Cairo University/Massachusetts Institute of Technology — Technological Planning Program

Linear Programming Analysis of the Use of Natural Gas in Egypt

Energy Project: Petroleum and Natural Gas in Egypt

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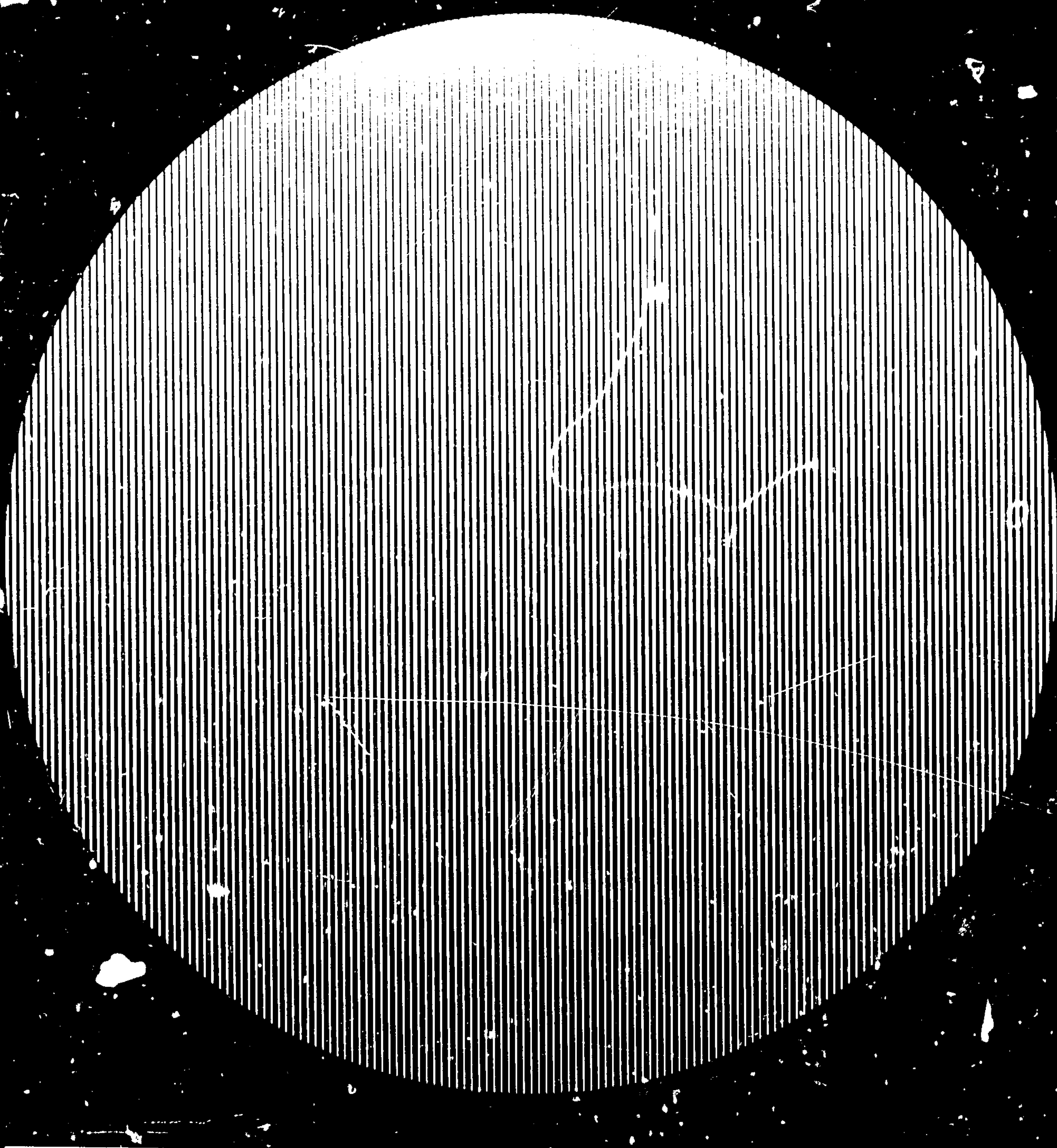

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ENERGY PROJECT:

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LINEAR PROGRAMMING ANALYSIS OF THE USE OF NATURAL GAS IN EGYPT

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PREFACE

The Energy Project, focusing on petroleum and natural gas, is designed to provide a comprehensive view of these sources of energy in the Egyptian economy. The purpose is to identify the longer term supply and production possibilities associated with oil and gas, and to identify the effects on supply and demand of different prices and quantities of oil and gas available for consumption internally.

The research project is composed of two parts:

* the <u>supply</u> side, which focuses on discovery and production of petroleum and natural gas; and

* the <u>demand</u> side, which focuses on uses of oil and gas in the Egyptian economy and the ways in which domestic uses would change if there were changes in domestic prices for these two products or changes in the amounts available for domestic use.

The prospects for natural gas in Egypt appear extremely encouraging. This report presents an analysis of the best uses of Egypt's natural gas and the price that reflects the real costs to the economy for its uses. The "shadow price" thus reflects the true scarcities in the economy. It is the best indication of the real price of natural gas for domestic use.

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CONTENTS

EXECUTIVE SUMMARY

1. Scope and Purpose

The purpose of the study is to determine how natural gas can best be used to improve Egypt's foreign exchange position. Natural gas can be used in many applications to displace the use of other fuels. For example, any use of gas to offset the use of oil will free oil which then can be sold abroad to gain foreign exchange for Egypt. This report examines the extent to which natural gas can replace other fuels in Egypt.

This study identifies the shadow price of natural gas in Egypt, namely the price that should be charged to users which reflects the value of natural gas to the Egyptian economy. The results indicate $.112/cu-m (for Abu Gharadiq gas) and $.115/cu-m (for Abu Madi gas).

The shadow prices of production capacity for processes which use natural gas are also identified. These prices yield an understanding of how valuable the use of natural gas is for each particular industry in improving Egypt's foreign exchange position. The shadow price depends on the particular industry, a larger shadow price indicating a more valuable application for natural gas.

A linear programming model has been constructed which describes the Egyptian natural gas production and transportation facilities, and which describes production in existing industries that use natural gas and other fuels. The algorithm of linear programming as it is used in this study systematically searches certain variables to find out what values for them will result in a minimal value for some linear function of the variables. The search is restricted to only those values which are specified by linear constraint equations, namely, equations which state certain limitations which must not be exceeded by the variables. Upon reaching the minimum solution, the algorithm reports shadow prices, each of which is a measure of how important some specific variable limitations is: the shadow price expresses by how much the solution may be improved by a unit easing of the given constraint.

The industries of the natural gas model were depicted as being capable of using a variety of fuels. The objective of the model is to minimize foreign exchange costs by choosing fuels for use in production in such a way as to meet exogenously specified demand for goods. The capacities for production and transportation of natural gas must not be exceeded by the model, as is true also for the capacities of the industries which are producing goods. The shadow prices express the willingness of planners to obtain extra production capacity if their only objective is to improve Egypt's foreign exchange position.

A strictly operational model was constructed where only presently existing facilities are considered, and the object is to find the best operating policy at a moment of time. The model is not for future investment planning, although some of the results indicate useful areas for investment.

The costs charged by the model against foreign exchange (which is to be minimized) are of two types: natural gas production and transportation costs, and world market costs of fuels other than natural gas. Note that the pricing of natural gas depends on its interactions with other fuels since presently there is no import or export possibilities for this fuel in Egypt. Thus the only cost to be charged for natural gas in the model is the foreign exchange costs of production and distribution, and its price to users is a shadow price which is determined by the model. This shadow price represents the economic rent which should be charged in view of its value in displacing other fuels, whose prices are determined by external international conditions.

2. The Natural Gas Industry in Egypt and its Customers

The major natural gas producing fields in Egypt are at Abu Gharadiq in the Western Desert, Abu Madi in the north of the Delta, Abu Qir near Alexandria on the Mediterranean coast, and Suez.

The supplies at Suez are the only in Egypt produced in association with oil, and were badly affected by the 1974 war. Facilities are presently under repair, and will soon serve many industries in the Suez area. Shortly some Suez gas will be used to supply domestic needs in Cairo. There is a fertilizer plant at Suez which is presently being supplied from the Western Desert, but it will switch over to Suez gas as facilities are brought up to operation.

Natural gas from Abu Gharadiq supplies not only the fertilizer plant at Suez but also a large industrial complex at Helwan, just south of Cairo. The industries that use natural gas there are: the iron and steel complex, electric power generation, and cement production.

Natural gas produced at Abu Madi is used primarily at the large Talkha fertilizer plant. Some supplies are available for electric power generation at Mahalla, and ultimately gas will be used there for the extensive textile facilities.

Abu Qir gas is available for fertilizer production and electric power generation. A large expansion is expected in this region as both onshore and offshore fields are further developed.

These major centers presently operate independently of one another. A national pipeline grid which will link them in the future is in the planning stages.

3. Results

Results of the model run are given for two cases: when demand for electricity is high (less than 4% of electric power generation is unused), and when electricity demand is low (demand is about half of full generation capacity).

