abundance. Countries for which suitable data were assembled numbered 41. They cover all the major producing regions of the world, excluding the former Soviet Union.

**Model Framework.** Data restrictions dictate simple model specification. Supply is represented by oil reserve additions. The basic model framework relates reserve additions to two variables. The first is the imputed *insitu* price of discovered but undeveloped reserves, an important factor governing exploration activity. Higher reserve prices should increase reserve additions, other things equal. The second variable is the passage of time. This is a surrogate for measuring the net impact of changes in prospectivity, resource depletion, cost efficiency and technology on supply conditions. The impact of time could be expansionary or contractionary.

This framework enables a distinction to be made between movements along a supply function and shifts in its position over time. It is shifts in the position of the supply function that are fundamental to the evaluation of oil supply prospects for a given country or region. The notion is illustrated in Figure 1 in the main text (page 15).

**Data.** Data on proved conventional oil reserves, reserve additions, production, drilling activity, well costs, development expenditures, operating costs, field prices and other factors were collected, by country, from the mid 1950s--when available--to 1994. Poor data quality--especially for reserves --necessitated frequent adjustments to eliminate anomalies. And lack of individual cost information for the majority of countries forced reliance on representative data from other sources, especially US cost data.

**Models Tested.** Two main versions of the basic model were tested. One was a straightforward linear function. The other was non-linear, assuming decreasing returns at any one point in time: higher prices would increase reserve additions, but at a decreasing rate. Both models yielded similar results.

An alternative formulation tested was to use the *insitu* price of developed rather than undeveloped reserves as the explanatory price variable. This was intended to reflect the fact that many reserves are added via reservoir development. No marked change in results occurred with this formulation and it is not discussed further in this summary.

**Results.** A high degree of fit was shown in most cases, after adjustment for outliers. Results for some countries showed some evidence of perverse price relationships: higher prices lowering reserve additions, other things equal. But mostly these were OPEC countries that cannot be anticipated to respond directly to market price mechanisms. This result, then, served to confirm rather than refute the model specification.

For any *one set* of model results for the 41 countries, the critical variable expressing shifts in supply functions over time was statistically insignificant for some 60 percent of them. This means that in most instances there is no evidence of secular movements in supply functions, either in a contractionary or expansionary direction, over the period of analysis.

*In combination* the model results revealed 26 countries displaying statistically significant shifts in supply functions. These were almost evenly split between those in an expansionary phase and those suffering contraction. The latter included countries with a long production history, such as the US, Trinidad and Tobago and Burma. Six of the 26 countries showed model deficiencies (perverse price relationships), of which four were for countries listed as contractionary. The flavor of these results is brought together in Table S-1.

**Table S-1**

**Typical Characteristics of Main Results**

<b><u>Country Grouping</u></b>	<b><u>Consistent Reserves-Price Relationship</u></b>	<b><u>Shifts in Supply Function</u></b>
Expanding non-OPEC Producers	Yes	Rightward
Contracting non-OPEC Producers	No	Leftward
North America	Yes	Leftward
Other Countries	Ambiguous	Neutral
OPEC	No	Ambiguous

Tests on a small sample of countries for differences between earlier and later periods displayed limited evidence of a shift in supply functions in a more expansionary direction from 1980 onwards. If widespread, this may well be the effect of strong technical advances over the past decade or so, which have significantly reduced costs. The same small sample of countries revealed partial evidence that technological change and exploration productivity were stimulated by lower oil prices. If so, sustained periods of flat oil prices need not be associated with deteriorating supply conditions.



We caution again that the results for many countries are not grounded in a strong set of underlying data, and that a lack of breakdown of reserve and cost data prevents estimation of more finely tuned models.

**Conclusions.** Overall, the study suggests that a gloomy outlook for world oil supply in general and for non-OPEC producers in particular is not warranted. A lot of countries show no shift in their supply functions, notwithstanding depletion. Outside of North America, on balance many non-OPEC producers have experienced a rightward, expansionary shift in their supply function. On the other hand, North America and in particular the USA, is probably moving in the contrary direction--contracting, with leftward shifts in the supply function of conventional oil. This does not mean that a country in a contractionary phase will not continue to add reserves. Additions from further investment in exploration and development can emerge over a long period. Rather, the implication is that the returns from such activity for a contracting country are diminishing.

Further research along the lines of this study requires improvements in the database, especially reserve and cost data, rather than employment of more elaborate models.

# 1. INTRODUCTION AND OUTLINE OF STUDY

Petroleum is the world's most widely traded commodity. Oil prices have fluctuated at times quite dramatically over the last twenty-five years or so, significantly affecting investment decisions not only in the oil sector, but in other energy industries as well. Changes in oil prices in part have been attributable to the interaction between the production practices of the Organization of Petroleum Exporting Countries (OPEC)--which has sought to limit output to generate higher oil prices--and rising volumes of non-OPEC production.

Since the two major price increases of the 1970s, world oil demand has grown much more moderately than prior to the first oil price shock in 1973. Non-OPEC supplies--outside the United States and former Centrally Planned Economies (CPEs)--have increased nearly four-fold since 1971. The rate of increase slowed following the collapse in oil prices in 1986, but in recent years production has again risen quite strongly partly due to significant technological advances and cost reductions. Since 1989, non-OPEC countries have supplied more than half of the net increase in demand resulting from the combination of higher consumption and declining output in some countries--especially the US and the former Soviet Union (FSU). Since 1993 the non-OPEC share has been over 80 percent.

Future oil prices primarily will depend upon three factors: levels of oil demand; availability and costs of oil supplies from all countries; and OPEC production capability and production decisions. This report focuses on the second factor, one that has implications for the third critical factor as well.

OPEC has had less influence on oil prices since 1986. Some analysts go so far to state that OPEC now has little impact on what has become a competitive market, implying that prices reflect marginal costs of production. This is not so: OPEC does limit its output; and prices are significantly above marginal cost in many regions of the world (costs here exclude royalties and taxes). Because of OPEC's attempts to maintain relatively high oil prices, the oil market operates in a seemingly perverse economic environment in which relatively low cost OPEC reserves are withheld while higher cost supplies elsewhere are developed.<sup>1</sup>

The conventional wisdom expects rising oil consumption and declining non-OPEC oil supplies increasing the demand for OPEC oil, inevitably leading to sustained increases in real oil prices. Crucial to this outlook is the view that aggregate non-OPEC production will decline. It is often based upon the notion that the world is running out of oil (resource scarcity) and that costs must therefore increase. For years, nearly all non-OPEC supply forecasts have been unduly pessimistic. The forecasts usually have production peaking in the very near future and then declining "forever", almost regardless of the oil price assumptions. To date these forecasts have been wrong.<sup>2</sup> Many such forecasts are still present, although milder, with price implications often grounded in the expected strong increase in East Asian oil consumption. But there is an unstated

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<sup>1</sup> Streifel [1995], and even before the emergence of OPEC as a price setter; see Adelman [1972].

<sup>2</sup> Lynch [1992].

major premise: that supply *somehow* cannot keep pace with consumption. This premise should be examined, not assumed.

**Supply Functions.** The concept of a supply function relates price to output and the reserves on which output depends. For a competitive producer price is equal to cost at the margin. The cost of oil consists mainly of the investment needed to create new reserves, not on extraction cost. The higher the price, the more attractive the investment, and vice versa.

In general: when output grows despite a stable or declining price, the supply curve has shifted outward, favorably. Oil has become less scarce. Contrariwise, when price is stable or rising and output contracts, the supply curve has shifted inward, unfavorably. Oil has become more scarce. The oil industry may lower its cost by downsizing--cutting back on poorer prospects and working the better ones. Similarly, costs may increase by moving up the supply function, making more use of deeper, more inaccessible deposits.

OPEC oil in general and particularly Middle East oil has always been so cheap that trends are hard to detect. Non-OPEC oil has gone through several phases corresponding to price movements. From 1960 through 1970, producers created 18.7 billion barrels of new reserves per year. Since prices were stable or declining, the supply curve probably shifted rightward. From 1970 through 1980, reserves were created at an average of 11 billion barrels per year. Since real prices between 1971 and 1980 increased more than tenfold, the supply curve seemingly shifted far leftward. From 1980 through 1993, new reserves created were 17.2 billion barrels per year, and tended to increase over time. Since real prices fell over 70 percent through 1986, then remained stable, the supply curve apparently shifted to the right. Oil had become much more plentiful. To compare pre-1970 with post-1980 is more difficult: expansion was less in the 1980s, but the price decline was steeper.<sup>3</sup>

**Outline of Study.** Our main purpose is to analyze oil supply in all countries for which suitable data were available, by distinguishing between movements along a supply function and shifts in the supply function itself. In all, supply functions were estimated for 41 countries.

The analysis is confined to conventional oil, excluding non-conventional sources such as oil sands in Canada and Venezuela. In broad measure, the study brings the approach developed in Bradley and Watkins [1994] to bear on a multi-country data set. The basic model framework relates reserve additions to reserve prices and to time, where time is a surrogate for shifts in supply functions.

The analysis cannot avoid importing a great deal of statistical noise, since there were many irregular changes; and reserve errors and misstatements are not mutually offsetting. But disaggregation by country seems essential to learn more about why and how such changes in reserve additions and apparent shifts in supply functions came about. In particular: why the abrupt reversal of the long-term trend toward greater oil plenty during the 1970s? Which countries have led and which lagged in the dramatic change since 1980? We would like to address these questions. However data limitations constrain our ability to compare individual

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<sup>3</sup> Summary data taken from comment by M.A. Adelman.

decades. Our analysis is mainly directed at the more modest goal of looking at overall trends over a period of three decades or more.

In particular the work focuses on whether the overall supply function in the selected non-OPEC and certain OPEC countries has shifted, and if so, in what direction? Has it shifted to the right, indicating that improvements in costs and in 'prospectivity'--the probability of discovery--are overcoming the effects of resource depletion? Or has it shifted to the left, indicating that depletion is paramount? These shifts cannot be discerned simply by looking at trends in reserve additions (or output) because these will be heavily influenced by the prevailing price which traces movements along a given supply function.

The report consists of four main sections. Section 2 discusses key concepts of oil supply from which two simple models are specified relating reserve additions to price, technology and 'prospectivity'. Simplicity is dictated by the scope of the data, the topic addressed in Section 3 which reviews the sources of data employed, discusses various adjustments required and comments on the constraints that data availability impose. Section 4 presents and discusses the results of the types of models estimated. Concluding remarks are made in Section 5. Appendix A lists the preferred statistical results by model and country.

## 2. SUPPLY CONCEPTS AND MODEL SPECIFICATION

The purpose of this section is to discuss key concepts relating to the analysis of petroleum supply in terms of reserve additions, and to define supply functions amenable to estimation. It commences by developing a framework for linking reserve *insitu* values or prices to relevant costs (Part A). These include development cost (the cost of installing capacity), user cost (the opportunity cost of producing now rather than later), and replacement cost. The review of replacement cost distinguishes between exploration activities, reservoir extensions, and enhanced recovery. *Inter alia*, how signals of scarcity might be identified is discussed.

In Part B, the notion of the oil supply function is delineated. Finally, on the basis of this analysis two simple models are outlined that will be used for estimation (Part C). These functions focus on trends in reserve additions in relation to values imputed for reserves in the ground--a crucial factor governing exploration activity--and to the passage of time, a surrogate for changes in underlying supply conditions. The discussion in this section (particularly parts A and B) draws substantially on that in Bradley and Watkins [1994].

### A. Key Oil Supply Concepts

#### Reserves

Reserves--specifically proved reserves--represent the prevailing resource inventory of the industry. In a closed economy, greater scarcity of reserves would be reflected in prices at the wellhead or for the purchase of reserves in the ground. However, where countries are price takers in a world oil market, increasing scarcity or more generous supply in individual regions requires detection by a less visible indicator than prices. This is because it cannot be assumed that more, or less, generous supply in one country is mirrored worldwide. And of itself the world oil price--as indicated in the introduction--may be a poor register of underlying supply conditions at any point in time.

#### Reserve Development and User Cost

Proved reserves, as noted above, are the resource inventory. Values of developed reserves are based on the wellhead price less extraction cost (including taxes). The latter is usually relatively small compared with price. Values of *undeveloped* reserves reflect wellhead prices less development cost.

To simplify, assume a fixed reserve is drawn down at a constant rate; the analysis can be readily generalized to the case of exponential production decline. The reserve is developed and of known quantity (R barrels). Development cost is already sunk and does not enter into the *insitu* price of the reserve, V (\$ per barrel). The fixed rate of reservoir output, Q (barrels per year), is set at well capacity and is governed by development intensity.

Assume both the price per barrel of output (P) and the extraction cost per barrel (C) are fixed over the reserve life with the former higher than the latter ( $P > C$ ). If the volume of recoverable reserves were invariant with respect to the fixed level of output ( $\partial R / \partial Q = 0$ ), the life of the reserve (the production period) would be simply  $R/Q$ , designated T. Since there is no productivity decline over time, the ratio of remaining reserves to output decreases as reserves are depleted and reaches unity in the last year.

The *insitu* value of the reserve depends on the discounted value of the stream of net profits that it generates. Given the simple framework outlined above, this value is equivalent to the present value of an annuity of  $(P - C)Q$  net revenue per year over T years. Call the annuity factor 'a' and write it in continuous form as:  $a = (1 - \exp(-rT))/r$ , where 'r' is the discount rate.

Hence the present value of the stream of future production (PVP) generated by the reserve until exhaustion is given by:

$$\text{PVP} = (P - C)Qa.$$

Since when  $\partial R / \partial Q = 0$ ,  $Q = R/T$ :

$$\text{PVP} = (P - C) (R/T)a.$$

Division of this expression by the quantity of reserves, R, yields the *insitu* price of a *developed* barrel of reserve as:

$$V = (P - C) a/T. \tag{1a}$$

In this expression the decision variable is T, governed by the level of output, Q, which in turn is governed by the level of development investment, I. Note that Q is embedded in (1a) by virtue of  $T = R/Q$ .

In the context of determining optimum output,  $Q^*$ , the reserve is assumed to be discovered but not developed. Finding cost does not have to be considered: it is sunk. Development cost is expressed per unit of capacity added. The reserve is fixed and output is set at the level given by capacity installed. It follows that the production life is set by the capacity variable. That is, T is governed by development intensity.

In a competitive market, the objective of development is to maximize the difference between the present value net revenue,  $(P - C)Qa$ , and the present value of the investment required to obtain Q. Assume  $\partial I / \partial Q > 0$ ; more output requires more wells because wells are assumed to produce at capacity. However, there is a resource constraint: cumulative production cannot exceed the reserve. And, since  $P > C$  throughout there is no reason not to exhaust the reserve. So the constraint is the equality  $R - QT = 0$ .

