Analyzing Oil Production in Developing Countries: A Case Study of Egypt

*Nazli Choucri, Christopher Heye and Michael Lynch**

This article presents a detailed simulation analysis of the domestic oil sector in Egypt; a near-typical, non-OPEC, oil-producing developing country. Egypt is a small producer by international standards, yet significant enough that its oil production is important for the country's economy and, under certain conditions, for the international oil market as well. A dynamic computer simulation model that depicts significant characteristics of the country's oil sector is utilized to explore the implications of alternative scenarios for government policies, world oil prices, and geological parameters on patterns of production, exports, and export earnings.

INTRODUCTION

The events of the 1970s contributed to a significant reorganization of international economic relations and, more broadly defined, of power politics. For nearly a decade, OPEC successfully exercised influence over world energy markets; shaping prices, as well as many parameters, on the supply side of the oil market. The political ramifications of OPEC's influence were far-reaching as well. These oil-producing developing countries exercised greater decision-making authority within their own borders, and considerably more influence internationally, than at any other period in modern history.

However, this new influence has not been realized without a cost to other developing countries. Most newly industrializing states witnessed a substantial increase in their total import bill during most of the 1970s and early 1980s. Changes in world oil prices not only influenced the energy component of imports, but seriously affected the acquisition of other goods, i.e., agricultural as well as manufactured commodities. The ability of most countries to meet higher prices was further curtailed (in much of the 1970s and early 1980s) by a slackening of aggregate demand in the OECD countries, which contributed to reduction of imports from the developing countries.

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*Massachusetts Institute of Technology, Cambridge, Massachusetts.

But there were also positive effects. Higher energy prices increased incentives for, and potential economic gains from, greater domestic exploration and production.[1] By 1981 world oil prices stood over 500% higher, in real terms, than in 1970; and oil (as well as other energy) production became profitable in many areas in which it had previously been unthinkable. Since 1973, many developing countries have explored for oil. Approximately 40 non-OPEC industrializing countries now produce crude oil to a significant degree, up from 14 in 1967. Comprising less than 8% of non-communist crude oil production in 1972, non-OPEC, non-OECD countries accounted for nearly 20% of all non-communist crude supply by 1988.[2] Having attained more than simple oil self-sufficiency, many developing countries, such as Angola, Syria, Malaysia, Tunisia and Mexico, have recently become oil exporters of some note.

The impacts of these developments are perhaps nowhere more evident than in Egypt. The productivity of the Egyptian oil sector has risen dramatically throughout the 1970s and 1980s. Since 1974, crude oil output in Egypt has roughly quadrupled, while export volumes and real revenues have increased 10 and 20 fold, respectively. But Egypt still encounters serious balance of payment difficulties. Between 1973 and 1985, the cost of all Egyptian imports rose by a factor of four in real terms, and by 1987 they represented over 23% of the country's total GNP.[3] In addition, Egypt's foreign debt continues to be one of the region's highest: roughly $40 billion in 1989. Because the oil sector is currently operating at near full capacity, Egypt, unlike many of its OPEC neighbours, cannot significantly augment output in order to offset current account revenue shortfalls. Any barrel consumed domestically -- and consumption in Egypt is increasing rapidly -- is a barrel not exported, depriving Egypt of foreign exchange. Like many other developing nations, Egypt is seeking to strike a balance between crude oil production, domestic consumption, and export revenue, while also seeking to maintain internal political harmony.

There are opportunity costs associated with this balancing act: controlling domestic oil consumption has become a particularly thorny issue for many countries, sharpening the trade-off between consumer quiescence and export earnings. This trade-off is complicated by a system of governmentally controlled domestic energy price supports. Many states have experienced rapid increases in domestic demand, and those which have been able to regulate consumption increases have been largely successful in improving their export earnings. Faced with the high rates of growth in consumption, the government has recently raised domestic prices in an

1. See *Petroleum Economist*, 1988.
2. *British Petroleum Review of World Energy*, 1989.
3. International Monetary Fund, 1989.

attempt to curtail this explosive growth and re-allocate resources more effectively. (This adjustment invariably provokes political opposition.)[4]

THE SIMULATION APPROACH

To examine the multiple challenges confronting small oil producers, the authors have developed a dynamic computer simulation model, designed to represent both the fundamental characteristics of energy production and the framework for relevant public policy interventions. The Egyptian Petroleum Model (EPM) is a dynamic analytical tool; simulating the processes of production, exportation, and domestic consumption of crude oil for a developing, oil-exporting state with limited reserves. Currently producing about 900 thousand barrels per day, Egypt is not at liberty to expand production in the short term. Egypt's oil reserve position implies crude oil supplies of only 12-15 years at current rates of crude production.[5] Egyptian energy consumption has also expanded markedly: annual increases in demand are outpacing increases in domestic production. These constraints provide formidable economic and political obstacles for countries like Egypt at a time when people are tending to expect more from their governments and the performance of the domestic economies, rather than less.

Method

The immediate purposes of the EPM are to explore three issues central to public policy: (i) the impacts of domestic energy pricing (affecting consumption directly); (ii) the impacts of international oil prices (affecting export earnings); and (iii) the consequences of geological uncertainties (influencing crude reserve positions).

The simulation method employed is system dynamics: a modelling approach developed at MIT,[6] drawing upon the intellectual world view associated with general systems theory, systems analysis, and cybernetics.[7]

4. This article can best be viewed in the context of related studies of small oil-exporting developing countries. See especially Choucri, 1982, pointing to the obstacles to development in Latin American countries whose demographic profiles, resource endowments and financial positions, in many cases, remain strikingly close to those in Egypt. See also *World Bank Staff Working Papers*, 1984; deLucia and Jacoby, 1982; Choucri, 1982; Fesharaki et al., 1982; Pachauri, 1977; Ebinger, 1981; Adelman, 1985; Alm and Weiner, 1984; Morse, 1986; Nasl, 1984; Pindyck, 1979.

5. However, this figure fails to include any new discoveries which will certainly occur in the future. It is likely that, as a result of new discoveries and increasingly effective enhanced recovery techniques, Egypt will be capable of producing oil well beyond this horizon. Still, its current reserve position remains less favourable than may of its OPEC neighbours.