Table 1 Results in the Natural Gas Sector (annual production in % of capacity, shadow prices in $/cu-m)

field:	low electric demand: production	price	high electric demand: production	price
Suez	6%	0	6%	0
Abu Madi	29%	0	83%	0
Abu Qir	18%	0	65%	0
Abu Gharadiq	80%	0	100%	.112
pipeline:				
Suez to Cairo	7%	0	7%	0
A. Madi to Talkha	35%	0	100%	.115
A. Qir to K. Dauwar	18%	0	65%	0
A. Gh. to Helwan	80%	0	100%	.112

Table 1 shows the load factors of the natural gas fields and pipelines for the two study cases. Bottlenecks in supply appear for Abu Gharadiq and for the Abu Madi pipeline in the high electricity demand case.

The price shown in the table is the shadow price of natural gas and can be interpreted as the amount that planners should be willing to pay to obtain an additional cu-m of natural gas. If gas were only obtainable at a higher price, alternate fuels would be used instead. Where there are additional unutilized supplies of natural gas, the shadow price is zero, since there is no demand for more gas.

Table 2 lists the shadow prices for new capacity of those industries in the model which are fully utilized in production. The unit used is $/cu-m, and thus represents the importance of using natural gas in the particular installation listed. The table is ordered in terms of the most important applications being listed first.

Table 2 Shadow Prices for Capacity in Some Gas Using Industries

plant	shadow price of production ($/cu-m): high electricity demand:	low electricity demand:
cement	.775	.887
Suez fertilizer	.666	.779
Abu Qir fertilizer	.317	.317
Talkha fertilizer	.221	.335
Dauwar gas boiler	.135	-
Helwan gas boiler	.044	-
iron and steel	-	.089
Cairo distribution	.017	.017

The model determines that the most important application for natural gas is the manufacture of cement. Although the importation of cement was not considered in the model, it is unlikely that this makes much difference in the result. The cement sector demand was chosen to reflect demand for domestically produced cement more faithfully than total demand, so that the inclusion of a term for imported cement would have little effect on the study conclusions.

The amount of natural gas consumed by sector for the two study cases are shown in Table 3. The industries are listed in the table in order of the importance of the use of natural gas, the cement sector having first priority. Note that iron and steel production switches away from natural gas use in the case of high electricity demand.

Table 3: Consumption of Natural Gas (Million cu-m per year)

	Low Electric Demand	High Electric Demand
Cement sector	725	725
Fertilizer sector	633	633
Electricity sector	29	1591
Iron and steel	83	0
Residential/commercial	70	70

A few shadow costs for the expansion of electric power generation were derived in the study. These are shown in Table 4. Comparison of these with reported costs for electric power generation capacity expansion shows that it is beneficial for Egypt to invest in additional gas fired capacity at Kafr el-Dauwar, but not at Helwan.

Table 4: Shadow Costs for Electric Power Capacities

Hydroelectric:	\$480/kW
Helwan gas fired boiler:	\$120/kW
Kafr Dauwar gas fired boiler:	\$377/kW

The model results indicate that the use of natural gas in the iron and steel sector as being of little importance assuming that coal is priced at \$90/tonne. If this price were higher than \$107/tonne, gas would be important in this sector.

4. Natural Gas Prices, Actual and Study Derived

It is almost impossible to determine a world market price for natural gas because of the special character of the trade. The size of the international gas market is small in comparison with crude oil, being less than 5% of world oil production in energy terms. Secondly, exports tend not to be concentrated in one region as they are for oil, so there is less pressure for the setting of a unified price. In fact two-thirds of total gas trade comes from four exporters in quite different locations: the Netherlands, the USSR, Canada, and Algeria.

Furthermore, natural gas does not have the delivery flexibilities of crude oil. Trade projects in gas involve enormous costs and long lead times since these involve pipeline construction or development of LNG facilities. Particular tankers or pipelines are dedicated to particular trades. There is then no equivalent to the crude oil spot market which can lead, check, or stabilize price movements.

There have been movements for pegging the price of gas to the price of oil on a BTU basis, and the highest prices have risen rapidly to be on a par with the price of oil. OPEC has stated that gas export prices should be in line with those of crude oil on a BTU basis, but has been vague on whether the pricing parity should be set on the basis of the landed (cif) price or be set at the port of exit (fob) price. Japanese gas imports have followed landed crude costs to within a close margin throughout the 11 year duration of LNG purchases by Tokyo.

Two shadow prices were found for natural gas in Egypt: $.112/cu-m for Abu Gharadiq gas, and $.115/cu-m for gas from Abu Madi. Since they represent the most Egyptian planners are willing to pay for gas if their intent is to improve the foreign exchange position, these are demand prices. These prices are exclusive of the costs of producing and delivering the gas. If these costs are added, then the prices for gas from the two fields both rise to $.130/cu-m. This represents a world market cif price as observed by Egyptian industries since it includes delivery infrastructure costs.

The table below includes a range of cif gas prices as reported in [17]. The price found for natural gas by the study falls within the range of quoted prices.

Table 5: Some Natural Gas Prices ($/cu-m, cif)

This Study (1979 to 1982)	.130
USA (March 1980)	
from Algeria (LNG):	.120
from Canada:	.168
from Mexico:	.136
Japan (March 1980)	
from Abu Dhabi (LNG):	.201
from Indonesia (LNG):	.186
from USA (LNG):	.131
Austria (March 1980)	
from USSR	.142
United Kingdom (March 1980)	
from Algeria	.116

Table 6 reports price elasticities that were found for the shadow prices given in the natural gas study. These are the percent increases (or decreases if negative) given a 1% increase in international prices for the indicated factor price.

The negative elasticities in the fertilizer sector show that the use of natural gas in the fertilizer industry is less important than where it may substitute directly for oil, such as in the cement industry. The negative elasticity indicates that the shadow price for fertilizer production capacity actually declines upon an increase of the international price for oil.

Prices for capacity in the fertilizer sector are quite sensitive to the international price for fertilizer, but insensitive to oil prices. There are no effects in the residential/commercial sector, since in this sector natural gas competes with lpg instead of oil or fertilizer.

Table 6: Elasticities of Various Shadow Prices

	with oil price	with fertilizer price
Natural Gas:	1.0	0.0
Production Capacities:		
Fertilizer		
Suez Fertilizer	-0.19	1.2
Talkha Fertilizer	-0.57	1.6
Abu Qir Fertilizer	0.0	1.1
Electricity		
Helwan Thermal	1.0	0.0
Kafr Dauwar Thermal	1.3	0.0
Hydroelectric	1.0	0.0
Cement	1.0	0.0
Residential/Commercial	0.0	0.0

1) INTRODUCTION

The natural gas industry in Egypt is still in the early stages of development, but it is not too early to see that natural gas will play an important role in Egypt for some time to come. From Table 1.1 we see that natural gas production has increased rapidly in the last few years. Proven reserves are also expanding rapidly as more knowledge becomes available about existing production fields. A recent paper ([15], p16), which is in accord with other sources, notes that proven reserves in Egypt now are 260 billion cu-m, and that total recoverable gas reserves could amount by the end of the century to a total of about 1,050 billion cu-m. "So considerable is the expected wealth in natural gas that the obvious choice for Egypt is to rely heavily on it for the satisfaction of its energy demand" ([15], p17). It is estimated that natural gas might increase its share of total energy supply in Egypt from about 10% in 1980 to about 75% in 2000 ([15], p17 and Graph 3).

Table 1.1 Growth of Natural Gas Production in Egypt

	Production (Bill. cu-m)				Reserves (Bill. cu-m)		
year:	1977	1978	1979	1980	Jan, 1979	Jan, 1981	end, 1981
amount:	0.50	0.80	1.11	2.19	90	84	260

references; [15], [13], [14]

Because the use of natural gas is in its infancy in Egypt, and because of its great potential it is important to determine now what is the best way of using this high quality fuel.

The purpose of the study described in this paper is to determine how natural gas can best interact with other energy supplies in Egypt. Oil in Egypt is exportable whereas natural gas is not at present, so it is beneficial for the Egyptian foreign exchange position to replace oil with natural gas in many applications. The question to be answered is what applications are most favorable, and to what extent natural gas should replace oil and other fuels. Thus the problem is one of optimizing the foreign exchange position taking into consideration the practicalities and costs of domestic fuel uses.

A most appropriate methodology to use is linear programming, which has proven its worth in many studies in operations research. Given a production situation with multiple inputs and outputs, linear programming can be used to determine their levels so that some measure of production is optimized. This measure may be costs of operation, profits, quantity of output, or some other numerical function. Thus linear programming is suitable for studying natural gas consumption in Egypt, where inputs are various available fuels, outputs are various products with domestic demands, and where it is desired to find the levels which optimize Egypt's foreign exchange position.

Linear programming as an analytical tool has at least two additional advantages. First, it is a common and well developed technique for which computer programs are readily available, thus making the study model easily transferrable to Egyptian analysts.

Secondly, the specification of linear programming models is sufficiently flexible and simple to allow for model alterations and expansions when more information becomes available, or when industry structural changes occur.

The study presented here uses linear programming to determine the optimal use of fuels at the current time for the production of domestic goods, where it is desired to minimize foreign exchange costs of production. The results will be the optimal magnitudes of production and their shadow prices, as well as shadow prices for natural gas. The study is concerned only with the presently existing natural gas industry and its customers.

The next section of this paper will describe in some detail the model being used in the study. The model consists of a description of interactions among natural gas production and transportation, and several industries which use the natural gas. The industries to be included in the description are those which have the capability of switching to other fuels. Probable flaws in the model specification will be mentioned, and it is hoped that readers will discover others and propose improvements.