In this case, the profit function can be written:

$$\pi = (P - C)Q \int_0^T \exp(-rt) dt - I(Q)$$

where  $I(Q)$  is the development investment function. The integral is the annuity factor in continuous form,  $(1 - \exp[-rT])/r$ .

Optimal  $Q$  is obtained by setting marginal profit ( $\pi$ ) equal to zero:

$$\partial\pi/\partial Q = (P-C)(1-\exp(-rT))/r - (P-C)T\exp(-rT) - \partial I/\partial Q = 0.$$

This yields the equality condition:

$$(P-C)a = \partial I/\partial Q + (P-C)T\exp(-rT). \quad (1b)$$

Expression (1b) is interpreted as follows. Selection of  $Q$  on the basis of maximizing net present value entails that the present value of the stream of receipts from installing an extra barrel of annual capacity is equal to the marginal development cost per barrel of capacity plus the present value of the barrels produced attributable to the unit increment in capacity, if these barrels were all produced at the *end* of the life of the reserve. The latter is the marginal *user cost* per unit of added capacity.

User cost is the alternative option of when to produce the capacity installed. Under the simple assumptions adopted here this is only at the end of the reserve life. There is no room to produce it earlier, given production at capacity under a given development intensity. To put it another way, the opportunity cost of producing  $T$  barrels of reserve spread uniformly over  $T$  years (the life of the reserve) is the option to extend the reserve's life. The present value profit on those barrels is what lowers the rate of optimal output over what it would be in the absence of the resource constraint. *User cost slows depletion.*

Equation (1b) is now transformed to an *insitu* unit basis by dividing by  $T$ . Thus equation (1) below equates the value of a barrel of developed reserve,  $V$ , given by its discounted net revenue *per unit of reserve*, to its development plus user cost *per unit of reserve*.

$$V = (1/T) (P - C)a = (1/T) dI/dQ + muc \quad (1)$$

where

- $V$  = *insitu* value of a barrel of developed reserves,
- $T$  = the life index ( $R/Q$  ratio)
- $P$  = field price per barrel of output
- $C$  = extraction cost per barrel of output
- $dI/dQ$  = development investment, per unit of capacity,
- $r$  = the discount rate,
- $v$  = the discount factor,  $\exp(-rT)$
- $a$  = the annuity factor,  $[1 - v]/r$
- $muc$  = marginal user cost per barrel of reserve.

The first expression on the immediate right-hand side of equation (1) represents the value of a proved barrel of reserve assuming it is produced at a fixed rate, price and extraction cost over the time span T. This component can be written succinctly as  $V = m(P-C)$ ; in industry practice 'm' is typically taken to be about<sup>4</sup> 0.4 to 0.5.

In a competitive market the price of the *insitu* developed reserve would equal its marginal cost, comprising marginal development cost per barrel of reserve plus marginal user cost per barrel of reserve. Equation (1) assumes unit development cost to be constant,  $dI/dQ = I_d$ , expressed as dollars per daily barrel of capacity. As discussed, the user cost (or shadow price) of a barrel of reserves,  $muc$ , indicates the future value given up when the incremental barrel of capacity is developed and oil is produced evenly over the reservoir life.

Rewriting Equation (1) in simpler form yields:

$$V = m(P-C) = I_d (1/T) + muc. \quad (2)$$

### User Cost and Scarcity

Hotelling's model of price and output trajectories applies to a fixed quantity of reserves, given maximization of present value profits<sup>5</sup>. In the context of *insitu* values it states that m would be unity, with P-C rising as if compounded at the rate at which future earnings are discounted. Thus the value of reserves would rise over time to reflect the increasing user cost. This model has been applied to oil reserves (Miller and Upton [1985a, 1985b]). Not surprisingly, the hypothesis of fixed supply doesn't play very well (Adelman [1990], Watkins [1992]).

There is a more sophisticated version of the Hotelling model in which the assumption of fixed supply at uniform development cost is replaced by the assumption that cost will rise at a known rate as remaining reserves diminish (alternatively, with cumulative output). Under this assumption, the cost of reserves has two components as before, the difference is that user cost now has a different interpretation. Since the resource will never be exhausted--it will just become so expensive that it will be displaced--user cost relates to using up *cheaper* reserves. In particular, it reflects the fact that using today's relatively cheap reserves hastens the day when reliance must be placed on more costly reserves (Levhari and Liviatan [1977]). Here, development cost,  $I_d$ , would rise over time as resource depletion occurred, and marginal user cost,  $muc$ , would fall eventually to zero. The framework does not comprehend rightward shifts in the supply function. Rather, resources are exploited in strict order of ascending cost by climbing up the (fixed) supply curve.

This second, somewhat more realistic view of user cost--also referred to as degradation cost--has in fact been applied to public policy. In Canada, the National Energy Board for a time

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<sup>4</sup> For example, see Adelman [1990, p. 6]; also see Adelman and Watkins [1996].

<sup>5</sup> See Hotelling [1931].



required that applicants for a license to export natural gas be able to show that the export price covered not only direct production, processing, and transportation costs, but also user cost (NEB [1989]). To compute user cost it was necessary to specify the anticipated supply price of future reserves. While this framework was more realistic than the notion of a fixed stock, in practice there is of course a great deal of uncertainty about the supply and cost of future reserves. So for that reason, among others, the policy was abandoned as impractical.

In the context of economic measures of scarcity, user cost as described is not useful, inasmuch as the somewhat more realistic version just described does not readily lend itself to measurement. If it did, a worse problem would surface--user cost would *decline* as the resource was depleted. Some analysts, building on the seminal work of Barnett and Morse (1963), have relied on extraction cost as an index of scarcity, which would be development cost in our formulation. This may be a useful index but it has an underlying logical flaw. If technology permits an economy to substitute away from the resource in question, leftward shifts in the derived demand curve could offset increasing extraction cost, so cost would provide a perverse index of scarcity. Indeed, in these circumstances the whole notion of scarcity would be of little interest.

### **Replacement Cost**

Future supply can be pictured as a series of *tranches*, that is, increments of reserves that can be developed only at successively higher unit cost. This structure has been incorporated in the Hotelling-derived literature, with successive tranches being exhausted (the first type of user cost) while the whole process conforms to the second type of user cost (degradation cost).<sup>6</sup>

A suitable point of departure is the belief that the quantity of reserves in each tranche is unknown. Moreover, at any given time reserves are being created in more than one tranche. The assumption of successive exhaustion of fixed quantities of reserves in each tranche fails to take into account the process by which oil reserves are continuously augmented. This is achieved by various types of investment: a) investment in exploration; b) investment in reservoir extensions; and c) investment in enhanced recovery. Here, the key to detecting increasing scarcity (or abundance) lies in the trends in *replacement cost*.

#### a) Exploration

One means of adding to reserves in a tranche is to explore for and then develop newly found reserves. This process can be described by a model which assumes that  $T$ , the reserves/production ratio, is fixed at its optimal value for the tranche, at  $T^*$ . The total stock of reserves ( $R$ ) and total capacity ( $Q$ ) are variable<sup>7</sup>. This is not unrealistic on a company basis. Company policy could be to sustain a target  $R/Q$  ratio. Or supply contracts may call for a constant  $R/Q$  ratio. Any production would need to be replaced by new reserves.

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<sup>6</sup> An example is Solow [1974].

<sup>7</sup> When  $T$  is fixed, the fixed resource constraint is implicitly dropped.

Constrained maximization will yield a result similar to Equation (2), except that the second term on the right would be ‘mrc’, marginal replacement cost, specifically, the replacement cost of *undeveloped* reserves. Designating marginal replacement cost as mrc yields the equation:

$$V = I_d (1/T) + \text{mrc}. \quad (3)$$

Marginal user cost for the tranche (muc) is unobservable, but marginal replacement cost (mrc) ostensibly could be observed. Marginal replacement cost can be portrayed as a rising supply curve, reflecting diminishing returns with increased exploration effort in a given period, for a given “play.”

#### b) Reservoir Extensions

Exploration, or wildcat drilling, is not the only means of seeking new reserves. A second approach can be characterized as “*extensions*,” whereby investment in the form of development drilling secures new reserves and simultaneously increases capacity. Especially in mature regions, reserve appreciation over time is the major source of reserve additions. On the assumption that no further capacity-specific investment need be made, we would have:

$$V = \text{mdc} \quad (4)$$

where mdc is marginal development cost.

Here the marginal replacement cost is represented by marginal *development* cost, that is, the cost of reserves gained through development drilling. Again, available information on newly created reserves won’t be broken down on a tranche-by-tranche basis.

#### c) Enhanced Recovery

A further means of adding oil reserves is through investment in enhanced recovery. In the context of a simple model, it could be treated in various ways. An extreme assumption is that enhanced recovery investment adds reserves but not capacity. Hence it would simply extend the life of the reservoir. Here the value of the added barrel of reserves would be the value of a barrel produced in T years, or  $(P - C)v_T$ , recalling that  $v_T$  is the relevant discount factor. This would imply, from expression (1), that marginal replacement cost by means of enhanced recovery, mec, would be related to reserves value by:

$$V(Tv_T/a) = \text{mec}. \quad (5)$$

A more appropriate assumption about the value of a barrel of reserves added through enhanced recovery would be that it would reduce the rate of decline of production from a reservoir as well as increasing the reserves. This could be incorporated in a more general model than the one here that assumes constant output.

Three ways, then, have been identified of adding to the stock of oil reserves--namely through exploration, extension and enhanced recovery.<sup>8</sup> Investment among these alternatives would be allocated so as to equate the value gained per dollar of investment at the margin. The three supply relations are:

$$\text{mrc} = V - I_d (1/T) \quad (6)$$

$$\text{mdc} = V \quad (7)$$

$$\text{mec} = V(Tv_T/a). \quad (8)$$

Recall that these expressions relate to a particular tranche. Additions to reserves are simultaneously drawn from several adjacent tranches, and at the margin the *total* cost of reserves additions will be equated to their value. The increasing cost of finding more potential reserves in a particular tranche makes it economic to also exploit reserves in an adjacent tranche with higher development cost. We next consider what can be garnered from this framework about resource depletion.

## B. Reserve Supply Curves

It was noted at the outset that scarcity is best measured by price. If the derived demand for crude oil did not diminish, the price of reserves would signal increasing scarcity. It was also noted that non-OPEC producing regions are price takers.<sup>9</sup> In these circumstances, the derived demand for reserves reflects the prevailing world price, and this trends upward or downward not in response to economic scarcity in a given region but rather to *contrived* scarcity, which is to say OPEC's success at controlling output. Thus for oil producing regions price is *exogenous*, unrelated to any indigenous scarcity. If price is exogenous, increasing scarcity (or abundance) is detected by changes in reserve *quantities*.

An upward sloping supply function is posited for a particular region's discoveries of *new potential reserves*. Recall that if this function were stationary, one could (with the appropriate data) measure the supply elasticity of a particular 'quality' reserve, that is, for a given tranche. In fact, the curve would be expected to be shifting. Leftward movement would indicate increasing scarcity--that is, depletion was not being offset by technology or new prospects. *Hence the*

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<sup>8</sup> Booked reserves can also be augmented or diminished by changes in wellhead prices themselves (P) since they, in combination with extraction cost, will determine well abandonment and hence the volume of oil eventually recovered from a reservoir. This source of reserve variation is not considered because it does not involve investment.

<sup>9</sup> Also, to the extent that OPEC countries have differences in preferred prices, a group price objective may nevertheless leave an individual OPEC country as a price taker.

*desired signal of changes in resource conditions would be the parameters describing shifts in supply functions.*

These notions are illustrated in Figure 1. The curve SS is the reserve supply curve at a given point in time. A rise in the price of reserves will increase reserve additions as more costly prospects become economic to develop (and vice versa).

An outward shift in the supply curve is indicated by the curve  $S_A S_A$ . Here the curve is lowered with costs reduced by technological improvement, or new areas or prospects may attract activity. In either case, at a given price, reserve additions increase because prospects with costs formerly exceeding price now become economic, or because new areas or 'plays' become accessible. An inward shift in the curve is depicted by the curve  $S_D S_D$ . Here, at a given price reserve additions decline; costs are increasing and remaining 'prospectivity' deteriorates--the resource is becoming more scarce.

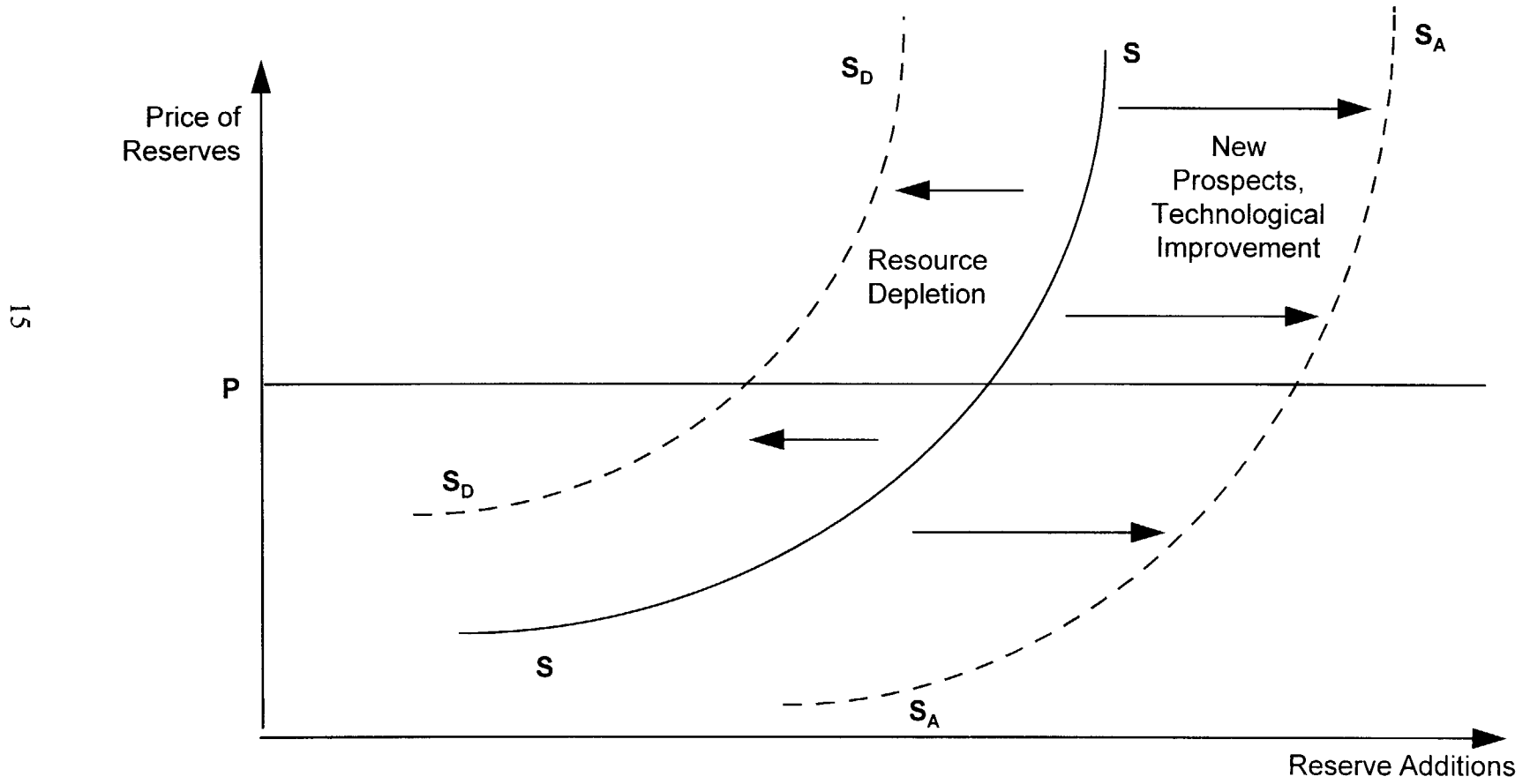
The depiction of supply from the two other sources of potential reserves identified earlier--reservoir extensions and enhanced recovery--would be similar. Unfortunately, the data that would permit estimation of any of these individually sourced supply functions are not available. Moreover, the data that are available relating to reserves additions are not broken down according to the tranches posited. In the absence of data specific to the different sources of reserves, reliance is placed on what can be learned from more piecemeal, aggregate information.

