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Technical Assessment of the Impact of Geopressure Development in the Corpus Christi Area of Texas

W. TOM KLEEMAN

Texas General Land Office, 1700 No. Congress, Austin, Texas 78711, USA

KINGSLEY E. HAYNES

Lyndon B. Johnson School of Public Affairs, University of Texas at Austin, Austin, Texas 78712, USA

THOMAS F. FREELAND

Systems Research Services, 3002 Oakcrest, Austin, Texas 78704, USA

ABSTRACT

This study is an outgrowth of a four-year ongoing U.S. National Science Foundation (RANN) project on the impact of alternative environmental policies on coastal-zone development in the Corpus Christi area of Texas. In recent years geothermal development has become a distinct possibility in the vicinity of the study area due to the identification of a belt of geopressured sands in the immediate off-shore area.

The economic interrelationships between alternative environmental policies and the development of a nearby geothermal energy source are examined. This examination is based on a localized version of the Texas Input-Output Model and on information generated from the environmental policy impact analyses.

In addition to the impact on output there are also changes in the rates of migration, expansion, and location of housing, and the location of economic activity.

INTRODUCTION

For the past three years each of the authors has participated at one time or another, either on a part-time or full-time basis, in a project sponsored by the U.S. National Science Foundation (NSF) Research Applied to National Needs (RANN) program. The project concerned the establishment of operational guidelines for Texas coastal-zone management. The result of this effort was the development of much of the methodology employed here.

Study Area

The area under consideration is known as the Coastal Bend COG (Council of Governments—a multicounty regional planning and coordinating agency). The Coastal Bend area is located on the broad Gulf coastal plain of Texas and includes 13 south Texas counties (Fig. 1), which encompass an approximate land area of 7 838 000 acres. The region is distinguished by low-lying tidelands, which in the interior give way to a gently rising surface and culminate in rolling hill country.

Underlying this sparsely populated, predominantly agrarian area are geopressured geothermal waters (Fig. 2). Because of the extensive oil and gas exploration that has taken place in the area, with the resulting blowouts, the existence of this resource has been verified for some time. The deposits seem to run in bands along the coast, offshore, and inland as far as 75 miles (Fig. 3). These deposits vary in depth from 5000 ft to 15 000 ft, with temperatures as high as 375°F and pressures up to 4000 to 5000 psi at the wellhead.

At this time it appears that the most productive region lies between Brownsville and Corpus Christi. However, the geopressure zone does stretch as far east as the Mississippi Delta Region.

Energy Situation

This area has been one in which there have been numerous and quite large reservoirs of oil and natural gas. Over the long run it is purely academic whether these reserves will be depleted in 15, 30, or 50 years. The rate of flow has already begun to decline.

South Texas is the poorest area of the state, and the diminishing energy reserves are not an encouraging prospect for an economically lagging area. Given this energy/economic future, the recent interest in the geopressured reservoirs of the area has made it a salient feature for investigation. (The Center for Energy Studies, The University of Texas at Austin, was awarded a $600 000 grant from the U.S. Energy Research and Development Administration to do an extensive geopressure resource assessment.)

The overall goal of this group was to carry out an effective analysis of the energy potential of the geopressured geothermal resources with the tools that had already been developed during the course of our work on the Coastal Bend region. Some changes were made in the methodology, and certain

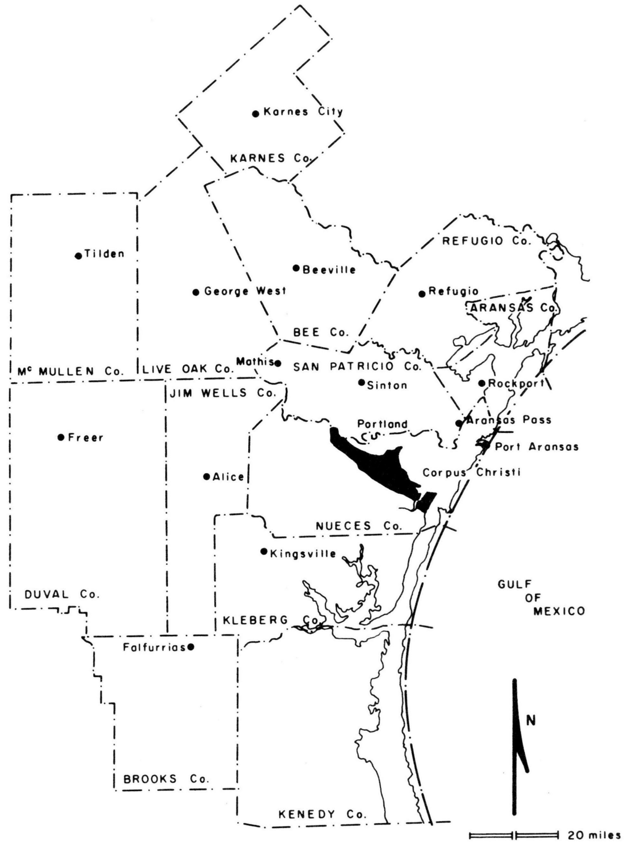

Figure 1. Coastal Bend region.

new techniques had to be employed. Specifically, the objectives were to: (1) analyze the microeconomic data for the types of power plants that could be used; (2) apply this data on an industry-wide basis in an input-output model to see what the interindustry impacts would be; and (3) measure the impacts of geopressured power plants in terms of electric utility rates in the region.

PREVIOUS RESEARCH INTO ECONOMIC FEASIBILITY

Until now there have been only two serious research efforts regarding the economic efficacy of geopressured geothermal power plants. These efforts have been carried out by House, Johnson, and Towse (1975) of Lawrence Livermore Laboratory and Wilson, Shepherd, and Kaufman (1974) of Dow Chemical.

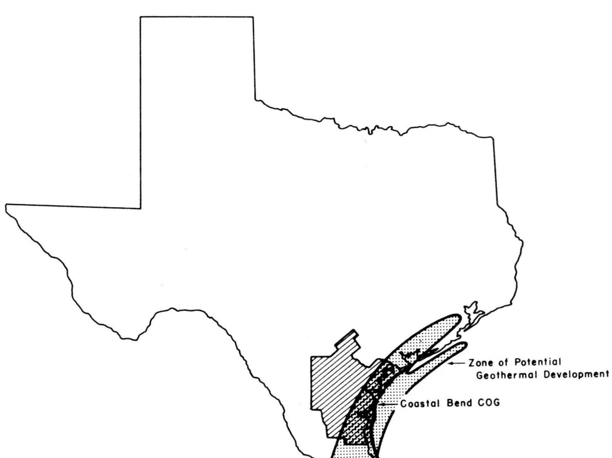

Figure 2. Texas coastal geopressured zone.