A complete description of the linear programming variables and equations is given in Section 3. The objective function is the sum of foreign exchange costs of the use of natural gas, the fuel costs in the represented industries, and minus the revenues earned from foreign sales of fertilizer. The constraints of the model are the domestic demands for production, industrial capacities, and gas production and pipeline capacities.

Section 4 presents the data used in the study. The model input values were assembled from a variety of sources, and some values are questionable since they are indirectly derived. A data base which is efficient for the linear programming analysis of natural gas in Egypt does not yet exist. It is hoped that this study will provide the impetus for its compilation.

Section 5 discusses the results of the study. It is found that despite inadequacies in model formulation and data the results are quite faithful to expectations. Many of the commonly known issues and problems of the natural gas industry in Egypt become evident. Values that are meaningful if not precise are found for production levels and shadow prices.

2 DESCRIPTION OF THE STUDY AND THE MODEL

2.1 On the Use of Linear Programming

2.1.a Applying linear programming to natural gas in Egypt

The general specification of a linear programming problem is as follows: minimize (or maximize) a given linear function of certain variables (called "decision variables" or "activity levels") such that each of a given set of linear equalities and inequalities involving the variables is satisfied. The equalities and inequalities which the variables must satisfy are called "constraints". In a typical application of linear programming each decision variable represents the magnitude of production of a good or amount of input to a process, and each constraint specifies some limitation concerning availability of inputs or levels of production.

Our particular application will be to find the minimum foreign exchange cost such that domestic demand for certain products is met subject to production capacities. The decision variables will be the amounts of natural gas supplied to various plants, the levels of production at these plants, and the levels of production at plants that use other fuels. The constraints of the problem will be the domestic demands for production and capacities of natural gas production and transportation, and levels of production at plants that use natural gas, and at plants that use other fuels.

2.1.b Requirements of linearity

Any industry or process that is being treated by linear programming must satisfy an axiom of linearity, which for us has two aspects. First, that total cost must be the sum of individual costs, and total input must be the sum of individual inputs. Secondly, that the total amounts of each input and the associated costs are proportional to the level of production. These assumptions mean that any industry must be viewed as working at constant returns to scale. Namely that production costs are strictly proportional to the quantity that is produced, and especially that no costs are incurred when there is no production.

The latter assumption will certainly fail for our application in certain cases. For example, if the production of a gas field is zero, then the assumption would require that the running costs of the field be zero. But this can not be so, for if the field is to remain available for future production some personnel must remain at the field as caretakers and maintainers. Figure 2.1 illustrates a possible situation, giving the production costs of a natural gas field as a function of output, and the linear approximation that is needed for linear programming.

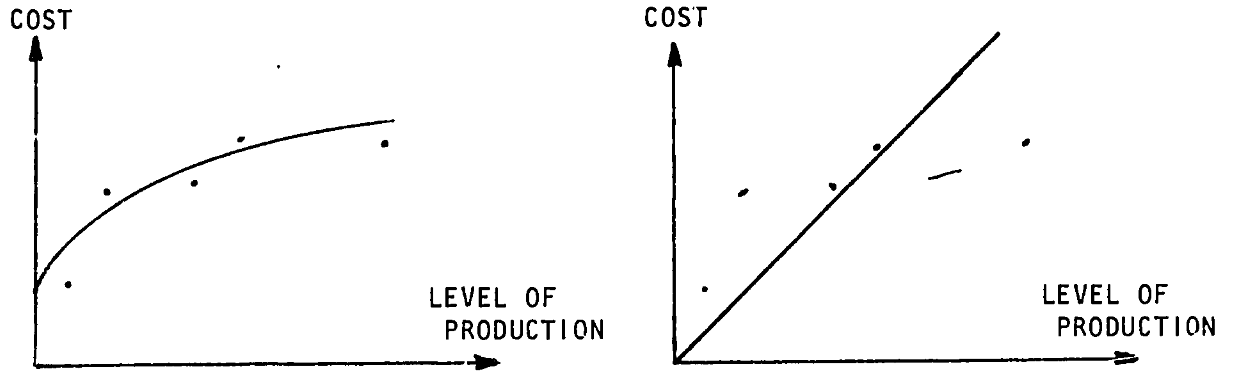

Fig 2.1: Hypothetical production cost and its linear equivalent

This difficulty is inherent in any application of linear programming. But if running costs are small at zero production levels, then the linear approximation will be adequate and the error in costs will be small. Also, the cost error may be fairly large and still not cause trouble as long as most of the rest of the model is correct in assigning linear production costs and the total of these are much greater than the problematic cost.

If the nonlinearity seriously affects the model then one can use a variant of the linear programming algorithm called "integer programming". This should be the last resort since applying this method will require prohibitively large amounts of computer time and memory if many nonlinearities are to be modeled.

2.1.c Results: activity levels and shadow prices

The constraints that are used in the model described here include the necessity of meeting demand for certain products, the production limitations due to plant capacities, and natural gas production and transportation capacities. If the constraints present a contradictory picture (for example, if capacity to produce or import a given good is smaller than demand for the good) then no feasible solution is possible.

If there is a feasible solution, then the theory of linear programming guarantees that an optimal solution will be found. The output of a successful computer run will include the levels of production (activity levels) that yield the optimal solution, and certain "shadow prices".

If a certain constraint is "binding", for example if some process is used to its capacity in the optimal solution, then one result that is found is the "shadow price" of easing the given constraint. This is interpreted as the price a producer would be willing to pay to gain additional productive capacity. If the marginal cost of gaining expanded capacity is less than this shadow price, it would profit the producer to invest in expansion.

To give an illustration, one run of this model resulted in electricity being produced solely by hydropower and natural gas. The constraint on hydro was binding, which meant that if more hydropower capacity had been available, the system would have used it to obtain lower operating costs. The resulting shadow price is interpreted as the amount of money policy makers would be willing to invest per unit generation capacity to gain more hydroelectric generation. But since natural gas was the only competitor to hydro in the computer run, this shadow price is also the opportunity price of gas as observed by Egypt for electrical generation. This follows, for if gas were cheaper than the shadow price of hydro capacity, the tendancy would be to use more gas generation instead of expanding hydroelectric generation.

If a certain production variable has a zero value in the solution, then this means that any use of the corresponding process would result in a loss to Egypt. For if not, then the resulting solution is not optimal; the solution could be improved by using the process in question. Associated with these zero-level production processes are "shadow costs" which are the foreign exchange losses to Egypt per unit use of the process.

2.2 Overview of the Model

2.2.a Specific variables and constraints

The model is used to determine the minimum foreign exchange costs needed to operate the Egyptian natural gas industry and those sectors which presently have the option of using natural gas as well as other fuels. Thus the model concerns the natural gas production fields and pipelines, and fertilizer, electric power generation, Helwan iron and steel, cement, and residential and commercial fuels.

Figure 2.2 shows a schematic of the model. Gas is supplied to the five sectors, which can also use the inputs shown outside