In that light, although for purposes of analysis reserve additions have been broken down by various sources, now we must, perforce, consolidate. Figure 2 depicts additions to proved reserves at varying reserve prices, combining reserves additions from all sources and all tranches. The incremental supply price is therefore  $I_d(1/T) + mrx$ , where  $mrx$  represents the combined replacement cost, derived from  $mrc$ ,  $mdc$  and  $mec$  (see equations (6), (7) and (8)).

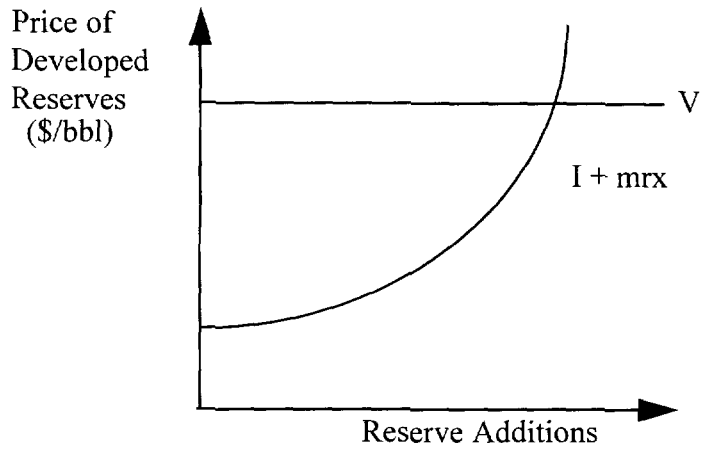
However, the information contained in a curve like that in Figure 2 is not likely to be helpful in identifying trends in resource scarcity or abundance. When the value of proved reserves goes way up, as it did for example after the second price shock of 1979-80, extensive development drilling can be expected where potential reserves were known to exist but had previously been uneconomic to develop. That is to say, a number of new tranches--corresponding to successively higher development costs--would be exploited. In this context the supply response would be largely attributable to the inventory of *proved* reserves built up over time.

What is required is to determine the extent to which the inventory of *potential reserves* is being augmented. This would be specified by a supply curve like that shown in Figure 3. This relates the supply of potential reserves to their implicit value,  $[V - I_d(1/T)]$ , the difference between the value of a developed reserve and its cost of development. This value can be thought of as a window--*it represents the opening, or margin, within which exploration must pay off.*

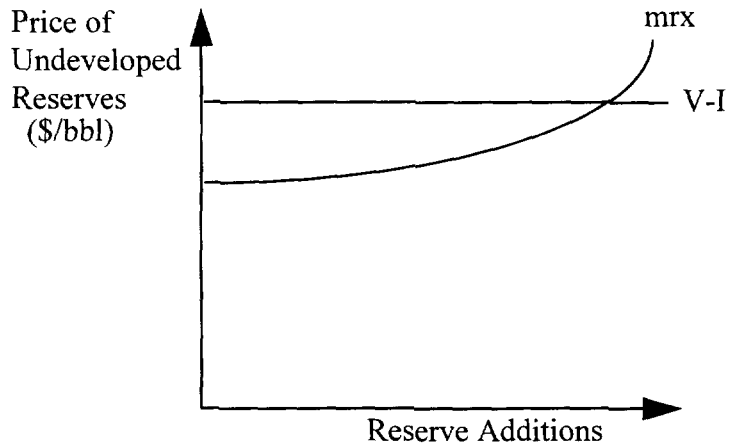
**Figure 1**  
**Supply Curves: Oil Reserves**



**Figure 2**  
**Relationship between Price of Developed Reserves and Reserve Additions**



**Figure 3**  
**Relationship between Price of Undeveloped Reserves and Reserve Additions**



Legend:  $V$  = in-situ value of developed reserves  
 $I$  = development cost per unit of proved reserves  
 $mrx$  = marginal replacement cost

The opening of the window varies. When the value of proved reserves (V) falls, the value of potential reserves  $[V - I_d(1/T)]$  falls as well, though some of the fall will be offset by declining development cost, as attention is restricted to the better prospects. This means that the exploration margin is being squeezed so that fewer exploration prospects will be entertained: the quantity of exploration activity will fall. Finding cost, assuming it can be measured, may be seen as declining. *However, such a decline would not be an indicator of more favorable exploration results.*

Just as changes in the value of proved reserves in various regions do not of themselves reflect scarcity, neither do changes in the implied value of potential or undeveloped reserves,  $[V - I_d(1/T)]$ . If the reserve were not potentially depletable, the supply-demand relationship depicted in Figure 3 would allow us to estimate the curve describing marginal replacement cost. One must contend, however, with the offsetting forces of depletion plus rising cost, and technical advance plus new prospects (see Figure 1). The key question is whether the supply curve (mrx) in Figure 3 is stationary or shifting, and if the latter, in which direction?

We now specify two supply models that attempt in a simple way to capture the distinction between movements along a supply function and inward or outward shifts in it.

### C. Estimating Equations for Supply of Reserves

#### First Model

A simple reduced form supply function can be specified for *potential* (undeveloped) reserves as a function of their value and of time. The function can be written as:

$$RA = a + b(V - I) + ct \quad (9)$$

where

RA = reserves additions in the given period

t = time

V = value of barrel of developed reserves in the ground

I = development investment per unit of proved reserve.

The time variable, t, is a surrogate for changes in 'productivity', and the sign of its coefficient, c, is critical. A positive "c" indicates a rightward shift in the supply curve over time; the remaining reserve endowment is expanding. A negative "c" indicates a leftward shift: the remaining reserve endowment is less generous<sup>10</sup>.

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<sup>10</sup> A possible alternative to the time variable is cumulative oil production (for example, see Scarfe and Rilkoff [1984]), which in turn is normally well correlated with time. However, our focus is on potential reserves; their shifts would not be well represented by output from developed reserves. Hence a preference for time.

*A priori*, the “b” coefficient of equation (9) is expected to be positive: the greater the spread between *insitu* values and the cost of placing reserves on production, the greater would be potential reserve additions. This spread is an estimate of the price of *undeveloped* reserves, what was referred to earlier as the *window of opportunity for exploration*. Higher prices of undeveloped reserves encourage exploration activity. To test for possible lagged relationships, equation (9) can also be expressed with a one year lag  $(V-I)_{-1}$  and a two year lag  $(V-I)_{-2}$ .

The data available for estimating this model are not what would be preferred. There are, of necessity, no reliable data describing the additions to potential or undeveloped reserves. Therefore we postulate that trends in the level of additions to proved reserves for a given value of such reserves reflect the success over time of all methods for replenishing the stock of potential reserves. The assumption implies a consistent proportional relation between potential and proved reserves.<sup>11</sup>

Regular patterns of proved reserve appreciation,<sup>12</sup> for which there is some evidence<sup>12</sup>, provide support for the assumption. But equally it might be expected that additions to potential reserves would shrink faster than additions in proved reserves. If so, the model would tend to understate any underlying resource depletion. No solution is seen to this problem without a finer distinction among the reserve and cost data.

Earlier mention was made that for many regions--especially as they mature--the main source of reserve additions is from reservoir development activity or *reserve appreciation* (extensions and enhanced recovery). This suggests that the imputed price of appreciated reserves,  $V-I_c$ , where  $I_c$  represents development costs not related to reservoir appreciation (such as infill drilling), as well as the imputed price of undeveloped reserves,  $V-I$ , might be influential in determining reserve additions. Since no information is available on  $I_c$ , the value of developed reserves,  $V$ , is used as a surrogate.<sup>13</sup>

Hence an alternative specification of equation (9) is to eliminate the term ‘I’ from equation (9). Here the equation would become:

$$RA = a + bV + ct. \quad (9a)$$

As for equation (9), equation (9a) can also be expressed with one and two year lags for  $V$ .

## Second Model

Another simple approach is grounded in and adapted from the hypothetical supply curves sketched in Adelman [1990, p29]. Again the notion is of a pristine supply function--reserve additions plotted against the (*insitu*) price of reserves. The function is forced through the origin: zero price, zero reserve additions. Also, the function is assumed to be concave upwards, not a

<sup>11</sup> As Paul Bradley has pointed out.

<sup>12</sup> See ERCB [1969] and Attanasi and Root [1994].

<sup>13</sup> This need not distort the statistical significance of behavioral parameters if  $I_c$  were a constant fraction of  $V$ .



straight line, implying diminishing returns for reserve additions as the price increases. A logarithmic transformation for the price term would be a simple expression of this feature. Call the slope of the function 'x'. It is the ratio of the log of the *insitu* price to reserve additions:

$$x = \ln(V - I + 1) / RA. \quad (10)$$

where RA is reserve additions, V is the (real) *insitu* price of reserves, and I is development cost. The '+I' element in (10) is to ensure that when V-I= 0, RA = 0.

The key concern is what happens to 'x' over time. If in this model costs were decreasing via shifts in the *slope* of the curve rather than through movements along the curve, then 'x' will be declining, that is the curve will be shifting downwards to the right. If costs are increasing, then 'x' will be increasing and the curve will be becoming steeper.

For any country, 'x' can be calculated as given by expression (10) for each year. To capture lagged relationships two sets of values for 'x' are computed, one where (V-I) and RA are contemporaneous, and one where there is a two year lag on (V-I)

Similarly to the first model, equation (10) can also be defined by using the price of developed reserves, V, rather than the price of undeveloped reserves, V-I. If so the equation becomes:

$$x = \ln(V + 1) / RA. \quad (10a)$$

And again V can also be expressed as a two year lag.

Any one set of values of 'x' by year  $\{x_t\}$  generated by equations (10) or (10a), were simply regressed on a time counter:

$$x_t = b + ct. \quad (11)$$

Interest focuses on the sign of the 'c' coefficient attached to the time variable. If it were negative, that would indicate more generous supply; if positive, more constrained supply<sup>14</sup>.

### Summary of Approach

Overall, the detection of trends in resource conditions must focus on reserve additions. In current market circumstances, of themselves these quantities will not signal trends. Instead, attention must be directed toward how the industry is responding over time in the face of changing values. The most useful analysis is a comparison among countries.

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<sup>14</sup> Note the difference in interpretation between the time coefficient (t) between the first and second models. In the first model a positive "t" indicates expanding supply, and in the second model, contracting supply.

We attempt to estimate simple oil supply functions implicit in equation (9) and equation (10) (and equations (9a) and (10a)) for 41 oil producing countries around the world. Many are non-OPEC oil exporting countries, some are net oil importers but nevertheless with significant levels of production. Several major Middle East oil producing countries and other OPEC countries are included. These countries have been restraining output and development in an effort to maintain higher oil prices. Previous surplus capacity has left them with little incentive to develop new reserves over the past two decades. In fact, *a priori*, we expect to find neither model appropriate for the main OPEC producers.

The form of the equations to be tested is intended to enable conclusions to be drawn about movements in supply functions over time--whether they are shifting to the right or left. The implications of such findings in the context of the world oil market were drawn earlier.

For a limited sample of countries, equations are estimated by dividing the data set into an earlier and later period to test for differences in model coefficients over time. Moreover, an attempt is made to introduce a composite time-related coefficient ( $c + dt$ ) in the first model to see whether any time-related shifts (representing changes in technology, efficiency and prospectivity) appear to be increasing or diminishing as a function of the *level* of field prices.

The next section describes the data collection efforts pursued to enable estimation of the models specified.

### 3. THE DATA

The intent was to estimate oil supply world functions in all the regions of the world--South America, North America, Europe, Africa, Middle East and Asia, but excluding the former Soviet Union (FSU). *In the end, the usable data set was for 41 countries.*

This section describes the data used to estimate the equations specified in Section 2. The three crucial elements here are: reserve additions; reserve prices; and development costs. Table 3.1 overleaf is a general key relating to the sources and data definition. Details and manipulations relating to each main element of data are provided below. A complete set of data for all 41 countries is available from the World Bank.

The data set is built upon earlier work by Adelman and Shahi<sup>15</sup>, estimating oil development-operating costs for 40 or so oil-producing nations from 1955 to 1985 from publicly available data. We updated these data to 1994, and then extracted the necessary items for construction of our data set--items primarily relating to investment expenditures, production and reserve data. Data (to 1985) for Rows 1 through 8a in Table 3.1 are from Adelman and Shahi. These data are described in detail in their paper, of which a description is summarized below.

As indicated in the sources used, the desired data for all countries are not available. And indeed the data for some countries, for example Thailand, were sufficiently flawed as to warrant their removal from the initial selection. Four countries were added to the Adelman-Shahi data set--Canada, Norway, the United Kingdom and the United States--and these are discussed separately below.

#### **Wells Drilled and Average Depth**

Wells drilled refers to all types of wells (oil, gas, dry, exploratory, development), and are obtained from the August "International Outlook" issues of *World Oil*, published two years after the year in question, (Row 1 of Table 3.1). In Row 2 the approximate average well depth is calculated by dividing the total footage drilled by the total number of wells drilled, also taken from the August *World Oil* issue.

#### **Average Costs Per Well**

The figures for average costs in Row 3a reflect the cost of drilling an onshore well of a given depth in the USA in 1985. It is generally assumed that drilling costs for a given depth are the same across all nations and are equivalent to the US drilling costs.<sup>16</sup> No country-specific drilling costs are available. For each depth class, the cost of drilling an onshore well in 1985 is calculated using figures published by the US Department of Energy, *Indexes and Estimates of*

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<sup>15</sup> Adelman, M.A. and Manoj Shahi, [1989]. We are grateful for provision of these data on disk.