6. See Forrester, 1968, 1961, and 1971; Meadows et al., 1972; Choucri and Robinson, 1978; Alker, 1981.

7. See Wiener, 1961; Cortes, Przeworski and Sprague, 1975; and Deutsch, 1963.

These approaches all share an emphasis on the importance of understanding the *structure* of a given system, the consequences of structure on the *behaviour* of the actors, and the *processes* which operate to define the characteristics of that system. They all assume that behaviour systems are dominated by non-linear *feedback* relations, characterized by a high degree of *endogenous* connections among variables, with causal relations between variables frequently operating in both directions. The distinction between *dependent* and *independent* (as well as *endogenous* and *exogenous*) variables, so crucial in econometric analysis, is less salient in system dynamics models.

Despite their often rather simple structure, feedback systems are capable of producing very complex patterns of behaviour. They may be de-stabilizing, producing exponential behaviours (often characteristic of population growth), or they may be self-correcting (displaying stable output like temperature readings in a room regulated by a thermostat). Shifting balances of a model's positive and negative non-linear feedback relations over time produce its observed patterns of behaviour. Behaviour that appears linear over a given interval may become exponential or cyclical in another period as unstable feedback loops dominate stable ones. System dynamics models are predicated on the analysis of functional relationships within a feedback system and not, as is common in econometrics, on the analysis of stochastic relationships. Because linearity is usually assumed in econometric research, and multi-collinearity avoided by statistical necessity, system dynamics modellers assert that statistical specifications are unlikely to adequately capture the assumed feedback dynamics, and that the resulting "best fit" equations can only imperfectly reproduce actual structure-driven behaviour.[8]

Dynamic Behaviour and Policy Analysis

Written in system dynamics, the EMP is a *simulation* model, not an optimization or estimation model. The flexibility of system dynamics makes it especially well suited for the analysis of alternative scenarios based on conditional assumptions about initial conditions (i.e. oil reserves) or parameter values (i.e., development costs). Primarily concerned with the overall behaviour of a system over time, it is used for policy testing to discern how interventions will alter the system behaviour over the simulation horizon.

Distinctive features of system dynamics as a modelling approach make it especially suitable for analyzing energy markets. The structure of oil production -- the relationship from investment in exploration, to development, to production, to sales, to investment in exploration, etc. -- exhibits strong

8. In theory, the two methodologies need not be mutually exclusive -- system dynamics models can benefit from stochastically determined parameter estimates, while econometric models can incorporate feedback-like structures -- but in practice their integration is rather limited.

feedback characteristics. Causal relations run in both directions (e.g., from investment to sales and back to investment), and responses are frequently non-linear. Furthermore, negative feedback loops are often described as "goal seeking," implying that certain systems are constantly striving to meet desired levels of a "stock" variable. Because oil production usually entails operating at a "desired" level of capacity utilization, setting in place a "desired" amount of new capacity or making a "desired" amount of new investment, loops specifying these relations in terms of dynamic feedback appear particularly appropriate.

THE EGYPTIAN PETROLEUM MODEL

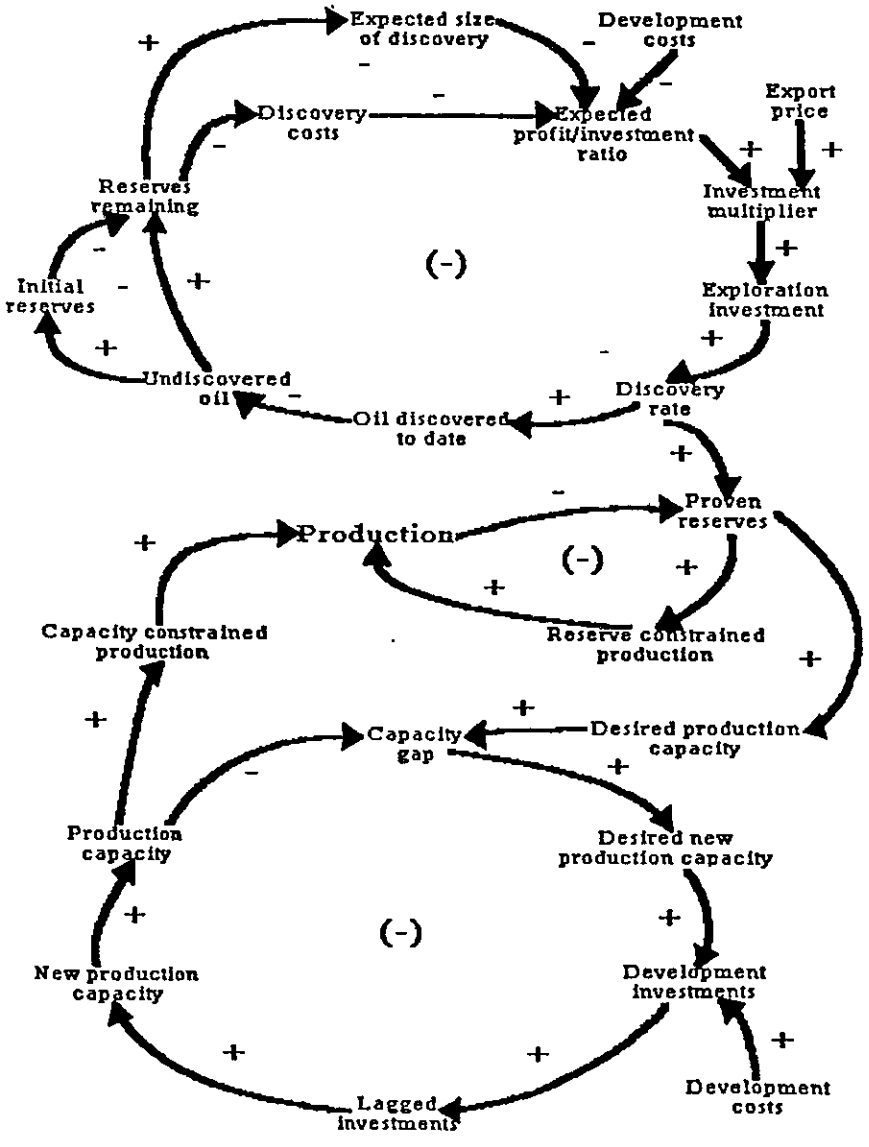
The Egyptian Petroleum Model depicts geological and geographical characteristics, exploration and development decision-making, and production sharing agreements, as well as estimates of oil output, demand, prices, and exports. Key inputs such as domestic and world crude oil prices, domestic economic growth, oil investments, and reserve levels may be adjusted by the user in order to explore the effects of a multiplicity of alternative factors influencing the oil industry in Egypt.