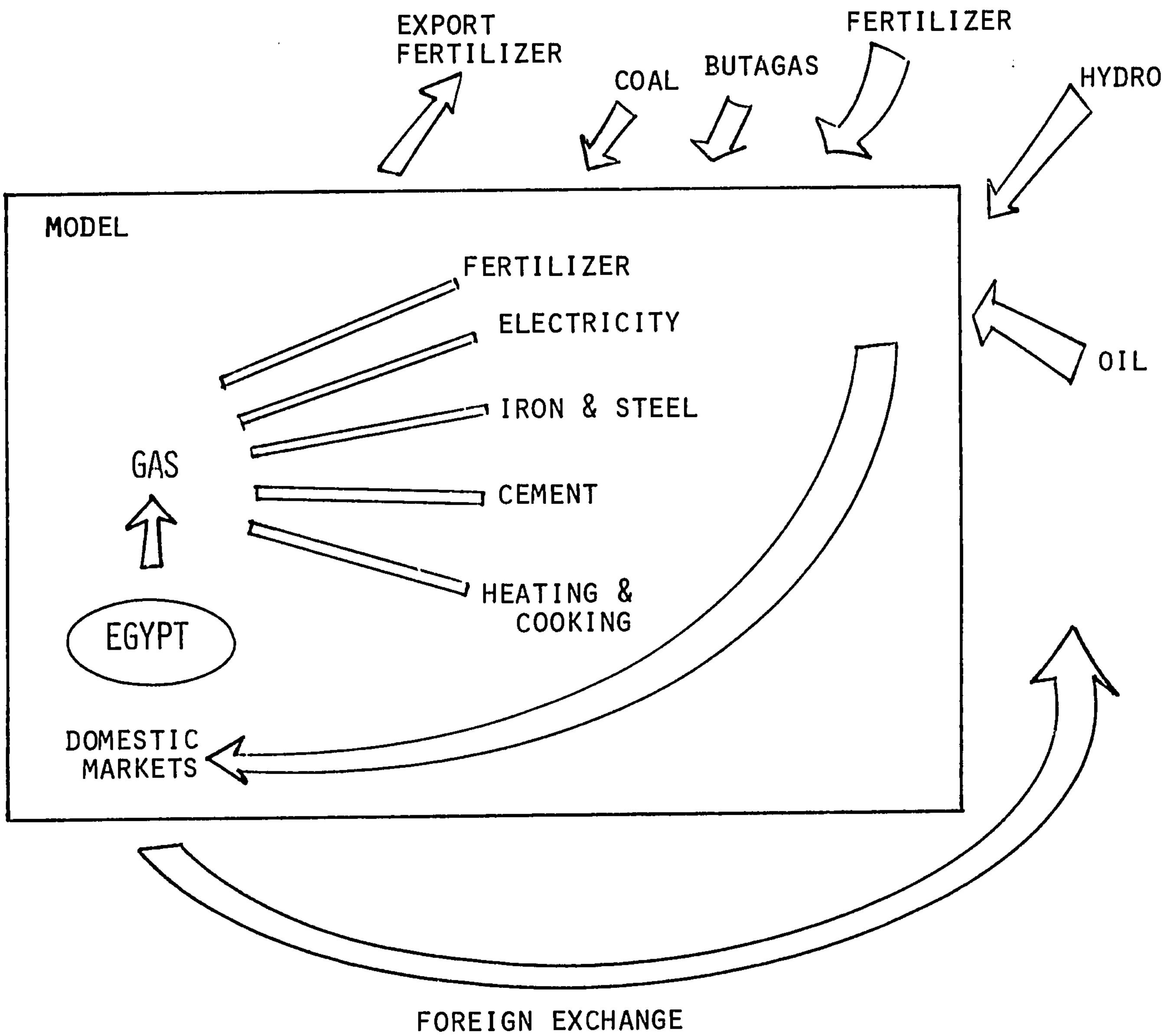

FIG. 2.2: MODEL SCHEMATIC

the rectangle. The inputs are obtained with the use of foreign exchange. the production of the five sectors are supplied to the domestic markets which have some predetermined level of demand for the products.

The following production inputs and outputs are treated as variables in the model. Values are sought for them which minimize foreign exchange costs.

* natural gas deliveries to the modeled sectors (cu-m per year)
* fertilizer for domestic use as produced at Suez, Talkha, Abu Qir, Aswan, and as is imported (tonnes of fertilizer per year)
* fertilizer for export produced at Talkha, Abu Qir, and Aswan (tonnes of fertilizer per year)
* Electric energy generation by hydro, oil, natural gas turbines, and natural gas fired boilers (kWH per year)
* use of natural gas, oil, and imported coke in iron and steel production at Helwan (kcals per year)
* use of natural gas and oil in cement production (kcals per year)
* use of LPG and natural gas in domestic and commercial distribution (kcals per year)

The above variables are allowed to take on nonzero values which satisfy constraints concerning production levels and demands for products. These constraints are;

* capacities of natural gas production at the various fields, and gas pipeline flow capacities (cu-m per year)

* fertilizer production capacities at Talkha, Suez, Abu Qir, and Aswan (tonnes of fertilizer per year)
* capacity for electric generation by hydro power, oil, natural gas turbine, and by gas fired steam boiler (kWH per year)
* capacity of use at Helwan iron and steel of coke, oil, and natural gas (kcal per year)
* capacity of residential and commercial distribution of natural gas (kcals per year)
* domestic demands for fertilizer, electric energy, and process heat demands for iron and steel, cement, and residential and commercial purposes.

Each sector is represented by two or more installations, each of which is restricted to operate with a single fuel. The demand for product from each sector is satisfied by operating in such a way that installations using the least expensive available fuels are used to the maximum. Natural gas is supplied by the natural gas sector of the model, while the other fuels are imagined to be supplied from the outside of the model. Costs are charged for operating the gas fields and pipelines, costs are charged for the other fuels, and net revenues are allowed for exported fertilizer. Charges for the fuels and imports are at the world market rates, as is the revenue for exported fertilizer.

Upon successful solution of the linear programming problem, all domestic demands are met, some fertilizer is exported, those plants which are least costly to run are running at capacity while the others are shut down, or running below capacity.

2.2.b Costs used in the model

The objective function of the linear programming problem is the total foreign exchange direct costs of the model, minus export revenues. Whenever production occurs in a given plant it is charged the world market price for externally supplied fuels, such as oil or coke. If the plant uses natural gas, it is charged only for gas production and transportation.

Because of Egypt's interaction with world markets, oil, coal, LPG, and fertilizer must be priced at the world market levels.

The pricing of natural gas depends on its interactions with other fuels since presently there is no import or export possibilities for this fuel in Egypt. Thus the direct cost charged for natural gas is zero, and its price is a shadow price determined by the model.

The price that policy makers should charge for natural gas to make it competitive with other fuels is one of the results of the solution of the linear programming problem. But there is an interesting way to imagine using the model to find the price of natural gas supposing that the government decides to encourage its use. Assume that an optimal solution has been found with zero costs charged to industries for natural gas use (gas production and transportation is still charged to users). If now a cost is charged for natural gas, and this cost is not much above zero, the solution will be unchanged in the sense that fuel users will still prefer natural gas, and will use it to the same extent as before. Now gradually increase the user cost of natural gas to a level where there is a shift in the solution, i.e., to where an alternate fuel is used to a greater extent in some sector. Then this cost represents what should be charged so that natural gas will always substitute for other fuels, and users are charged in a way that properly reflects the value of natural gas in Egypt.

Since the foreign exchange costs to the Egyptian government are what are being studies here, it makes little sense to run the model using subsidized costs for fuels. If this were done however, it would be found that natural gas would be less valuable since it would have a smaller shadow price than in a model run using world market fuel costs.

2.2.c Results

The results to be expected from the linear programming model are;

* a set of values for the production levels that satisfies demand at minimum foreign exchange costs of fuels and fertilizer
* shadow prices for all production capacities
* shadow costs for unused production processes
* shadow costs of extra demand in each sector
* shadow prices for natural gas

In the optimal solution those production levels that use natural gas will be maximized subject to model constraints except where alternate fuel prices are lower than costs of gas production and transportation. The shadow prices for capacity will give the value to Egypt of expanding production, and the shadow prices for natural gas will express its value in displacing other fuels. Shadow costs for demand will express the costs of supplying an additional unit of output in the particular sector; namely the production marginal costs. Finally, the shadow costs for unused production processes give the foreign exchange cost to Egypt of increasing production in a given process. All of the costs and prices will reflect interactions among fuels, in that the reduction of the use of one fuel will entail an increase in another to satisfy demand.

2.3 Description of Industrial Sectors

Data limitations and lack of knowledge of the details of some of the sectors has made it necessary to oversimplify parts of the model. The model will be improved in this respect as more information becomes available.

A qualitative picture is given below of the model's view of natural gas use in Egypt. For the values of capacities, demands, etc., that were used in the study see Section 4 on model data.

2.3.a Natural gas sector

Natural gas is modeled as being produced solely at Abu Gharadiq, Abu Madi, Abu Qir, and at Suez. Although gas is not yet available from Suez, it is included here to gauge the value of natural gas in displacing bottled gas in areas of Cairo.

Five major pipelines are imagined as existing in Egypt, and their disposition is shown in Table 2.2. In actuality pipelines 1 and 2 are the same from Abu Gharadiq to Helwan, but they are considered as separate to simplify the model.

Table 2.2: Status of the Gas Pipelines in the Model

pipeline	from:	to:	delivery costs of gas ($ per cu-m)
1	Abu Gharadiq	Helwan steel electric (turbine) electric (thermal) cement	.015
2	Abu Gharadiq	Suez fertilizer	.016
3	Abu Madi	Talkha fertilizer electric (turbine)	.012
4	Abu Qir	Kafr el-Dauwar fertilizer electric (thermal)	.036
5	Suez	Cairo distribution	.017

Gas pipelines are treated in a better way by using a linear programming "transhipment model" where certain constraints are formulated that specify the movement of gas from a supply point to various take-off points in a network. A future improvement of the present study could include such a treatment.

2.3.b Fertilizer sector

The model covers three fertilizer plants that use natural gas at Suez, Talkha, and Abu Qir, and the KIMA plant at Aswan which uses electricity to produce ammonia by electrolysis. Both imports and exports of fertilizer are considered. Fertilizer is produced or imported to satisfy demand, and fertilizer may be produced for export to yield foreign exchange.

All plants are operated to fulfill overall national demand targets. The fact that fertilizer plants may operate to satisfy demand in their region of location is not accounted for. Transportation costs for fertilizer destined for domestic markets are not considered, but the cost of transporting export fertilizer to the port of Alexandria is deducted from gross export revenues.

2.3.c Electric power sector

Power generation facility types that are considered in the model are:

* hydroelectric generation
* gas turbine (combustion turbine)
* steam generation by gas fired boilers
* steam generation by oil fired boilers

Gas turbines and gas fired boilers can be run using natural gas or gasoline, and both of these fuels are used for this purpose in Egypt. The study references are not clear on which of these fuels is used at specific plants, so we shall simply assume that gasoline is never used for electric power generation.

It is supposed that gas turbines are located at Helwan and Talkha, and gas fired steam generation exists at Helwan and Kafr el-Dauwar. Since oil transport costs are not considered in the model, oil fired generation is aggregated.

The electric generation production variables are in units of energy per year, and the model operates to supply annual energy demand. The effect of variable demand for electricity has been investigated by solving the linear programming problem for three cases of electricity demand; high demand, low demand, and medium demand.

2.3.d Iron and steel sector

Only iron and steel production at the Helwan plant is accounted for, since it is believed to be the only one which currently uses natural gas.

It is imagined that the factory annual requirements for kilocalories may be equally well supplied by gas, oil, or coal. Prices of these, and the plants capacity for using them determines the fuel mix.

As will be seen in the results the assumption that the need of the iron and steel plant for kilocalories can be equally well supplied by the three fuels does not lead to a reasonable representation.