<sup>16</sup> This assumption is not distortive given widespread use of US equipment, a competitive equipment market, and the low labor intensity of drilling cost.

**Table 3.1 Sources of Country Oil Reserve Development Cost and Price Data.**

Row	Variable	Source or formula
1	Wells drilled	August "International Outlook" Issue, World Oil
2	Approximate average well depth (thousand ft)	(Total footage drilled/wells drilled); total footage drilled from International Outlook issue, World Oil
3a	1985 Average cost /well (\$million)	Calculated from costs given in "Indexes and Estimates of Domestic Well Drilling costs 1984 and 1985," DOE/EIA-0347(84-85) and average depth in Row 2
3b	Ditto., adjusted	Row 3a multiplied by the ratio of as indicated by adjustment class.
3c	Adjustment class	See note below
3c.1	Adjustment (a): total US	Total US drilling cost from Joint Association Survey on drilling costs
3c.2	(JAS) onshore	Total onshore US drilling cost from Joint Association Survey on drilling costs
3c.3	Adjustment (aa): offshore	Total offshore US drilling cost from Joint Association Survey on drilling costs
3c.4	(JAS) onshore	Total onshore US drilling cost from Joint Association Survey on drilling costs
4	Investment (\$million)	Adjusted average cost x wells drilled = (Row 3b x Row 1 X 1.66)
5	Average output, thousand bbl/day	International Outlook Issue, World Oil
6	Operating wells (year-end)	International Outlook Issue, World Oil
7	Average output per well (thousand bbl/day)	Average daily output/number of operating wells = (Row 5/Row 6)
8	Year-end reserves (billion bbl)	Oil and Gas Journal, Year-end Worldwide Production Report
8a	Adjusted year-end reserves (billion bbl)	Adjusted for unusual swings in reserve data
9	Annual Oil Production (million barrels)	Annual production = (Row 5 x 365/1000)
10	Reserve additions (million bbl) (Original calculation. If negative Row 10=Row 9)	Change in adjusted year-end reserves plus annual production = ((Row 8a(t) - Row 8a(t-1)) x 1000) + Row 9 (if calculation negative use Row 9) If calculation in Row 10 is negative, annual production is used for reserve additions.
11	Cost reserve additions (1985\$/bbl)	Investment/reserve additions, adjusted for inflation = (Row 4/Row 10)/(Row 13*100)
11a	Adjusted cost reserve additions (1985\$/bbl)	Adjusted for unusual swings in cost calculations
12	Representative field price (\$/bbl)	Annual average prices for bechmark crudes; PIW, other sources
13	US GDP Deflator (1985=100)	World Bank
14	Real Field Prices (1985\$/bbl)	Constant \$1985 field price = (Row 12/Row 13 x 100)
15	Operating costs (1985\$/bbl)	Varies according to square root of output, and proportional to constant 1985 US operating costs (\$3/b for well producing 50 b/d)= 3/(Sq Rt (Row 7/50))
16	Net Prices (1985\$/bbl)	Real field price minus operating costs = Row 14 - Row 15
17	(1) In-situ price of developed reserves (1985\$/bbl)	Net Price x 0.4 = (Row 16 x 0.4)
18	(2) In-situ price of developed reserves (1985\$/bbl)	Real field price x 0.3 = (Row 14 x 0.3)
Notes:	<p>Drilling costs per well (Row 3b) are adjusted for mixed (both onshore and offshore) drilling. Only those fields with average daily production equal to at least 3% of the national output are used.</p> <p>Adjustment Class: (a)=Row 3c.1/Row 3c.2 (correction for mixed drilling)                      (aa)=Row 3c.3/Row 3c.4 (correction for entirely offshore drilling)                      (b)=maximum cost/Row 3a. Maximum costs calculated from DOE and shore cost from JAS                      Used only for Iran and Nigeria</p>	

Row numbers refer to data format. The complete set of data tables are available from the World Bank.

*Domestic Well Drilling Costs, 1984 and 1985.* For Iran and Nigeria, where costs are very high due to exceptionally difficult drilling conditions, maximum rather than average values are used.

When a country is engaged in mixed drilling (both onshore and offshore) or entirely offshore, Row 3a is multiplied by the appropriate weights calculated from the current Joint Association Survey on Drilling Costs (JAS) for each year, and is shown in Row 3b. For countries engaged in both offshore and onshore drilling the weight used is the ratio of total drilling expenditures per well to onshore drilling expenditures per well for a given depth class (from Row 3c.1 and Row 3c.2). For entirely offshore drilling countries, the weight used is the ratio of offshore drilling expenditures per well to onshore drilling expenditures per well (from Row 3c.3 and Row 3c.4).

Alignment to 1985 data is partly dictated by lack of data to provide a consistent time series. But it is also deliberate in that technological change that may increase or decrease unit drilling costs (especially decreasing them since 1985), one element of technological change that the time variable in the estimation equations (see Section 2) is intended to capture.

### **Total Country Investment**

Total country investment is the adjusted average cost per well multiplied by the total number of wells drilled in that given year (Row 3b x Row 1). However this represents strictly drilling costs. There are other important expenses for overhead, lease equipment, etc. These expenses have historically been about 66% of drilling costs. Thus drilling costs are raised by this percentage in Row 4. This "Investment" calculation is somewhat upward biased because it includes not only oil wells, but also development wells in non-associated gas fields. We have not been able to segregate gas wells not related to oil developments.

### **Output, Operating Wells and Average Output Per Well**

Output in Row 5 is the average number of barrels of oil produced daily per year. Operating wells in Row 6 are the total number of wells producing naturally or artificially at year end. These figures are from the August "International Outlook" issue of *World Oil*, published two years after the year in question. Average output per well in Row 7 is total oil output divided by the number of operating wells at year end (Row 5/Row 6).

### **Reserves and Production**

Oil reserves in Row 8 are taken from the year-end Worldwide Production issue of the *Oil and Gas Journal*. The published reserves are as of January 1 of the upcoming year, but treated as reserves at the end of the current year.

For some countries, reserves show erratic annual fluctuations upwards and downwards. And for some years the reserves do not appear to be reasonable or consistent estimates. Often aggregate reserves were probably overestimated and then subsequently corrected. Or they may even have been manipulated. In certain cases, it may have been an error in recording or

publishing reserves, e.g., Saudi Arabia in 1976. Sometimes the erratic fluctuations were only observed for a few years while in other countries they extended for several years. These fluctuations severely distort the critical calculation of “Reserve Additions” in Row 10.

Where erratic figures occurred, reserves figures were adjusted or “smoothed” to remove unusual fluctuations and show more consistent trends, largely on a judgmental basis. These adjusted reserve figures are shown in Row 8a, immediately below published reserve figures. The reader is able to see where all adjustments were made. The adjustments were simply to smooth erratic fluctuations--there was no attempt to reverse obvious trends.

Annual oil production in Row 9 is simply the average daily oil output in Row 5 multiplied by the number of days in the given year.

### **Reserve Additions and Cost of Reserve Additions**

Reserve additions are the change in remaining reserves between years, plus production during the year. That is, net reserve additions in Row 10 is calculated by taking the reserves at the end of a given year minus the reserves in the preceding year, and then adding the total number of barrels produced in the current year.

In some cases downward revisions to reserves resulted in negative reserve additions, even after adjustments to the aggregate reserve data mentioned above. Negative reserve additions imply revision of previous reserve estimates. In the absence of information on when to attribute such revisions, where negative reserve additions occurred production for that year (Row 9) was used for reserve additions in Row 10. In cases where production figures have been substituted, the original calculation of negative reserve additions is shown immediately below the entry. Again, the reader can observe all cases where such adjustments were made.

The deflated cost of reserve additions in Row 11 is the estimated real average cost of adding a barrel of oil to reserves in a given year. It is calculated by dividing total investment in Row 4 by the net reserve additions in Row 10, and adjusted for inflation using the US GDP deflator in Row 13. In some cases fluctuations in the estimated cost of reserve additions were erratic. This was often attributed to a very low reserve additions figure that resulted in a seemingly high cost calculation, e.g., Saudi Arabia in 1982. In the few instances where cost calculations differed very markedly from an established trend, the figures were adjusted in Row 11a. For example, Saudi Arabia was adjusted in 1982.

### **Field Prices and Operating Costs**

Representative field prices are shown in Row 12. They are mainly spot f.o.b. oil prices from *Petroleum Intelligence Weekly*. Prices were not available for the entire sample period. Here differentials among the spot prices available were calculated and extended backwards to the beginning of the sample period, 1955. Where spot prices were not available, spot prices available in a given region were used. Where a different countries’ price was used, it is so noted immediately under Row 12. There was no attempt to adjust these prices for transportation costs

back to the field. Nor was there an attempt to correct for differences in crude quality. Most of the prices used were for a light/medium crude. Thus the representative field prices may err on the high side.

Real field prices (1985 US\$/bbl) are shown in Row 14. The nominal field prices in Row 12 were adjusted for inflation by the US GDP deflator in Row 13.

Operating costs are calculated in Row 15. For most countries, operating costs are not available, and therefore need to be estimated. It is assumed that operating costs vary according to the square root of output per well<sup>17</sup>, and are proportional to US operating costs. US operating costs in 1985 dollars are assumed to be \$3/bbl for a well producing 50 barrels per day<sup>18</sup>. It is assumed that operating costs per barrel of production were constant throughout the period.

For a given year in each country, the \$3/bbl US constant cost is divided by the square root of the ratio of the average daily well production (Row 7) over the reference well productivity (50 b/d). These costs are in real terms (1985 US\$/bbl).

An absence of operating cost data by country entails reliance on US data. To the degree that operating costs are labor intensive and that fiscal takes vary (see below), operating costs attributed to a given country will be flawed. However, operating costs are not a crucial variable.

### ***In situ* Price of Developed Reserves**

The real field price minus operating costs is calculated in Row 16 (Row 14 minus Row 15).

The estimated *insitu* prices of developed reserves are shown in Rows 17 and 18. In Row 17, the *insitu* value of a developed barrel of oil is calculated as 40% of the net price value in Row 16. In Row 18, the *insitu* value is calculated as 30% of the real field price in Row 14. These ratios are based on data in Adelman and Watkins [1996, p85]. That paper relates to the US. The operating costs used in arriving at the net price include a rent component (royalties and severance taxes). This wedge of rent for the yardstick well is implicit in the calculation of *insitu* values elsewhere--which of course may not hold. However, some unpublished estimates by Adelman using 1991 international transactions showed ratios of 0.36 to 0.41 which are compatible with the assumption of 0.4 factor we used.

Nevertheless, we do caution that variations in fiscal regimes across countries are not reflected in our *insitu* prices. However, to the extent that the fiscal take per value of a reserve barrel were constant over time for a given country, the assumption of a 0.4 factor would not noticeably distort estimation of model coefficients since if the appropriate factor were, say, 0.7 it would simply act as a scaling factor and not affect their statistical significance.

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<sup>17</sup> Adelman [1972, p.47].

<sup>18</sup> Adelman and Watkins [1996, p24]; 1992 adjusted to 1985 using the US GDP deflator.

## Data for Norway, United Kingdom, United States, and Canada

These important oil producers are outside of the Adelman-Shahi data set. Extensive data are available for these countries, and thus it was not necessary to estimate the *insitu* values and certain costs using the same lengthy process described beforehand. The presence of direct development and operating expenditures reduced any need for data manipulation.<sup>19</sup> Moreover the data were available for oil developments only, and thus exclude expenditures for non-associated gas wells. The tables for these four countries are different in form from the other countries, and are included in the complete data set (available from the World Bank).

**Norway and the United Kingdom.** Oil development and operating expenditures and production figures were supplied by Petroleum Economics Limited. Reserve figures are from the *Oil and Gas Journal*. The representative field price for both countries is the UK Brent spot price.

Operating costs per barrel (1985\$) are calculated from nominal operating expenditures and from average output, and adjusted for inflation. All other calculations are as described beforehand (reserve additions, cost of reserve additions, field prices, operating costs, and *insitu* prices).

**United States.** For the US, direct data were available for development expenditures, reserve additions, cost of reserve additions, and *insitu* values. These were largely obtained from publications by Adelman et. al. These data only go to 1992; thus the estimation period only extends to this year as well.

The *real* cost of reserve additions is calculated using the nominal costs of reserve additions, and adjusted for inflation. Similarly the *real insitu* value is calculated from the nominal *insitu* value.

**Canada.** Data for Canada were obtained from the Canadian Association for Petroleum Producers, *Statistical Handbook, 1995*. Data include gross additions to reserves, oil development expenditures, operating expenditures for oil wells, and the average crude oil price. The latter three variables are shown in real terms per barrel. Net prices were calculated. Two *insitu* values were defined according to whether these were predicated on gross or net prices.

We now turn to the results obtained from estimating the supply functions specified in Section 2 using the data described in this section.

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<sup>19</sup> For example, development expenditure data seemed sufficiently comprehensive as to not require adjustment for overhead and lease equipment, as described earlier from the Adelman-Shahi data set.



#### 4. ESTIMATION RESULTS

Two simple model specifications were developed in Section 2. To recapitulate: the first (Model 1) treats reserve additions as a straightforward linear function of the imputed price of undeveloped reserves and of time. The second model (Model 2) estimates the slope of a notional supply function over time by calculating the ratio of the logarithm of the price of undeveloped reserves to reserve additions for each year. These annual values are then regressed on time. Both models were also redefined to use the imputed price of developed rather than undeveloped reserves.

Interest mainly focuses on the behavior of the time variable for each country, the surrogate for measuring the net impact of depletion, technological and efficiency changes and 'prospectivity' on the oil supply function for a given country. That is, 'time' is the variable for measuring whether the supply curve is shifting inward or outward (see Figure 1 earlier).

Full details on the statistical results are provided in tables appearing in Appendix A. For convenience, the results are listed there by country in alphabetical order. The commentary below draws on the information in Appendix A and provides summary tables.

One technical statistical issue is that of identification. If market prices were endogenous and set by the interaction of demand and supply functions, then in general both functions need to be simultaneously estimated. However, during the 1950s and 1960s oil price 'management' by major oil companies made prices essentially exogenous for any one country. Exogeneity of price also applied beyond 1970 for non-OPEC countries--either through adherence to prices set in the world oil market, or through price regulation. For OPEC countries, attempts at price setting made prices partly endogenous, which perhaps accounts for some of the deficiencies evident in the models estimated for these countries (see later). Overall, we are satisfied that with the exception of some OPEC countries we have been able to identify supply functions by model estimation on a stand alone basis.

We start by looking at Model 1 (Part A). There are two main versions of this model, depending on how the time series are expressed. In addition, there are two subsidiary versions for a few countries, intended to test for differences within the estimation periods, and for the relationship between the level of oil prices and technological change. Adjustments were made for outlier values of the dependent variable (reserve additions), notwithstanding the smoothing of certain reserve data discussed in Section 3.