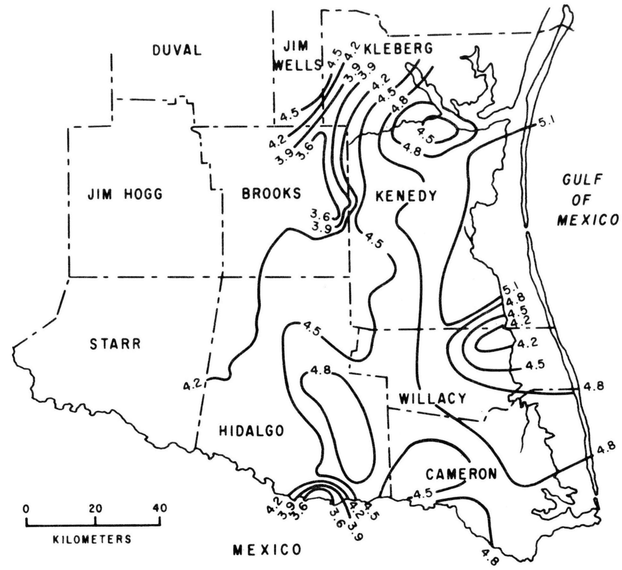

Figure 3. Depth of occurrence of the 150°C (302°F) isothermal surface in the south Texas coastal plain. Line of equal depth of 150°C isothermal surface, interval is 0.3 km, datum is land surface (Wilson, Shepherd, and Kaufman, 1974).

While the House report should be of interest to anyone not familiar with the geopressured area, the microeconomic information in the Wilson report was employed in our study. The data were much more detailed and far more amenable to adaptation to input-output (I-O) applications.

Dow's team investigated six possible scenarios. Three different types of power plants, isobutane, 1-stage flashed steam, and 2-stage flashed steam were used in Model 1 (developed from the data obtained from the Geological Section, Oil and Gas Division, of Dow Chemical, U.S.A.). This was the Hidalgo County model. The second model, using the same three variations in power plants, was developed by Paul Jones of Lousiana State University. This model represented an area in the lower Rio Grande embayment. For the purposes of this study, cost estimates came from the Jones 2-stage plant, as published by Dow (think of it as the Dow-Jones model). Below are the specifications of the Jones model.

Dimensions	10 × 50 miles
Net sand thickness	1000 ft
Porosity	18%
Average water and rock compressibility	9×10^{-6} vol/vol/psi
Viscosity	0.2 centipoise
Well radius	0.3 ft
Permeability	
1	0.0275 darcy
2	0.08 darcy

The Jones 2-stage system was chosen for two reasons: (1) there were definite cost advantages; it was nearly 4 mill/kWh cheaper than the next cheapest method (1-stage flash); and (2) after consulting with engineers working in the field, the authors became convinced that the technology for this system was at a more advanced stage of development than the isobutane system. House, Johnson, and Towse (1975) at the Lawrence Livermore Laboratory based their analysis on the use of a total flow system. Once it becomes operational it looks to be very promising.

Methane Gas

In addition to the high-temperature and high-pressure characteristics of these deposits, the resource is also unique because of the presence of methane gas in the waters. Many of the deposits are known to have economically attractive levels of methane saturation. The Dow models dealt with a reservoir in which the methane content was assumed to be 30 standard cubic feet for each barrel of water. In both the Dow and the Lawrence Livermore studies, the presence of methane was an important factor in determining whether or not a deposit was marginal.

However, all the deposits will not be laden with methane, so that for this study methane saturation was not assumed. Additionally, the Dow study shows a cost for a 50-mile pipeline for moving the gas. This was a curious expenditure since the region is crisscrossed with natural-gas transmission lines. If the natural gas were not going to be used by the power plant, it would appear likely that a natural-gas transmission facility would be closer than 50 miles away. One inference that can be drawn from this expenditure is that Dow was looking at the possibilities of piping the gas back to its own facilities for feedstock purposes with the assumption that a similar plant might be located up the coast nearer to Dow's Freeport, Texas, location.

Kinetic Energy Power Production

The Lawrence Livermore report discussed the potential for producing electric power by using the high-pressured kinetic energy potential present, especially in the deeper wells. Dow discounted this possibility principally for three reasons: (1) there would be design and operational problems associated with the attempts at methane removal while geopressured fluids were passing through hydraulic turbines; (2) there could be considerable operation and maintenance problems caused by the erosion resulting from the entrained sand in the fluids: and (3) there was the additional possibility of silica deposits. Possibly each of these problems will be resolved by different types of technologies in the near future. However, for the purposes of this paper, it was assumed that the kinetic energy potential would not be a factor in energy production.

ECONOMICS OF THE PLANT

Original Estimates of Capital Costs

As mentioned earlier, the Jones 2-stage flashed-steam system was the only model evaluated. The Dow report contains an extensive price breakdown of the capital components (see Table 1). The Dow cost figures represent the entire system, from the well to the lines leading out of the plant. Under these assumptions, the total capital costs

Table 1. Estimated capital and unit costs for Jones No. 2 power plant (66.5-MWe capacity).

Item	Cost ($)
Wells	24 400 000
Collection and disposal piping	470 000
Methane extraction	49 000
Dehydration	112 000
Cooling and separation	1 856 000
Methane pipeline and compressor	6 157 000
Flash chamber and separator	286 000
Turbine generator	18 646 000
Condenser	6 274 000
Cooling tower	2 024 000
Step-up transformer	532 000
General site development	400 000
Total estimated capital costs	61 206 000
Annual cost of ROI, depreciation, management, and operation	22 646 220

Source: Wilson, Shepherd, and Kaufman (1974).

came to $61 206 000. Given a capacity of 66 500 kW, this results in a unit capital cost of $920/kW—hardly a fortunate figure for utilities that are already strapped for capital. Given the fact that nuclear plants can be constructed for $650/kW and even small-scale coal-fired plants are being constructed for approximately $600/kW, the geopressured reservoirs would not appear attractive.

Reappraisal of Capital Costs

However, a closer look at the cost figures reveals other possibilities. To begin with, the Dow costs are for the total geothermal operation. This is analogous to assuming that utilities which burn coal would have to acquire and operate the coal mines and transportation systems which provide them with fuel. Dow's own operations span the entire process from well drilling to electric consumption; this is an atypical situation with regard to the electric utilities. A more meaningful investigation would concentrate on "inside-the-fence" costs. This proposition assumes that the petroleum sector would drill the well and provide the hot water for the utility. Therefore, the power plants would need only equipment for utilitzing the hot water and not for its acquisition.

With this approach in mind, a second look at the capital costs yields significantly different results (see Table 2). Under this assumption, none of the costs found in the first six rows of the Jones cost table (wells, methane pipeline, and compressor) would be incurred by the electric utility. This means that the total estimated capital costs for each plant would be $28 162 000. Given the 66.5-MW capacity, the unit capital cost is $423.50/kW.