EPM is a specialized application of a generic simulation model of the world oil market developed at MIT (Choucri, 1981), drawing upon rich descriptions of oil production processes and the decisions that govern petroleum production (Adelman, 1972). While EPM is a detailed, parameterized model of one country -- its unique geological conditions, exploration and investment regimes, production possibilities, and the influence of international and domestic oil prices -- it also provides a framework for analysis of other small oil producers, given attendant parameter changes and re-specifications of functional forms where necessary.

Model Structure

EPM integrates in one analytical framework the factors that influence oil production in Egypt. The model is composed of four oil-producing *regions*, disaggregated geologically (Gulf of Suez, Western Desert, North Sinai, and Other Egypt), and two sets of *actors* as decision-makers and investors (international oil companies and the Egyptian government), in order to represent the characteristics of oil production. The overall causal relationships in Figure 1 are presented as a guide to the model description in the following sections.

Figure 1. Simplified Causal Relationships of the EPM



Regions and Actors

The model is disaggregated by *geological* region due to differences in the structure of costs and opportunities. Costs are a function of infrastructure and accessibility, as well as actual field characteristics (such as depth, size, and flow rate). These attributes tend to vary by region. Therefore, separate accounting procedures are appropriate for each region. Within each geological region a further differentiation is made by actor in terms of *foreign oil company* and *governmental agent*. Both groups are active in the Egyptian petroleum industry but differ markedly in their production goals and operational strategies. Motivated by profit, the international oil companies generally seek to maximize return on their investments. By contrast, the Egyptian government has a variety of developmental and social concerns beyond generating revenues from its oil sales.

Exploration Decision-making

The supply of petroleum in EPM is determined by the desire to produce crude oil, indicated by the actors' investments in oil exploration activities. The model assumes that oil discovered will be produced at some point in the future. Exploration for new reserves is made by both foreign oil companies (corporate investments) and the Egyptian government (government investments). The discovery rate at which new reserves are added to the existing reserve base is calculated as the quotient of exploration investments divided by the per barrel cost of exploring for oil. Corporate exploration investments are specified to be a function of an endogenously determined feedback mechanism relating the expected profit to investment ratio, to actual investments. This ratio is determined by the expected costs of future production and the expected value of the oil companies' share of future oil revenues.

Reserve Calculations

Proven reserves is the amount of oil estimated (with a high level of certainty) to be in the ground at any given point. Undiscovered oil is a more subjective quantity, namely the amount of recoverable oil which might be discovered and added to the reserve base at some point in the future. EPM estimates both for reserves and undiscovered oil; and the model is designed to simulate the process generating new discoveries -- depleting the stock of undiscovered oil and adding to the level of proved reserves. Thus, for each region, reserves in the current period equal the level of reserves existing in the previous period, plus new discoveries, less current production.

Development Decision-making

Corporate investment behaviour towards development is better understood than corporate investment behaviour towards exploration. Once crude oil has been discovered, the uncertainty surrounding production is greatly reduced. Development investments are calculated as the product of desired new production capacity additions and the per barrel cost of installing the new capacity. Desired new production capacity is the gap between current levels of total production capacity and desired levels of total capacity. (The gap between actual and desired capacity reflects the discrepancy created by any increase in proved reserves available for development, as well as by the depreciation of old production capacity stock requiring replacement.) Desired production capacity is therefore assumed to be 6.7% of reserves in a given area, with a slight upward adjustment being made for expected production shortfalls due to maintenance, bad weather, etc. This assumption reflects the industry rule of thumb that the optimal production level is roughly one-fifteenth of reserves.

Production

Given Egypt's desperate need for oil revenues, the EPM assumes that production will be maintained at full capacity. Therefore, production in every region is set as proportional to capacity, less 10% as a maintenance factor.[9]

Production Sharing Agreements

Since August 1973, Egypt has been engaged in production sharing contracts in its concessions to oil companies. The standard contract divides oil produced into cost recovery and production sharing oil, with the allocations varying from contract to contract. In most cases, a maximum of 40% of oil produced is reserved for costs recovery; although the exact allocation depends on expected costs of oil, and world prices at the time of production. In recent years, approximately 10% of the oil produced in Egypt has gone to cost recovery, with the remaining 90% going to production sharing. Overall, an 80/20 split in favour of the government is standard in production-sharing contracts.

9. An exception to this rule occasionally occurs when, as a result of the delayed response of changes in total production capacity to changes in the reserve base, 90% of total capacity exceeds the Maximum Efficient Rate (MER) in a given area. Under these circumstances, production is limited to the product of the MER and total proven reserves.

Domestic Demand

Once the oil shares have been apportioned, the Egyptian share goes to domestic demand and exports. Oil consumption is modelled fairly simply as a function of domestic prices, economic growth, and income elasticity. (Income elasticity is estimated from past economic growth and demand, and appears to be approximately 1.)[10] Historical estimates of Egyptian economic growth (based largely on United Nations' estimates) are exogenous inputs for the period 1970-1986, and range from 4-10%. Real economic growth for the remainder of the simulation horizon has been assumed at an annual rate of 6%.

Exports and Government Oil Income

Once domestic consumption is met, the remaining government oil share is exported. Since crude oil products offered for domestic consumption are priced exceptionally low, the Egyptian government now receives virtually no income from these domestic sales. (Price changes altering this outcome could be easily accommodated in scenario analyses.) Government oil income is set as a function of the volume of crude exports multiplied by the existing world oil price.

Exogenous Variables

Despite its highly endogenous nature, several important exogenous variables are required to complete the model structure: (1) prices, (2) costs and (3) reserve levels.