Part B looks at results for Model 2. There were no variations of this model, except the testing of a two period lag for reserve prices. Again, adjustments were made to accommodate apparent outliers.

Models 1 and 2 were also estimated with the price of developed reserves rather than undeveloped reserves.

Conventional Durbin-Watson procedures were used to detect autocorrelation. Where detected, adjustments were made to parameter estimates, assuming first order autocorrelation. No formal test was made for heteroscedasticity. Visual inspection of the data indicated few if any secular trends that might provoke a systematic change in the variance of the error term over time.

The discussion below, among other things, covers: adjustments to the data in the model estimation exercise; the degree of fit; lagged relationships; autocorrelation; and coefficient signs.

#### **A. Results for Model 1 (Linear Model)**

To recapitulate, the basic specification for Model 1 was<sup>20</sup>:

$$RA = A + b(V-I) + ct$$

where

RA = reserves additions in the given period

t = time

V = value of barrel of developed reserves in the ground

I = development investment per unit of proved reserve.

There are four variants for Model 1. The first employs the straightforward time series data, adjusted as described below. This is termed Model 1A. The second variant, Model 1B, employs three year moving averages for the dependent variable (reserve additions) and for the independent variable, the price of undeveloped reserves. The time variable is aligned to the center of the moving average. The third Model simply splits the time period to which Models 1A and 1B apply. The fourth variant, Model 1D, extends the basic model to include an *insitu* field price-time interaction term.

The results summarized in Table 4-1, which relate to Model 1A and 1B, are for the *preferred choice* among various runs. Such choices mainly related to alternative lags for the reserve price variable. The choice criteria included the degree of fit, the statistical significance of the variables, and the plausibility of their signs.

#### ***Model 1A (Strict Time Series Data)***

**Adjustments to the Data.** As discussed in Section 3, various adjustments were made to the raw data. But where outlier values still emerged for certain years for various countries, dummy variables were inserted in the regression equation. In Table 4-1, the presence or absence of dummy variables for a given country is shown in column 6. Such dummies were confined to the intercept in the regression equation. That is, the dummies related to outlier values for reserve

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<sup>20</sup> See equation (9), Section 2.

additions (RA) , not to the slope coefficient attaching to the imputed value of *insitu* undeveloped reserves (V-I). Separate dummies were assigned to each year in which an outlier was identified.

Dummy variables were inserted in 31 of the 41 sets of country data examined. In other words, some 75 per cent of the countries had apparent outliers. But in most instances one dummy was sufficient, that is, outliers were confined to one year of the data for a given country.

Problems relating to data for the price of undeveloped reserves, V-I, were dealt with directly either via adjustments to the development cost per barrel of reserves, I, as described in Section 3, or by eliminating years for which there were negative values of V-I. The rationale here is that while the value of undeveloped reserves could be zero, in the absence of contingent claims or the like it would not be reasonable to admit negative values. The owner would not pay the developer to acquire the owner's property or the rights to exploit it. Moreover, the *insitu* values of developed reserves, V, were treated as non-negative. An exception would be if developed reserves were on production at a loss (wellhead revenues were less than extraction costs) and there were significant costs to be incurred in shutting down wells. Such situations were not identified in the analysis, dealing as it does with country aggregate data.

Recall that V is calculated from the formula  $0.4(P-C)$ , where P is the field price of oil and C is the operating cost (see Section 3). When average production per well is low, as it would be early in the life of a region under development or when reservoirs are nearing exhaustion, the well production rate sensitive formula (see Section 3) used for calculating operating costs could result in negative values for P-C. Such negative values were suppressed. Thus, for any country, years where net field prices (P-C) were negative were removed from the observations included in the regression analysis. Typically such years were early in the period of analysis where a country was undergoing initial development, or late in the period if wells were approaching exhaustion. As mentioned above, years with negative values for V-I were also removed. This need normally arose where high development costs associated with intensive well drilling were not matched by reserve additions.

**Degree of Model Fit.** Table 4-1 distinguishes between poor, modest and high degrees of fit. The measure is the adjusted  $R^2$  ( $\text{adj}R^2$ ). Poor is defined as  $\text{adj}R^2 < 0.1$ ; modest as  $0.1 < \text{adj}R^2 < 0.5$ ; and high as  $\text{adj}R^2 \geq 0.5$ .

Of the total of 41 country sets, 30 or some 70 per cent had high fits, six were medium, and five were classified as poor. This quite favorable result partly reflects screening--the  $R^2$  was one of the criteria in choosing the so-called best results listed in Table 4-1. Also, several high fits were attributable to the way the dummy variables absorbed the impact of outliers.

**Lagged Price Relationships.** The conventional equation specification makes reserve additions a function of the attributed price of undeveloped reserves (V-I) in that year, and of time. Obviously, changes in reserve additions for a given year might be affected more by changes in reserve prices one or two years prior, rather than just by changes in the current year.

Table 4-1

## Summary of Results for Model 1

	Model 1A						Model 1B					
	Adjusted R <sup>2</sup> (1)	Sign of V - I (2)	Lag of V - I (3)	Sign of Time (4)	Auto Correlation (5)	Dummy Variable (6)	Adjusted R <sup>2</sup> (7)	Sign of V - I (8)	Lag of V - I (9)	Sign of Time (10)	Auto Correlation (11)	Dummy Variable (12)
Abu Dhabi	h	neg	L0	neg*	N	Y	h	neg	L0	neg	Y	Y
Algeria	p	pos	L2	neg	Y	N	h	pos	L0	neg	Y	N
Angola	h	pos	L1	pos	Y	N	h	pos	L1	neg	Y	Y
Argentina	p	pos*	L0	pos	N	N	m	pos*	L0	pos	Y	N
Australia	p	pos	L0	pos	N	N	m	pos	L0	pos	Y	N
Bahrain	h	neg	L0	pos	N	Y	h	neg*	L0	pos	Y	Y
Bolivia	h	neg	L2	pos	N	Y	h	pos	L0	pos	Y	Y
Brazil	m	neg	L1	pos*	N	Y	h	neg	L1	pos*	Y	Y
Brunei	h	pos*	L0	neg	Y	Y	h	neg	L0	neg*	N	Y
Brunei/Malaysia	h	pos*	L0	pos*	N	N	h	pos*	L0	pos*	N	N
Burma	h	pos	L1	neg*	Y	Y	m	neg	L0	neg	Y	N
Cameroon	h	pos*	L1	pos	N	Y	h	pos*	L0	pos*	N	N
Canada	m	pos*	L0	neg	Y	N	h	pos*	L0	pos	Y	N
Colombia	h	neg	L0	pos	N	Y	m	neg	L1	pos	Y	Y
Congo	h	pos	L0	pos*	N	Y	m	pos	L0	pos*	N	Y
Dubai	h	neg	L0	neg	N	Y	h	neg	L1	pos	N	Y
Ecuador	p	neg	L0	neg	Y	N	h	pos	L0	pos	Y	Y
Egypt	h	pos	L2	pos*	Y	Y	h	neg	L1	pos*	N	N
Gabon	h	neg	L0	neg	Y	Y	h	neg	L0	pos	Y	Y
India	h	pos	L1	pos	N	Y	h	pos	L0	pos	N	Y

**Key**

Column (1), (7) p = poor R<sup>2</sup> (<0.1); m = modest R<sup>2</sup> (0.1 - 0.49); h = high R<sup>2</sup> (0.5+)

Column (2), (8) positive or negative; \* = statistically significant at 90% confidence level; some 85% levels included

Column (3), (9) L0 = no lag; L1 = one period lag; L2 = two period lag

Column (4), (10) positive or negative; \* = statistically significant at 90% confidence level; some 85% levels included

Column (5), (11) Y = yes; N = no

Column (6), (12) Y = yes; N = no

Note: V = *in situ* value of developed reserves; I = development cost per unit of reserve

Table 4-1

## Summary of Results for Model 1

	Model 1A						Model 1B					
	Adjusted R <sup>2</sup> (1)	Sign of V - I (2)	Lag of V - I (3)	Sign of Time (4)	Auto Correlation (5)	Dummy Variable (6)	Adjusted R <sup>2</sup> (7)	Sign of V - I (8)	Lag of V - I (9)	Sign of Time (10)	Auto Correlation (11)	Dummy Variable (12)
Indonesia	m	pos	L0	neg	N	Y	h	pos	L0	pos	Y	N
Iran	h	neg	L0	neg	N	Y	h	neg	L0	neg	Y	Y
Iraq	h	pos*	L2	neg	N	Y	h	pos*	L1	neg	Y	Y
Kuwait	h	neg	L0	neg	N	Y	h	pos	L0	neg*	N	Y
Libya	h	neg*	L0	neg*	N	Y	m	neg*	L0	neg*	N	Y
Malaysia	h	pos	L0	pos*	N	Y	h	pos	L0	pos	N	Y
Mexico	h	pos*	L2	neg	N	Y	h	pos*	L0	neg*	N	Y
Neutral Zone	m	neg	L0	neg*	N	Y	h	neg	L0	neg*	Y	Y
Nigeria	h	neg	L1	neg	Y	Y	h	neg*	L0	neg*	Y	Y
Norway	m	pos	L2	pos*	N	N	h	pos*	L1	pos*	Y	N
Oman	h	pos	L0	pos*	N	Y	h	pos	L0	pos	Y	N
Peru	h	pos*	L1	pos	Y	Y	h	pos*	L0	neg	N	Y
Qatar	h	neg*	L0	pos	N	Y	h	neg	L0	neg	Y	Y
Saudi Arabia	h	pos	L0	neg	N	Y	h	pos	L0	neg	Y	Y
Syria	h	neg	L2	pos*	N	Y	m	neg	L1	pos	Y	N
Trinidad	h	neg*	L0	neg*	N	Y	h	neg	L1	neg*	Y	N
Tunisia	h	neg	L0	neg*	N	Y	h	neg	L1	neg*	N	Y
Turkey	h	neg	L0	pos	N	Y	m	pos	L0	pos	Y	N
United Kingdom	p	pos	L1	neg	N	N	m	pos	L0	pos	Y	N
United States	m	pos*	L0	neg*	N	N	h	pos*	L1	neg*	Y	N
Venezuela	h	pos*	L2	pos*	N	Y	h	pos	L1	pos*	Y	Y

**Key**

Column (1), (7) p = poor R<sup>2</sup> (<0.1); m = modest R<sup>2</sup> (0.1 - 0.49); h = high R<sup>2</sup> (0.5+)

Column (2), (8) positive or negative; \* = statistically significant at 90% confidence level; some 85% levels included

Column (3), (9) L0 = no lag; L1 = one period lag; L2 = two period lag

Column (4), (10) positive or negative; \* = statistically significant at 90% confidence level; some 85% levels included

Column (5), (11) Y = yes; N = no

Column (6), (12) Y = yes; N = no

Note: V = *insitu* value of developed reserves; I = development cost per unit of reserve

Accordingly, the basic equation was run with the reserve price variable lagged one year, and then with a two year lag. No clear single specification preference emerged between the zero, one and two year lags. However the preferred results listed in Table 4-1 leaned towards the specification without lags. It appeared in 26 cases, with the remaining 15 split evenly between one and two period lags for the V-I variable.

**Autocorrelation.** As might be expected in dealing with time series data, autocorrelation in the error terms could arise and did arise in several instances. If present and left uncorrected, this could bias parameter coefficients and standard errors. Corrections for first order autocorrelation were made where Durbin-Watson statistics indicated. Autocorrelation was detected in nine countries for the runs summarized in Table 4-1

**Signs: Reserve Price Variable.** The expected sign of the reserve price coefficient was positive: higher reserve prices would encourage reserve additions, other things equal. Of the countries listed in Table 4-1, 18 had negative coefficients for the V-I term. Of these 18, only three were statistically significant at the 90 per cent level. To put it another way: of the 41 sets of country data, approaching one half had perverse negative signs. However, of these the null hypothesis that the coefficient is not significantly different from zero would have been accepted (or not rejected) in all but three cases.

What is notable is that of the 18 countries with negative V-I coefficients, 11 were OPEC or Persian Gulf countries, precisely those countries where either a wealth of reserves or other factors such as production quotas would weaken any link between putative *insitu* undeveloped reserve prices and reserve additions.<sup>21</sup> OPEC countries are not price takers in the world market to the same degree as non-OPEC countries. Hence the framework of Model 1 is not so applicable. Also notable is the fact that the four IEA oil producers included in our sample--the US, UK, Norway and Canada--all have positive V-I coefficients of which two were significant (Canada and the US).

Of the 23 country data sets reported with positive coefficients for V-I, nine or approaching one half were statistically significant.

**Signs: Time Variable.** No *a priori* expectation attached to the sign of the coefficient of the time variable. The supply function could be moving to the left, lowering reserve additions over time, other things equal. Or it could be moving to the right, increasing reserve additions over time. The former would be indicated by a negative sign, the latter by a positive sign. And there could be a mix of effects if sufficient data were available to split the period of analysis--a procedure attempted for four countries (see later discussion of Model 1C).

The positive and negative signs were split almost in half: 20 countries exhibited positive coefficients, 21 negative coefficients. However, of the 41 time coefficients, only 15 were statistically significant. Of these, seven were negative and eight were positive. Hence, of the 21

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<sup>21</sup> This finding is also consistent with evidence of a lack of stable relationships between both futures and spot prices and OPEC production; see Quan [1990, p.87, 127].

negative coefficients, 14 were not statistically significant from zero. In other words, for these countries the null hypothesis that the supply function did not show any distinctive contractionary or expansionary trend during the period of analysis could not be rejected. Of the 20 countries with positive time coefficients, as mentioned eight were in the category where the null hypothesis would be rejected.

These results are brought together in Table 4-2. Only those countries with statistically significant time trends are listed. Of the seven with *negative* coefficients, Abu Dhabi, Libya and the Neutral Zone can be readily discounted in that for reasons mentioned above the model as specified may well be flawed. But of the remaining four, two of those (Trinidad and Tobago and Tunisia) also have perverse signs for the price coefficient. Inclusion of Trinidad and Tobago and Burma in the negative list seems to correspond to the mature degree of development of those countries. The result for the United States is consistent with earlier analysis (Bradley and Watkins [1994] and Adelman [1995]).

Note that a leftward shift in the supply function does *not* mean a country will not continue to add reserves. For a country already endowed with substantial volumes of proved reserves, a lot more reserves may await finding and development. In fact, reserves accruing from development investment can continue over a long period. It is just that the returns from further exploration have started to diminish to a degree that more than offsets continuing technological improvement, or the opportunity to exploit new plays. The US lower-48 states onshore may be a good example of this phenomenon.

The *positive* list includes one South American country--Brazil--and in Asia, Malaysia and Brunei-Malaysia<sup>22</sup>, again not a surprising result. Egypt, Syria, Oman and the Congo represent countries at relatively early stages of development. Norway's status is testimony to the potential for further offshore activity. However, both Brazil and Syria have models with perverse price coefficients.