2.3.e Cement sector

The only cement production facility in Egypt that uses natural gas is located in Helwan. All other cement production is assumed to use oil and is aggregated to one variable.

2.3.f Residential and commercial sector

Two fuels are considered in this sector; butane (LPG), and natural gas. Other fuels such as kerosine are not considered since in the areas where natural gas will be distributed (eastern Cairo zone), LPG and electricity appear to be the only competitors for heating.

Domestically produced LPG and imported LPG are lumped together because they should each be priced at world market rates. The capacity for natural gas consumption is estimated from the future size of the distribution network (4.7.b), and it is assumed that there is no constraint on the quantity of the propane that can be imported.

The model does not consider electricity as an alternate source for heating, since it is clearly an uneconomical choice in comparison with natural gas and propane. Since there is no constraint on the use of propane, no hydrocarbon fuel shortfall could arise which necessitates the use of electricity.

3 LINEAR PROGRAMMING SPECIFICATION

3.1 The Objective Function

The objective will be to find values of the variables X_{ij}, F_i, E_i, S_i, M_i, and D_i that minimize total costs:

$$1) \qquad C = C_P + C_F + C_E + C_S + C_M + C_D$$

Definitions of the costs and the definition of the variables are given in the following.

3.1.a Costs of natural gas production and pipelines

The costs of producing and transporting the gas to each of its users is given by:

$$2) \qquad C_P = \sum_{i=1}^{4} \sum_{j=1}^{5} k_{ij} X_{ij}$$

where X_{ij} and k_{ij} are the levels of use of natural gas in the industrial sectors and their foreign exchange production costs respectively. Index i ranges over gas production fields (Abu Gharadiq, Abu Madi, Abu Qir, and Suez) and index j ranges over industries which are consumers of the natural gas (fertilizer, electric power generation, iron and steel industry, cement, and residential and commercial distribution). For example, $X_{1,2}$ would represent the amount of natural gas from Abu Gharadiq which is devoted to gas turbine electric power generation at Helwan, and $k_{1,2}$ is the corresponding gas production and piping costs. Some of the X_{ij} will not actually appear in the model, since the corresponding industries don't exist: for example, since none of the gas from Abu Madi is used for residential or commercial distribution, then $X_{2,6}$ will not appear in equation 2).

3.1.b Costs of fertilizer production

Fertilizer may be produced or imported. Domestically produced fertilizer may be exported. The net of costs and revenues are:

3) $$C_F = \sum_{i=1}^{5} k_i^F F_i - \sum_{i=2}^{4} k_i^{XF} F_{xi}$$

where F_i (tonnes) is the level of production of fertilizer for domestic sales, F_{xi} is the level of production of fertilizer for export, and k_i^F and k_i^{XF} are the respective production costs. Index i denotes the plant location. More precisely, variables F_1 through F_4 are the levels of production for domestic consumption at Suez, Talkha, Abu Qir, and Aswan. Variables F_{X2}, F_{X3}, and F_{X4} are the levels of production for fertilizer which is to be exported at Talkha, Abu Qir, and Aswan. k_2^{XF}, k_3^{XF}, and k_4^{XF} are net revenues for the export sale of fertilizer. Because of the properties of CN fertilizer, the output of Suez is not considered suitable for export trade.

The use of separate variables for domestic use fertilizer and exportable fertilizer causes the model to freely choose for each plant what part of production is devoted to export and what part to domestic consumption. If in reality there are constraints on export, the model can be altered to reflect this.

3.1.c Costs of electric power generation

Electric generation costs are:

4) $$C_E = \sum_{i=1}^{6} k_i^E E_i$$

The variables involved are: total hydroelectric generation (E_1), total oil fired steam generation (E_2), generation by gas turbines at Helwan and Talkha (E_3 and E_4), and by gas fired steam generation at Helwan and Kafr el-Dauwar (E_5 and E_6). Due to lack of data it is believed that the picture presented here concerning the location of electric generation is incomplete, but better data will used in future treatments. One complication which is not addressed here is that many steam generation plants may be easily switched from one fuel to another.

3.1.d Process heat costs of the iron and steel industry

Heat costs at Helwan iron and steel are:

5) $$C = \sum_{i=1}^{3} k_i^S S_i$$

where S_1, S_2, and S_3 are the levels of use in kilocalories of natural gas, oil, and coke, and the k_i^S are their costs. In the iron and steel industry only the plant at Helwan uses natural gas at present, and it obtains this fuel from Abu Gharadiq. The model assumes perfect substitutability among oil, gas, and coke. But coke cannot be totally replaced by other fuels in iron and steel production, and a better version of this model would necessarily take this into account.

3.1.e Process heat costs in the cement industry

Heating costs in the cement industry are:

6) $$C_M = k_1^M M_1 + k_2^M M_2$$

where M_1 is the level of use in kilocalories of natural gas, and M_2 is the level of oil use. k_1^M and k_2^M are the corresponding costs. Only one variable is used for natural gas since presently the cement industry uses natural gas at only one installation.

3.1.f Fuel costs for residential and commercial distribution

Fuel use costs in the residential and commercial use sector are:

7) $$C_D = k_1^D D_1 + k_2^D D_2$$

The variables of fuel use are; D_1 = the level of distribution of natural gas, and D_2 = the level of distribution of LPG (butagas). The k_i^D are the corresponding costs. A system is being constructed in the east Cairo area which is supplied from Suez. This system has been modeled to get an idea of the value of distributed natural gas to potential small users.

3.2 The Constraints

The objective function of total gas and industrial costs will be minimized subject to the constraints that are listed in the following. The symbols that appear on the left side of the inequalities are the variables of the model, and they have all been defined in the preceeding section.

3.2.a Gas production capacities

Gas field production capacities are specified by:

8) $$\sum_{j \in I_i} X_{ij} \leq S_i \qquad i = 1,2,3,4$$

where S_i is the production capacity of each of the four gas producing fields in Egypt. I_i is the index set of industries that use natural gas produced at field i.

3.2.b Gas pipeline capacities

Properly speaking, the existance of a pipeline connection between Suez and Abu Gharadiq requires transhipment model constraints. But for the sake of simplicity treatment we will assume that gas always flows towards Suez for fertilizer production, and flows separately from Suez to Cairo for residential and commercial distribution. The pipeline constraints are:

9) $$\sum_{j \in J_i} X_{ij} \leq Q_i \qquad i = 1,2,3,4$$

where the Q_i, i = 1,2,3,4, are the capacities of the pipelines in Egypt which link Abu Gharadiq to Helwan, Abu Madi to Talkha, Abu Qir to Kafr el-Dauwar, and Suez to Cairo. The pipeline system in Egypt is actually more complex than this, and future models may address that fact. J_i is the index set of industries that use the pipeline connection i.

3.2.c Industrial demands

The next set of constraints establishes the requirement that national demand for various products be satisfied by production or importation.

Demand for fertilizer:

10) $$\sum_{i=1}^{5} F_i \geq F^D$$

where F_i is fertilizer produced for domestic demand at Suez, Talkha, Abu Qir, and Aswan, and imported fertilizer. F^D is the annual national demand for fertilizer.

Demand for electrical energy:

11) $$\sum_{i=1}^{6} E_i \geq E^D$$

where E_i, i = 1,2,...,6 is electric energy (kWH per year) generated by natural gas at Helwan (one gas turbine and one steam boiler), at Talkha, and at Kafr el-Dauwar, and total hydroelectric and total oil fired generation. E^D is the annual national demand for electric energy.

Demand for heat at Helwan iron and steel:

12) $$\sum_{i=1}^{3} S_i \geq S^D$$

where S_1, S_2, and S_3 are the respective kilocalorie useage of natural gas, oil, and coke, and S^D is the annual demand for process heat at the iron and steel works.

Demand for heat in the cement industry:

13) $$\sum_{i=1}^{2} M \geq M^D$$

where M_1 and M_2 are respectively the kilocalorie use of natural gas and oil in the cement industry and M^D is the annual national demand for kilocalories in production of cement.

Demand for heat in the residential and commercial sector:

14) $$\sum_{i=1}^{2} D \geq D^D$$

where D_1 and D_2 are levels of use of natural gas and butagas respectively. D^D is the yearly national demand for kilocalories in this sector.

3.2.d Industrial capacities

Fertilizer production capacities:

15) $$F_1 \leq F_1^C$$

$$F_{xi} + F_i \leq F_i^C , \qquad i = 2,3,4$$

where F_i^C, i = 1,2,3,4, is the maximum annual capacity of fertilizer production at Suez, Talkha, Abu Qir, and Aswan. F_1 is fertilizer production level at Suez, and F_{xi} and F_i are the production levels for exported fertilizer and fertilizer for domestic use respectively at the other plants.

Electric power generation capacities:

16) $$E_i \leq E_i^C, \qquad i = 1,2,...,6$$

where E_i^C, i = 1,2,...,6, is respectively the annual energy generation capacity of total hydroelectric, total oil fired steam generation, gas turbines at Helwan and Talkha, and gas fired steam generation at Helwan and Kafr el-Dauwar.

Process heat capacities at Helwan iron and steel:

17) $$S_i \le S_i^C, \qquad i = 1,2,3$$

where S_i^C, i = 1,2,3, is the annual kilocalorie capacity of natural gas use, oil use, and coke use.