1. Both the price Egypt receives for its exports, and the subsidized domestic price, are exogenous. The export price largely reflects world oil market conditions. The domestic price, on the other hand, is a political variable, subject to change by government fiat rather than market mechanisms. EPM utilizes values of Egypt's medium grade Belayim crude oil as a proxy for an average export price. Historical values for Belayim crude were estimated from the *OPEC Bulletin* and *Petroleum Intelligence Weekly*; forecast figures are obtained from the most recent base case forecast of the International Petroleum Exchange (IPE) model.[11] World prices affect exploration decisions directly, and these exploration decisions, in turn, reverberate throughout virtually

10. Abdel-Chalek, 1988, pp. 47-58.
11. See Choucri with Ross, 1981.

every major aspect of the model. Changes in the export price of oil influence the level of expenditures targeted for oil exploration: higher international prices induce greater expenditure levels while lower prices tend to depress exploration spending. Exploration investments in each region, in turn, govern the rates of oil discovery in the same way: greater investments generate more discoveries, and lower investments yield fewer findings. Domestic oil prices represent a major input into the demand segment of the EPM. A single price for domestic crude oil is used, based on prices calculated in the early 1980s[12] and from the *Middle East Economic Survey* and the *Middle East Economic Digest*.

2. Cost data for both discovery and development, estimated by region, affect the performance of exploration and development variables.[13] Discovery costs influence the volume of oil discovered and added to reserves; development costs govern the amount of oil removed from reserves as production oil. These costs increase as the level of undiscovered oil in a given region is reduced. Development costs are specified to increase over time -- a function of the amount of reserves remaining as well as other technical and economic factors.[14] Development costs are based on historical evidence, while discovery costs are assumed to be roughly 1/4 of the development estimates. Field development costs in Egypt on a country-wide basis are still quite low, roughly on the order of only $1 per barrel. Historical data for these costs are rather sketchy but roughly in line with development costs in neighbouring African and Middle Eastern countries.

3. Initial levels of reserves and undiscovered oil are significant determinants of the future costs associated with discovering new oil as well as the prospective level of actual oil production. Higher levels of undiscovered oil imply lower discovery costs, as well as greater oil production potential in the future, whereas lower levels suggest higher costs and less production.[15] There is, of course, a considerable amount of uncertainty associated with these estimates. The initial figures currently in the base case have been estimated based

12. Abdel-Khalek, 1988, pp. 47-58.

13. Based on official contracts published by the government of Egypt, as released by the Egyptian General Petroleum Corporation.

14. See Choucri with Ross, 1981.

15. Modelled here are actual costs, as opposed to a growth rate in costs.

on data, for various years, from the U.S. Geological Survey, the *Oil and Gas Journal*, and the *British Petroleum Review of World Energy*.

An analytical summary of the EPM model is presented in Table 1 and Table 2 presents a summary of model parameters. A comparison of historical versus simulated production and exports (1970-1986) is presented in Figure 2.

Table 1. Analytical Representation of the Egyptian Petroleum Model*

Supply		
PROD = f(PC,R)	PROD	= production
	PC	= production capacity
R = f(DR,PROD)	R	= reserves
	DR	= discovery rate
DR = f(UND,INVE)	UND	= undiscovered oil
	INVE	= exploration investments
PC = f(DPC,INVD)	DPC	= desired production capacity
	INVD	= development investments
DPC = f(R)		
Demand		
D = f(DP,EG,IE)	D	= Egyptian domestic demand
	DP	= domestic (subsidized) price
	EG	= economic growth
	IE	= income elasticity
Financial Identities		
TOX = CRO + CPSS + EGOX	TOX	= total oil exports
	CRO	= cost recovery oil
EGOX = EPSS - D	EGOX	= Egypt government exports
	CPSS	= company profit-sharing share
TPSO = PROD - CRO = EPSS + CPSS	EPSS	= Egypt profit-sharing share
	TPSO	= total profit-sharing oil

*A full computer listing of the EPM model may be obtained from the authors upon request.

MODEL RESULTS

The remainder of this article is devoted to a discussion and evaluation of the results of seven simulation scenarios for Egypt between now and the turn of the century. Since production levels in Egypt, when not severely constrained by international events as they were in 1986, are highly influenced by public policy, this assessment of alternative futures is particularly

Table 2. Key Model Constants, Initial Values and Parameters

Constants*	
Capacity constraint on production	90% for all regions
Egypt production sharing fraction	80/20
Egyptian income elasticity*	1
Initial Values**	
Undiscovered oil	estimated by region, based on geological estimates
Exploration investments	estimated by region
Development investments	estimated by region
Parameters	
Discovery costs	by region, decreasing function of reserve levels
Development costs	by region, increasing function of time
Domestic prices	policy based estimates
WOrld prices	based on authors' IPE model base forecast
Egyptian economic growth	estimated

*See Abdul-Khalek (1988)

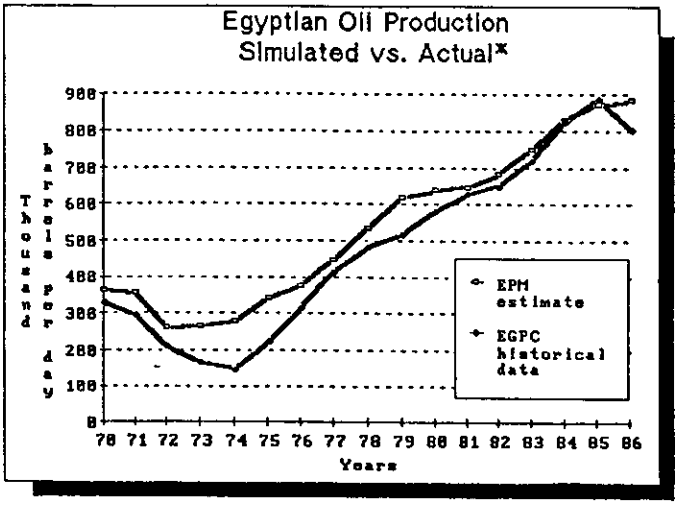
**It is important to note that these initial values themselves are influenced by other variables during a model run. For example, initial investment levels are constantly adjusted over time by changes in world prices.

appropriate. The *base* case is presented first, followed by the results of six *alternative* simulations.