As seen later, these results are quite robust as to whether Model Type 1 or Model Type 2 is specified.

### ***Model 1B (Moving Average Data)***

This model uses three year moving averages for the dependent variable and for the reserves price independent variable. As mentioned earlier, the time variable was centered at the three year moving average. The salient aspects of the results are summarized in the second panel of Table 4-1. Commentary on Model 1A that applies equally to Model 1B is not repeated here.

**Adjustments to the Data.** Years for which negative values were recorded for the *insitu* reserve price (V) and for the difference between V and development costs (I) were eliminated, as

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<sup>22</sup> Data for Malaysia and Brunei shown separately from 1973 onwards. Prior to 1973, data for these countries are combined as Brunei-Malaysia.

**Table 4-2**

**Shifts in Supply Functions for Model 1**

	<b>Evidence of Contraction</b>		<b>Evidence of Expansion</b>	
	Model 1A	Model 1B	Model 1A	Model 1B
Number of Countries	21	18	20	24
		of which		
Statistically Significant Coefficients	7	9	8	7
Statistically Insignificant Coefficients	14	9	12	17
		<b>Countries with Statistically Significant Coefficients</b>		
	Abu Dhabi* Burma Libya* Neutral Zone* Trinidad and Tobago* Tunisia* United States	Brunei* Kuwait Libya* Mexico Neutral Zone* Nigeria* Trinidad and Tobago* Tunisia* United States	Brazil* Brunei/Malaysia Congo Egypt Malaysia Norway Oman Syria*	Brazil* Brunei/Malaysia Cameroon Congo Egypt* Norway Venezuela

\*countries with perverse reserve price coefficient signs.



for Model 1A. Outlier values for the moving average of reserve additions were handled by inserting dummy variables.

**Degree of Model Fit.** Of the 41 country model sets, the great majority (33) had a high degree of fit (as defined earlier); the remainder (8) had medium fits--there were no poor fits. This seemingly favorable outcome is partly influenced by the quite high incidence of dummy variables accounting for outliers. They entered the equations for 25 countries of the 41, or some 60 per cent.

**Autocorrelation.** This was prevalent; adjustments were required to 28 country equations, or some 70 per cent of the total.

**Lagged Price Relationships.** Given the moving average data employed, only a one period moving average lag was tested. It was preferred in just 13 instances or some 30 per cent of the sample.

**Signs: Reserve Price Variable.** The expected sign is positive. There was a close correlation between the moving average model results and those for Model 1A. Contrary negative signs were recorded in 18 cases (of which many were OPEC or Middle East Gulf countries); four were statistically significant. Of the 23 cases with positive signs, nine were statistically significant. In only six cases did the sign of the reserve price variable switch between Models 1A and 1B.

**Signs: Time Variable.** Recall that no expected sign attaches to the time variable--a positive sign indicates an outward shift in the supply function, a negative sign an inward contraction. The results are reasonably compatible with those for Model 1A, and are shown in Table 4-2. The main differences are a somewhat smaller number of countries with *negative* coefficients (18 compared with 21). However, more of these are statistically significant (9 compared with 7). Two OPEC countries (Kuwait and Nigeria) join the list, as do Brunei and Mexico. Abu Dhabi and Burma are dropped, compared with Model 1A. However, as for Model 1A most countries (Brunei, Libya, Neutral Zone, Nigeria, Trinidad and Tobago, Tunisia) in the negative group have models with perverse price signs.

For countries with significant *positive* coefficients, compared with Model 1A Malaysia, Oman and Syria are dropped; Cameroon and Venezuela are added. Two countries (Brazil and Egypt) have perverse price coefficients. At first glance it might seem that Venezuela--an OPEC country--might be an unlikely candidate in light of strictures mentioned above about the applicability of the basic model to this group. However, Venezuela produces at a rate in relation to reserves more commensurate with commercial ratios and hence is less likely to be affected by any omitted variables.<sup>23</sup> The result is consistent with the apparent degree of remaining prospectivity the country enjoys. But budget constraints have affected the rate of activity in the past, and may continue to do so.

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<sup>23</sup> Algeria is another OPEC country with a relatively low R/P ratio, but one where the sign of the time variable was negative, although insignificant.

### ***Model 1C (Split in Sample Period)***

The sample period may mask important shifts in the supply function. For example, it may be that there has been a shift between a positive and a negative time relationship. Or it may be that the magnitude of the time coefficient was markedly different within the sample period, although of the same sign. For example, recent technological changes may have slowed down the degree to which a supply function would be moving to the left.

To test for shifts in the supply function within the period of analysis four countries were selected where the time coefficient was statistically significant, where the reserve price variable had a positive sign, where the degree of fit of the equation was reasonable, and where breaks in the time series observations did not make testing within a period awkward.

The four countries so selected were: Egypt, United States, Venezuela, and Mexico. The break point selected to bifurcate the two periods for testing was 1977-1978. Many series run from 1960 or so to 1994. The year 1977 thus was a typical midpoint. But more importantly, it was a year when some of the stimulus that the first oil price shock may have had on technological development and hence on modifying the supply function could have started to emerge.

Thus the time period was split between pre 1978 and post 1977. Separate models were run for each period. Chow tests were made to determine whether there was evidence of a significantly different time coefficients between the two sample periods. Egypt and the US were run using Model 1A; the Mexico and Venezuela test relied on the moving average data model, Model 1B. The results are summarized below:

Country	Null Hypothesis of No Change in Coefficient	Direction of Apparent Shift Between Periods
Egypt	not rejected	neg to pos
US	not rejected	neg to pos
Mexico	rejected	pos to neg
Venezuela	not rejected	pos to more pos

Only Mexico showed a statistically significant change in the time coefficient between periods and this was in the direction of a contraction in the supply function. If valid, it may well reflect a combination of dwindling prospectivity for oil in the main offshore producing regions, inefficiencies in Mexican drilling operations, less reliance on advanced technologies, and constraints on the availability of funds for reinvestment.

The other countries may not have statistically significant results but they nevertheless at least indicate the likely direction of any apparent shift: outwards. This seeming augmentation of

the supply function in the latter part of the estimation period is at least directionally consistent with the degree of cost savings afforded by the recent surge in upstream technological improvements--savings that tend to confound warnings about resource depletion.

### ***Model 1D (Inter-relationships Between Price and Technological Changes)***

The purpose of Model 1D is to test the notion that the incentive for technological change is inversely proportional to the price of oil. Lower prices, or an expectation of lower prices, exert strong pressure to reduce costs. And such cost reductions are most likely to be manifest via improved technology.

An attempt was made to detect these kinds of influences by respecifying the basic Model 1 in the following way. The coefficient attaching to the time variable was broken down in to two components: a non price sensitive coefficient; and a price sensitive coefficient. Hence we write the adjusted model as:

$$RA = a + b(V-I) + (c + dP)t \quad (4-1)$$

where P is the field (wellhead) price of oil. If technology were sensitive to price in the way we have suggested, the expectation is that the sign of the coefficient 'd' would be negative: a reduction in price would lead to an outward shift in the supply function.

The same four countries used for testing the effect on the model time coefficients of splitting the time periods were also used to test specification (4-1) above, namely Egypt, US, Mexico, and Venezuela.

The results were as follows. For the US and Egypt the 'd' coefficient attaching to the product term (price x time) was negative and significant, and the sign and significance of the other coefficient which attached simply to the time term did not alter compared with the basic specification. For Venezuela, the product term coefficient was also negative and significant, but the single time term (c in equation (4-1)) switched sign from positive to negative, although now insignificantly different from zero. In the case of Mexico, the product term was negative but insignificant, as was the sole time term. Beforehand (Model 1B), the latter term was also negative but significant as well.

Overall the (limited) results of the Model 1D specification supported the notion that technological change would be stimulated by lower oil prices.

### ***Results with the Price of Developed Reserves***

As discussed in Section 2, the basic equation for Model 1 was redefined with the price variable set as the price of *developed* reserves, V, rather than the price of undeveloped reserves, V-I (see equation (9a), Section 2). Estimation of the model in this form did not have a great impact on the results.

In terms of Model 1A, there were no changes among the categories of degree of fit. More countries (4) had perverse negative signs for the price coefficient; one country switched from negative to positive. The choice of preferred lags changed for 10 countries, but with no clear pattern. The presence or absence of autocorrelation only changed for two countries.

More importantly, there were no changes in the critical signs attaching to the time coefficients. However, there were four countries for which previously insignificant time coefficients became significant. These were : Algeria and Brunei ( negative); India and Turkey (positive). One country lost significance--Burma (negative).

Much the same pattern of modest changes were recorded for Model 1B, employing moving averages. However, there were some shifts in the time coefficient, with four countries changing from positive to negative, and two from negative to positive. Four countries with previously insignificant coefficients became significant, three to positive significance (Colombia, Malaysia and India), one to negative significance (Abu Dhabi). Two countries became insignificant--United States (negative); Norway (positive).

Model 1C tested for differences between time periods, for the selected four countries. The results using the V specification showed the US as rejecting the null hypothesis, whereas the V-I specification did not reject the hypothesis; the other countries did not change (Mexico rejected; Egypt and Venezuela not rejected). Thus the earlier finding of some evidence of augmentation of supply functions in the later period was upheld and somewhat strengthened.

In contrast, the results for Model 1D - testing for the influence of the level of prices on shifts in the supply function - were more ambiguous. Whereas before the balance of the evidence had been that the lower prices had stimulated cost reductions, with the use of the price of developed reserves, V, as the price variable, no clear pattern emerged.

## **B. Results for Model 2 (Non-Linear Model)**

Estimation of Model 2 consists of two stages. First was calculation of the ratios of the log of (undeveloped) reserve prices (V-I) to reserve additions (RA) by year. This was designated 'x' in equation (10) in Section 2, repeated here:

$$x = \ln(V - I + 1) / RA$$

where

RA = reserve additions

V = value of barrel of developed reserves in the ground

I = development investment per unit of reserve.

Second was the regression of the 'x' values on time:  $x_t = b + ct$  (see equation (11), Section 2). The results are summarized in Table 4-3.

**Table 4-3**  
**Summary of Results for Model 2**

	Adjusted R <sup>2</sup> (1)	Sign of Time (2)	Auto Correlation (3)	Dummy Variable (4)
Abu Dhabi	m	pos*	N	Y
Algeria	h	pos*	N	Y
Angola	h	neg	Y	Y
Argentina	h	neg*	N	Y
Australia	h	pos	N	Y
Bahrain	h	pos	N	Y
Bolivia	h	neg	Y	Y
Brazil	h	pos	Y	N
Brunei	h	pos	N	Y
Brunei/Malaysia	h	neg*	N	Y
Burma	p	pos	Y	N
Cameroon	h	pos	Y	Y
Canada	h	pos*	N	Y
Colombia	h	neg	Y	Y
Congo	h	neg*	Y	N
Dubai	h	neg	N	Y
Ecuador	h	pos	N	Y
Egypt	h	neg	N	Y
Gabon	h	pos	N	Y
India	h	neg	Y	Y
Indonesia	h	pos	N	Y
Iran	h	pos*	N	Y
Iraq	h	pos	N	Y
Kuwait	h	pos*	N	Y
Libya	h	pos	N	Y
Malaysia	m	neg	N	Y
Mexico	m	pos*	N	Y
Neutral Zone	h	pos*	N	Y
Nigeria	h	neg	N	Y
Norway	h	neg	Y	Y
Oman	h	neg	N	Y
Peru	h	pos	N	Y
Qatar	h	pos	N	Y
Saudi Arabia	h	neg	N	Y
Syria	h	neg*	N	Y
Trinidad	h	pos*	N	Y
Tunisia	h	pos	N	Y
Turkey	m	pos	Y	Y
United Kingdom	h	neg*	Y	Y
United States	h	pos*	Y	Y
Venezuela	h	pos	N	Y

**Key**

Column (1) p = poor R<sup>2</sup> (<0.1); m = modest R<sup>2</sup> (0.1 - 0.49); h = high R<sup>2</sup> (0.5+)

Column (2) positive or negative; \* = statistically significant at 90% confidence level;  
some 85% levels included

Column (3) Y = yes; N = no

Column (4) Y = yes; N = no

**Adjustments to the Data.** Outlier values for 'x' were handled by inserting dummy variables. Dummy variables were included for all but three countries.

**Degree of Model Fit.** The great majority of the countries had a high degree of fit, namely 35 out of 41. Of the six remaining countries, one had a poor fit and five had medium fits. However, to a large degree the high fits can be ascribed to the way the dummy variables picked up unusual variations in the reserve price to reserve additions ratio.

**Lagged Price Relationships.** Lagging the price variable by two years had little influence on the results.

**Autocorrelation.** Corrections for (first order) autocorrelation were made where Durbin-Watson statistics indicated. Adjustments were required in 12 cases of the total 41, or for approaching 30 per cent of the countries.

**Signs: Time Variable.** In the Model 2 specification a positive value for the time coefficient indicates the supply function is getting steeper over time, that is, the function is rotating in an inward direction. This is in contrast to Model 1, where a positive time coefficient indicated an outward shift in the supply function. Similarly, with Model 2 a negative time coefficient indicates an expansionary phase (whereas with Model 1 a negative coefficient indicated contraction).

The results for the time variable are shown in Table 4-4. Twenty five countries showed evidence of contraction of which nine countries had a statistically significant coefficient; 16 countries showed evidence of expansion, five significantly so. Of the nine statistically significant 'contraction' countries, four were common to either one or both of the corresponding lists for Model 1; the newcomers were Algeria, Canada, and Iran. Of the five statistically significant 'expansion' countries, four were common to Model 1; the newcomers were the UK and Argentina ( see Table 4-2).<sup>24</sup>

### ***Results with the Price of Developed Reserves***

When the estimating equation relies on V for the price variable rather than V-I (see equation (10a), Section 2), little changes. Three time coefficients that were positive become negative. One insignificant negative time coefficient becomes significant (Egypt); one country with a significant positive coefficient becomes insignificant (Mexico).

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<sup>24</sup> Note that the issue of perverse price coefficients which arose in discussing the results of Table 4-2 for Model 1 does not apply to Model 2. The specification of the first stage of this model calculating the ratio of prices to reserve additions for any year imposes an upward sloping supply curve.

**Table 4-4**

**Shifts in Supply Functions for Model 2**

	<b>Evidence of Contraction</b>	<b>Evidence of Expansion</b>
Number of Countries	25	16
	of which	
Statistically Significant Coefficients	9	5
Statistically Insignificant Coefficients	16	11
	<b>Countries with Statistically Significant Coefficients</b>	
	Abu Dhabi Algeria Canada Iran Kuwait Mexico Neutral Zone Trinidad and Tobago United States	Argentina Brunei/Malaysia Congo Syria United Kingdom

**In summary**, this Section has reported on the results of estimating two models that focus on the essential factors governing reserve additions. The fact that the data are far from ideal (see Section 3) means any results must be treated with caution.