Not only were there capital savings, but there were additional savings in the category of annual costs. Dow assumed a return on investment (ROI) of 20% and maintenance and operation costs of 8%. While a 20% ROI might be characteristic of Dow's own operations, such a return is not representative of the electric utility industry which operates at best on a 15% ROI. The 8% operation and maintenance cost came from the Federal Power Commission's report, "Steam-Electric Plant Construction Cost and Annual Production Expenses." The Dow report states, "It

Table 2. Estimated "inside-the-fence" costs for Jones No. 2 power plant (66.5-MWe capacity).

Item	Costs ($)
Flash chamber and separator	286 000
Turbine generator	18 646 000
Condenser	6 274 000
Cooling tower	2 024 000
Step-up transformer	532 000
Site development	400 000
Total estimated capital costs	28 162 000
Unit capital costs ($/kW)	423.50
ROI (straight line, 15%)	4 224 300
Depreciation (straight line, 5%)	1 408 100
Insurance (0.00275%)	74 446
Overhead (1.3%)	366 106
General and administrative (1.6%)	450 592
Maintenance and production (6%)	1 689 720
Total annual cost	8 213 264
Annual credit for condensate	212 000
Net annual cost	8 001 264
Annual electric energy production (kWh/yr) at 90% load capacity 5.243 × 10⁸	
Unit power cost (mill/kWh) 15.3	

is felt that this (8% rate) is a reasonable figure to apply to geothermal power plants." After discussions with John Wilson of Dow, we agreed that if several plants were constructed this cost could probably drop to around 6% of the capital investment. These two changes decreased the annual costs by 7%.

After we subtracted the annual water condensate credit, the net annual cost became $8 001 264. The unit power cost at a 90% load factor (5.243×10^8 kWh/yr) is 15.3 mill/kWh.

There is one additional mitigating factor that could make the annual costs even smaller, although this facet is still extremely speculative. There has been recent interest in secondary oil recovery operations, and the hot water that is coming out of these plants might prove to be useful to the oil industry. Since the viscosity of oil is so great, secondary recovery operations require hot water. Such water requires the burning of fuel to heat it. The recycling of geothermal waters for such a purpose would serve a revenue-generating (cost-cutting) function similar to receiving a credit for condensate.

INPUT-OUTPUT MODEL

During the past three years the members of this research team have performed a series of environmental policy analyses. An input-output model was constructed as part of the effort to assess the interaction of the economy and the environment. What follows is a brief description of input-output analysis.

Regional Economic Model

The region under study consisted of the 13 counties of the Coastal Bend COG. This region was chosen for study because of the large amount of economic activity taking place near the coastline and its relative isolation from large metropolitan complexes, such as Houston. The COG is a subregion inside the larger South Texas Region (number 7), which is a designation used in the ongoing Texas Inter-industries Project. This project is sponsored by the Texas Governor's Office of Information Services (OIS). This office has constructed a state input-output model for 1967, as well as nine regional models for the same year. Since the Region 7 model contained the required data, location quotient techniques were used to derive the smaller Coastal Bend subregional model.

The model consists of 71 processing sectors that may be categorized as: agriculture, Sectors 1 to 12; mining, Sector 13; construction, Sectors 14 to 16; manufacturing, Sectors 17 to 34; transportation and communications, Sectors 35 to 39; utilities, Sectors 40 to 42; wholesale trade, Sectors 43 to 49; retail trade, Sectors 50 to 60; finance, insurance, real estate (FIRE), Sectors 61 and 62; and services, Sectors 63 to 71. Final demand consisted of seven sectors: households; federal, state and local government (one sector each); capital formation; exports; and net inventory changes. Final payments contained seven sectors: households; federal, state and local government; depreciation; imports; and residual (which included retained earnings, profits, dividends, savings, and account-balancing entries).

Individual factory and business establishments of the economy were classified according to the major product or service produced. Establishments in multiproduct lines of production were classified according to the major product and the establishment's entire activities were included in the section into which the major product is placed. The Standard Industrial Classification System (SIC codes for 1967 published by the U.S. Department of Commerce) was used as the method of defining and delineating the sectoral groupings (for the actual example see Table I-1 in Appendix I). The single exception to the sectoring concept was for agricultural sectors which were defined along activity or enterprise lines of economic endeavor, rather than along establishment lines.

Explanation of Input-Output Model

The fundamental advantage of the input-output approach is that it allows an examination of the symbiotic relationships between different industries. Not only can the results of a change in demand for a given industry be measured in terms of how it will affect that particular industry, but the effects on each of the input-supplying industries can be measured and traced throughout the entire economy.

A clear and concise explanation of how input-output models function is presented by Miernyk (1965). The hypothetical example presented below was taken from Miernyk. A more detailed mathematical explanation of input-output analysis is presented in Appendix II.

Transactions Table

The transactions table of a hypothetical economy is given in Table 3. The transactions of each industrial sector may be characterized in two ways. When reading across the table, the sales of each sector are expressed along its row. For example, in the hypothetical table, Industry A (row 1) sold 10 units to other firms in Industry A (intraindustry sales); 15 units to Industry B; 1 unit to Industry C; 2 units to Industry D; 5 units to Industry E; and 6 units to Industry

F. These sales are interindustry sales and would not appear directly in gross national product accounts, since they are not sales to final consumers. (The cells showing interindustry sales make up what is known as the processing sector.) These sales represent the transactions that take place during the stages of production before goods are finished and ready for sale to consumers. If a slaughterhouse sells hides to a tanner, it is considered an interindustry transaction. If a tanner sells leather to a shoe manufacturer, it is still considered an interindustry transaction. But, in input-output analysis, when the shoe manufacturer has completed the many tasks of putting leather and other materials together into completed shoes, it is considered that he sells his finished goods (f.o.b. the shipper) to the final consumer, either as sales to the local economy's households or an exports to other economies. Although the shoe wholesaler and the shoe retailer each in turn buy and sell the finished shoes, these finished goods purchased for resale by the trades sectors are deleted from the trade sectors' sales, so that only the markup or margins added by the trades sectors are shown as outputs by the trades sectors. This convention of input-output analysis whereby the last-stage processor is considered to sell finished goods to consumers permits the input-output analyst to see the direct customer-producer linkage for finished goods at the factory. In addition, the transportation from factory to retail outlet, wholesale trade margin, retail trade margin, and other brokerage and selling expenses are each tabulated separately and displayed as sales to final consumers.

Columns 7 through 11 of Table 3 (gross inventory accumulation, exports, government purchases, capital formation, and households) make up the final demand sectors of the model. One of the underlying assumptions of the model is that the final demand sectors are autonomous of the processing sector. Exogenous events will influence the level of demand, for example, a "babyboom" would increase consumption on the part of households, but the increased level of transactions in the processing sector would be the result, rather than the cause, of this increased final demand.

The last column of (12), total gross output, measures all outputs of each industrial sector. This is a summation of all transactions across a row.

In addition to listing each industry's sales, the transactions table also lists purchases. In order for an industry to produce the desired level of output, it must purchase inputs which are used in the production process. In the processing sector these purchases are measured down the industry's column. In the hypothetical example we see that Industry B's purchases are shown by its payments to A of 16 units; B (intraindustry purchases), of 4 units; C, of 2 units; and so on.