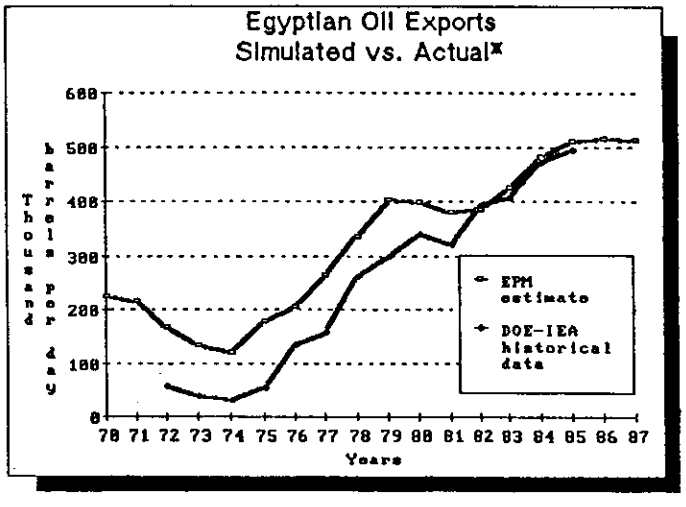
Base Case

The base case assumes continued stability on both foreign and domestic political and economic fronts. The logic is as follows: Egypt will continue to produce oil at approximately the current level for the foreseeable future. The recent Egyptian Five Year Plan seeks to maintain production at roughly 44 million tons (about 880 thousand barrels per day) through fiscal year 1991/92. Egypt is expected to continue working closely with the many foreign companies now operating on its soil to ensure adequate levels of exploration and development. The government is expected to continue its policy of gradually raising domestic prices, but not reaching international prices over the forecast horizon. Energy consumption remains closely tied to economic growth in Egypt (with the elasticity of income remaining at 1), and economic growth itself remains close to historical levels. Further, geological explorations and discoveries are also expected to remain near present levels. Finally, no significant political upheavals are forecast, implying an uninterrupted flow of investment and production. In the base case, therefore,

Figure 2. EPM: Historical Simulation vs. Actual



*Actual data from the publications of the Egyptian General Petroleum Corporation (various years).



*Historical data prior to 1980 have been obtained from Energy Economics Research Limited's World Oil Trade and exclude product exports. These figures also include exports to only 20 industrialized countries, and therefore underestimate the total volumes.

Egypt will sell its entire exports in world markets at the prevailing international price (though this price will continue to remain below what Egypt received for its crude oil only a few short years ago).

The base case shows slight production increases over the next five years, followed by deteriorating reserves and reduced total output. The forecast for future oil supply reflects this production stability and shows a relatively flat trajectory for crude output. Production will increase slightly in the coming years, largely in response to the recovery in export prices and favourable discoveries in the Western Desert area of Egypt. Following a lengthy period of stagnation, or even deterioration, world prices are anticipated to increase gradually in the 1990s in real terms; encouraging more exploration, adding to existing reserves, and somewhat increasing actual production. The recent production gains in the Western Desert -- nearly doubling between 1986 and 1987, from 1.5 million metric tons (30 tbd) to almost 3 million metric tons (60 tbd) -- are projected to continue. (Many analysts now expect this region to supply at least 100 tbd in the near future, and possibly more by the late 1990s.)

Production of crude petroleum is forecasted to peak in the early 1990s, followed by a slow decline for the remainder of the decade. Most of the fall-off occurs in Egypt's largest producing region, the Gulf of Suez, as existing fields begin to dry up, and exploration and development costs increase. Exacerbated by the continued sluggishness in oil prices, this decline deters substantial new interests in oil exploration by depressing investments. Despite this mixed performance, it is important to note that the EPM base case tends to produce somewhat *more* oil than the current Five Year Plan calls for.

Growth in Egyptian domestic oil consumption is expected to continue. Overall, demand will grow by nearly 50% between 1988 and 2000, implying a compound growth rate of nearly 3% per year. Over the same interval domestic prices will roughly double, in real terms, transforming the subsidized price of oil products in Egypt from a little over one-third of world prices today to about two-thirds by the year 2000. The conjunction of increased oil consumption, economic growth, and limited production gains results in a *gradual deterioration of Egypt's export position from its peak in 1985.* Total crude volumes available for export are forecast to decline from 510 tbd, in 1988, to 291 tbd in 2000. However, the government's share of total exports is projected to slide even faster, from 204 tbd (40%) to only 31 tbd (10%), as the government's share of total production diminishes while domestic consumption increases. This base case result is especially troublesome as Egypt now relies on export earnings for approximately 25-30% of all its foreign exchange income and 10-15% of all government revenue.[16]

16. These figures refer to earnings prior to the 1986 price declines.

Alternative International Price Paths

There are obvious contingencies associated with any forecast of international oil prices. We explore the impact of two contending scenarios: a high-price case and a low-price path.

Higher Prices

The high price scenario is based on the view that OPEC is able to re-establish its dominance in world energy markets and, once again, unilaterally raise crude oil prices. The high-price EPM simulation stipulates international prices increasing gradually through 1990, and then rapidly thereafter, reaching a peak of $30 per barrel (1987 dollars) by 1996, and remaining at that plateau through 2000.[17]

Not surprisingly, Egypt would stand to gain substantially from this upsurge in crude oil pricing. Oil production climbs unimpeded through 2000, at which point output is projected to exceed 1 million barrels per day (mbd). At 1.04 mbd production in the year 2000, in this high-price scenario, surpasses the base case figure by roughly 17%. Increased production results primarily from enhanced exploration and development which are results of the higher price levels: rising prices induce more investment, triggering the search for more oil, which in turn permits increased levels of production. While real prices appear considerably higher (more than 60% above the base case estimates), reserve constraints on production, higher costs associated with greater exploration and development, and governmental policy goals, act in concert to limit overall growth in output.