The first model showed several countries had perverse relationships between the (imputed) price of undeveloped reserves and reserve additions. This seemingly indicates model deficiencies. But of these countries, several were OPEC members, countries to which the model is not expected to apply. The critical variable expressing shifts in supply functions over time was statistically insignificant in the majority of cases, suggesting no secular change. Those countries where it was significant were fairly evenly split between expansionary and contractionary phases.

Results for the second basic model were similar. The majority of countries showed little evidence of any systematic shift in the supply function over time. Where significant shifts were indicated, again the countries were fairly evenly divided between expansionary and contractionary modes. The results by country for each of the two basic models were reasonably compatible.

Limited tests for differences within the estimation period displayed some evidence of a shift in an expansionary direction for the latter part of the period of analysis--roughly from 1980 onwards. Tests on a restricted number of countries also revealed some evidence that technological innovation and exploratory productivity were stimulated by lower oil prices.

Respecifying the price variable in the model as the price of developed rather than undeveloped resources did not alter the tenor of the results.



## 5. CONCLUSIONS

**Purpose.** Published analyses of the economics of oil producing countries are generally sparse. The reason is straightforward--lack of consistent and, often even very basic, data. Moreover, the deficiencies are not confined to countries lacking strong data collection agencies, and may be getting worse. It seems US reserve data will now be published only for alternate years.

Yet the essence of whether crude oil supply functions are shifting and if so, in what direction is at the crux of any assessment of the outlook for the world oil industry. Expectations of more stringent supply, especially in non-OPEC countries, often lie behind the view of those who foresee a return to OPEC dominance and strong price increases.

This study has attempted to shed light on this issue by estimating supply functions for 41 countries, using publicly available data. These countries cover a wide range of locations including all the major oil producing regions of the world, except the former Soviet Union. They range from established oil producers, mature oil producers, and more recent entries on the production scene.

**Model Specification.** The essence of the model framework was to relate reserve additions to the *insitu* price of discovered but undeveloped reserves, and to the passage of time. The latter was intended to measure the net impact of changes in 'prospectivity', resource depletion, cost efficiency and technology. It enables a distinction to be made between shifts along the supply function and shifts in the position of the supply function--a fundamental aspect of the research.

Two basic models were specified. The first (Model Type I) was a straightforward linear function relating reserve additions to the price of undeveloped resources and to time. The second (Model Type 2) estimated the slope of a notional non-linear supply function over time and then expressed the slope coefficient series as a function of time.

For a limited sample of countries, tests were made of the impact of splitting the estimation period between earlier and later intervals. The model was also modified to see whether there was any evidence that the level of reserve prices themselves would affect shifts in supply functions. Since the majority of reserve additions typically consist of extensions to already discovered reserves, the price of developed reserves was also used as the price variable in the models.

**The Data.** Model estimation required an extensive effort to gather and assemble data on reserves and reserve additions, production, drilling activity, well costs, development expenditures, operating costs, wellhead prices and other elements for an initial total of 45 countries over a period of time from the mid 1950s to 1994. Insurmountable problems for a few countries led to their deletion from the list, reducing it to 41--still a very considerable number.

Much of the data gathering for the earlier part of the period of analysis relied on previous efforts by M.A. Adelman. In large measure we extended his series forward, and included some revisions to old data. New data was also developed as required. It became obvious that the reserve information for many countries contained a lot of anomalies. Adjustments made to eliminate these were quite frequent and relied heavily on judgment.

We emphasize our concern about the inadequate coverage and poor quality of some of the basic data, especially the time series of reserve additions. It is true that for some countries the data reliability met good standards--for example the US and Canada. But the degree of adjustment for other countries underlined poor collection procedures and even political influences on the numbers, such as the booking of reserves. Moreover, an absence of detail on the components of reserve additions and corresponding costs necessitated reliance on total reserve additions as a surrogate for potential reserves--the preferred focus. And lack of cost information for individual countries forced reliance on data from other sources such as the US.

In this light, the typically cautionary tenor of researchers' comments about data problems and quality apply with peculiar force here. The situation dictated the need for simplicity in model specification. The quality of the data will not support any sophisticated supply modeling techniques, and few simple ones. Hence the quite rudimentary nature of the two types of models we sought to test.

***Estimation Results.*** The results were broadly similar for the two versions of the simple models specified. Several countries showed seemingly perverse effects of higher reserve prices apparently discouraging rather than encouraging reserve additions. This was a suitable reminder that the models specified suffer from the omission of variables needed to adequately explain the supply behavior of some countries. Nowhere is this more apparent than in the case of those OPEC countries with very high reserve-production ratios, mainly the Middle Eastern producers.

However, paradoxically the poor results for many OPEC countries are reassuring. We would be concerned had a model based on competitive responses with countries acting as price takers worked well for OPEC producers marching to a different beat.

When the preferred results of all the models estimated were combined, 26 countries displayed statistically significant shifts in supply functions. These were fairly evenly split between those in an apparent expansionary phase and those suffering contraction. Some of the latter were countries with an especially long production history, such as Burma, Trinidad and Tobago and the US. Some were OPEC producers--again countries where the model specification involving price responses is suspect. Table 5-1 brings together these results.

For any given model run, the critical variable expressing shifts in supply functions over time was statistically insignificant for the majority of countries. This means that in most instances there is no evidence of a distinctive shift in oil supply functions, either towards more

constrained conditions or towards greater abundance. The functions are quite stationary, notwithstanding reserve depletion.

**Table 5-1**

**Countries with Evidence of Contractionary  
or Expansionary Supply Conditions\***

<b>Evidence of Contraction</b>	<b>Evidence of Expansion</b>
Abu Dhabi	Argentina
Algeria	Brazil
Brunei	Brunei/Malaysia
Burma	Cameroon
Canada	Congo
Iran	Egypt
Kuwait	Malaysia
Libya	Norway
Mexico	Oman
Neutral Zone	Venezuela
Nigeria	Syria
Trinidad and Tobago	United Kingdom
Tunisia	
United States	

\* The list is from the combination of Model 1 and 2 results for those countries with statistically significant time coefficients; see Table 4-2 (Model 1) and Table 4-4 (Model 2). Six of the Model 1 countries that were not confirmed by Model 2 had perverse signs for the reserve price coefficient (Libya, Tunisia, Brunei, Nigeria, Brazil, and Egypt).

Excluding OPEC countries (to which the models do not properly apply), those countries showing evidence of contraction account for some 80 billion barrels of the world proved oil reserves or for about one third of total non-OPEC reserves<sup>25</sup>; those countries showing evidence of expansion account for 40 billion barrels, one half of the “contractionary” total.

Tests on a limited sample of countries for differences within the estimation period displayed some evidence of a shift in a more expansionary direction for the latter part of the period of analysis--roughly from 1980 onwards perhaps indicating the influence of new

<sup>25</sup> Source: *Oil and Gas Journal*, date of issue; the non-OPEC reserves include the FSU.

technology. The same limited sample also revealed some evidence that technological innovation, cost efficiency and exploration productivity were stimulated by lower oil prices.

The tenor of all these results was not materially altered when the price of developed reserves, rather than the price of undeveloped reserves, was used in the models.

***Implications for Oil Supply.*** A gloomy outlook for non-OPEC production is not warranted. Several countries are still in an underlying expansionary phase. Others show no evidence of entering period of decline. Moreover, there is slight evidence--based on a limited sample--that contractionary shifts in supply functions may have been mitigated or arrested over the past 15 years or so.

The same limited sample of countries yielded some evidence that the lower the price of oil, the greater the stimulus for cost reduction. If so, recent technological enhancements in the upstream petroleum sector--albeit not well measured as yet--are no surprise. It follows that a sustained period of flat prices may not be associated with a steady deterioration in supply from non-OPEC countries.

We emphasize again that a leftward shift in the supply function does not mean a country will not continue to add reserves. In a country endowed with substantial proved reserves, significantly more oil resources await finding and development. Reserves accruing from development investment can continue over a long period, as has happened in the US. Rather, what a leftward movement indicates is that the returns from further exploration have started to diminish, and are not offset by continuing technological or efficiency improvements, or by the opportunity to exploit new plays.

Generalizations all too often gain currency as precise statements. Nevertheless, we do suggest our overall results can be characterized in the following broad way. Outside of North America, on balance non-OPEC countries have a rightward (expanding) shifting supply function. Reserve additions can increase even with constant prices. North America is probably moving in the contrary direction--contracting: less will be found at a given price. Supply conditions in OPEC countries cannot be depicted by the interaction of conventional supply functions with price; other factors intrude.

***Further work.*** We believe that significant further progress along the lines of this study will not likely emerge from simply pursuing modifications to the kinds of models we have employed. Rather, it will have to await improvements in the underlying supply data base. This could be assisted by a more intense focus on selected countries.

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**APPENDIX A**

**Compendium of Statistical Results**

Table A1: Results for Model 1A

Country	Estimation Period	C	TIME	V-I(i)	RDUM1	RDUM2	RDUM3	RDUM4	AR(1)	Adj. R2	D.W.
Abu Dhabi	65-94	102002.400 (-1.372)	-50.615 (-1.344)	-96.255 (-1.438)	61138.740 (37.822)					0.980	2.285
Algeria	61-94	54576.070 (2.007)	-27.384 (-1.984)	29.224 (1.185)						0.056	1.885
Angola	62-93	-385224.000 (-0.287)	193.109 (0.291)	5.702 (0.538)					0.958 (6.335)	0.664	2.032
Argentina	74-94	-8831.836 (-1.473)	4.508 (1.495)	8.849 (1.863)						0.098	1.380
Australia	73-94	-3404.838 (-0.423)	1.807 (0.446)	0.514 (0.083)						-0.093	2.115
Bahrain	58-94	-96.905 (-0.170)	0.063 (0.220)	-1.656 (-2.524)	94.296 (5.538)					0.532	1.617
Bolivia	74-94	-407.996 (-0.610)	0.213 (0.632)	-0.589 (-1.217)	113.465 (12.030)					0.883	1.501
Brazil	57-94	-26493.190 (-3.643)	13.537 (3.676)	-8.129 (-1.031)	-17.771 (-0.105)					0.434	1.998
Brunei	74-94	1311.421 (0.273)	-0.651 (-0.269)	6.504 (1.963)	1144.943 (7.226)	-31.893 (-0.470)			-0.131 (-0.562)	0.935	1.964
Brunei-Malaysia	56-72	-68254.970 (-5.563)	34.689 (5.568)	262.756 (4.791)						0.666	2.395
Burma	68-94	1167.712 (2.107)	-0.584 (-2.095)	-0.134 (-0.379)	39.756 (8.491)				0.257 (0.697)	0.787	0.993
Cameroon	78-94	-1488.943 (-0.590)	0.753 (0.596)	4.675 (3.120)	220.108 (9.982)					0.927	1.912
Canada	64-88	48040.290 (1.220)	-24.088 (-1.205)	69.304 (2.221)					0.509 (2.058)	0.312	1.220
Colombia	62-94	-4381.889 (-0.531)	2.341 (0.561)	-10.978 (-1.466)	1,353.414 (7.099)					0.714	1.498
Congo	73-94	-6646.223 (-3.677)	3.372 (3.704)	0.670 (0.436)	158.288 (5.808)	106.694 (3.955)				0.768	1.947
Dubai	70-94	7088.512 (0.750)	-3.452 (-0.723)	-8.233 (-1.114)	1050.074 (5.997)	1469.483 (8.404)				0.811	2.248
Ecuador	72-94	18702.690 (0.942)	-9.288 (-0.929)	-10.903 (-0.797)					0.334 (1.557)	0.091	1.796
Egypt	71-94	-33958.080 (-3.150)	17.241 (3.164)	11.500 (1.570)	1510.930 (6.226)				-0.468 (-2.246)	0.740	1.759
Gabon	64-94	3884.997 (0.420)	-1.875 (-0.401)	-8.180 (-1.110)	367.899 (4.273)	-50.338 (-0.607)	624.055 (6.196)		0.559 (3.254)	0.696	2.026
India	70-94	-23965.560 (-1.045)	12.195 (1.055)	10.846 (0.722)	1955.720 (5.398)	2013.657 (5.644)				0.729	1.870
Indonesia	56-94	22217.930 (1.382)	-11.021 (-1.349)	8.789 (0.457)	2111.847 (4.304)	798.497 (1.675)	1461.354 (3.065)	185.767 (0.385)		0.453	1.561



Table B1: Results for Model 1A

Country	Estimation Period	C	TIME	V-l(i)	RDUM1	RDUM2	RDUM3	RDUM4	AR(1)	Adj. R2	D.W.
Iran	56-94	49875.110 (0.675)	-23.961 (-0.638)	-107.274 (-1.166)	41153.940 (17.735)					0.894	2.314
Iraq	58-94	75,773.440 (1.197)	-38.249 (-1.189)	205.485 (2.860)	51740.060 (28.976)					0.961	2.055
Kuwait	56-94	12415.160 (0.491)	-5.719 (-0.445)	-41.411 (-1.361)	9290.119 (11.931)	9306.300 (12.009)	5922.526 (7.848)	25818.430 (34.066)		0.975	2.047
Libya	61-94	53753.710 (2.643)	-26.584 (2.579)	-56.026 (-2.898)	9151.281 (17.037)	8460.012 (15.791)				0.952	1.386
Malaysia	73-94	-47476.800 (-2.671)	24.041 (2.691)	6.691 (0.669)	1109.840 (4.342)	1360.185 (5.967)				0.678	1.964
Mexico	68-94	105846.800 (1.436)	-52.911 (-1.419)	83.406 (1.673)	11744.100 (8.765)	14000.430 (10.422)				0.877	2.127
Neutral Zone	56-94	60197.050 (2.550)	-30.268 (-2.526)	-5.872 (-0.216)	-814.926 (-1.105)	1843.787 (2.561)	1891.467 (2.633)	1036.125 (1.450)		0.408	2.136
Nigeria	68-94	128210.200 (1.193)	-63.997 (-1.181)	-36.875 (-0.868)	-327.566 (-0.410)	2944.691 (5.208)			0.681 (4.494)	0.805	1.405
Norway	76-90	-60202.030 (-1.629)	30.667 (1.647)	18.339 (1.181)						0.157	1.347
Oman	67-94	-22579.350 (-1.914)	11.535 (1.937)	0.977 (0.105)	1911.142 (7.585)	2496.605 (10.038)				0.849	1.765
Peru	74-94	-472.485 (-0.514)	0.252 (0.544)	1.881 (2.465)	202.660 (8.945)				-0.671 (-3.574)	0.818	1.766
Qatar	56-94	-1748.266 (-0.360)	1.027 (0.418)	-13.768 (-2.407)	591.259 (3.844)	1498.287 (9.935)				0.769	1.867
Saudi Arabia	56-94	19281.550 (0.170)	-7.881 (-0.136)	11.962 (0.089)	60394.950 (17.073)	83092.200 (23.101)				0.957	2.255
Syria	73-94	-17798.980 (-2.731)	9.034 (2.750)	-3.585 (-0.841)	670.171 (6.827)	806.744 (8.352)				0.878	2.561
Trinidad	71-94	21913.270 (3.584)	-10.968 (-3.560)	-7.627 (-1.621)	678.340 (6.085)					0.791	1.912
Tunisia	67-94	6450.780 (1.853)	-3.212 (-1.824)	-4.112 (-1.440)	1586.775 (21.378)					0.946	2.196
Turkey	63-94	-953.605 (-0.441)	0.506 (0.465)	-1.093 (-0.555)	216.835 (4.530)	317.558 (6.695)				0.745	1.839
UK	76-94	1480.720 (0.030)	-0.382 (-0.016)	19.970 (0.800)						-0.075	1.857
US	59-92	66491.690 (2.920)	-32.594 (-2.820)	212.794 (2.610)						0.229	1.394
Venezuela	58-94	-23452.700 (-0.657)	12.524 (0.691)	42.671 (1.084)	30070.050 (30.344)					0.966	1.835