Process heat capacities in the cement industry:

18) $$M_i \le M_i^C, \qquad i = 1,2$$

where M_1^C and M_2^C are the annual kilocalorie capacities of the use of natural gas and oil respectively.

Fuel use capacity in the residential and commercial sector:

19) $$D_1 \le D_1^C$$

where D_1^C is the annual kilocalorie capacity of the Cairo zone natural gas distribution system. It is assumed that any amount of LPG can be available through imports.

3.2.e Natural gas user identities

The following identities are necessary to link production variables for plants that use natural gas with the required gas flow variables:

20) $a_{21}X_{21} = F_2 + F_{X2}$ Talkha fertilizer production

$a_{31}X_{31} = F_3 + F_{X3}$ Abu Qir fertilizer production

$a_{11}X_{11} = F_1$ Suez fertilizer production

$a_{12}X_{12} = E_3$ gas turbine electric at Helwan

$a_{13}X_{13} = E_5$ gas fired electric at Helwan

$a_{22}X_{22} = E_4$ gas turbine electric at Talkha

$a_{33}X_{33} = E_6$ gas fired electric at Kafr Dauwar

$a_{14}X_{14} = S_1$ gas use at Helwan iron and steel

$a_{15}X_{15} = M_1$ gas use in cement at Helwan

$a_{46}X_{46} = D_1$ distribution of natural gas

where the coefficients a_{ij} express the amount of production available per unit use of natural gas.

4 DESCRIPTION OF DATA

In this section we present the values used in the model and their sources. Rough approximations had to be made in some cases due to the lack of proper data. The values that are needed for the study are costs of industrial production and fuels, gas production and transportation capacities, industrial production capacities, demands for industrial production, and certain factors that relate levels of production to the corresponding consumption of natural gas.

4.1 Costs

Only the foreign exchange fuel costs are considered in production. The cost for oil is taken at a world market price of $33 per barrel, and the cost of coal is taken to be $90 per tonne, cif port of Alexandria. The cost of LPG is taken to be $400 per tonne [1]. Natural gas users are charged only for foreign exchange production and piping costs. No direct charges are made for natural gas, since the question of what is the proper "economic rent" for natural gas is contained in the solution of the linear programming model.

4.2 Natural Gas Sector

4.2.a Costs

Gas production costs are $.013/cu-m for onshore non-associated gas, and $.035/cu-m for offshore non-associated gas (1980 prices, [1]; these are assumed to be foreign exchange costs). If these values are correct then, for example, the annual operation costs for the Abu Madi field is about $12 million.

Operation and Maintenance costs of a natural gas pipeline are said to run about 5% of capital costs ([4], p74). Using this fact gas transportation costs were calculated from a table of average capital costs of pipeline per kilometer, and a listing of pipeline lengths and diameters in Egypt [1]. The results of the calculation are given in Table 4.1. The running costs per cu-m of gas transported that are shown in the last column were derived from values for pipeline capacities.

Table 4.1 Pipeline Capital Costs and Running Costs in Egypt

	capacity costs (mill. $)	running costs (mill. $/yr)	annual running costs ($/cu-m)
Abu Gharadiq to Helwan	66.4	3.3	.00292
Suez to Cairo	10.4	.52	.00051
Abu Madi to Talkha	5.00	.25	.00024
Abu Qir to Kafr el-Dauwar	17.1	.86	.00067

The total costs for the production and transportation of natural gas are given in Table 4.2.

Table 4.2 Pipeline Capacities and Total Natural Gas Costs

	Capacity (Mill. cu-m/day)	Costs (Mill. $)
Abu Gharadiq to Helwan	3.1	.015
Abu Gharadiq to Suez fertilizer	2.8	.016
Abu Madi to Talkha	2.8	.012
Abu Qir to fertilizer and electric	3.5	.036
Suez to Cairo distribution	2.8	.017

4.2.b Capacities

The pipeline capacities assumed for the model are given in Table 4.2. Natural gas production capacities [1] for Abu Gharadiq, Abu Madi, Abu Qir, and Suez are respectively 3.1, 3.4, 3.5, and 3.4 million cu-m per day.

4.3 Fertilizer Sector

4.3.a Production costs and export revenues

Fertilizer production at Aswan is based on ammonia produced by electrolysis, so that production cost is primarily the cost of electricity. The marginal cost of electricity in Egypt is about $.06/kWH, based on the use of oil fired generation as the marginal generation unit [11], and the free market price of oil. Then given good electric power generation efficiencies for oil fired units, the cost of ammonia produced at Aswan is $720/tonne. (This is considerably greater than the international market price of $160/tonne [11].) Then the cost of calcium ammonium nitrate (CAN) produced at Aswan is taken to be $220 per tonne, since the fraction of ammonia in CAN at Aswan is 31%.

It will be assumed that CAN is the only type of fertilizer which is imported, so that imports will cost $140 per tonne ([10], p197, inflated by 10% per annum).

Revenues from exported fertilizer are derived from FOB ex-factory prices ([10], p227 inflated by 10% per annum). The latter are adjusted by dropping fixed charges, assuming that due to subsidy the figures are 18% of true costs, and by converting LE to $ (1 LE = $1.5). This procedure results in road transport charges of $.12 per tonne-km, and water transport charges of $.025 per tonne-km. Table 4.3 gives the results of the calculation, where water transport to Alexandria is assumed for Aswan, and road transport is assumed for all others. The negative sign for Aswan revenue indicates a loss incurred when its fertilizer is sold for export.

Table 4.3 Net Revenues for Fertilizer Exports ($/tonne)

	type of fertilizer	FOB price	transport charge	production charge	net revenue
Aswan	CAN	124	28	220	-124
Abu Qir	urea	169	1	0	168
Talkha	CAN	124	20	0	104
Talkha	urea	169	20	0	149

Since Talkha fertilizer is represented by only a single variable in the model, its revenue due to export of CAN and urea is assumed to be in proportion to its production capacities for each (38% and 62% respectively; [9], p73). The resulting net revenue for Talkha fertilizer is $132/tonne for Talkha.

4.3.b Production capacities

The capacities of fertilizer production were derived from daily production capacity figures ([9], p73) by assuming a 330 day working year. The results for Suez, Aswan, Talkha, and Abu Qir are respectively 250, 363, 875, and 495 thousand tonnes of fertilizer per year.

4.3.c Fertilizer demand

A figure for fertilizer demand can be assumed given an estimated figure of 552,000 tonnes of nitrogen demand in Egypt for 1983 ([9], p231). Assuming that total demand for fertilizer is in proportion to demand for each type as total production capacity is to each type of capacity, then the percent of nitrogen in the total demand for fertilizer is 37%. Then the national demand for fertilizer is 552,000/.37 = 1.5 million tonnes. If correct, this figure implies a capacity factor of 76% for fertilizer production in Egypt.

4.3.d Amount of natural gas used

The energy required for ammonia production using natural gas (fuel and feedstock) is 34 billion joules per tonne of ammonia ([9], p81). Then given 13.1 million kilocalories per tonne of natural gas, and 1.38 thousand cu-m per tonne of gas, the mass of the nitrogen fraction of ammonia produced per cubic meter of natural gas is .000964 tonne of nitrogen per cu-m. Then given the proportion of nitrogen in the different fertilizer types, and assuming that production at Talkha is divided into 38% for CAN and 62% for urea, the fertilizer production per unit natural gas use at Suez, Talkha, and Abu Qir are respectively .00567, .00248, and .00210 tonnes/cu-m.

4.4 Electric Power Sector

4.4.a Heat rates

Assuming that electricity generation on the margin is provided by the 300MW units referenced in ([12], appendix 2, p4), the heat rate is chosen to be 230 gm/kWH for oil fired and gas fired steam generation. Assuming the marginal gas turbine unit is similar to those at Helwan and Talkha, the heat rate is 310 gm/kWH ([12], Appendix 2, p4). It is assumed that the only fuel that is used in gas turbine power generation is natural gas.

4.4.b Costs

The charge for using natural gas in electric generation is zero, and the cost of hydroelectric generation is taken to be zero. Given a heat rate for electricity generation by oil fired steam generation of 230 gm/kWH, and an oil cost of $33 per barrel of oil at 7.3 bbl/tonne ([5], p221), the cost of generation by oil fired boiler is $.055/kWH.

4.4.c Electricity production capacities and demand

Electrical power capacity in Egypt in 1980/81 consisted of 2095 MW hydroelectric, 569 MW of gas turbine, and 1201 MW of steam turbine generation [6]. The references of this study do not make clear what part of gas turbine generation and steam turbine generation make use of natural gas instead of gasoline. Thus it is assumed that gas turbine generation consists solely of a 120 MW unit at Helwan and a 180 MW unit at Talkha, and that natural gas fired steam generation consists of a 45 MW unit at Helwan and a 220 MW unit at Kafr el-Dauwar. It is also assumed that 800 MW of oil fired generation is available. In the case of hydro, full power capacity is not available year-round because of water supply limitations and irrigation needs. The figure to be used for hydro capacity will be the energy supplied in 1980/81 which comes to 9.91 billion kWH [1]. This figure is acceptable as a capacity since optimal use is being made of hydro power in Egypt.

The demand for electrical energy in 1981 was 20.98 billion kWH (personal communication, M. Hassan el-Sayed).

4.4.c Natural gas use

Given the assumed heat rates, and given that there are 1.4 thousand cu-m volume per tonnes of natural gas ([5], p218), the electrical output per unit use of natural gas is 2.3 kWH/cu-m for gas turbines, and 3.1 kWH/cu-m for gas fired steam generation.