In contrast to the base case, the high-price alternative forecast implies an essentially flat trajectory for government exports (with only a slight decline in the final three years of the simulation period). Higher prices and increased export volumes combine to produce a rather favourable forecast for Egyptian export oil revenues. Foreign exchange earnings from oil exports increase throughout most of the forecast period, in contrast to the base case outlook in which revenues continuously decline. Revenues, through most of the 1990s, appear between 5 and 10 times greater than their base case counterparts, peaking in 1996 at $2.3 billion (1987 dollars). By 2000, oil income received by the Egyptian government is projected to be $1.96 billion, in comparison to the base case estimate of only $.21 billion.

Lower Prices

A lower price path is predicated on the assumption that technological innovations and developments will overcome current obstacles. This will produce greater well productivity and increased demand conservation. While

17. This $30 figure is roughly in line with estimates from the latest U.S. Department of Energy high price scenario, which forecasts a price of $30.80 per barrel in 2000.

enhanced recovery methods will prolong the production life of many fields, and technological improvements may increase energy efficiency, even at low prices ($10 or so per barrel), in many regions oil will remain profitable to produce.

The lower prices scenario results immediately in disincentives for exploration and development. Egyptian crude oil output declines steadily throughout the 1990s: from a peak of 924 tbd in 1990, production slides to 812 tbd by 2000, nearly a 10% shortfall relative to the base case and roughly 22% lower than with higher prices. Consequently, Egypt receives less production sharing oil, but must still pay the oil companies more cost recovery oil as a consequence of the lower export prices. Therefore, oil available to the Egyptian government for exports decreases rapidly over time, leaving Egypt without oil exports by 1997. Lower prices also imply that Egypt would not only sell *less* oil under this scenario, but also earn *less* on each barrel it did manage to export. Oil revenues dwindle from $1.12 billion in 1988 to zero by 1997. Between 1988 and 2000, the Egyptian government would secure a cumulative total of only $5.21 billion for its exports under these price assumptions, compared to $10.89 billion over the same period in the base case, and $24.05 billion in the higher prices case.

Improved Reserve Status

To measure the impact of expanded reserves, we set the volume of undiscovered oil 20% higher (in all geological regions) than base case levels. (In this and all other scenarios, all exogenous variables, including prices, costs, and investment levels, are held at the base case levels.) The high reserve case shows both oil production and government exports increasing markedly from their base case levels. Production rises to 1.03 mbd by 2000 (16% above the base case estimate), while exports improve to 136 tbd (440% beyond the base case figure). Since total domestic consumption remains unchanged, the Egyptian government diverts the entirety of its increased share of production to export markets. Overall, revenues from oil sales improve markedly, up from $.21 billion in the base case in 2000 to $.93 billion, implying a cumulative sum, by 2000, of $15.13 billion (versus $10.89 billion).

Comparative production forecasts for the base case, higher and lower world prices, and high reserve scenarios, are presented in Table 3.

Domestic Prices

Domestic petroleum product prices remain highly subsidized: although the relationship between domestic prices and internationally traded prices varies across products, petroleum prices in Egypt currently equal about one-third of the prevailing world prices. Earlier, this discrepancy was even greater, as domestic prices were allowed to decrease in real terms during the

Table 3. Crude Oil Production (thousand barrels per day)

Date	Base Case	High Export Price	Low Export Price	High Reserves
1989	918.5	918.5	918.4	918.7
1990	926.3	926.5	926.0	930.2
1991	923.8	925.2	920.6	940.6
1992	925.2	930.6	916.4	959.5
1993	929.7	944.7	913.8	980.8
1994	930.0	962.2	902.5	995.4
1995	924.7	978.1	887.1	1003.2
1996	920.6	997.7	872.0	1016.0
1997	916.4	1016.7	855.9	1028.3
1998	908.1	1029.4	838.0	1034.5
1999	898.6	1039.1	820.8	1034.1
2000	893.6	1043.8	812.4	1033.5

1970s while international prices exploded. Recently, the Egyptian government has attempted to bring product prices more in line with world prices. Nevertheless, domestic energy prices still remain quite low.

Lower Domestic Prices

Under the lower price case, domestic prices remain at their current levels throughout the forecast period. If the government were incapable of reducing the energy subsidies in the face of formidable domestic political opposition, domestic consumption of oil would continue to grow swiftly, expanding to roughly 720 tbd by 2000, or to a level approximately 20% above the base case projection. With roughly a 5.1% per annum growth in demand, Egypt's export potential would be completely exhausted by the end of 1997.

Higher Domestic Prices

If, on the other hand, the Egyptian government were able to raise domestic prices to their world levels, there would be significant positive impacts on export earnings. If local prices for crude oil had been set to the export price in January 1990, domestic demand would be dampened significantly for most of the 1990s. Under this scenario, domestic consumption reaches only 439 tbd, or 25% and 37% below the base and low price alternatives, respectively. Government exports expand markedly, reaching 193 tbd in 2000 versus only 30 tbd in the base case and 0 in the low price simulation.

The impact of alternative domestic pricing schemes on government revenues is profound. The difference in oil export earnings, between the high and low price cases in the year 2000, is $1.33 billion (1987 dollars).

Cumulative values produce a 12 year total differential of $8.91 billion between the two price scenarios. Discounting these figures at 5 or 10% fails to alter these relationships to any discernable degree. These estimates provide a stark example of the trade-off between meeting domestic consumption at subsidized prices and earning foreign exchange in the world market. However stark the trade-off, these figures do not address the political obstacles that must be surmounted if domestic prices are to be substantially increased.

Production Sharing Arrangements

It is important to consider that Egypt can also influence its oil reserves. By altering production sharing arrangements with the multinational oil companies, the government can, to some extent, modify the course of production and its revenues. By lowering Egypt's production share by 5% (from roughly 80% to 75%), the EPM forecasts an immediate drop in revenues of about 14%. However, the higher percentage accruing to the oil companies encourages greater exploration within Egypt, yielding increased production (vis-a-vis the base case) throughout the 1990s and higher oil revenues by 1996.

Despite the potential for expanded production under this alternative scheme, Egypt is unlikely to postpone current revenues for future ones, as it would still receive less revenue over the entire period than it would under the base case. Furthermore, any discounting would make that alternative income stream even less desirable. Since Egypt is likely to possess a high discount rate, any trade-off between present and future consumption would arise only if extremely favourable (and risk-free) revenues could be assured at some point in the future.