t-statistics in parenthesis

Table A2: Results for Model 1B

Country	Esimation Period	C	TIME	MAV_I	MRDUM1	MRDUM2	MRDUM3	MRDUM4	MRDUM5	MRDUM6	AR(1)	Adj.R2	D.W.
Abu Dhabi	65-93	144188.700 (1.729)	-72.182 (-1.711)	-13.109 (-0.187)	20327.910 (24.738)	20184.940 (21.841)	20271.790 (24.542)				0.550 (3.097)	0.983	1.639
Algeria	62-93	36048.520 (1.036)	-18.026 (-1.025)	26.750 (-1.128)							0.654 (-4.199)	0.533	1.420
Angola	64-92	32360.560 (1.128)	-16.387 (-1.124)	12.217 (1.117)	25.278 (0.270)	-4.874 (-0.049)					1.368 (7.511)	0.831	0.848
Argentina	75-93	-27153.560 (-1.441)	13.704 (1.448)	16.297 (2.561)							0.712 (4.316)	0.377	1.344
Australia	74-93	-2829.068 (-0.212)	1.523 (0.228)	0.132 (0.016)							0.570 (2.753)	0.257	1.239
Bahrain	58-93	-184.403 (-0.375)	0.108 (0.432)	-1.866 (-3.189)	52.961 (3.897)	41.259 (3.038)						0.544	1.057
Bolivia	75-93	-285.885 (-0.179)	0.149 (0.186)	0.002 (0.002)	38.762 (7.073)	40.263 (5.787)	38.546 (7.840)				0.507 (1.727)	0.923	1.127
Brazil	76-93	-37682.450 (-4.179)	19.149 (4.227)	-1.598 (-0.234)	43.946 (0.565)						0.225 (0.661)	0.709	1.722
Brunei	74-93	19303.410 (-2.593)	-9.675 (-2.584)	-3.179 (-0.581)	427.845 (4.526)							0.704	2.028
Brunei-Malaysia	57-71	-53114.640 (-7.411)	27.012 (7.425)	188.633 (5.393)								0.792	1.373
Burma	69-93	748.529 (-0.723)	-0.370 (-0.710)	-0.276 (-0.554)							0.714 (3.380)	0.396	2.595
Cameroon	78-93	-13721.280 (-3.237)	6.872 (3.233)	15.056 (6.597)								0.821	2.045
Canada	64-88	-231805.100 (-0.385)	-116.640 (0.387)	-107.436 (3.253)							0.294 (6.391)	0.778	1.698
Colombia	66-93	-36713.390 (-1.434)	18.668 (1.449)	-12.568 (-0.866)							0.588 (2.496)	0.439	1.330
Congo	73-93	-10095.870 (-3.591)	5.113 (3.617)	1.994 (0.717)	69.709 (0.681)							0.385	0.523
Dubai	72-93	3650.751 (0.402)	-1.667 (-0.363)	-15.915 (-2.201)	769.700 (5.217)	759.213 (5.077)						0.720	1.843
Ecuador	73-93	-63498.300 (-0.811)	31.947 (0.813)	14.045 (0.962)	139.013 (2.137)	137.576 (1.872)	165.814 (2.256)	107.098 (1.672)			0.810 (5.998)	0.703	1.888
Egypt	71-93	-71732.730 (-8.567)	36.428 (8.621)	-14.114 (-2.153)								0.774	1.528
Gabon	66-93	13.664 (0.001)	0.120 (0.025)	-15.104 (-1.805)	137.140 (2.140)	53.112 (0.838)					0.684 (4.182)	0.652	1.284
India	70-93	-32278.480 (-1.460)	16.427 (1.476)	3.365 (0.234)	595.955 (1.990)	585.864 (1.976)	551.762 (1.879)	945.161 (3.260)	948.162 (3.252)			0.541	1.385
Indonesia	58-93	-10430.020 (-0.536)	5.454 (0.554)	15.213 (0.892)							0.625 (7.842)	0.635	1.320

Table A2: Results for Model 1B

Country	Estimation Period	C	TIME	MAV_I	MRDUM1	MRDUM2	MRDUM3	MRDUM4	MRDUM5	MRDUM6	AR(1)	Adj.R2	D.W.
Iran	59-93	28928.580 (0.282)	-13.112 (-0.252)	-183.184 (-1.812)	14024.810 (13.148)	13209.480 (11.029)	13363.180 (12.414)				0.606 (3.982)	0.929	2.193
Iraq	59-93	71949.280 (0.760)	-36.147 (-0.753)	146.369 (1.663)	17626.420 (20.834)	18205.090 (18.987)	17637.870 (20.562)				0.657 (4.398)	0.972	1.677
Kuwait	57-93	61069.580 (2.096)	-30.164 (-2.037)	-58.765 (-1.616)	5229.974 (6.375)	8338.473 (10.236)	8262.670 (10.224)	9030.520 (11.294)				0.905	1.553
Libya	62-93	95230.490 (2.582)	-47.322 (-2.530)	-92.222 (-2.678)	5224.285 (6.021)	5368.176 (6.206)						0.810	1.655
Malaysia	74-93	-8734.873 (-0.701)	4.535 (0.723)	0.750 (0.111)	643.494 (4.637)	398.420 (3.042)	350.646 (2.623)					0.677	2.334
Mexico	68-93	127599.300 (1.705)	-64.184 (-1.695)	223.604 (3.288)	6804.649 (4.606)	6356.302 (4.086)						0.776	1.699
Neutral Zone	58-93	54213.780 (1.964)	-27.181 (-1.941)	-17.907 (-0.632)	183.637 (0.573)						0.561 (3.567)	0.633	1.569
Nigeria	69-93	207535.800 (2.644)	-103.453 (-2.616)	-159.740 (-3.059)	95.495 (0.159)	585.609 (0.864)	581.227 (0.968)				0.549 (4.121)	0.818	0.810
Norway	81-93	-354236.200 (-4.051)	178.576 (4.062)	106.795 (3.143)							-0.175 (-0.649)	0.707	2.215
Oman	69-93	-26579.160 (-0.891)	13.545 (0.904)	1.937 (0.095)							0.574 (4.070)	0.521	2.299
Peru	74-93	258.524 (0.185)	-0.123 (-0.174)	5.394 (4.674)	-11.692 (-0.617)	44.094 (2.179)						0.708	1.854
Qatar	58-93	6102.229 (0.536)	-2.918 (-0.505)	-15.530 (-1.462)	237.470 (2.436)						0.662 (4.712)	0.664	1.494
Saudi Arabia	57-93	44195.300 (0.578)	-20.766 (-0.534)	93.863 (1.093)	22285.020 (11.552)	19566.340 (10.128)	20789.580 (10.759)	26895.780 (13.557)	27860.890 (13.978)	28198.270 (14.089)		0.959	0.927
Syria	75-93	-73706.750 (-0.699)	37.173 (0.703)	-2.172 (-0.153)							0.793 (3.180)	0.448	1.727
Trinidad	73-93	8827.689 (2.111)	-4.405 (-2.094)	-0.533 (-0.184)							0.318 (3.727)	0.723	1.610
Tunisia	68-93	11675.400 (1.701)	-5.842 (-1.682)	-1.966 (-0.363)	-36.989 (-0.293)	-77.663 (-0.646)	458.077 (3.824)	440.816 (3.670)				0.555	2.042
Turkey	64-93	-2317.924 (-0.173)	1.177 (0.175)	2.744 (0.811)							0.870 (8.518)	0.812	1.664
UK	76-93	-70057.210 (-1.350)	35.531 (1.363)	31.930 (1.124)							0.352 (3.820)	0.459	2.425
US	76-93	111162.000 (2.581)	-55.286 (-2.527)	251.842 (2.422)							0.506 (2.751)	0.589	1.384
Venezuela	59-93	-78282.750 (-1.691)	40.198 (1.717)	57.373 (1.376)	-1338.595 (-3.094)	8868.218 (17.701)	9657.995 (19.186)	10137.220 (23.055)			0.597 (3.585)	0.980	1.596

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**Table A3: Results for Model 2**

	Period	C	TIME	ADUM1	ADUM2	ADUM3	AR(1)	Adj.R2	D.W.
Abu Dhabi	63-94	-0.185 (-2.119)	0.000 (2.151)	0.010 (4.253)				0.421	1.656
Algeria	61-94	-0.591 (-3.594)	0.000 (3.624)	0.144 (30.307)	0.091 (18.836)			0.975	1.907
Angola	62-93	0.392 (0.290)	0.000 (-0.278)	0.081 (7.106)			0.625 (4.276)	0.637	1.621
Argentina	74-94	0.780 (2.321)	-0.000 (-2.289)	0.171 (35.456)	0.176 (36.550)			0.992	1.885
Australia	73-94	-0.556 (-0.531)	0.000 (0.547)	0.224 (13.910)				0.901	2.127
Bahrain	58-94	-43.127 (-0.963)	0.022 (0.976)	10.319 (6.999)	2.705 (1.813)			0.585	2.061
Bolivia	74-94	26.239 (0.904)	-0.010 (-0.897)	0.853 (7.776)			0.649 (3.465)	0.657	1.395
Brazil	57-94	-0.087 (-0.181)	0.000 (0.200)				0.205 (4.513)	0.480	1.646
Brunei	73-94	-0.930 (-0.154)	0.001 (0.164)	1.318 (14.229)				0.906	1.602
Brunei-Malays	56-72	2.312 (3.828)	-0.001 (-3.810)	0.007 (1.153)				0.464	1.923
Burma	68-94	-7.946 (-0.794)	0.004 (0.815)				0.077 (0.620)	-0.032	1.426
Cameroon	78-94	-1.047 (-0.176)	0.001 (0.184)	0.138 (3.809)			0.463 (1.525)	0.625	1.534
Canada	64-88	-0.165 (-2.011)	0.000 (2.044)	-0.001 (-0.415)				0.103	1.232
Colombia	62-94	0.178 (0.083)	-0.000 (-0.074)	0.534 (29.287)			0.582 (3.136)	0.963	2.150
Congo	73-94	12.558 (6.371)	-0.006 (-6.339)				-0.199 (-1.527)	0.554	0.865
Dubai	70-94	1.983 (1.294)	-0.001 (-1.281)	3.132 (110.144)				0.998	1.427
Ecuador	72-94	-0.665 (-0.116)	0.000 (0.126)	0.553 (5.904)				0.602	2.181
Egypt	71-94	1.229 (1.504)	-0.001 (-1.487)	0.212 (14.846)				0.907	2.121
Gabon	64-94	-0.203 (-0.163)	0.000 (0.182)	1.243 (39.075)				0.981	1.843
India	70-94	0.715 (0.646)	-0.000 (-0.637)	0.038 (4.303)			0.432 (1.615)	0.581	1.646
Indonesia	56-94	-0.655 (-1.099)	0.000 (1.113)	1.248 (58.124)				0.989	1.942

**Table A3: Results for Model 2**

	Period	C	TIME	ADUM1	ADUM2	ADUM3	AR(1)	Adj.R2	D.W.
Iran	56-94	-0.067 (-1.840)	0.000 (1.881)	0.031 (23.585)	0.025 (18.900)	0.026 -19.446		0.970	1.513
Iraq	56-94	-0.364 (-1.558)	0.000 (1.581)	0.143 (17.021)				0.883	2.259
Kuwait	56-94	-1.224 (-1.688)	0.001 (1.700)	0.321 (12.289)				0.803	2.201
Libya	61-94	-0.439 (-1.045)	0.000 (1.061)	0.086 (7.018)	0.092 (7.487)			0.755	1.692
Malaysia	73-94	0.955 (1.549)	-0.000 (-1.531)	0.019 (1.967)				0.231	2.326
Mexico	68-94	-0.123 (-1.886)	0.000 (1.910)	0.004 (3.313)	0.003 (2.472)			0.417	1.412
Neutral Zone	56-94	-2.915 (-2.750)	0.001 (2.770)	1.299 (33.986)				0.969	1.744
Nigeria	68-94	0.036 (0.061)	-0.000 (-0.049)	0.067 (5.369)				0.509	1.872
Norway	76-88	1.0328 (1.324)	-0.001 (-1.323)	0.002 (2.351)			0.694 (4.004)	0.795	2.856
Oman	67-94	0.775 (0.775)	-0.000 (-0.761)	0.356 (16.181)				0.906	1.371
Peru	74-94	-3.285 (-0.400)	0.002 (0.409)	0.898 (7.639)				0.738	2.211
Qatar	56-94	-0.717 (-0.624)	0.000 (0.642)	1.148 (27.717)				0.954	1.945
Saudi Arabia	56-94	0.008 (0.334)	-0.000 (-0.302)	0.024 (28.147)				0.954	2.203
Syria	73-94	5.942 (1.667)	-0.003 (-1.653)	1.015 (18.544)				0.944	1.746
Trinidad	71-94	-2.359 (-2.392)	0.001 (2.419)	0.077 (4.453)				0.541	1.693
Tunisia	67-94	-2.700 (-1.062)	0.001 (1.082)	1.046 (18.746)	0.885 (15.874)			0.956	2.170
Turkey	63-94	-2.606 (-0.495)	0.001 (0.507)	0.150 (3.197)			0.556 (2.952)	0.413	2.315
UK	76-94	0.255 (1.645)	0.000 (-1.629)	0.118 (119.295)			0.369 (1.621)	0.999	1.873
US	60-92	0.00 (-0.191)	0.000 (0.201)	0.000 (5.885)	0.001 (9.736)		0.883 (4.996)	0.849	1.049
Venezuela	56-94	-0.052 (-1.298)	0.003 (1.329)	0.035 (24.639)				0.946	1.651

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