4.5 Iron and Steel Sector

4.5.a Costs and natural gas use

Three fuels are examined in the iron an steel sector; coal, oil, and natural gas. The direct cost of natural gas is taken to be zero. The cost of oil is $33/bbl, and the cost of coal is assumed to be $90/tonne, cif port of Alexandria. The amount of heat produced per unit of natural gas is taken to be 9432 kcal/cu-m at Helwan [1].

4.5.b Demand and capacities for fuel use

Due to the lack of data concerning capacities, the kilocalorie limit for the use of coke and the limit for the combined use of oil and natural gas is each assumed to be equal to what is required for maximum steel production. The steel mill capacity at Helwan is 1.75 thousand tonnes of steel per year ([9], p21). Using values given for tonne of fuel needed per tonne of steel ([9], p25) and energy efficiencies (energy needed per tonne of steel production, [9], p26), we find that the capacity for coke use is 14.0 trillion kilocalories per year, and for fuel oil is 2.35 trillion kilocalories per year. (This implies that fuel use capacity in tonnes per year for coke is 1.9 million and for oil is 0.24 million.) It is further assumed that one-third of the use of oil at Helwan iron and steel has been replaced by natural gas, so that the capacities assumed for the model are; 1) 14 billion kcal/yr for coking coal, 2) 1.57 billion kcal/yr for fuel oil, and 3) 0.78 billion kcal/yr for natural gas. The last factor would imply that Helwan iron and steel is presently capable of using 0.23 million cu-m of gas per day.

The lack of data or analysis concerning demand for kilocalories makes necessary the use of a figure which is artificially reckoned. It is assumed that the kilocalorie requirement at Helwan is 80% of total Capacity of coal and oil, so that demand is taken to be 12.5 trillion kcal/yr.

4.6 Cement Sector

4.6.a Costs and use of natural gas

The importation of cement was not taken into account, so no import prices are used. The direct costs for the fuels used in the cement sector are taken to be zero for natural gas, and $33 per barrel for oil. The amount of heat produced per unit natural gas is 9432 kcal/cu-m [1].

4.6.b Capacities and demand

The capacity for the use of kilocalories of natural gas was derived from figures giving cement industry gas consumption in 1980, and assuming a 75% capacity factor. Thus the capacity for the use of natural gas is taken to be 18.0 billion kcal/yr.

To find the kilocalorie capacity of oil consumption for cement production, use was made of figures that give the capacity of existing plants [1]. The figures are given in Table 4.4. Then using a value for kilocalorie requirements for wet-process cement (1.6 million kcal/tonne), one arrives at a cement industry oil consumption capacity of 9.02 trillion kcal/yr.

Demand for kilocalories is set at 80% of total capacity, or 12.5 trillion kcal/yr.

Table 4.4 Capacities of Cement Plants in Egypt that use Oil

plant	capacity (cement, million tonnes/yr)
Tourah	1.2
Helwan	1.2
el-Tabbin	1.04
Alexandria	2.2
Total:	5.64

4.7 Residential and Commercial Sector

4.7.a Fuel costs and use of natural gas

Zero direct costs are charged for natural gas, and a price of $400 per tonne for LPG is assumed [1]. The amount of heat available per unit volume natural gas from Suez is 9975 kcal/cu-m.

4.7.b Capacities and demand

160,000 customers will consume 200 thousand cubic meters of natural gas per day in 1985 [1]. We will assume that this is the capacity of natural gas distribution, which then represents a kilocalorie consumption capacity of .70 trillion kcal/yr. No upper limit on the use of LPG is assumed.

To calculate demand, use is made of the fact that 62% of LPG is imported and that domestic production is 380 tonnes per day. This would imply that the daily consumption of butagas is about 1000 tonnes, or in terms of annual heat content, 4.4 trillion kcal/yr. Adding to this the projected figure for natural gas distribution capacity yields 5.1 trillion kcal/yr. It is assumed that this figure represents the heat demand for this sector.

5. RESULTS

The linear programming problem was solved for three cases; high electricity demand, low electricity demand, and a case of medium electricity demand where demand was set equal to the electrical energy consumed in 1981. In this way we were able to assess the impact of variable demand for electricity on the model.

It was found that the solutions were basically the same for the medium and the high demand cases. The only difference between the two was that more oil fired generation was used in the high demand case, all other production levels and shadow prices remaining the same. In the discussion of the results only the high and the low electricity demand cases will be compared. In the high demand case natural gas supply is used to capacity at Abu Gharadiq and Abu Madi, but in the other case, additional gas supplies are available from all pipelines. Consequently, the shadow price of natural gas in the low electric demand case is zero.

The solution values given in what follows are not to be fully trusted because of the crudeness of the data and of the modeling of some sectors. Nevertheless the overall results will be seen to be quite reasonable. We will be able to form a good picture of the direction of the use of natural gas in Egypt given the assumptions of the study, and the shadow prices will appear to be meaningful.

We will examine the results of the linear programming problem solution sector by sector, starting ith the simplest.

5.1 Residential and Commercial Fuel Use

The only supplier of natural gas to this sector is Suez oil-associated gas, which is treated as supplying no other user. Consequently the outcome is very simple. Natural gas is used to capacity and LPG (butagas) fills the rest of demand. The production levels and shadow prices are unaffected by electricity demand since no electric power generation uses Suez gas.

In such a setting the shadow price for natural gas is equal to the price of LPG on a BTU basis. The cost to Egypt for delivering from Suez an additional cu-m of natural gas is $.0170, then the shadow price for the expansion of the Cairo distribution system is the cost of LPG (in equivalent natural gas cubic meters) less $.0170, or $.0169/cu-m. The Egyptian government would be willing to pay $.0169 or less to increase the use of natural gas in the distribution system by one cubic meter of capacity.

5.2 Cement Production

Conditions in the use of natural gas in the cement industry are affected by the level of electricity demand since the source of supply is also available for power generation (Helwan gas turbine). Under both cases of high demand and low demand for electric power, natural gas is used to capacity in cement production, but the shadow price of the gas differs.

In the case of low electricity demand the shadow price of cement production capacity using natural gas is \$.89/cu-m, and under the high demand case, the price is \$.78/cu-m. In the latter case natural gas is less valuable in cement production since the more limited supplies are being used to greater advantage in other sectors.

During high electricity demand, natural gas is being used to the capacity of the Abu Gharadiq field deliveries, whereas in the low demand case some supplies are unutilized. In the later case the shadow price of natural gas is zero, so that the difference between the capacity shadow prices given above is the shadow price of the gas (\$.112/cm-m) under high electricity demand conditions.

5.3 Helwan Iron and Steel

Table 5.1 summarizes results in this sector. Note that the proportion of heat delivered by natural gas is small in comparison to coke heating capacity, and no heat is provided by oil. The low shadow price of heating by natural gas reflects the costs of coke use. In fact, this price plus the costs of supplying natural gas is equal to the cost of coal used in the model.

Table 5.1 Results for the Iron and Steel Sector (production in % of capacity, price in $/cu-m)

fuel	low electric demand: production	price	high electric demand: production	price
natural gas	100%	.089	-	-
oil	-	-	-	-
coke	87%	-	93%	-

The model solution rates the use of natural gas in the iron and steel sector as being of low importance. This is apparent in the relatively low shadow price and in the fact that in the case of high electricity demand coke completely displaces gas in providing kilocalories.

Sensitivity analysis shows that a structural change occurs in the solution if the cost of coal is increased to $107/tonne. At this cost level (and above) it is found that gas is used to displace coal at Helwan during peak electricity demand periods as well as during low demand periods. Less gas is found to be available in the electrical sector implying that natural gas is more important for displacing coal at Helwan than oil in power generation.

It could well be that the cost of coal at Helwan is greater than $107/tonne due to transportation charges and due to the fact that coal of a coke producing quality is required. It is important for the study that the cost of coal at Helwan be well established.

At present a policy of rapid conversion of the plant to an intensive use of natural gas is being implemented. The process was started five years ago at which time 200 tonnes of mazout were being used per day. At the present the consumption of mazout has been reduced to 70 tonnes/day, and the goal is to completely displace this fuel. The model shows that it is not important to displace the use of coke at Helwan, unless its price is ove. $107/tonne. Note that coke is displaced by natural gas when it is used in blast furnaces to improve efficiency.

The picture of the iron and steel industry given by the model is too crude to allow detailed conclusions to be drawn in this sector. An improved version of the linear programming problem must picture the iron and steel facility in greater detail to yield meaningful results. Levels of fuel uses in subsectors would be specified, such as coke ovens, blast furnaces, rolling mills, and so forth. The shadow price of natural gas would be found to be higher, since there are applications in the iron and steel sector in which its use is valuable.

5.4 Electric Power Generation

The results are given in Table 5.2. In the case of low electricity demand the marginal generation unit is the gas fired unit at Helwan. Since the gas supply is not operating to capacity, its shadow price is zero, and the shadow price of kWH at hydrogeneration simply reflects the costs of supplying natural gas to Helwan generation. What we see in this case is that if gas supplies were unlimited electricity would be very cheap to supply.