The assumptions and key results of the base case, and the alternative scenarios for key parameters of Egyptian oil, are summarized in Table 4. A comparison of results of government exports, government oil revenues, and outcomes under alternative production sharing arrangements, are in the Appendix.

CONCLUSIONS

In most developing countries, oil production, consumption and pricing are generally regulated by the government. As a result, energy issues become highly politicized, often embedded in other socio-economic issues, such as income equality, industrial modernization, domestic employment and foreign relations. Far from being simple numerical trade-offs between consumption and exportation, energy issues often strike at the heart of a country's economic and political well-being. The analysis of the Egyptian case was conducted with a concern for the plight of other energy-producing, developing countries confronted by such stark political and economic circumstances.

Table 4. Key model results

Simulation		
Base Case	World prices increase to about $19 per bbl (1987 S's) by 2000 Domestic prices to about $11	Production at appr. 900 tbd by 2000, domestic demand at 600 tbd, govt. exports at 31 TBD, revenues at $210 million (1987 S's)
High World Price	World prices increase to $30 by 1996 and remain at $30	Production up to 1043 tbd by 2000, exports at 177 TBD, govt. revenues to $2000 mill.
Low World Price	World prices decrease to $10 by 1996 and remain at $10	Production down to 812 by 2000, exports to 0, revenues to 0, production covers only domestic consumption by 1997
High Domestic Price	Domestic prices increase by $10 1990 and continue to increase to about $19 by 2000	Consumption lowers to 438 tbd by 2000, exports up to 194 tbd, revenues up to $1326 million by 2000
Low Domestic Price	Domestic prices remain at their 1988 levels	Consumption increases to 723 tbd by 2000, exports and revenues decrease to 0 by 1998
High Reserves	Undiscovered oil estimates increased by 20% in all regions	Production up to 1034 tbd by 2000, exports up to 136 tbd, revenues up to $925 million
Lower Profit Share	Egyptian profit share reduced from 80% to 75%	Production to 971 tbd by 2000, exports up to 42 tbd, revenues up to $234 million

*Discounting of revenue streams for all scenarios fails to change the relevant results across scenarios.

Seven alternative simulations were explored. Though clear differences separated each of the scenarios, the choices and trade-offs facing the Egyptian government are by no means obvious or simple. Many factors influencing Egypt's oil lie beyond the country's immediate control. For Egypt, world prices are clearly significant exogenous and uncontrollable influences. Egypt's crude oil reserve position, although somewhat more manageable, also represents largely ungovernable circumstances. While it is important to measure the impacts of changing world oil prices or geological parameters, few policy instruments can effectively regulate these exogenous factors.

By contrast, simulations of domestic prices and production sharing arrangements involve areas which, at least nominally, appear under the influence of Egyptian authorities. Although the choices embedded in these

alternative simulations remain controversial, they provide a window of opportunity for Egyptian policy makers to shape their oil industry. Given the importance of oil revenues, these alternatives also allow for a significant degree of influence over other aspects of Egyptian life. The last three simulation analyses assume a degree of policy control, in contrast to the other simulations, which explore exogenous reactions to circumstances.

The policy conclusions are as follows. First, domestic pricing policies remain crucial, especially for the small oil-producing countries: they simply cannot sustain the subsidizing of energy prices for domestic uses. Second, small oil producers are especially vulnerable to the vagaries of geology: uncertainties around reserves and production prospects remain essential variables for policy planning and investments in exploration are among the most significant factors potentially improving their reserve position. Third, contractual arrangements with the foreign oil companies are salient elements in an overall oil policy program: the companies provide two important inputs -- capital and technology -- that small oil exporters cannot readily obtain on their own. Fourth, small oil producers are always sensitive to the terms of the contractual arrangements, and striking an appropriate bargain becomes a crucial determinant of their prospects for exploration, development, and actual production. The relationship to the foreign oil companies invariably becomes a strategic factor in the government's energy policy.

There are implications for the foreign companies as well. Given changing circumstances, oil companies are now no longer viewed as villains by many developing countries. For small oil exporters, foreign financial investments and production technology are necessary for the development of the energy sector. Egypt has successfully pursued partnerships with many foreign companies, contributing to its development of an energy sector and to aspirations of a role in the international marketplace. This partnership is modelled here by parameterizing the key investment variables of the contractual arrangements between Egypt and the foreign investors, contract by contract.

The interdependence between a developing country and the multinational oil corporations has clear implications for the international oil industry. Without government permission, the pursuit of new oil reserves would not occur. Without new discoveries and new oil to produce, multinational activities would be severely constrained. The era of oligopolistic economic and political domination by the multinationals (and their home governments) of global energy production and pricing ended long ago, leaving many developing country governments with greater control over their economy. As a result, small oil-exporting developing countries can stand to gain from this emerging system of private-public cooperation, as well as competition among foreign corporations for favourable investment agreements in the developing states. We view this simulation analysis and the EPM framework as a step toward understanding the structural and behavioral relations linking actors and agents in the world oil market. While we have

focused on the developing country's side, nonetheless, we recognize that this is only one side of complex international relationships.

APPENDIX: Results

	Export Prices (1987 dollars per barrel)			Domestic Prices (1987 dollars per barrel)		
Date	Base Case	High Export Price	Low Export Price	Base Case	High Domestic Price	Low Domestic Price
1988	15.60	15.85	15.08	6.24	6.24	6.05
1989	16.00	16.80	14.41	6.64	6.64	6.05
1990	16.42	18.31	13.73	7.04	16.42	6.05
1991	16.87	20.47	13.06	7.45	16.87	6.05
1992	17.15	22.63	12.39	7.85	17.15	6.05
1993	17.24	24.79	11.71	8.25	17.24	6.05
1994	17.36	26.94	11.04	8.65	17.35	6.05
1995	17.49	29.10	10.36	9.06	17.50	6.05
1996	17.69	30.27	10.00	9.46	17.69	6.05
1997	17.96	30.27	10.00	9.86	17.93	6.05
1998	18.23	30.27	10.00	10.27	18.23	6.05
1999	18.50	30.27	10.00	10.67	18.50	6.05
2000	18.63	30.27	10.00	10.88	18.63	6.05