In addition to the payments to other industries, there are also payments to nonindustry sectors. These payments, called final payments, are represented in rows 7 through

Table 3. Hypothetical transactions table. The processing sector includes industries A through F.

	Outputs											
	Processing sector						Final demand					
Inputs	(1) A	(2) B	(3) C	(4) D	(5) E	(6) F	(7) Gross inventory accumulation	(8) Experts	(9) Government purchases	(10) Capital formation	(11) Households	(12) Total gross output
(1) A	10	15	1	2	5	6	2	5	1	3	14	64
(2) B	5	4	7	1	3	8	1	6	3	4	19	50
(3) C	7	2	8	1	5	3	2	3	1	3	5	40
(4) D	11	1	2	8	6	4	0	0	1	2	4	39
(5) E	4	0	1	14	3	2	1	2	1	3	9	40
(6) F	2	6	7	6	2	6	2	4	2	1	8	46
Final Payments												
(7) Gross inventory depletion	1	2	1	0	2	1	0	1	0	0	0	8
(8) Imports	2	1	3	0	3	2	0	0	0	0	2	13
(9) Payments to government	2	3	2	2	1	2	3	2	1	2	12	32
(10) Depreciation	1	2	1	0	1	0	0	0	0	0	0	5
(11) Households	11	23	7	5	9	12	1	0	8	0	1	85
(12) Total gross outlays (payments)	64	59	40	39	40	46	12	23	18	18	72	431

Source: Miernyk (1965).

11. Payments to households may take the form of wages, salaries, profits, or rents.

The last row (12), total gross outlays, represents the summation of all of the above 11 rows.

In the hypothetical model, as in all input-output models, the total gross outlays for each of the industries in the processing sector balance with respective total gross outputs. Obviously not very many industries are going to have purchases equaling sales. In more sophisticated models a residual row is included which includes such items as savings, retained earnings, and other account balancing entries.

Last is the area where the final payment rows (7 through 11) intersect the final demand columns. These are the estimated financial transactions among households, government, and exporters and importers. While it is possible to arrive at the actual value of government purchases from households (the element at row 11 and column 9), other transactions must be estimated. The intersection of row 9 and column 11 reflects the amount of taxes households paid to government, but it may not fully measure the value of services that government provided households.

Direct Requirements Table

The direct requirements table, also called the technical coefficients table, gives the value of each industry's inputs as a percentage of its total output. Such a table for our hypothetical economy is given in Table 4. If an industry were to increase its output as a result of an increase in the level of the autonomous final demand sector, it would have to purchase more inputs. The technical coefficients reveal how much of each additional dollar of final demand will go to each input source. These coefficients are derived for the processing sector only.

The process of finding the value of the technical coefficients is relatively simple (in this example the adjustment of total gross output is a routine followed by Miernyk, which does not occur in all models; some will use the total outputs as they are expressed in their respective columns). Inventory depletion is subtracted from total gross output to obtain adjusted output. Next, each entry in an industry's column is divided by the adjusted output for that industry.

In our hypothetical model the adjusted output for Industry A is 63. When this is divided into A's input from A, the result is 0.16. When the adjusted output of A is divided into its input from B, the result is 0.08; for C the result is 0.11; for D the result is 0.17; for E the result is 0.06; for F the result is 0.03 (Table 4). This means that if Industry A's sales increased by $1, then its purchases from C will go up 11¢, its purchases from E will go up 6¢, and so on.

Table 4. Technical coefficient table, direct purchases per dollar of output for industries A through F.

Industries producing	Industries purchasing A	B	C	D	E	F
A	.16	.26	.03	.05	.13	.13
B	.08	.07	.18	.03	.08	.18
C	.11	.04	.21	.03	.13	.07
D	.17	.02	.05	.21	.16	.09
E	.06	0	.03	.36	.08	.04
F	.03	.11	.18	.15	.05	.05

Source: Miernyk (1965).

Table 5. Hypothetical direct and indirect requirements per dollar of final demand.

Final demand	Direct and indirect production A	B	C	D	E	F
A	1.38	.25	.28	.41	.27	.23
B	.45	1.21	.16	.19	.12	.24
C	.27	.38	1.38	.23	.17	.39
D	.35	.25	.25	1.53	.65	.41
E	.35	.26	.31	.39	1.28	.25
F	.38	.35	.22	.30	.21	1.32

Source: Miernyk (1965).

Obviously this table lends itself to understanding the interrelationships that exist among the various industries in the economy. It also serves as a handy tool for comparing the technical relationships between different economies, for example, labor-intensive versus capital-intensive, petroleum-dependent versus coal-dependent.

However, the interindustry effects of a change in one sector's final demand do not stop with the direct requirements. Just as A's increase in final demand stimulates each of the other five sectors to provide it with inputs, those sectors in turn will need to purchase additional inputs. For instance, when Industry B provides inputs that account for 8% of A's output, then B must purchase 26% of its new sales to A in the form of inputs from A. Intraindustry purchases within industry sector B will account for 7% of its sales to A, 4% will come from inputs purchased from C, and D and F will provide inputs accounting for 2% and 11%, respectively. When B purchases these inputs, each of the supplying sectors will have an additional stimulation to the one received from A. This brings us to the direct and indirect effects.

Direct and Indirect Requirements Table

As mentioned above, the increase in one sector's outputs will spread itself throughout all the sectors of an economy. After all of the iterations are carried out, the result will be a direct and indirect requirements table, such as the one shown for the hypothetical example in Table 5. Instead of going through the long and tedious (costly on a computer) process of iteration, there is another method of deriving the table. This method is known as "inverting the matrix" and is discussed in Appendix II. Thus, Table 5 shows the total dollar production directly and indirectly required from every industry at the top for each dollar of delivery to final demand by industry, at the left (the table contains a slight rounding error).

Lower Rio Grande Regional Model

In the Texas input-output work, individual regional models were calculated. Data collection was done for each region and an input-output model was formulated which included all sectors operative in the region. The regional data were then aggregated and used to estimate the state model. As mentioned in the previous section, the regional models were estimated from a combination of survey and published data. The following information was collected: (1) dollar value of sales and purchases of the establishment for the calendar year 1967; (2) breakdown of sales and purchases by destination and source; and (3) Standard Industrial Classification, at the four-digit level, of purchases and sales.

The regional input-output model which contained 12 of the 13 counties in the study area was the Region 7 (Lower Rio Grande Region) model. This region includes 19 counties in the southernmost tip of Texas. The remaining county in the study area, Karnes, was contained in the Region 6 model.

Table 7. Number of geothermal power plants needed to meet 1980 demand. Each plant supplies 5.099×10^8 kWh/yr.