Table 5.2 Results for Electricity Generation (production in % of capacity, prices in $/kWH)

generation	low demand case: production	---price	high demand case: production	---price
hydro	100%	.0048	100%	.055
oil	-	-	98%	-
Helwan boiler	23%	-	100%	.014
K. Dauwar boiler	-	-	100%	.043
Helwan gas turbine	-	-	45%	-
Talkha gas turbine	-	-	94%	-

When electricity demand is high, or even when it is at average annual values, the marginal fuel for generation is oil. This shown by the shadow price for hydropower, which is equal to the cost of oil fired generation used in the study. Any additional demand would be supplied by oil up to the capacity of oil fired generation. That the gas turbine units are not used instead shows that no more gas will be allocated to generation because of supply limitations and greater advantage in gas use elsewhere. The explanation for the shadow prices shown for gas fired units is probably complex, and depends upon interactions with fuels in other sectors as well as upon the fact that gas supply is limited.

Each of the energy use shadow prices can be translated into a generation power capacity shadow price with the following reasoning: the price represents what Egypt will be willing to pay for each additional kWH of energy supplied by the given generation over the year represented in the study. But one kWH in one year is generated by 1/8760 kW of capacity, where 8760 is the number of hours in a year. Then the power capacity price is found by multiplying the energy capacity price in Table 5.2 by 8760. The results of this calculation are given in Table 5.3.

Table 5.3 Shadow Costs for Power Capacities

Hydroelectric:	$480/kW
Helwan gas fired boiler:	$120/kW
Kafr Dauwar gas fired boiler:	$377/kW

A recent study ([9], Vol. 5, Annex 13, p28) reports that a 600 mW gas fired power plant in Egypt would cost 58.4 million LE in 1978. Assuming 10% inflation to 1981 and a conversion rate of 1 LE to $1.50, this amounts to 130 million dollars, which means a capacity charge of about $220/kW. The data of Table 5.3 shows that at this price it is to the benefit of Egypt to invest in additional capacity at Kafr el-Dauwar, but not at Helwan.

Additional hydroelectric facilities are presently being installed at Aswan (Aswan II power plant). An early feasibility study estimated that 240 mW of generation should be installed where the cost on completion would be 130 million LE ([16], p4) ($195 million at the rate 1 LE to $1.50) which amounts to a capacity charge of $810/kW. (There is reason to believe that the actual charge is a good deal less.) The model derived shadow cost for hydro capacity expansion is considerably smaller than this, making it appear that the Aswan II project is uneconomical if the only benefit is electricity generation.

An additional benefit which isn't taken into account here is the greater control over electricity generation that Aswan II will allow. Presently the hydrogeneration at Aswan Dam is run base loaded, since the water available after passing through the High Dam generation is greater than the hydro capacity at Aswan. A good deal of water must be spilled at Aswan. Once Aswan II is put into operation all of the water of the Nile will pass through hydrogeneration, and control of waterflow can be made responsive to the needs of the electrical power grid. This will offset the use of demand peaking thermal units, which are more expensive to run than the thermal units which are used to meet base load.

5.5 Fertilizer Production

We note from Table 5.4 that the level of electricity demand does not effect production levels in the fertilizer sector. This would imply that the value of natural gas is greater in fertilizer production than in electricity generation.

Table 5.4 Results in the Fertilizer Sector (Production in % of capacity, prices in $/tonne production capacity)

plant	low electricity demand: production	price	high electricity demand: production	price
Suez, domestic	100%	137	100%	118
Talkha, domestic	100%	135	100%	89
Abu Qir, export	100%	151	100%	151
Aswan	0%	-	0%	-

For both the high and the low electricity demand cases domestic fertilizer demand is satisfied with production at Suez and Talkha, and with imports, which provide the marginal supply. All production capacity at Abu Qir is devoted to export fertilizer, and there is no production at Aswan.

In the low electrical demand case the shadow prices at Suez and Talkha deviate from the marginal cost of fertilizer of $140/tonne (the cost of imports) because of the costs of supplying natural gas. Similarly the shadow price at Abu Qir is the price of exported urea ($168/tonne) less gas supply costs. Since the revenues due to exporting urea are greater than the costs of importing CAN fertilizer, the solution choice is obvious.

When electricity demand is high the gas fields that supply Suez and Talkha run at capacity, and are constrained. The shadow prices for production capacity are higher for Suez and Talkha in the low electricity demand case because of differences in the shadow price of gas. This price is zero in the low demand case but not in the other because in the high demand case there is a bottleneck in the supplies of gas. Thus natural gas must be displaced by alternate fuels, which cost the model in foreign exchange. The value to Egypt of an increment of fertilizer production at Suez and Talkha is smaller in the high demand case because of the greater cost of using natural gas.

At present the Aswan fertilizer plant is used to full capacity by Egypt, and its large electric energy requirement is included in total domestic demand for electricity. One problem that must be examined is whether the model fails by using an incorrect value for total annual electrical demand when it determines that the Aswan plant should not be operated. Does it happen when Aswan is turned off that electrical demand slips to a point where gas boiler generation becomes the marginal unit? If this occurs, then the model will charge too high a price for production at Aswan.

In fact the linear programming solution using standard demand for electricity has oil generation operating as the marginal unit at a capacity of 5.8 billion kWH (86% of capacity). Namely any needed additional power generation will come from oil fired units. Since the electrical demand of the Aswan plant was 1.4 billion kWH in 1981 (private communication, Fayik Farid, EEA), and this level has varied by only a small percent over the years, if Aswan demand for electricity is removed, oil generation will still be the marginal unit.

5.6 Natural Gas Sector

Under conditions of standard electrical demand results are the same for natural gas as in the high demand case. Reference to Table 5.5 shows that in the linear programming model gas capacity is fully utilized at Abu Madi and Abu Gharadiq, and moderately well used at Abu Qir. The poor showing of the Suez field is due only to the fact that the project examined there is just one of a group of projects that will be in operation in the near future.

Table 5.5 Results in the Natural Gas Sector (annual production in % of capacity, shadow prices in $/cu-m)

field:	low electric demand: production	price	high electric demand: production	price
Suez	6%	0	6%	0
Abu Madi	29%	0	83%	0
Abu Qir	18%	0	65%	0
Abu Gharadiq	80%	0	100%	.112
pipeline:				
Suez to Cairo	7%	0	7%	0
A. Madi to Talkha	35%	0	100%	.115
A. Qir to K. Dauwar	18%	0	65%	0
A. Gh. to Helwan	80%	0	100%	.112

The table shows that pipeline capacity from Abu Madi must be expanded, and that industries at Helwan require new supplied of gas, whether delivered from Abu Gharadiq or elsewhere. The two shadow prices for natural gas (0.112 and 0.115) are derived from the need for additional capacity.

5.7 Conclusion

The shadow price for natural gas in this study derives from situations where either a production field or a pipeline is being used to capacity. In those cases in which gas is not being utilized to full capacity the shadow price is simply the delivery costs. This is because additional supplies are available at no direct foreign exchange costs. On the other hand, when a supply of natural gas is being used to capacity the linear programming model yields a shadow price which is interpreted as the amount policy makers would be willing to spend to increase capacity. The exact interpretation is that if the capacity is increased by 1 cu-m of gas, then the objective function (in our case the foreign exchange outlay for fuels, production, etc.) will decrease by an amount equal to the price. Thus planners will be will be willing to pay no more than that to increase gas capacity, for in doing so the foreign exchange outlay does not increase.

For example, if the shadow price is found to be $.20/cu-m, and it were possible to increase capacity by spending $.17 then each cu-m expansion in capacity would decrease the foreign exchange outlay by $.03.

The shadow price of natural gas production or distribution capacity is really the shadow price for gas as a fuel commodity in competition with other fuels. If there is an additional demand in the model and it were not possible to gain natural gas at the shadow price or less, then it is more economical to use an alternate fuel. This is a consequence of the fact that the model allocates fuel useage according to a best solution for foreign exchange.

Table 5.6 lists the shadow prices for new capacity of those industries in the model which are fully utilized in production. The unit used is $/cu-m, and thus represents the importance of using natural gas in the particular installation listed. The table is ordered in terms of the most important applications being listed first.

Table 5.6 Shadow Prices for Capacity in Some Gas Using Industries

plant	shadow price of production ($/cu-m): high electricity demand:	low electricity demand:
Cement	.775	.887
Suez fertilizer	.666	.779
Abu Qir fertilizer	.317	.317
Talkha fertilizer	.221	.335
Dauwar gas boiler	.135	-
Helwan gas boiler	.044	-
Iron and steel	-	.089
Cairo distribution	.017	.017

The model determines that the most important application for natural gas is the manufacture of cement. Although the importation of cement was not considered in the model, it is unlikely that this makes much difference in the result. The cement sector demand was chosen to reflect demand for domestically produced cement more faithfully than total demand, so that the inclusion of a term for imported cement would have little effect on the study conclusions.

v.7.a Electric power peaking requirements

That the model is very sensitive to electric power demands indicates something of importance for the near term development of the use of natural gas. Any expansion of the use of natural gas in electric power generation must be matched by a much greater expansion of the gas delivery infrastructure. It is clear from the results of the model that as the electric power authorities increase power generation to meet peak demand a bottle neck develops in natural gas supplies. This could cause stress to other users, who might be forced to cut back production during periods of peak power demand.

Presently the bottle neck is dealt with by fuel switching at electric power stations that use natural gas. But the alternate supplies, such as solar (gasoline) are very expensive, and the solution in the long run must be to use natural gas exclusively.

Egyptian planners must take careful account of electric power peaking requirements as they expand the natural gas delivery system.

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