Domestic Consumption (thousand barrels per day)

Date	Base Case	Low Domestic Price	High Domestic Price
1988	398.6	398.6	398.6
1989	419.4	419.6	419.4
1990	438.7	440.1	438.3
1991	456.9	461.4	448.6
1992	474.4	484.1	447.7
1993	491.2	508.7	440.3
1994	507.9	535.4	431.5
1995	524.4	564.4	424.7
1996	541.2	595.6	421.6
1997	558.2	629.0	422.4
1998	575.5	664.8	426.7
1999	593.3	702.8	433.9
2000	602.3	722.6	438.3

Appendix: Results (continued)

Government Exports (thousand barrels per day)

Date	Base Case	High Export Price	Low Export Price	High Reserves	Low Domestic Price	High Domestic Price
1988	208.6	210.7	204.1	208.6	208.6	208.6
1989	205.8	211.7	191.9	206.0	205.6	205.8
1990	200.0	212.2	176.7	203.0	198.6	200.4
1991	186.7	207.2	152.2	199.7	182.3	195.1
1992	175.0	204.6	128.3	201.4	165.3	201.6
1993	163.8	206.5	104.6	203.0	146.3	214.7
1994	148.6	209.3	72.8	198.5	121.0	224.9
1995	128.5	209.2	36.2	188.1	88.5	228.2
1996	109.0	209.0	2.6	181.3	54.6	228.6
1997	89.7	205.1	0.0	174.2	18.8	225.5
1998	66.9	195.8	0.0	162.3	0.0	215.8
1999	43.1	183.9	0.0	145.0	0.0	202.6
2000	30.9	177.7	0.0	136.1	0.0	194.9

Government Revenues (millions of 1987 dollars)

Date	Base Case	High Export Price	Low Export Price	High Reserves	Low Domestic Price	High Domestic Price
1988	1187.1	1218.8	1123.6	1187.1	1187.0	1187.1
1989	1201.8	1298.0	1009.4	1202.7	1200.6	1201.8
1990	1198.6	1418.5	886.0	1216.5	1190.4	1201.3
1991	1149.7	1548.0	725.6	1229.5	1122.6	1201.2
1992	1095.2	1689.8	580.0	1260.5	1034.4	1262.0
1993	1030.9	1868.4	447.0	1277.9	920.9	1351.4
1994	941.4	2058.3	293.1	1257.7	766.7	1425.1
1995	820.3	2222.3	136.9	1200.7	565.2	1457.0
1996	704.1	2308.3	12.9	1170.6	352.6	1476.2
1997	587.9	2266.0	0.0	1141.9	123.3	1478.0
1998	467.2	2163.5	0.0	1079.7	0.0	1435.7
1999	291.4	2031.6	0.0	979.4	0.0	1367.7
2000	210.2	1963.3	0.0	925.5	0.0	1325.8
Cumulative	10885.8	24054.7	5214.4	15129.6	8463.7	17370.3

Appendix: Results (continued)

Discounted Government Revenues (millions of 1987 dollars)

5% Discount Rate

Date	Base Case	High Export Price	Low Export Price	High Reserves	Low Domestic Price	High Domestic Price
1988	1187.1	1218.8	1123.6	1187.1	1187.0	1187.1
1989	1144.5	1236.2	961.3	1145.5	1143.4	1144.5
1990	1087.2	1286.6	803.6	1103.4	1079.7	1089.6
1991	993.2	1337.2	626.8	1062.1	969.8	1037.6
1992	901.0	1390.2	477.1	1037.0	851.0	1038.3
1993	807.8	1463.9	350.2	1001.3	721.6	1058.9
1994	702.5	1536.0	218.7	938.5	572.1	1063.5
1995	582.9	1579.3	97.3	853.3	401.7	1035.4
1996	476.6	1562.4	8.8	792.3	238.6	999.2
1997	379.0	1460.7	0.0	736.1	79.5	952.7
1998	286.8	1328.2	0.0	662.8	0.0	881.4
1999	170.4	1187.8	0.0	572.6	0.0	799.6
2000	117.0	1093.3	0.0	515.4	0.0	738.3
Cumulative	8836.0	17680.5	4667.4	11607.3	7244.4	13026.1

10% Discount Rate

Date	Base Case	High Export Price	Low Export Price	High Reserves	Low Domestic Price	High Domestic Price
1988	1187.1	1218.8	1123.6	1187.1	1187.0	1187.1
1989	1092.5	1180.0	917.6	1093.4	1091.4	1092.5
1990	990.6	1172.3	732.2	1005.4	983.8	992.8
1991	863.8	1163.0	545.2	923.7	843.5	902.5
1992	748.0	1154.1	396.1	860.9	706.5	862.0
1993	640.1	1160.1	277.5	793.5	571.8	839.1
1994	531.4	1161.9	165.4	709.9	432.8	804.5
1995	420.9	1140.4	70.2	616.1	290.0	747.7
1996	328.5	1076.8	6.0	546.1	164.5	688.7
1997	249.3	961.0	0.0	484.3	52.3	626.8
1998	180.1	834.1	0.0	416.3	0.0	553.5
1999	102.1	712.1	0.0	343.3	0.0	479.4
2000	67.0	625.6	0.0	294.9	0.0	422.4
Cumulative	7401.5	13560.2	4234.0	9274.9	6323.6	10198.9

Appendix: Results (continued)

Alternative Production Sharing Scenario (Egypt share decreasing from 80% to 75%)

Date	Production (tbd)	Government Exports (tbd)	Government Revenue (millions of 1987 dollars)
1988	905.2	183.2	1042.5
1989	920.2	172.6	1008.2
1990	928.9	162.3	973.0
1991	931.0	151.7	933.9
1992	940.6	144.9	906.9
1993	957.5	141.4	890.0
1994	973.7	136.6	865.4
1995	983.0	126.0	804.7
1996	990.1	113.8	734.7
1997	989.5	96.3	631.1
1998	966.8	77.5	515.3
1999	976.7	53.5	361.3
2000	971.8	41.6	283.0

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