Year	Intermediate projection	10-year increment in energy consumption	Number of geothermal plants needed for demand
1970	4081	3189	6.25
1980	7270		

METHODOLOGY FOR MEASURING IMPACT

Given the fact that both the petroleum sector and the electric-utility sector are highly capital intensive, employment impacts were expected to be minimal. The original interest in carrying out this investigation centered around the question of whether or not the introduction of electricity production from geopressure geothermal power would demonstrate inflationary tendencies. The increased production costs resulting from the new technology might bring about cost-push inflation pressures.

In order to determine what the changes in the technical relationships would be if total output remained the same when the utilities sector made the additional purchases, a new table of direct requirements was derived. To do this, a new "A" matrix was derived; each total output entry was divided back into each entry of its respective column, $a_{ij} = X_{ij}/X_i$ (see Appendix II). Since the total output values were divided into each element of the column, all 78 rows, this would mean the column total would be greater than one if the geothermal related transactions were added and nothing else, except gas purchases, were reduced in the column. However, at this point only the first 71 rows and columns are used.

With the new set of technical coefficients it was possible to establish what effect they would have on future dollar values of total output. To do this, the first 71 rows and columns were extracted and subtracted from the identity matrix of similar dimensions. The difference was then inverted, $(\mathbf{I} - \mathbf{A})^{-1}$. This created what Miernyk calls the table of direct and indirect requirements. The table was multiplied by the final-demand vector that had previously been used in the original set of total output projections. This provided a basis to make a comparison, in dollar values, between the total output projections before and after implementation of the policy. That is to say, total output for each industry in the processing sector would be influenced by the transactions resulting from the power generation change. A "pass-through" assumption was implicit in the treatment of increased costs. This means that all of the additional costs incurred by the electric utility were passed on to the utility's customers.

The seven sectors in the final-payments section were summed into one row, including the additional payments resulting from the switch to geothermal. Next, the total output for each row was divided into each element in that sector's row in the altered transactions table; this produced a new matrix labeled "B". The "B" matrix was subtracted from the identity matrix and the result was inverted $(\mathbf{I} - \mathbf{B})^{-1}$. The resulting matrix was multiplied by the new final-payments vector, which included the increased residuals row. In order to avoid confusion, the reader is warned that this "B" matrix is not the same thing as the "B" matrix Leontief (1970) has discussed.

As far as the authors know, this is an unique approach to tracing inflationary trends in an input-output model. Hansen and Tiebout (1963) did develop a somewhat similar technique in their rows only approach. However, their methodology was used only for measuring the impact of exogenous forces on employment within a region. Electric consumption rates for 1980 are given in Table 6. The number of geothermal plants required is given in Table 7.

Interface with the Input-Output Model

The previous work with the input-output model was performed with constant 1967 dollars. Therefore, it was necessary to reduce all of the costs in the Jones 2-stage steam model by the amount of increase in the wholesale price index during the period between 1967 and the assembly of the model, 1.557%.

Table 8 shows the increased costs experienced by the petroleum sector (sector 13 in the input-output model). Since this sector performs the drilling function for the region it was assumed to be the provider of hot water for the power plants.

The payments of petroleum (column 13) for ROI, overhead, and general administrative expenses were added to the residuals row (row 78) in the earlier set of 1980 projections. The column 13 depreciation payments (row 76) were increased by 5% of the value of the new wells and pipes. Payments to insurance (row 62) in the old 1980 model were increased by the new amount. Finally the petroleum sector's

Table 6. Projected energy consumption (kilowatt-hours per capita multiplied by the population) and required generating capacity (MW) under alternative growth policies.

Year	Zero Population Growth projection: Energy (kWh × 10^6)	Zero Population Growth projection: Capacity (MW)	Intermediate projection: Energy (kWh × 10^6)	Intermediate projection: Capacity (MW)	Chamber of Commerce projection: Energy (kWh × 10^6)	Chamber of Commerce projection: Capacity (MW)
1970	–	–	4081	1682	–	–
1975	5560	2300	5630	2300	5730	2400
1980	7050	2900	7270	3000	7580	3100

Source: Moseley (1973).

Table 8. Increased costs to petroleum sector.

Item	Costs ($)
Wells	24 400 000
Collection and disposal piping	470 000
Total cost (without methane)	24 870 000
ROI (straight line, 20%/yr)	5 367 600
Depreciation (straight line, 5%/yr)	1 341 900
Overhead (1.3%)	323 310
Insurance (.00275%)	68 392
General and administrative (1.6%)	397 920
Maintenance and production (2%)	497 400
Total annual costs	7 996 522
Fuel costs (mill/kWh) 15.7	

purchase of labor from households, to perform the maintenance and production operation, was added to the previous 1980 purchases from households (row 72).

In estimating how much the utility would pay the petroleum sector it is very easy for an economist to get into hot water. Since geopressured geothermal power plants are still hypothetical, there are not many examples for guidance. In order to determine "fuel" costs for the power plant the petroleum sector was assumed to pass on its annual costs as a "fuel" charge. This figure replaced the old level of transactions between row 13 and column 41.

Since the fossil-fuel plants would only account for 56% of the electric generation in 1980 the sale of gas to power plants (element at row 40 and column 41) were reduced by 44%.

The rest of the payments by the electric utility were treated in the same fashion as those made by petroleum, with one exception. Financing for the capital investment necessary to construct the geothermal plants was expected to come from outside of the region. Therefore, payments to imports (element at row 77 and column 41) reflect the cost of principal plus interest.

Analysis of Results

A comparison of the changes in total output is presented in Table 9. The only sectors with the largest positive and negative changes in output levels were 41 (electricity) and 40 (gas utilities).

Sector 13, petroleum, did have an increase in total sales to 41, electricity, of $7 996 522; but this transaction is rather small in comparison to the total output for that sector of $5 530 399 056.

Total output for sector 40 decreased, as expected, because it lost 44% of its previous market. The 46% increase in output for sector 41 represents the increase in price that resulted from the implementation of a new technology. The petroleum sector was the only economic sector that experienced an additional actual increase in physical output (sales of hot water to power plant) over the previously projected 1980 levels. Increases in all other sectors represent the rise

Table 9. Comparison of two total output vectors for 1980, old computed with fossil-fuel electric generating only, new computed with both fossil-fuel and geothermal electric generating.

Sector	Old	New	Change	%	Sector	Old	New	Change	%
1	8 889	8 967	78	0.88	37	24 237	24 247	10	0.04
2	2 857	2 879	21	0.74	38	32 262	32 382	120	0.37
3	6 575	6 626	51	0.77	39	87 049	87 360	311	0.36
4	24 059	24 245	186	0.77	40	643 305	638 181	−5 124	−0.80
5	37 585	37 918	334	0.89	41	101 953	149 105	47 152	46.25
6	3 350	3 373	23	0.70	42	17 068	17 616	547	3.21
7	57 154	57 495	340	0.60	43	17 734	17 772	39	0.22
8	18 283	18 496	213	1.16	44	45 215	45 511	296	0.65
9	1 883	1 908	25	1.31	45	4 837	4 994	157	3.25
10	2 397	2 500	103	4.29	46	1 279	1 287	7	0.56
11	9 589	9 685	96	1.00	47	58 819	59 070	251	0.43
12	45 816	45 925	109	0.24	48	17 970	18 015	46	0.25
13	5 530 399	5 573 333	42 933	0.78	49	141 508	142 453	945	0.67
14	25 212	25 296	84	0.33	50	14 117	14 123	6	0.04
15	25 138	25 199	62	0.25	51	5 121	5 133	11	0.22
16	215 858	216 480	622	0.29	52	7 922	7 990	68	0.86
17	22 892	23 048	156	0.68	53	57 729	58 107	378	0.66
18	17 175	17 245	70	0.41	54	1 175 992	1 184 412	8 420	0.72
19	3 434	3 455	21	0.62	55	123 241	123 804	563	0.46
20	82 311	83 284	973	1.18	56	19 141	19 506	366	1.91
21	10 188	10 226	38	0.37	57	11 784	11 936	153	1.30
22	188	188	0	0.22	58	7 883	7 986	103	1.31
23	15 119	15 152	33	0.22	59	59 891	60 329	438	0.73
24	26 904	27 000	96	0.36	60	27 266	27 462	197	0.72
25	313 665	321 077	7 412	2.36	61	124 418	124 704	286	0.23
26	391 926	393 037	1 111	0.28	62	105 008	106 170	1 162	1.11
27	553	565	12	2.25	63	19 821	20 315	494	2.49
28	51 977	52 017	40	0.08	64	43 164	43 732	568	1.32
29	201 312	203 079	1 766	0.88	65	50 850	51 132	282	0.55
30	6 626	6 641	15	0.23	66	7 952	8 153	201	2.53
31	12 602	12 618	16	0.13	67	2 355	2 357	2	0.07
32	3 262	3 268	6	0.18	68	28 678	28 827	149	0.52
33	6 625	6 640	15	0.23	69	543 569	547 689	4 121	0.76
34	5 922	5 972	50	0.84	70	204 103	205 398	1 295	0.63
35	94 905	95 877	972	1.02	71	89 674	89 944	270	0.30
36	147 032	147 210	178	0.12	Total	11 352 579	11 470 699	118 120	1.04

in utility rates that is implicit in the pass-through assumption.

The final row in Table 9 is the summation of all total-output rows. This represents the total output of all sectors of the regional economy. In terms of inflationary tendencies, the effect of geothermal plants would appear negligible. The overall price increase is approximately 1%.

The 46% increase in electrical rates seems large when first compared with the previous projections. However, those projections were based on the assumption of continued gas supplies and continued government-controlled low gas prices, two assumptions which have already become obsolete (or if you will, inoperative). Given the increases in electric utility rates that have occurred during the past three years, the geothermal plants compare quite favorably.

Environmental Effects

One of the positive externalities associated with the use of geothermal power is the fact that large volumes of pollutants are not being released into the atmosphere as is the case with coal- and oil-burning plants. As long as the hot waste water is reinjected or used for other purposes, secondary recovery of oil, installation heat, and so on, there would be no problem in meeting the requirements of the 1973 Water Quality Act.

Probably the most significant potential problem area is that of subsidence. Because of excessive ground-water withdrawals in the Houston-Galveston area large-scale subsidence has occurred in that region of the upper Texas coast. Whether or not geopressured water removal will result in subsidence in a problem that can only be answered by careful monitoring of geological phenomena as development progresses.

APPENDIX I: THE BRIDGING TABLE

The bridging table (Table I-1) which follows provides a means of examining the sectoral make-up of the regional and subregional models and comparing them to the state model. Since there are many activities going on in other parts of the state that are not present in Corpus Christi, it was convenient to eliminate altogether some sectors which appear in the state model, which has 175 sectors in the processing section of the transactions table. Also, some activities that occur in the rest of the state are of relatively minor ranking in the COG. Therefore, it was possible to aggregate a lot of activity that occurs in the state model and represent it as one sector in the COG model. For example, Sector 65 in the subregional model is an agglomeration of such diverse services as advertising, duplicating, addressing, photographing, research and development, and other business services. Undoubtedly each of these activities would be more important sectors for the whole state, or especially for subregional models for such cities as Houston and Dallas. In the Coastal Bend COG area, they are not of such significance.

A careful examination of the Standard Industrial Classification (SIC's) will reveal duplication and listings that appear to be out of order: the reason for this is that they are. SIC's are nationally developed. The industry-mix for the COG displays its own regional peculiarities that differ from the industry-mix of the nation as a whole. The SIC's are of necessity arbitrary. Therefore, when the same products are produced by different firms in different sectors that SIC grouping for the respective sector will reflect this. As for the SIC's being out of order, this is another problem of aggregating different economic activities in one sector.

Finally, there are a few sectors that are composed of two- and three-digit SIC's only. These are relatively minor sectors and could only be expressed with such designations and still retain anonymity for cooperating firms in the region.

APPENDIX II: MATHEMATICS

Miernyk (1965) points out that there are three fundamental assumptions on which the input-output model is based: (1) each group of commodities is supplied by a single production sector; (2) the inputs to a sector are a unique function of the level of output of that sector; and (3) there are no external economies or diseconomies.

There are $n + 1$ sectors in the model and only one sector, final demand, is autonomous. The other n sectors are nonautonomous and the processing sector displays their structural interdependence.

The following definitions are used throughout:

$X_i \equiv$ total output of sector i
$X_{ij} \equiv$ sales by sector i to sector j
$X_{fi} \equiv$ final demand for products of sector i
$\mathbf{X}_f \equiv$ final demand vector (the X_{fi} are elements of $\mathbf{X}_f$)
$X_i' \equiv$ new total output of sector i after an exogenous change in final demand

Total output of sector i for any given period of time is represented by X_i.

$$X_i = X_{i1} + X_{i2} + \dots + X_{in} + X_{fi} \qquad i = 1, \dots, n \quad (1)$$

where X_{fi} is final demand (the autonomous sector) for the products of sector i and the remaining terms on the right-hand side of the equation represent the nonautonomous, interindustry transactions.

The second assumption stated that sector j's demand for inputs from sector i will depend only upon the level of output of sector j, which can be expressed as

$$X_{ij} = a_{ij} X_j. \quad (2)$$

When Equation (2) is substituted into Equation (1), we find that

$$X_i = a_{i1}(X_1) + a_{i2}(X_2) + \dots + a_{in}(X_n) + X_{fi} \qquad i = 1, \dots, n \quad (3)$$

which is to say

$$X_i = \sum_{j=1}^{n} a_{ij}(X_j) + X_{fi}, \; i = 1, \dots, n \quad (4)$$

where X_j is the output of the jth sector and X_{fi} represents the end product (final) demand for the output of sector i.

Schematically the model would appear as in Figure II-1.

Table I-1. Bridging table, Coastal Bend COG subregional model, Region 7 model and Texas input-output state model*.

Subregional and region sector number	Regional industry sector description	State sector number	Standard industrial classification
	Agriculture		
1	Irrigated cotton	1	0112
2	Irrigated grains	3	0313
3	Vegetables, citrus, and other irrigated crop products	4	0122, 0123, 0119
4	Dryland cotton	5	0212
5	Dryland feed grains	7	0413
6	Other dryland crop production	8	0219, 0141
7	Range and feedlot livestock production	9, 10	0235, 0135, 0136
8	Dairy, poultry and eggs	11, 12	0132,0133, 0134
9	Agricultural supply, except farm machinery	13	5962, 5969
10	Ginning	14	0712
11	Agricultural services	15	0713, 0714, 0715, 0719, 0722, 0723, 0729, 0731, 0741
12	Fisheries	17	0912, 0913, 0914, 0919, 0989
	Mining		
13	Crude petroleum, natural gas, and services	18, 19, 20	1311, 1321, 1381, 1382, 1389
	Construction		
14	Residential construction, alteration and repair	22	1511
15	Commercial, educational and institutional construction	23	1511
16	Facility and other construction	24, 25, 26	1511, 1611, 1621, 1700
	Manufacturing		
17	Meat products	27	2011, 2013
18	Dairy manufacturing	29	2021, 2022, 2023, 2024, 2026
19	Canned, preserved, pickled, dried, and frozen food	33	2035, 2036, 2037, 2038
20	Other food and kindred products	30, 31, 32, 34	2041, 2043, 2044, 2045, 2046, 2042, 2051, 2052, 2061, 2062, 2063, 2069, 2071, 2072, 2091, 2092, 2093, 2094, 2095, 2096, 2097, 2098, 2099, 2121
21	Beverages	35	2082, 2084, 2086. 2089
22	Textile mill products, furnishings, and apparel	36, 37, 38	2211, 2221, 2231, 2241, 2251, 2253, 2256, 2259, 2261, 2262, 2269, 2271, 2272, 2279, 2281, 2284, 2291, 2293, 2294, 2295, 2297, 2298, 2299, 2311, 2321, 2322, 2323, 2327, 2328, 2329, 2331, 2335, 2336, 2337, 2339, 2341, 2342, 2351, 2352, 2361, 2363, 2369, 2371, 2381, 2384, 2385, 2386, 2387, 2389, 2391, 2392, 2393, 2394, 2395, 2396, 2397, 2399, 2292, 2296
23	Wood furniture and other wood and paper products	41, 42, 45, 46	2431, 2432, 2433, 2441, 2442, 2443, 2445, 2491, 2499, 2511, 2512, 2515, 2519, 2521, 2541, 2591, 2599, 2641, 2642, 2643, 2645, 2646, 2647, 2649, 2651, 2652, 2653, 2654, 2655
24	Newspapers, publishing and printing	47, 48, 49, 50, 51	2711, 2721, 2731, 2741, 2732, 2751, 2752, 2753, 2761, 2711, 2982, 2789, 2791, 2793, 2794, 2799
25	Chemicals, drugs, and related products	52, 54, 55, 59, 61, 62	28121, 28122, 28123, 28124, 28132, 28133, 28134, 28182, 28183, 28185, 28191, 28192, 28193, 28194, 28195, 28196, 28197, 28198, 28199, 2879, 2871, 2872, 2879, 2851, 2871, 2891, 2892, 2893, 2895, 2899
26	Petroleum, refining and products	63, 64	2911, 2951, 2952, 2992, 2999
27	Clay, cut stone, and shell products	69, 70, 71	3221, 3229, 3231, 3251, 3253, 3255, 3259, 3261, 3262, 3269, 3281, 3291, 3292, 3295, 3296, 3297, 3299, 3274, 3275, 3201, 3293
28	Cement and concrete products	72	3271, 3272, 3273, 3241
29	Primary metals, foundaries, and forgings	75, 76, 77, 78	3321, 3322, 3323, 3331, 3332, 3333, 3334, 3339, 3341, 3362, 3369, 3391, 3392, 3399

Source: Grubb, et al. (1969).
*The sectoral groupings for the subregion and for Region 7 are the same, as are the sectoral descriptions and the SIC's.

Table I-1 (*continued*)

Subregional and region sector number	Regional industry sector description	State sector number	Standard industrial classification
30	Fabricated steel and other metal products	79, 80, 81, 86, 87, 88	3441, 3443, 3444, 3446, 3449, 3471, 3479, 3494, 3498, 3481, 3491, 3492, 3493, 3499
31	Machinery and processing equipment	89, 91, 92, 94, 95, 97	3522, 3531, 3537, 3532, 3533, 3511, 3519, 3551, 3552, 3553, 3554, 3555, 3559, 3561, 3562, 3564, 3565, 3566, 3567, 3569, 3581, 3582, 3586, 3589, 3599
32	Electric and electronic equipment	98, 100, 101	3611, 3612, 3613, 3621, 3622, 3623, 3624, 3641, 3642, 3643, 3644, 3629, 3651, 3661, 3662, 3671, 3672, 3673, 3674, 3679, 3691, 3693, 3694, 3652, 3699
33	Transportation equipment	105, 106, 107	3713, 3715, 3714, 3711, 3731, 3732, 3741, 3742, 3791, 3751, 3799
34	Other manufacturing	65, 67, 68, 110, 111, 112, 113	3011, 3079, 3111, 3121, 3131, 3141, 3142, 3151, 3161, 3171, 3172, 3199, 3841, 3842, 3843, 3851, 3861, 3962, 3963, 3964, 3991, 3982, 3983, 3984, 3987, 3993, 3994, 3995, 3999
	Transportation		
35	Highway motor freight, passenger service and warehousing	115, 116	4131, 4132, 4213, 4231, 4212, 4214, 4224, 4221, 4222, 4223, 4224, 4226
36	Water transportation	117	4411, 4421, 4441, 4452, 4453, 4454, 4459, 4463, 4464, 4469
37	Air transportation	118	4511, 4521, 4582, 4583
38	Other transportation services	114, 119, 120, 121	4011, 4013, 4021, 4041, 4612, 4613, 4619, 4111, 4119, 4121, 4140, 4150, 4141, 4142, 4151, 4171, 4172, 4742, 4782, 4783, 4784, 4789, 4721
39	Communications	122, 123, 124	4811, 4821, 4832, 4833, 4899
	Utilities		
40	Gas services	125	4922, 4923, 4932, 9149, 9249, 9349
41	Electric services	126	4911, 4931, 9151, 9251, 9351
42	Water and sanitary service systems	127	9102, 9202, 9302, 4941, 4952, 4953, 4959, 4961
	Wholesale trade		
43	Wholesale auto parts and supplies	128	5012, 5013, 5014
44	Wholesale groceries and related products	129	5041, 5042, 5043, 5044, 5045, 5046, 5047, 5048, 5049
45	Wholesale farm products	130	5052, 5053, 5059
46	Wholesale livestock	131	5054, 4731
47	Wholesale machinery, equipment, and supplies	132	5081, 5082, 5084, 5085, 5083, 5088, 5087
48	Wholesale petroleum and petroleum products	133	5092
49	General wholesale	134	5022, 5028, 5029, 2033, 5034, 5036, 5037, 5039, 5063, 5064, 5065, 5072, 5074, 5077, 5091, 5093, 5094, 5095, 5096, 5097, 5098, 5099
	Retail trade		
50	Retail lumberyards	135	5211
51	Farm equipment dealers	136	5252
52	Hardware, heating, electrical, paint, and wall paper	137	5221, 5231, 5241, 5251
53	Department and variety stores	138	5311, 5331, 5399
54	Food stores	139	5411, 5421, 5431, 5441, 5451, 5462, 5499
55	Automotive dealers and repair shops	140	5511, 7549, 5521, 5531, 7531, 7534, 7535, 7538, 7539, 7542
56	Gasoline service stations	141	554
57	Apparel acessory stores	142	5611, 5621, 5631, 5641, 5651, 5661, 5671, 5681, 5699
58	Furniture, home furnishings equipment stores	143	5712, 5713, 5714, 5715, 5719, 5722, 5732, 5733
59	Eating and drinking places	144	5812, 5813
60	All other retail	145	5912, 5921, 5932, 5933, 5942, 5943, 5952, 5953, 5591, 5592, 5599, 5971, 5982, 5983, 5984, 5992, 5993, 5994, 5996, 5997, 5999, 5995, 5341, 5351

Table I-1 (*continued*)

Subregional and region sector number	Regional industry sector description	State sector number	Standard industrial classification
	Finance, insurance, real estate (FIRE)		
61	Banking and credit agencies	146	60, 61
62	Insurance carriers, real estate insurance n.e.c.	147, 148	62, 63, 64, 65, 66, 67
	Services		
63	Lodging services	150	7011, 7021, 7041, 7031, 7032
64	Personal services	151	7211, 7212, 7213, 7214, 7215, 7216, 7217, 7218, 7231, 7241, 7251, 7261, 7271, 7299
65	Advertising, duplicating, addressing, and photographic services	152, 153, 154, 155, 156, 157	7311, 7814, 7815, 7821, 7395, 7221, 7391, 8921, 7341, 7342, 7349, 7351, 7392, 7393, 7394, 7397, 7398, 7309
66	Motion picture, amusement and recreation services	158	7816, 7817, 7818, 7832, 7833, 7911, 7929, 7932, 7933, 7441, 7942, 7943, 7945, 7946, 7947, 7948, 7949
67	Auto rentals and parking services	170, 171	7512, 7513, 7519, 7523, 7525
68	Miscellaneous repair services	161, 162	7622, 7623, 7629, 7631, 7641, 7692, 7694, 7699
69	Medical and dental services	163, 164, 165	8011, 8021, 8031, 8041, 8061, 8071, 8072, 8092, 8099
70	Education (public and private)	166, 167, 168	8211, 8221, 8222, 8231, 8241, 8242, 8299
71	Professional services	169, 170, 171, 172	8111, 8911, 8931, 8411, 8421, 8641, 8651, 8661, 8671, 8699, 8811

Direct Requirements

As stated in the text direct requirements are found by dividing total output for any given sector into each cell of that sector's respective column. It is the same as Equation (2), only rewritten as

$$a_{ij} = \frac{X_{ij}}{X_j}. \qquad (5)$$

The whole matrix of a_{ij}'s would be

$$\mathbf{A} = \begin{bmatrix} a_{11} \cdots a_{1j} \cdots a_{1n} \\ a_{i1} \cdots a_{ij} \cdots a_{in} \\ a_{n1} \cdots a_{nj} \cdots a_{nn} \end{bmatrix} \qquad (6)$$

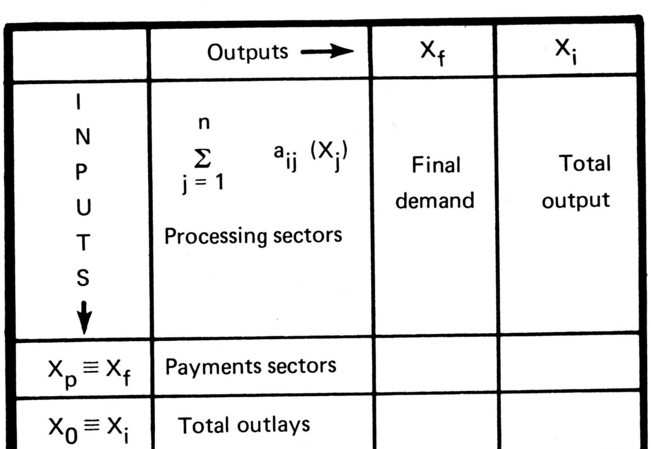

Figure II-1. Schematic diagram of the input-output model.

Direct / Indirect Requirements

The direct/indirect requirements matrix is another matrix of the same order as the direct requirements matrix. It is found by the operations $(\mathbf{I} - \mathbf{A})^{-1}$ which yields another matrix

$$\mathbf{R} = \begin{bmatrix} r_{11} \cdots r_{1j} \cdots r_{1n} \\ r_{i1} \cdots r_{ij} \cdots r_{in} \\ r_{r1} \cdots r_{nj} \cdots r_{nn} \end{bmatrix} \qquad (7)$$

To find new output levels that follow changes in final demand we multiply the final demand vector by **R**. The computation will be as follows:

$$\sum_{j=1}^{n} X_{fi} r_{ij} = X_i' \qquad (8)$$

then

$$a_{ij} X_i' = T' \qquad (9)$$

Equation (8) shows that each column of $(\mathbf{I} - \mathbf{A})^{-1}$ is multiplied by the corresponding row of the new final demand vector. Each row is summed to obtain a new total output level for sector i, X_i'.

In Equation (9) each column of the table of direct requirements is multiplied by the new total output for the corresponding row to yield the elements (T') of a new transaction table, the balancing equation for which would be

$$X_i' = \sum_{i=1}^{n} a_{ij}(X_j') + X_{fi}', \; i = 1, \ldots, n \qquad (10)$$

The same sort of processes were followed to trace through the inflationary pressures.

However, instead of finding an "A" matrix we found a "B" matrix which was determined by dividing total output (or total payments, since they are equal) back across the rows. This is expressed as:

$$b_{ij} = \frac{X_{ij}}{X_i} \tag{11}$$

or as stated in Equation (2)

$$X_{ij} = b_{ij} X_i. \tag{12}$$

The result would be a matrix similar to the one in Equation (6)

$$\mathbf{B} = \begin{bmatrix} b_{11} \cdots b_{ij} \cdots b_{1n} \\ b_{i1} \cdots b_{ij} \cdots b_{in} \\ b_{n1} \cdots b_{nj} \cdots b_{nn} \end{bmatrix} \tag{13}$$

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